Development, implementation and demonstration of a reference processing pipeline for the future production of official statistics based on multiple Mobile Network Operator data (TSS multi-MNO)

Service Contract Number – 2021.0400

D4.3 – Third code release and documentation

In association with:

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Deliverable 4.3: Third code release and documentation

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\ ABSTRACT

The Multi-MNO project aims to **develop, implement and demonstrate a proposal for a reference standard processing pipeline for the future production of official statistics in Europe based on Mobile Network Operator (MNO) data from multiple operators**. The term "processing pipeline" refers to the combination of a methodological framework and a reference open-source software adhering to such a framework. This report presents the list of software artefacts developed within the Multi-MNO project based on the requirements and specifications provided by the methodological framework defined in deliverables D2.2 and D3.2. The software artefacts include: (i) open-source software and testing datasets, (ii) technical documentation (including software requirements, design and tests), (iii) developers guide and (iv) user manual. This report provides detailed information about the software technological stack, requirements and design. Rest of software artefacts (code, testing datasets, user manual, developer guide, etc.) are provided in the project's Github repository publicly available at the following link: https://github.com/eurostat/multimno.

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On behalf of the contractor, project management is ensured by Florabela Carausu (GOPA).

DOCUMENT VERSION STATUS AND FUTURE UPDATES:

The document is a work-in-progress interim version of the first project deliverable. Therefore, its content may change in future versions. This document and any future updates will be publicly disseminated on the Multi-MNO project webpage: https://cros.ec.europa.eu/multi-mno-project

Readers are invited to submit comments and corrections or share their views via email to multimno-project@gopa.de

Abbreviations

5G	Fifth-generation technology
AWS	Amazon Web Services
EMR	Elastic MapReduce
ESS	European Statistical System
GCP	Google Cloud Platform
GSM	Global System for Mobile Communications
IDE	Integrated Development Environment
ISO	International Organisation for Standardisation
LCL	Lower Control Limit
LTE	Long Term Evolution (mobile networks)
MNO	Mobile Network Operator
n/a	not applicable
PEP 8	Python Enhancement Proposal 8
QW	Quality Warnings
UCL	Upper Control Limit
UMTS	Universal Mobile Telecommunications System
UTC	Universal Time Coordinated

Table of Contents

Index of Figures

Index of Tables

1 INTRODUCTION

1.1 BACKGROUND AND OBJECTIVES

The Multi-MNO project aims to develop, implement and demonstrate a proposal for a reference standard processing pipeline for the future production of official statistics in Europe based on Mobile Network Operator (MNO) data from multiple operators. If successful, the proposal developed by the project may be endorsed as European Statistical System (ESS) standard by the relevant ESS bodies. The term 'processing pipeline' refers to the combination of a methodological framework and a reference open-source software adhering to such a framework. The methodological framework mainly includes the definition of scenarios, use cases, methods, business processes and a quality framework. Detailed information about the methodological framework developed in this project is provided in the following documentation:

\ **D2.2- Updated version of technical documentation for scenarios, requirements, use cases and methods, and high-level architecture**
\ **D3.2- Updated version of technical documentation for Business Processes and Quality Framework**

Based on the requirements and specifications derived from the methodological framework, an open-source software for the production of official statistics has been developed.

1.2 SCOPE OF THE DOCUMENT

This document presents the complete list of the software artefacts developed within the Multi-MNO project, providing detailed information about the software technological stack, requirements and design. Rest of software documentation (user manual, developer guide, etc.) is provided in the project's Github repository publicly available at the following link: https://github.com/eurostat/multimno.

***[Remark:** The documentation provided so far covers the scope of the multi-MNO release 0.7. The documentation will be updated as long as new releases are published]*

1.3 DOCUMENT STRUCTURE

In addition to this introductory section, the remainder of this document is organised as follows:

- **Chapter 2 'Overview of software artefacts and mapping with the methodological framework'** presents the list of artefacts developed within the project and provides a mapping between the software components and the methods described in D2.2
- **Chapter 3 'Software requirement specification'** provides the requirements of the software, addressing both general requirements and component-specific requirements.
- **Chapter 4 'Technological Stack':** describes the technology stack established for the software, providing a rationale for the decision taken.
- **Chapter 5 'Design'** provides the design of the software, addressing both general design and component-specific design.
- **Annex I 'Data objects'** presents a detailed description of the data objects generated by the software.
- **Annex II 'Notes for future revision'** annotates a partial list of pending points for improvement in future releases of this deliverable.

2 OVERVIEW OF SOFTWARE ARTEFACTS AND MAPPING TO THE METHODOLOGICAL FRAMEWORK

2.1 SOFTWARE ARTEFACTS AND REPOSITORY STRUCTURE

Table 1 presents the list of software artefacts developed in this project. Main artefacts cover: (i) open-source software and testing datasets, (ii) technical documentation (including software requirements, design and tests), (iii) developers guide, to facilitate maintenance and the future development of the software and (iv) user manual, to guide the deployment and execution of the software. Most of the documentation is publicly available in the project GitHub repository: https://github.com/eurostat/multimno. The GitHub repository includes a README.md file to facilitate the navigation through the software documentation, as well as HTML documentation that enables interactive web-based navigation.

Table 1: List of software artefacts and location of the associated documentation

ARTEFACTS	DESCRIPTION	REPOSITORY
Open-source software	• Open-source code • Synthetic datasets (inputs and components outputs for a set of scenarios)	https://github.com/eurostat/multimno
Technical documentation	• Requirement specifications • Software design	Present document, Chapter 3 (requirements) and Chapter 5 (design)
	• Testing codes and documentation	https://github.com/eurostat/multimno
Developers guide	• Guide for future developers to be able to contribute to the software • Methods and functions documentation as well as code-level comments	https://github.com/eurostat/multimno
User manual	• (how-to guide) on the deployment • (how-to guide) use of the software (data and infrastructure requirements, installation of the software, how to configure and run the software, etc.).	https://github.com/eurostat/multimno

2.2 MAPPING TO THE METHODOLOGICAL FRAMEWORK

Table 2 shows the software components developed for the multi-MNO codes release 0.7 and their correspondence with the methods described in the deliverables from Task 2. The software developed consists of a set of components covering the different use cases defined in Task 2. Software components usually cover one or more functionalities described in Task 2 methods (e.g. the component 'CellConnectionProbabilityEstimation' covers the functionalities described by the methods: 'Cell Connection Probability Estimation Module' and 'Posterior Probability Estimation Module'). Note that it could be the case that a software component is not directly related with any method described in Task 2; nonetheless, its implementation is needed for the correct functioning of the solution (e.g. 'InspireGridGenerator' module creates the INSPIRE grid that is used as the reference grid for posterior analyses).

Table 2: Mapping of the software modules in the multi-MNO codes release 0.7 to the methods described in the deliverables from Task 2

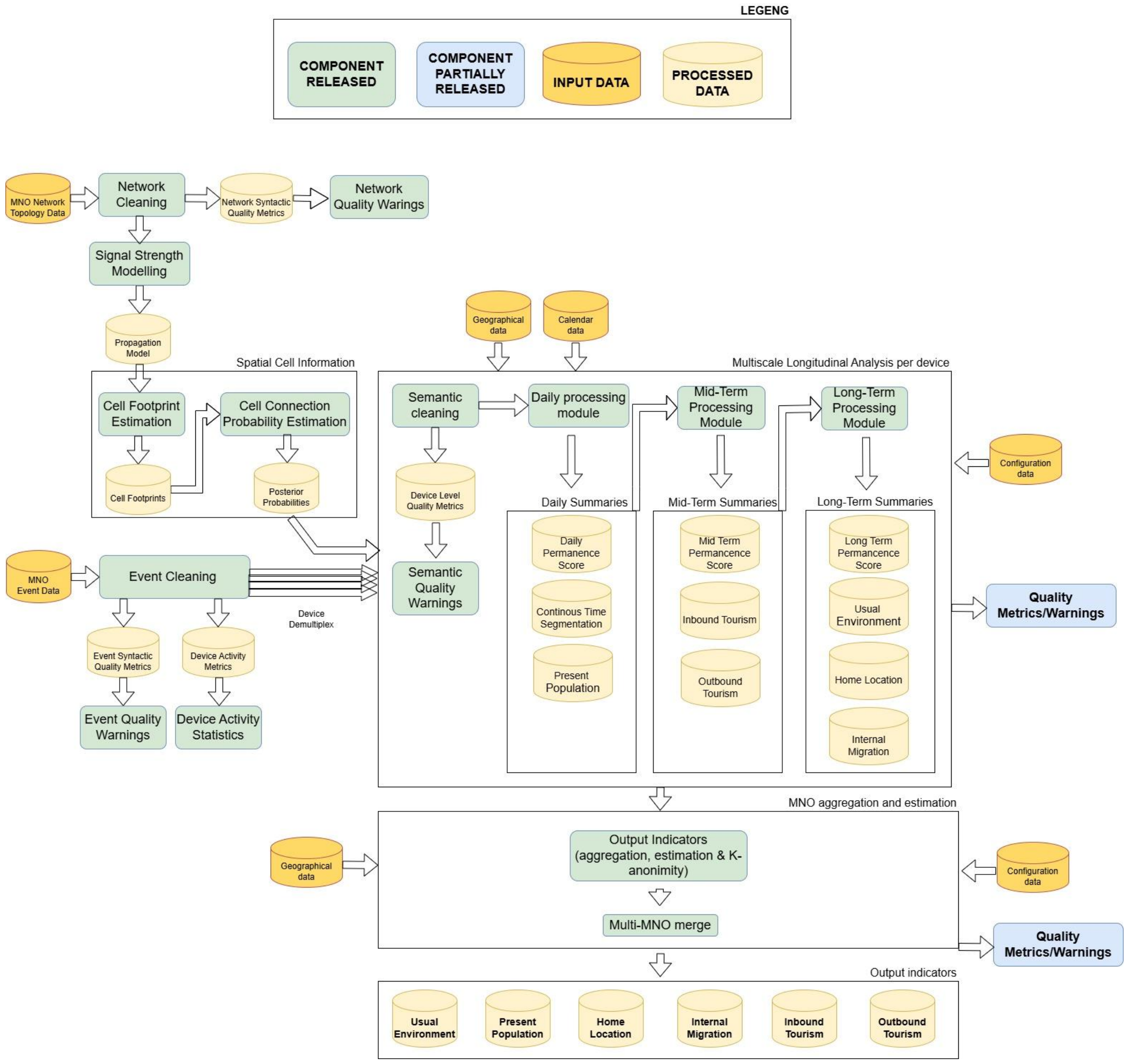
#	SOFTWARE COMPONENTS	METHOD NAME IN TASK 2
1	NetworkCleaning	1.1 Cleaning of MNO Network Topology Data
2	NetworkQualityWarnings	2.1 Generation of MNO Network Topology Data Syntactic Quality Warnings
3	SignalStrengthModeling	3.1 Propagation Estimation Module
4	CellFootprintEstimation	4.1 Cell Footprint Estimation Module
5	CellConnectionProbabilityEstimation	• 5.1 Cell Connection Probability Estimation Module • 6.1 Posterior Probability Estimation Module
6	EventCleaning	• 7.1 Cleaning of MNO Event Data - Syntactic Checks • 9.1 Demultiplexing of MNO Event Data
7	EventQualityWarnings	8.1 Generation of MNO Event Data Syntactic Quality Warnings
8	DeviceActivityStatistics	9.1 Generation of Device Activity Quality Warnings
9	SemanticCleaning	11.1 Cleaning of MNO Event Data at Device Level - Semantic Checks
10	SemanticQualityWarnings	12.1 Generation of MNO Event Data at Device Level Semantic Quality Warnings
11	DailyPermanenceScore	13.2 Estimation of the permanence score for usual environment and home location assignation
12	ContinuousTimeSegmentation	13.3 Estimation of Continuous Time Segmentation
13	InspireGridGenerator	n/a
14	SyntheticDiaries	n/a
15	SyntheticNetwork	n/a
17	Synthetic Events	n/a
17	PresentPopulation	13.1 Present Population Estimation
18	GridEnrichment	n/a
19	GeoZonesGridMapping	n/a
20	MidTermPermanenceScore	14. Mid-Term Processing Module
21	LongTermPermanenceScore	15. Long-Term Processing Module
22	UsualEnvironmentLabelling	15. Long-Term Processing Module
23	UsualEnvironmentAggregation	15. Long-Term Processing Module
24	CellsProximityEstimation	n/a
25	InternalMigration	20.1 Home Location changes detection method

#	SOFTWARE COMPONENTS	METHOD NAME IN TASK 2
26	TourismStaysEstimation	[upcoming in D2.3]
27	TourismStatisticsCalculation	[upcoming in D2.3]
28	TourismOutboundStatisticsCalculation	[upcoming in D2.3]
29	OutputIndicators	16. Device Filtering & Single MNO Data Aggregation 18. Projection of Multi-MNO Aggregates from the finest level to the geographic unit systems relevant for the use case 19. Estimation
30	MultiMNO Aggregation	17. Merge Single MNO Aggregates in Multi-MNO Aggregates
31	DailyPermanenceScoreQualityMetrics	n/a
32	CellFootprintQualityMetrics	n/a

2.3 GENERAL OVERVIEW OF THE SOFTWARE SOLUTION DESIGN AND RELEASE STATUS

In this section, we provide an overview of the software solution design and status of the multi-MNO release 0.7 implementation. The following diagram provides a high-level overview of the software pipeline. The components are presented in boxes of different colours to indicate the current development status: (i) green means that the component is available in release 0.7 and (ii) blue means that the component is available in release 0.7 but does not contain yet all the functionalities planned within the project framework. On the other hand, the data is represented by cylindrical objects in various colors: (i) bright yellow indicates that the data is an input to the process and (ii) light yellow indicates that the data was generated during the process. It is important to note that the available or partially available components may be improved throughout the project's lifecycle. The enhancements to be incorporated will mainly be driven by the tests conducted in real-world environments with different MNOs.

Figure 1: Design and status of the multi-MNO codes release 0.3 compared to the methodological framework



3 SOFTWARE REQUIREMENTS

This chapter describes all the functional and non-functional requirements that each software module of the pipeline must fulfil. A requirement is a singular documented physical and functional need that a particular design, product or process must be able to perform. In the definition of the software requirements it is important to comply with the following set of rules:

1. **Clear and Unambiguous**: requirements should be expressed in a clear and unambiguous manner, leaving no room for interpretation. Ambiguity can lead to misunderstandings and errors.
2. **Complete**: requirements should cover all necessary aspects of the software's functionality, leaving no critical features or behaviours undocumented.
3. **Consistent**: requirements should not contradict each other, and they should align with the project's goals and constraints. Inconsistencies can lead to confusion and conflicts.
4. **Feasible**: requirements should be technically achievable within the project's constraints, including time, budget, and available resources.
5. **Measurable**: requirements should be quantifiable so that they can be objectively verified during testing or upon delivery. This often involves specifying criteria for success.
6. **Testable**: requirements should be written in a way that allows for effective testing. Test cases should be derived directly from the requirements to ensure thorough testing coverage.
7. **Modular**: requirements should be modular and encapsulate individual pieces of functionalities or features. This modularity simplifies development and maintenance.
8. **Traceable**: requirements should be traceable throughout the software development lifecycle, from the initial concept to the final implementation. Traceability ensures that all requirements are met.
9. **Approved**: requirements should go through an approval process by relevant stakeholders to ensure that they accurately represent their needs and expectations.
10. **Non-Functional Requirements**: these include aspects like performance, security, scalability, usability, and reliability, in addition to functional requirements.
11. **Constraints**: requirements should identify any constraints, such as regulatory, hardware, or budget limitations, that may impact the project.

General requirements (Section 3.1 General requirements) as well as specific module requirements (Section 3.2 Component requirements) are provided. Requirements are provided using a table template (see Table 3) that contains the following information:

- **ID**: requirement identifier with the following naming 'TSS-AAA-NNN', where 'AAA' is the abbreviation of the requirements group (e.g. 'GEN' refers to 'general' requirements) and 'NNN' the number of the requirement within the requirement group (e.g. '001' for the first requirement). Must be unique.
- **Definition**: requirement specification. Must be atomic and not ambiguous.

Table 3: Requirements table template with examples

ID	DEFINITION
TSS-MNO-001	Timestamp data shall be given in the UTC standard.
TSS-MNO-002	The pipeline shall process a single combination of MNO and country data at each instance within the MNO infrastructure

3.1 GENERAL REQUIREMENTS

The general requirements, covering the functional, infrastructure, software, data and performance dimensions are described in this section. Some of the requirements are derived by the fact that Big Data sources are used in the calculation of the indicators[1]. Therefore, the software must be executable within the Apache Big Data ecosystem (Hadoop, Hive, Spark…). Other requirements consider the convenience of using state-of-the-art infrastructure for Big Data analyses (e.g. the use of cloud environments like AWS, GCP or Azure) or the need of local execution (in conventional laptop and desktops) with synthetic datasets for development and/or demonstration scenarios purposes. A complete list of the general requirements considered for the development of the software is presented in Table 4.

Table 4: Software general requirements classified by category

ID	DEFINITION
Functional	
TSS-GEN-001	The software shall process data with a minimum temporal scope of a single day.
TSS-GEN-002	The software shall process a single combination of MNO and country data at each execution.
TSS-GEN-003	Timestamp data shall be given in the UTC standard.
TSS-GEN-004	The software shall be able to generate synthetic data for an end-to-end pipeline execution.
TSS-GEN-005	The software shall generate data quality indicators for a set of pipeline components.
Infrastructure	
TSS-GEN-006	The software shall be executable in cloud environments (AWS, GCP, Azure) of MNO Operators.
TSS-GEN-007	The software shall use the Spark framework for big data processing.
TSS-GEN-008	The software shall be executable on a single computer.
TSS-GEN-009	The software shall be executable on Windows, Linux and Mac operating systems.
Software	
TSS-GEN-010	The software shall execute a pipeline of isolated components which do not share in-memory information between them.[2]

[1] The Multi-MNO project introduces several use cases that involve the processing of MNO data and lists for each use case the statistical indicators that can be produced. In the reports from the project, the terms statistical indicator and indicator are used interchangeably. The use cases and targeted statistical indicators are detailed in the project deliverables D2.

[2] Rationale: by resetting both the Spark Session and the Python cache before the execution of each component, the isolated components paradigm helps maintaining the integrity and predictability of the PySpark application. It ensures that each component can be executed independently, without being influenced by the state or results of other components. This promotes modularity, simplifies debugging, and enhances overall reliability.

ID	DEFINITION
TSS-GEN-011	The software shall use a general configuration file and a specific component configuration file for each of the components in the pipeline.
TSS-GEN-012	Configuration files shall be in INI format.
TSS-GEN-013	If the same configuration value is specified in the component configuration file and the general configuration file, the component configuration value shall be the one to be used by the software.
TSS-GEN-014	Each component execution shall be performed through a *spark-submit* command.
TSS-GEN-015	All software dependencies shall be open source.
TSS-GEN-016	All software dependencies shall be free to use.
TSS-GEN-017	The software shall be able to perform spatial computations in a distributed environment.
TSS-GEN-018	The software shall be able to generate code documentation from docstrings.
TSS-GEN-019	The software shall be implemented with modular components following the object-oriented paradigm.
TSS-GEN-020	The software shall be open source and stored in a public repository.
TSS-GEN-021	The software shall use the European Union public license v. 1.2.
TSS-GEN-029	Each component shall log the configuration used in a log file at the start of its execution.
Data	
TSS-GEN-022	The software shall write intermediate and output data in parquet format file.
TSS-GEN-023	If data to be written contains a geometry column, the software shall write intermediate and output data in geoparquet format file.
TSS-GEN-024	The software shall be able to read and write in local filesystems and distributed filesystems (HDFS, AWS S3, GCP, Azure).
TSS-GEN-025	The software shall be able to ingest reference data in csv, json, txt, shapefile and geojson formats.
TSS-GEN-026	The software shall use a spatial grid following the INSPIRE specification for representing spatial data in intermediate calculations through the pipeline.
TSS-GEN-027	Input data, configuration data and all output data generated by a demo execution of an end-to-end pipeline shall be provided in the code repository.
Performance	
TSS-GEN-028	The software shall be able to execute an end-to-end pipeline for any of the use cases in less than 24 hours.

3.2 COMPONENT REQUIREMENTS

*[**Remark** - This section contains the requirements for the components available in the release 0.7 of the software.]*

3.2.1 NetworkCleaning

ID	DEFINITION
TSS-NET-001	The software shall read network topology input data from parquet files stored partitioned by year (YYYY), month (MM), and day (DD).
TSS-NET-002	The software shall be able to write processed network topology data in parquet format, partitioned by year (YYYY), month (MM), and day (DD).
TSS-NET-003	The software shall be able to write processed network topology top frequent errors data in parquet format, partitioned by year (YYYY), month (MM), and day (DD).
TSS-NET-004	The software shall be able to write processed network topology row error metrics data in parquet format, partitioned by year (YYYY), month (MM), and day (DD).
TSS-NET-005	The software shall check that all the mandatory columns specified in Annex I - I.7 Cell Locations with Physical Properties - Raw exist in the input data.
TSS-NET-006	The software shall be able to read network topology input data with the data type scheme specified in Annex I - I.7 Cell Locations with Physical Properties - Raw.
TSS-NET-007	The software shall write output network topology data following the data type scheme specified in Annex I - I.8 Cell Locations with Physical Properties – Cleaned.
TSS-NET-008	The software shall write output syntactic quality metrics following the data type scheme specified in Annex I - I.9 MNO Network Topology Data Quality Metrics.
TSS-NET-009	The software shall write output top frequent error data following the data type scheme specified in Annex I - I.26 MNO Network Topology Top Frequent Erros.
	The software shall write output row error metrics following the data type scheme specified in Annex I – I.27 MNO Network Topology Row Error Metrics.
TSS-NET-10	The software shall discard records where any of the mandatory fields are null.
TSS-NET-011	The software shall discard records where the cell_id field is not a string of length 14 or 15.
TSS-NET-012	The software shall impute a null value in records where the valid_date_start cannot be parsed as a valid timestamp following the ISO:8601 format YYYY-MM-DDThh:mm.ss.
TSS-NET-013	The software shall impute a null value in records where the valid_date_end, if it is not null, cannot be parsed as a valid timestamp following the ISO:8601 format YYYY-MM-DDThh:mm.ss.
TSS-NET-014	The software shall impute null values where the valid_date_start and valid_date_end fields are both non-null, can be parsed to timestamp, and the valid_date_end is an earlier point in time than the valid_end_start.
TSS-NET-015	The software shall discard records where the latitude field is not within the configuration-specified bounding box.
TSS-NET-016	The software shall discard records where the longitude field is not within the configuration-specified bounding box.
TSS-NET-017	The software shall discard records where the antenna_height is less than or equal to 0.
TSS-NET-018	The software shall discard records where the directionality is not equal to either 0 or 1.
TSS-NET-019	The software shall discard records where the azimuth_angle field is null and the directionality field is equal to 1.
TSS-NET-020	The software shall discard records where the azimuth angle is less than 0 or greater than 360, and the directionality field is equal to 1.
TSS-NET-021	The software shall discard records where the elevation_angle is less than -90 or greater than 90.
TSS-NET-022	The software shall discard records where the horizontal_beam_width is less than 0 or greater than 360.
TSS-NET-023	The software shall discard records where the vertical_beam_width is less than 0 or greater than 360.
TSS-NET-024	The software shall discard records where the power is equal to or less than 0.
TSS-NET-025	The software shall impute a null value in records where the range is equal to or less than 0.
TSS-NET-026	The software shall impute a null value in records where the frequency is equal to or less than 0.
TSS-NET-027	The software shall impute a null value in records where the technology is not equal to one of the allowed configuration-specified values.

ID	DEFINITION
TSS-NET-028	The software shall impute a null value in records where the cell_type is not equal to one of the allowed configuration-specified values.
TSS-NET-029	The software shall record the time when the component was executed and save it as the result_timestamp field of the output quality metrics data.
TSS-NET-030	The software shall count the number of records that the input network topology dataset had before performing any transformation or check.
TSS-NET-031	The software shall record a quality metric with the number of registers in the original input network topology dataset, with a field_name of null, and a type_code equal to the "total rows at the start of the method" corresponding error code.
TSS-NET-032	The software shall count the number of records that the output network topology dataset has after all transformations and checks are performed.
TSS-NET-033	The software shall count the number of records that are deleted after the transformations and checks are performed.
TSS-NET-034	The software shall count the number of records that had any erroneous or missing value in any of its fields.
TSS-NET-035	The software shall record a quality metric with the number of registers in the original input network topology dataset, with a field_name of null, and a type_code equal to the "total rows at the end of the method" corresponding error code.
TSS-NET-036	The software shall count, for each of the fields of the input data object I.7 Cell Locations with Physical Properties - Raw (see Annex I), the number of records that had a correct value for that field.
TSS-NET-037	The software shall record a quality metric with the number of correct values in a given field, with a field_name equal to that field's value, and a type_code equal to the "no error" corresponding error code.
TSS-NET-038	The software shall count, for each of the fields of the input data object I.7 Cell Locations with Physical Properties - Raw (see Annex I), the number of records that had a non-admitted null value for that field.
TSS-NET-039	The software shall record a quality metric with the number of null values in a given field, with a field_name equal to that field's value, and a type_code equal to the "null error" corresponding error code.
TSS-NET-040	The software shall count, for each applicable field of the input data I.7 Cell Locations with Physical Properties - Raw (see Annex I), the number of records that had a value that could not be parsed.
TSS-NET-041	The software shall record a quality metric with the number of non-null values that could not be parsed in a given field, with a field_name equal to that field's value, and a type_code equal to the "could not parse" corresponding error code.
TSS-NET-042	The software shall count, for each applicable field of the input data object I.7 Cell Locations with Physical Properties - Raw (see Annex I), the number of records that had a value outside of the accepted value range.
TSS-NET-043	The software shall record a quality metric with the number of non-null values that could not be parsed in a given field, with a field_name equal to that field's value, and a type_code equal to the "out of range" corresponding error code.
TSS-NET-044	The software shall record a quality metric with the number of registers with non-null valid_date_start and valid_date_end fields such that valid_date_end was an earlier point in time than valid_date_start, with a field_name of null, and a type_code equal to the "out of range" corresponding error code.
TSS-NET-045	The software shall be able to count the number of invalid entries found for each of the fields of the input data, as well as the frequency of each particular invalid value.
TSS-NET-046	The software shall be able to record the top *k* most frequent invalid values found in the input data, where *k* is an integer representing the number of most frequent values to record specified via configuration, whenever an absolute number of the most frequent invalid values is indicated via configuration.
TSS-NET-047	The software shall be able to record the most frequent invalid values found in the input data that represent a *k* percentage of all total invalid values ordered by absolute frequency, where *k* is a number larger than 0 and equal or less than 100, whenever a percentage number of the most frequent invalid values is indicated via configuration.

ID	DEFINITION
TSS-NET-048	The software shall read via configuration the parameter *k* and the parameter frequent_error_criterion, indicating whether the top *k* most frequent invalid values or the most frequent invalid values covering *k* percentage of all invalid values must be recorded.
TSS-NET-049	The software shall read via configuration the float parameter latitude_min that will define the bounding box used to check for out-of-range values.
TSS-NET-050	The software shall read via configuration the float parameter latitude_max that will define the bounding box used to check for out-of-range values.
TSS-NET-051	The software shall read via configuration the float parameter longitude_min that will define the bounding box used to check for out-of-range values.
TSS-NET-052	The software shall read via configuration the float parameter longitude_max that will define the bounding box used to check for out-of-range values.
TSS-NET-053	The software shall read via configuration the comma-separated parameter cell_type_options that will define accepted values of the cell_type field.
TSS-NET-054	The software shall read via configuration the comma-separated parameter technology_options that will define accepted values of the technology field.
TSS-NET-055	The software shall read via configuration the date parameter data_period_start, the starting date (included) for which data is to be processed.
TSS-NET-056	The software shall read via configuration the date parameter data_period_end, the ending date (included) for which data is to be processed.

3.2.2 NetworkQualityWarnings

ID	DEFINITION
TSS-NQW-001	The software shall read network topology syntactic quality metrics input data from parquet files stored partitioned by year (YYYY), month (MM) and day (DD).
TSS-NQW-002	The software shall be able to write quality warnings log table in parquet format, partitioned by year (YYYY), month (MM), and day (DD).
TSS-NQW-003	The software shall be able to write line plot data in parquet format, partitioned by variable, year (YYYY), month (MM), day (DD), and execution timestamp.
TSS-NQW-004	The software shall be able to write pie plot data in parquet format, partitioned by variable, year (YYYY), month (MM), day (DD), and execution timestamp.
TSS-NQW-005	The software shall be able to read network topology syntactic quality metrics data following the data type scheme specified in Annex I - I.9 MNO Network Topology Data Quality Metrics.
TSS-NQW-006	The software shall be able to write the output quality warnings log table following the data type scheme specified in Annex I - I.10 MNO Network Topology Data Quality Warnings – log table.
TSS-NQW-007	The software shall be able to write the output line plot data following the data type scheme specified in Annex I - I.23 MNO Network Syntactic Quality Warnings Line Plot Data.
TSS-NQW-008	The software shall be able to write the output pie plot data following the data type scheme specified in Annex I - I.24 MNO Network Syntactic Quality Warnings Pie Plot Data.
TSS-NQW-009	The software shall check that all the metrics for the current date, as well as for the previous period used for comparison, exist in the input data, and stop the execution of the do not.
TSS-NQW-010	The software shall be able to compute the average value of every quality metric for the previous period used for comparison.
TSS-NQW-011	The software shall be able to compute the sample standard deviation of every quality metric for the previous period used for comparison.
TSS-NQW-012	The software shall record, for each quality warning, the date of execution of the quality warnings component.
TSS-NQW-013	The software shall record, for each quality warning, the study date of the metric that raised the warning.
TSS-NQW-014	The software shall record, for each quality warning, the value of the metric that raised the warning.
TSS-NQW-015	The software shall record, for each quality warning, the value of the threshold crossed by the metric that raised the warning.
TSS-NQW-016	The software shall record, for each quality warning, the condition that had to be checked in order to raise the warning
TSS-NQW-017	The software shall record, for each quality warning, a warning text giving context to the raised warning.
TSS-NQW-018	The software shall be able to create a warning when the number of rows before the syntactic checks in the study date, N, verifies some of the following: a) 100 * (N - AVG) / AVG > T1, b) 100 * (N - AVG) / AVG < T2, c) N > AVG + T3 * S, d) N < AVG - T3 * S, e) N > T4, f) N < T5; where AVG and S are the average and standard deviation of the number of rows before the syntactic checks over the previous period respectively, T1 and T2 are percentage thresholds, T3 is a number-of-standard-deviations threshold, and T4 and T5 are absolute thresholds.
TSS-NQW-019	The software shall be able to create a warning when the number of rows before afterthe syntactic checks in the study date, N, verifies some of the following: a) 100 * (N - AVG) / AVG > T1, b) 100 * (N - AVG) / AVG < T2, c) N > AVG + T3 * S, d) N < AVG - T3 * S, e) N > T4, f) N < T5; where AVG and S are, respectively, the average and standard deviation of the number of rows before the syntactic checks over the previous period respectively, T1 and T2 are percentage thresholds, T3 is a number-of-standard-deviations threshold, and T4 and T5 are absolute thresholds.
TSS-NQW-020	The software shall be able to create a warning when the error rate in the study date, E, verifies some of the following: a) 100 * (E - AVG)/AVG > T1, b) E > AVG + T2 * S, c) E > T3; where AVG and S are, respectively, the average and standard deviation of the error rate over the previous period, T1 is a percentage threshold, T2 is a number-of-standard-deviations threshold, and T3 is an absolute threshold.

ID	DEFINITION
TSS-NQW-021	The software shall be able to create a warning when the rate of missing values for any applicable field in the study date, M, verifies some of the following: a) 100 * (M - AVG)/AVG > T1, b) M > AVG + T2 * S, c) M > T3; where AVG and S are, respectively, the average and standard deviation of the rate of missing values for a given field over the previous period, T1 is a percentage threshold, T2 is a number-of-standard-deviations threshold, and T3 is an absolute threshold.
TSS-NQW-022	The software shall be able to create a warning when the rate of out-of-range values for any applicable field in the study date, R, verifies some of the following: a) 100 * (R - AVG)/AVG > T1, b) R > AVG + T2 * S, c) R > T3; where AVG and S are, respectively, the average and standard deviation of the rate of out-of-range values for a given field over the previous period, T1 is a percentage threshold, T2 is a number-of-standard-deviations threshold, and T3 is an absolute threshold.
TSS-NQW-023	The software shall be able to create a warning when the rate of parsing errors for any applicable field in the study date, P, verifies some of the following: a) 100 * (P - AVG)/AVG > T1, b) P > AVG + T2 * S, c) P > T3; where AVG and S are, respectively, the average and standard deviation of the rate of parsing errors for a given field over the previous period, T1 is a percentage threshold, T2 is a number-of-standard-deviations threshold, and T3 is an absolute threshold.
TSS-NQW-024	The software shall be able to write into a parquet file the necessary data to create a line plot showing the time evolution of the number of rows before the syntactic checks over the previous period and the study date, along with the average, upper control limit, and lower control limit over the previous period.
TSS-NQW-025	The software shall be able to write into a parquet file the necessary data to create a line plot showing the time evolution of the number of rows after the syntactic checks over the previous period and the study date, along with the average, upper control limit, and lower control limit over the previous period.
TSS-NQW-026	The software shall be able to write into a parquet file the necessary data to create a line plot showing the time evolution of the error rate over the previous period and the study date, along with the average and upper control limit over the previous period.
TSS-NQW-027	The software shall be able to write in a parquet file the necessary data to create, for each field of the network topology data, a pie plot showing the percentage distribution of errors for that field in the current date.
TSS-NQW-028	The software shall be able to read the extent of the lookback period from a configuration file with the following options: “week” (7 days), “month” (30 days), and “quarter” (90 days).
TSS-NQW-029	The software shall be able to read from a configuration file the percentage threshold over the average for all quality metrics , one per metric.
TSS-NQW-030	The software shall be able to read from a configuration file the percentage threshold under the average for the number of rows before the syntactic checks and the average number of rows after the syntactic checks, one for each metric.
TSS-NQW-031	The software shall be able to read from a configuration file the number of standard deviations threshold over the average for all quality metrics, one per metric.
TSS-NQW-032	The software shall be able to read from a configuration file the number of standard deviations threshold under the average for the number of rows before the syntactic checks and the average number of rows after the syntactic checks, one for each metric.
TSS-NQW-033	The software shall be able to read from a configuration file the absolute threshold over the average for all quality metrics, one per metric.
TSS-NQW-034	The software shall be able to read from a configuration file the absolute threshold under the average for all quality metrics, for the number of rows before the syntactic checks and the average number of rows after the syntactic checks, one for each metric.
TSS-NQW-035	The software shall contain default values for every threshold to be used in case they were not specified via configuration file.

3.2.3 SIGNALSTRENGTHMODELING

ID	DEFINITION
TSS-SSE-001	The software shall read input data objects from parquet files stored partitioned by year (YYYY), month (MM), and day (DD).
TSS-SSE-002	The software shall read INSPIRE grid data from geoparquet files.
TSS-SSE-003	The input shall be I.8 Cell Locations with Physical Properties – Cleaned and I.11 Reference Grid Data Objects (in Annex I).
TSS-SSE-004	The output shall be I.12 Cells Signal Strengths Data Object (in Annex I).
TSS-SSE-005	The software shall read input data for a date range based on the configuration parameter.
TSS-SSE-006	The software shall perform all processing steps for each date in the given date range independently.
TSS-SSE-007	The software shall write output data into parquet format partitioned by year, month, and day.
TSS-SSE-008	The software shall verify the presence of all required attributes of cells for signal strength propagation modeling. The required attributes are: power, antenna_height. If directionality is equal 1, then elevation_angle, vertical_beam_width, horizontal_beam_width shall be present as well.
TSS-SSE-009	The software shall impute missing attributes with default values for different cell types. Default values are provided for 2 cell types: normal cells and micro cells. Default values for normal cells are: power = 10, antenna_height = 30, elevation_angle = 5, vertical_beam_width = 9, horizontal_beam_width = 65 Default values for micro cells are: power = 5, antenna_height = 8, elevation_angle = 5, vertical_beam_width = 9, horizontal_beam_width = 65
TSS-SSE-010	The software shall add additional attributes which are not part of I.8 Cell Locations with Physical Properties – Cleaned, but are required for signal strength modeling. These attributes are: range, path_loss_exponent, azimuth_signal_strength_back_loss, elevation_signal_strength_back_loss
TSS-SSE-011	The software shall add additional attributes with default values for different cell types. Default values are provided for 2 cell types: normal cells and micro cells. Default values for normal cells are: range = 10000, path_loss_exponent = 3.75, azimuth_signal_strength_back_loss = -30, elevation_signal_strength_back_loss = -30 Default values for micro cells are: range = 1000, path_loss_exponent = 6.0, azimuth_signal_strength_back_loss = -30, elevation_signal_strength_back_loss = -30
TSS-SSE-012	If the cell type is missing the software shall impute missing attributes and add necessary additional attributes using a single set of default values. The default values are: power = 5, antenna_height = 8, elevation_angle = 5, vertical_beam_width = 9, horizontal_beam_width = 65, range = 5000, path_loss_exponent = 3.75, azimuth_signal_strength_back_loss = -30, elevation_signal_strength_back_loss = -30
TSS-SSE-013	All default properties for a set of different cell types shall be provided in the configuration file.
TSS-SSE-014	The software shall convert cell antenna power parameters from watts to decibel milliwatts using formula: P(dBm) = 10 * log10(P(W)) + 30
TSS-SSE-013	The software shall create 3D point geometry of cells using latitude, longitude, and elevation plus the height of the antenna.
TSS-SSE-014	The software shall create 3D point geometry of grid centroids by adding elevation.
TSS-SSE-015	If elevation or height of the antenna is missing in the input data, the software shall set these attributes to 0.
TSS-SSE-016	The software shall perform a spatial join of cells with grid centroids based on cell range.
TSS-SSE-017	For signal strength propagation modeling, the software shall calculate planar and 3D cartesian distances between each cell and grid centroids within the cell radius. If both cells and grid centroids' elevations are 0, only planar distance is calculated.

ID	DEFINITION
TSS-SSE-018	The software shall calculate signal strength per grid tile based on the path loss exponent and power attributes of a cell and 3D distance from cell to grid tile. Formula for it is: Sg,a = S0 - Sdist(Rg,a), where S0 is P(dBm), Sdist is path_loss_exponent * 10 * log10(distance_to_cell_3D).
TSS-SSE-019	For directional cells, the software shall support the option for adjusting calculated previously signal strength values using formula Sg,a = S0 - Sdist(Rg,a) - Sazi(δg,a), where S0 - Sdist(Rg,a) is previously calculated signal strength values, Sazi(δg,a) is relation between signal loss and the offset azimuth angles between main direction of a cell and a grid tile. Sazi(δg,a) is calculated using linear transformation of the Gaussian formula: f(φ) = c - c * exp(-(φ^2) / (2 * σ^2)) where c and $\sigma 2$ are constants, whose value is determined by the cell's direction, horizontal beam width and the difference in signal strength between back and front of the cell (azimuth_signal_strength_back_loss). Whether to perform the adjustment or not shall be a configuration parameter.
TSS-SSE-020	For directional cells, the software shall support the option for adjusting signal strength values using formula Sg,a = S0 - Sdist(Rg,a) - Selev(εg,a), where S0 - Sdist(Rg,a) is previously calculated signal strength values, Selev(εg,a) is relation between signal loss and the offset elevation angles between tilt of a cell and a grid tile. Selev(εg,a) is calculated using linear transformation of the Gaussian formula: f(φ) = c - c * exp(-(φ^2) / (2 * σ^2)) where c and $\sigma 2$ are constants, whose value is determined by the elevation angle (tilt), vertical beam width and the difference in signal strength between back and front of the cell (elevation_signal_strength_back_loss). Whether to perform the adjustment step or not should be a configurable parameter.

3.2.4 CELLFOOTPRINTESTIMATION

ID	DEFINITION
TSS-CFE-001	The software shall read input cell plan data from parquet files stored partitioned by year (YYYY), month (MM), and day (DD).
TSS-CFE-002	The software shall read INSPIRE grid data from geoparquet files.
TSS-CFE-003	The input shall be I.8 Cell locations with Physical Properties - Cleaned and I.11 Reference Grid Data Objects.
TSS-CFE-004	The output shall be I.13 Cell Footprints Data Object.
TSS-CFE-005	The software shall write output data objects into parquet format partitioned by year, month, day.
TSS-CFE-006	The software shall read input data for a date range based on the configuration parameter.
TSS-CFE-007	The software shall perform all processing steps for each date in the given date range independently.
TSS-CFE-008	The software shall verify the presence of all required attributes of cells for signal strength propagation modeling. The required attributes are: power, antenna_height. If directionality is equal to 1, then elevation_angle, vertical_beam_width, horizontal_beam_width shall be present as well.
TSS-CFE-009	The software shall impute missing attributes with default values for different cell types. Default values are provided for 2 cell types: normal cells and micro cells. Default values for normal cells are: range = 10000, power = 10, antenna_height = 30, elevation_angle = 5, vertical_beam_width = 9, horizontal_beam_width = 65. Default values for micro cells are: range = 1000, power = 5, antenna_height = 8, elevation_angle = 5, vertical_beam_width = 9, horizontal_beam_width = 65.
TSS-CFE-010	The software shall add additional attributes which are not part of I.8 Cell locations with Physical Properties - Cleaned, but are required for signal strength modeling. These attributes are: path_loss_exponent, azimuth_signal_strength_back_loss, elevation_signal_strength_back_loss
TSS-CFE-011	The software shall add additional attributes with default values for different cell types. Default values are provided for 2 cell types: normal cells and micro cells. Default values for normal cells are: path_loss_exponent = 3.75, azimuth_signal_strength_back_loss = -30, elevation_signal_strength_back_loss = -30. Default values for micro cells are: path_loss_exponent = 6.0, azimuth_signal_strength_back_loss = -30, elevation_signal_strength_back_loss = -30.
TSS-CFE-012	If the cell type is missing the software shall impute missing attributes and add necessary additional attributes using a single set of default values. The default values are: power = 5, antenna_height = 8, elevation_angle = 5, vertical_beam_width = 9, horizontal_beam_width = 65, range = 5000, path_loss_exponent = 3.75, azimuth_signal_strength_back_loss = -30, elevation_signal_strength_back_loss = -30.
TSS-CFE-013	All default properties for a set of different cell types shall be provided in the configuration file.
TSS-CFE-014	The software shall convert cell antenna power parameters from watts to decibel milliwatts using formula: P(dBm) = 10 * log10(P(W)) + 30.
TSS-CFE-015	The software shall create 3D point geometry of cells using latitude, longitude, and elevation plus the height of the antenna.
TSS-CFE-016	The software shall create 3D point geometry of grid centroids by adding elevation.
TSS-CFE-017	If elevation or height of the antenna is missing in the input data, the software shall set these attributes to 0.
TSS-CFE-018	The software shall perform a spatial join of cells with grid centroids based on cell range.
TSS-CFE-019	For signal strength propagation modeling, the software shall calculate planar and 3D cartesian distances between each cell and grid centroids within the cell radius. If both cells and grid centroids' elevations are 0, only planar distance is calculated.
TSS-CFE-020	The software shall calculate signal strength per grid tile based on the path loss exponent and power attributes of a cell and 3D distance from cell to grid tile. Formula for it is: Sg,a = S0 - Sdist(Rg,a), where S0 is P(dBm), Sdist is path_loss_exponent * 10 * log10(distance_to_cell_3D).

ID	DEFINITION
TSS-CFE-021	For directional cells, the software shall adjust calculated previously signal strength values using formula Sg,a = S0 - Sdist(Rg,a) - Sazi(δg,a), where S0 - Sdist(Rg,a) is previously calculated signal strength values, Sazi(δg,a) is relation between signal loss and the offset azimuth angles between main direction of a cell and a grid tile. Sazi(δg,a) is calculated using linear transformation of the Gaussian formula: f(φ) = c - c * exp(-(φ^2) / (2 * σ^2)) where c and $\sigma 2$ are constants, whose value is determined by the cell's direction, horizontal beam width and the difference in signal strength between back and front of the cell (azimuth_signal_strength_back_loss). This step shall be optional.
TSS-CFE-022	For directional cells, the software shall adjust signal strength values using formula Sg,a = S0 - Sdist(Rg,a) - Selev(εg,a), where S0 - Sdist(Rg,a) is previously calculated signal strength values, Selev(εg,a) is relation between signal loss and the offset elevation angles between tilt of a cell and a grid tile. Selev(εg,a) is calculated using linear transformation of the Gaussian formula: f(φ) = c - c * exp(-(φ^2) / (2 * σ^2)) where c and $\sigma 2$ are constants, whose value is determined by the elevation angle (tilt), vertical beam width and the difference in signal strength between back and front of the cell (elevation_signal_strength_back_loss). This step shall be optional.
TSS-CFE-023	The software shall produce a 'footprint' attribute of type float in the domain [0, 1] from 'signal strength' input.
TSS-CFE-024	Transformation of 'signal strength' to 'signal dominance' shall be performed using logistic equation: $s(g, a)$ = 1 / (1 + exp $(-Ssteep(S(g, a) - Smid))$).
TSS-CFE-025	Parameters for signal strength transformation equation - Ssteep and Smid shall be defined in configuration file. Default values are Ssteep = 0.2, $Smid$ = -92.5.
TSS-CFE-026	The software shall have functionality to prune records by selecting cells which share to the total signal dominance of a grid tile is higher than the given threshold.
TSS-CFE-027	The software shall have functionality to prune records by selecting top X cell footprints per grid tile.
TSS-CFE-028	The software shall have functionality to prune records by selecting signal dominance values higher than given threshold.
TSS-CFE-029	Pruning steps are optional. Whether the step is performed or not shall be based on config parameters.
TSS-CFE-030	Parameters for defining top X cells per grid tile and threshold signal dominance values shall be defined in configuration file.

3.2.5 CELLCONNECTIONPROBABILITYESTIMATION

ID	DEFINITION
TSS-CCPPPE-001	The software shall read input data objects from parquet files stored partitioned by year (YYYY), month (MM), and day (DD).
TSS-CCPPPE-002	The software shall have one or two inputs: cell footprint values (mandatory) and land use prior probabilities (optional).
TSS-CCPPPE-003	The input schema for the cell footprint values input dataset shall be I.13 Cell Footprints. This input is mandatory.
TSS-CCPPPE-004	The input schema for the land use prior probabilities input dataset shall be I.11 Reference Grid. This input is optional.
TSS-CCPPPE-005	The software shall write output data objects to parquet files stored partitioned by year (YYYY), month (MM), and day (DD).
TSS-CCPPPE-006	The software shall have one output: cell connection probability values.
TSS-CCPPPE-007	The output schema for cell connection probability values shall be I.15 Cell Connection and Posterior Probabilities.
TSS-CCPPPE-008	The software shall receive a configurable value for the validity period of input data (start and end dates).
TSS-CCPPPE-009	The software shall receive a configurable boolean value for deciding whether to use the land use prior probabilities input data in calculating the posterior_probability column.
TSS-CCPPPE-010	For each date in the validity period, for each grid tile, the software shall calculate the sum of cell signal dominances on that grid tile using the corresponding data from the cell footprint values input dataset.
TSS-CCPPPE-011	For each date, for each grid tile, for each cell, the software shall calculate normalized signal dominance. Normalized signal dominance is calculated by dividing the cell signal dominance value by the sum of signal dominance values of the same grid tile on the same date.
TSS-CCPPPE-012	For each date, for each grid tile, the normalized signal dominance values shall add up to a sum of 1.
TSS-CCPPPE-013	If using land use prior probabilities is enabled, for each date, for each grid tile, for each cell, the software shall calculate the posterior probability. Posterior probability is calculated by multiplying the normalized signal dominance value by the prior probability value of the same grid tile in the land use prior probabilities input dataset.
TSS-CCPPPE-014	If using land use prior probabilities is not enabled, the posterior probability value is equal to the normalized signal dominance value.
TSS-CCPPPE-015	For each date, for each grid tile, for each cell, the software shall calculate the cell connection probability. The cell connection probability is calculated by dividing the posterior probability value by the sum of posterior probability values of the same cell on the same date.
TSS-CCPPPE-016	For each date, for each cell, the normalized cell connection probability values shall add up to a sum of 1.
TSS-CCPPPE-017	For each date, for each grid tile, for each cell, the output shall contain both the normalized signal dominance and the normalized cell connection probability.

3.2.6 EVENTCLEANING

ID	DEFINITION
TSS-EVN-001	The software shall read event input data from parquet files stored under a folder structure with the format year=YYYY/month=MM/day=DD/user_id_modulo=x where YYYY represents the year, MM the month, DD the day for the event, x the user id modulo value and the '/' symbol denotes different folders.
TSS-EVN-002	The software shall be able to write the syntactically cleaned event output data in parquet format, partitioned by year (YYYY), month (MM) and day (DD), and user_id_modulo in the schema defined I.2 MNO Event Data – Syntactically Cleaned.
TSS-EVN-003	The software shall be able to write the quality metrics frequency distribution in parquet format, partitioned by date, in the schema defined in I.4 MNO Event Data Syntactic Quality Metrics – frequency distribution.
TSS-EVN-004	The software shall be able to write the quality metrics by column in parquet format, partitioned by date, in the schema defined in I.3 MNO Event Data Syntactic Quality Metrics – by column.
TSS-EVN-005	The software shall check that all the mandatory columns specified in I.1 MNO Event Data – Raw data object exist in the input data.
TSS-EVN-006	If the input data is missing an optional column, the software shall create the optional column with all its values set to the null value.
TSS-EVN-007	The software shall create a year column of the pyspark datatype ShortType from the timestamp data.
TSS-EVN-008	The software shall create a month column of the pyspark datatype ByteType from the timestamp data.
TSS-EVN-009	The software shall create a day column of the pyspark datatype ByteType from the timestamp data.
TSS-EVN-010	The software shall sort the output data to be written by the user_id and timestamp column.
TSS-EVN-011	The software shall write output data in parquet format partitioned by year, month, day and user_id_modulo.
TSS-EVN-012	The software shall infer the domain of the data following the logic: • If the plmn value is not null, the domain is outbound. • If the mcc value is equal to local_mcc (defined in the configuration), the domain is domestic. • Otherwise, the domain is inbound.
TSS-EVN-013	The software shall discard domestic and inbound records which do not meet at least one of the following conditions: • the cell_id value is valid; • latitude and longitude values are valid.
TSS-EVN-014	The software shall discard records in which any mandatory field doesn't comply with the field requirements specified in the I.1 MNO Event Data – Raw data object.
TSS-EVN-015	The software shall be able to receive by configuration a *bounding_box* value composed of four decimal numbers that define a square within WGS84 bounds.
TSS-EVN-016	The software shall discard records in which the user_id is not a binary data type of 32 bytes.
TSS-EVN-017	The software shall discard domestic and inbound records which do not meet both of the following conditions: • the mcc value is a 3-digit code; • the mnc is a 2- or 3-digit code (can also begin with 0).
TSS-EVN-018	The software shall discard outbound records where the plmn value is not a 5 or 6 digit number.
TSS-EVN-019	The software shall discard domestic and inbound records if no latitude and longitude values are given and the cell_id does not follow CGI and eCGI standards.
TSS-EVN-020	The software shall discard domestic and inbound records if no cell_id value is given and the latitude or longitude values are not within WGS84 bounds and the *bounding_box* if given by configuration.
TSS-EVN-021	The software shall receive timestamp data in UTC format.
TSS-EVN-022	The software shall extract the first 12 characters of the user id hash, convert it into integer of base 10, and apply the modulo function on that result to calculate the user_id_modulo.
TSS-EVN-023	The software shall discard records with identical timestamps and identical location information for every user, i.e. it shall remove same location duplicates from the data. Two rows have an identical location information when user_id, timestamp, cell_id, longitude and latitude and plmn columns are identical.

3.2.7 EVENTQUALITYWARNINGS

ID	DEFINITION
TSS-EVN-QW-001	The software shall be able to perform Quality Warnings checks after MNO Event Cleaning - Syntactic Checks.
TSS-EVN-QW-002	The software shall be able to read and process configs of Event Cleaning Quality Warnings.
TSS-EVN-QW-003	The software shall read Quality Metrics of MNO Event Cleaning in parquet format stored under a folder structure with the format date=YYYY-mm-dd. The Quality Metrics include Frequency Distribution and By Column Data Objects, with schema specified in I.4 MNO Event Data Syntactic Quality Metrics – frequency distribution and I.3 MNO Event Data Syntactic Quality Metrics – by column.
TSS-EVN-QW-004	The output of the component shall be a Log Table and ForPlots Data Objects following the data type scheme specified in I.5 MNO Event Data Quality Warnings – log table and I.22 MNO Event Data Quality Warnings – for plots.
TSS-EVN-QW-005	The software shall perform Quality Warnings based on Quality Metrics data. Given that data_period_startand data_period_end define the time boundaries of Event Quality Warnings, the period of available data of Quality Metrics should span over [data_period_start - lookback_period, data_period_end], since the intermediate results for Quality Warnings are calculated based on previous data.
TSS-EVN-QW-006	The software shall write Quality Warnings Log Table and ForPlots data into parquet format partitioned by date column, the storing period of Log Table should be [data_period_start , data_period_end], ForPlots - [data_period_start - lookback_period, data_period_end].
TSS-EVN-QW-007	The software shall compute Quality Warnings and store results in Log Table Data Object regarding data size (initial and final frequency), which includes checking if a size within a range of two absolute numbers (upper and lower limit) and between [mean+X*std, mean-X*std] boundaries (calculated based on lookback data). Applicable only for Event Cleaning Quality Warnings.
TSS-EVN-QW-008	The software shall compute Quality Warnings and store results in Log Table Data Object regarding error rate (formula = (Total initial frequency - Total final frequency) / Total initial frequency*100))on four granularity levels: by date, by date and cell_id, by date and user_id, by date and cell_id and user_id. The error rate is checked on three warnings: should not be higher than some absolute number; should not be higher than average of previous error rates by some X%, should not be higher than mean + X*std (average and std are calculated on lookback data). Applicable only for Event Cleaning Quality Warnings.
TSS-EVN-QW-009	The software shall compute Quality Warnings and store results in Log Table Data Object regarding error type rate for each specified error rate&field name combination (formula = number of errors of error type&field name combination / Total initial frequency *100). The checks on error type rate contains three warnings: it must not exceed a specific absolute number; it should not surpass the average of prior error type rates by a certain percentage X; and it cannot be greater than the mean plus X times the standard deviation (where both average and standard deviation are determined using historical data). Applicable for Event Cleaning Quality Warnings.
TSS-EVN-QW-010	The software shall store data in ForPlots Data Object to plot three variables' distribution - initial frequency, final frequency, and error rate by date along with their corresponding mean, mean+X*std (UCL - upper control limit), mean-X*std values (LCL - lower control limit), computed on lookback period. Applicable only for Event Cleaning Quality Warnings.
TSS-EVN-QW-011	The software’s orchestration shall provide the option to flexibility define what group of Quality Warnings to compute and what values for different thresholds to choose.

3.2.8 EVENTDEDUPLICATION

ID	DEFINITION
TSS-EVNDED-001	The software shall perform removal of same and different location duplicates and calculate corresponding quality metrics.
TSS-EVNDED-002	The software shall read and process configs of EventDeduplication module.
TSS-EVNDED-003	The input event data schema shall be I.2 MNO Event Data – Syntactically Cleaned.
TSS-EVNDED-004	The software shall calculate and write three quality metrics: (i) *same location deduplication discarded row count*, (ii) *different location deduplication discarded row count*, (iii) *record frequency distribution.*
TSS-EVNDED-005	The output schema for deduplicated event data shall be I.6 MNO Event Data – Deduplicated.
TSS-EVNDED-006	The software shall distinguish between two types of duplication errors: same location duplicates and different location duplicates. In case of same location duplicates, only one row is kept. In case of different location duplicates, all rows are dropped. All rows that remain are considered deduplicated event data.
TSS-EVNDED-007	The software shall apply same location deduplication before different location deduplication.
TSS-EVNDED-008	The software shall identify as a group of same location duplicates any two or more event records that meet each of the following conditions: (i) identical user id, (ii) identical timestamp, (iii) identical location (either (iiia) identical cell id or (iiib) identical longitude-latitude pair).
TSS-EVNDED-009	The software shall for each group of same location duplicates keep one record and discard all other records.
TSS-EVNDED-010	The software shall calculate the *same location deduplication discarded row count quality metric* as the total number of records discarded by same location duplicate removal for each date.
TSS-EVNDED-011	The output schema for the *same location deduplication discarded row count quality metric* shall be I.3 MNO Event Data Syntactic Quality Metrics – by column, using the error code reserved for same location duplicate errors.
TSS-EVNDED-012	The software shall identify as a group of different location duplicates any two or more event records that meet each of the following conditions: (i) identical user id, (ii) identical timestamp, (iii) non-identical location (either (iiia) non-identical cell id or (iiib) non-identical longitude-latitude pair).
TSS-EVNDED-013	The software shall for each group of different location duplicates discard all the records.
TSS-EVNDED-014	The software shall calculate the *different location deduplication discarded row count quality metric* as the total number of records discarded by different location duplicate removal for each date.
TSS-EVNDED-015	The output schema for the *different location deduplication discarded row count quality metric* shall be I.3 MNO Event Data Syntactic Quality Metrics – by column, using the error code reserved for different location duplicate errors.
TSS-EVNDED-016	The software shall calculate the *record frequency distribution quality metric* as the number of records per user per cell before deduplication and after deduplication for each date.
TSS-EVNDED-017	The output schema for the *record frequency distribution quality metric* shall be I.4 MNO Event Data Syntactic Quality Metrics – frequency distribution.

3.2.9 SEMANTICCLEANING

ID	DEFINITION
TSS-ESC-001	The software shall be able to read deduplicated event input data from parquet files stored partitioned by year (YYYY), month (MM), day (DD), and user_id_modulo.
TSS-ESC-002	The software shall be able to read clean network topology input data from parquet files stored partitioned by year (YYYY), month (MM), and day (DD).
TSS-ESC-003	The software shall be able to read syntactically clean event input data with the data type scheme specified in I.2 MNO Event Data - Syntactically Cleaned.
TSS-ESC-004	The software shall be able to read clean network topology input data with the data type scheme specified in I.8 Cell locations with Physical Properties - Cleaned.
TSS-ESC-005	The software shall be able to write the semantically clean event output data in parquet format, partitioned by year (YYYY), month (MM), day (DD), and user_id_modulo.
TSS-ESC-006	The software shall be able to write the semantic quality metrics output data in parquet format, partitioned by year (YYYY), month (MM), and day (DD).
TSS-ESC-007	The software shall be able to write the output semantically cleaned event data at device level following the data scheme specified in I.16 MNO Event data - Semantically Cleaned.
TSS-ESC-008	The software shall be able to write the output device semantic quality metrics following the data scheme specified in I.17 MNO Device Semantic Quality Metrics. The software shall be able to identify outbound events as events where the MCC component of the PLMN column differs from the configuration-specified local MCC value. The software shall apply only duplicate error checking (TSS-ESC-021) to outbound records. Outbound records shall not be tested for other error types.
TSS-ESC-009	The software shall be able to flag with the corresponding error code those event registers which make a reference to a cell ID that does not exist in the input network topology data for the date in which that event was registered.
TSS-ESC-010	The software shall be able to flag with the corresponding error code those event registers which make a reference to a cell ID that does in the input network topology data for the date in which that event was registered, but is not operational at the moment the event was registered.
TSS-ESC-011	The software shall be able to flag with the error code corresponding to certain incorrect location an event register where the estimated distance and speed between this event and both the previous and following event are above some distance and speed thresholds specified via configuration.
TSS-ESC-012	The software shall be able to flag with the error code corresponding to suspicious incorrect location an event register where the estimated distance and speed between this event and either the previous or the following event, but not both at the same time, are above some distance and speed thresholds specified via configuration.
TSS-ESC-013	The software shall be able to flag with the error code corresponding to suspicious incorrect location the first event of a user if the estimated distance and speed with the second event register are above some distance and speed thresholds specified via configuration.
TSS-ESC-014	The software shall be able to flag with the error code corresponding to different location duplicate
TSS-ESC-015	The software shall not delete any event registers when they are flagged.
TSS-ESC-016	The software shall be able to count the number of events flagged with each error code for a given day.
TSS-ESC-017	The software shall be able to count the number of events not flagged with any error code for a given day.
TSS-ESC-018	The software shall be able to record each quality metric together with the timestamp of the moment when the component was executed.
TSS-ESC-019	The software shall be able to record each quality metric together with the date to which it refers.
TSS-ESC-020	The software shall be able to read from a configuration file the minimum distance threshold, in meters, above which an event might be flagged with a location related error code.
TSS-ESC-021	The software shall be able to flag with the corresponding error code those event registers which are different location duplicates. These are rows which have identical timestamp values for a given user, but non-identical values in any other columns.

3.2.10 SEMANTICQUALITYWARNINGS

ID	DEFINITION
TSS-ESW-001	The software shall be able to read semantic quality metrics input data from parquet files stored partitioned by year (YYYY), month (MM) and day (DD).
TSS-ESW-002	The software shall be able to read semantic quality metrics input data with the data type scheme specified in I.17 MNO Device Semantic Quality Metrics.
TSS-ESW-003	The software shall be able to write bar plot data in parquet format, partitioned by variable, year (YYYY), month (MM), day (DD), and execution timestamp.
TSS-ESW-004	The software shall be able to write the output quality warnings log table following the data type scheme specified in I.18 MNO Event Data at Device Level Semantic Quality Warnings – log table.
TSS-ESW-005	The software shall be able to write the output bar plot data following the data type scheme specified in I.25 Event Data at Device Level Semantic Quality Warnings Bar Plot Data.
TSS-ESW-006	The software shall be able to calculate the percentage with which each error type occurs, including the "no error" type, defined as the fraction of the number of said error type over the total number of events for a given date.
TSS-ESW-007	The software shall be able to calculate, for each error type, the sample standard deviation of the percentage of each error type over a lookback period specified via configuration file for each particular error type.
TSS-ESW-008	The software shall be able to raise a warning, in the case that all lookback period dates are present, when the percentage of a given error type is greater than the average percentage over its lookback period by more than a given number of standard deviations
TSS-ESW-009	The software shall be able to raise a warning, in the case that all lookback period dates are present but are strictly lower than 3, when the percentage of a given error type is greater than a given absolute threshold.
TSS-ESW-010	The software shall not raise a warning for a given error type when any of the dates in its lookback period is missing.
TSS-ESW-011	The software shall record the percentage of each error type (excluding the "no error type").
TSS-ESW-012	The software shall record the threshold computed for a given error type from the average and sample standard deviations of its lookback period whenever all dates in its lookback period are present.
TSS-ESW-013	The software shall be able to write into a parquet file the necessary data to create a bar plot with the dates in its horizontal axis, ranging from the furthest lookback period in the past to the study date, and the absolute count of each error type, including the "no error" type, in the vertical axis, for the dates in which this data exists.
TSS-ESW-014	The software shall be able to write into a parquet file the necessary data to create a bar plot with the dates in its horizontal axis, ranging from the furthest lookback period in the past to the study date, and the percentage of each error type, including the "no error" type, in the vertical axis, for the date in which this data exists.
TSS-ESW-015	The software shall be able to read from a configuration file the lookback period to be considered, measured in days, one per metric.
TSS-ESW-016	The software shall be able to read from a configuration file the number of standard deviations to be considered to compute the thresholds, one per metric.
TSS-ESW-017	The software shall be able to read from a configuration file the percentage threshold to use as threshold when the standard deviation cannot be computed, one per metric.
TSS-ESW-018	The software shall contain default values for every threshold and lookback period, to be used in case they are not specified via configuration file.

3.2.11 DAILYPERMANENCESCORE

ID	DEFINITION
TSS-DPS-001	The software shall read semantically cleaned event input data from parquet files stored partitioned by year (YYYY), month (MM), day (DD), and user_id_modulo.
TSS-DPS-002	The software shall be able to read semantically cleaned event input data with the data type scheme specified in I.16 MNO Event Data - Semantically Cleaned.
TSS-DPS-003	The software shall read cell footprint input data from parquet files stored partitioned by year (YYYY), month (MM), and day (DD).
TSS-DPS-004	The software shall be able to read cell footprint input data with the data type scheme specified in I.13 Cell Footprints.
TSS-DPS-005	The software shall be able to write daily permanence score data to parquet files stored partitioned by year (YYYY), month (MM), day (DD), user_id_modulo, and id_type.
TSS-DPS-006	The software shall write output daily permanence score data following the data type scheme specified in I.21 Daily Permanence Score.
TSS-DPS-007	The software shall load parameter values from a configuration file.
TSS-DPS-008	The software shall load all events of the user within the analyzed date, also including the last event preceding this date and the first event following it.
TSS-DPS-009	The software shall mark outbound events
TSS-DPS-010	The software shall find, for each user and analysed date, each group of 3 events.
TSS-DPS-011	The software shall calculate the minimum Euclidean distance between the cell footprints of the event sequence. E.g.: d(A,B), d(B,C), d(A,C).
TSS-DPS-012	The software shall calculate the sum of the distance from the first cell of the 3-cell event sequence (A) to the second cell (B) plus the distance from this "intermediate" cell (B) to the last cell of the event sequence (C). E.g.: d(A,B,C) = d(A,B) + d(B,C)
TSS-DPS-013	The software shall select the maximum distance from d(A,C) and d(A,B,C). E.g.: d = max(d(A,C),d(A,B,C))
TSS-DPS-014	The software shall calculate the time difference between the first and the last event of each event sequence. E.g.: Δt = t(C) - t(A)
TSS-DPS-015	The software shall calculate the speed resulting from dividing the maximum distance by the time difference between the first and last events of the sequence. s = d / Δt
TSS-DPS-016	The software shall tag all the intermediate events between the first and last events of the sequence as "move" events if the maximum speed (s) is higher than a specified threshold (e.g. 50 km/h).
TSS-DPS-017	The software shall generate a preliminary initial timestamp and a preliminary final timestamp for each permanence-associated event (events which have not been tagged as "move"). The preliminary initial timestamp shall be equal to the average time point between the previous event of the user and this event, and the preliminary final timestamp shall be equal to the average time point between this event and the following. If no previous event or no posterior events are available, a standard predefined displacement (max_time_thresh/2) shall be applied to the event time in order to obtain the initial/final timestamp (e.g. 15 min).
TSS-DPS-018	The software shall modify the preliminary initial timestamp when the previous event happens in the same cell as the current event if the time between the previous event and the current event is higher than a specified threshold. This threshold shall be configurable for day (max_time_thresh_day for 9:00-22:59) and night (max_time_thresh_night for 23:00-8:59) periods (e.g. 2h from 9:00h to 22:59h and 8h from 23:00 to 8:59h). In case the time difference is higher than the theshold, a standard predefined displacement (max_time_thresh/2) shall be applied to the current event time in order to obtain its initial timestamp (e.g. 15 min).
TSS-DPS-019	The software shall modify the preliminary final timestamp when the posterior event happens in the same cell as the current event if the time between the posterior event and the current event is higher than a specified threshold. This threshold shall be configurable for day (max_time_thresh_day for 9:00-22:59)

ID	DEFINITION
	and night (max_time_thresh_night for 23:00-8:59) periods (e.g. 2h from 9:00h to 22:59h and 8h from 23:00 to 8:59h). In case the time difference is higher than the theshold, a standard predefined displacement (max_time_thresh/2) shall be applied to the current event time in order to obtain its final timestamp (e.g. 15 min).
TSS-DPS-020	The software shall modify the preliminary initial timestamp when the previous event happens in a different cell from the current event cell if the time between the previous event and the current event is higher than a specified threshold (max_time_thresh). In case the time difference is higher than the theshold, a standard predefined displacement (max_time_thresh/2) shall be applied to the current event time in order to obtain its initial timestamp (e.g. 15 min).
TSS-DPS-021	The software shall modify the preliminary final timestamp when the posterior event happens in a different cell from the current event cell if the time between the posterior event and the current event is higher than a specified threshold (max_time_thresh). In case the time difference is higher than the theshold, a standard predefined displacement (max_time_thresh/2) shall be applied to the current event time in order to obtain its final timestamp (e.g. 15 min).
TSS-DPS-022	If the current event is abroad event and previous or next event is NULL, the software shall modify initial and final timestamps by subtracting/adding max_time_thersh_abroad time duration from/to current event's timestamp.
TSS-DPS-023	The software shall split the day into N time slots of equal length, where N is the "time_slot_number" parameter loaded from the configuration file and can only take the integer values 24, 48, or 96.
TSS-DPS-024	The software shall intersect each of the N time slots with the permanence events of the user in the analyzed date, and thus obtain, for each time slot, the cells in which the user presents permanence and for how long within the time slot.
TSS-DPS-025	The software shall compute for each user and time slot, the total time in seconds that the user has not presented permanence in any cell.
TSS-DPS-026	The software shall convert from cell to tile by using the cell footprint data, obtaining the information of how long the user presents in each tile in each time slot.
TSS-DPS-027	The software shall map the total time in seconds in a time slot that a user has not presented permanence in any cell to a virtual tile under the name "unknown".
TSS-DPS-028	The software shall map the total time in seconds in a time slot that a user has permanence abroad to a virtual tile with ID value of a mobile country code of the foreign country
TSS-DPS-029	The software shall generate a daily permanence score (DPS) for each time slot and tile combination according to the time that the user presents permanence in that tile during the time slot, *t*, and the duration of that time slot, *T*. The DPS shall be an integer between 0 and 1, following this rule: • If the user presents permanence in a tile for 0 < t < T/2 during the time slot, then DPS = 0 for that user, tile and time slot. • If the user presents permanence in a tile for T/2 <= t <= T during the time slot, then DPS = 1 for that user, tile and time slot.
TSS-DPS-030	The software shall aggregate all grid tiles with DPS=1 per subscriber and timeslot so that DPS is stored as a sparse matrix.
TSS-DPS-031	The software shall add a metadata record for each timeslot in the "id_type" field: • a value of "grid" whenever the "dps" field contains the IDs of grid tiles • "unknown" when the "dps" field contains the "unknown" value. • "abroad" when the "dps" field contains foreign mobile country code

3.2.12 CONTINUOUSTIMESEGMENTATION

ID	DEFINITION
TSS-CTS-001	The software shall read input data from parquet files stored under a folder structure with the format year=YYYY/month=MM/day=DD.
TSS-CTS-002	The input data shall be I.16 MNO Event Data - Semantically Cleaned and I.14 Cell Intersection Groups Data Objects.
TSS-CTS-003	The optional input data is previously calculated I.20 Daily Continuous Time Segments for the date before current processing date.
TSS-CTS-004	The output data shall be I.20 Daily Continuous Time Segments Data Object.
TSS-CTS-005	The software shall write output data in parquet format partitioned by year, month, day.
TSS-CTS-006	The software shall read input data for a date range based on the configuration parameter.
TSS-CTS-007	If the clearing of output directories parameter is set to true, The software shall delete all existing output directories.
TSS-CTS-008	The software shall process date in the configuration-specified data period separately.
TSS-CTS-009	For each date, the software shall read input event data which is from that date and has the error flag value as one of the configuration-specified accepted values.
TSS-CTS-010	For input event data, the software shall mark as abroad all events where the MCC component of the PLMN column does not match the local MCC parameter value.
TSS-CTS-011	For each date, the software shall read input cell intersection groups data which is from that date.
TSS-CTS-012	If the configuration parameter *is_first_run=False*, the software shall read input Daily CTS data which is from that date and has the flag *is_last=True*.
TSS-CTS-013	The software shall add overlapping cell ids to event data by joining event data to cell intersection groups data on cell id.
TSS-CTS-014	If previous Daily CTS data does not exist, the software shall set event data CTS columns to null values.
TSS-CTS-015	If previous Daily CTS data does exist, the software shall perform and outer join between event data to previous Daily CTS data on user_id and set event data CTS columns to the existing CTS values.
TSS-CTS-016	The software shall Convert user_id column to String for Pandas processing and back to binary hex before output.
TSS-CTS-017	For each date, the software shall perform segments aggregation for each user separately using a Pandas UDF.
TSS-CTS-018	The UDF shall retrieve user id, partition modulo, MCC and MNC values from the first row of event data.
TSS-CTS-019	The UDF shall determine current date start timestamp and end timestamp.
TSS-CTS-020	If the user has no data for the current date, the UDF shall generate one time segment for the current date.
TSS-CTS-021	If the user has no data for the current date and the user's latest previous time segment state is ABROAD and the time gap between the previous segment and the end of the current date is below the configuration-specified maximum time threshold, the UDF shall create one time segment starting from the start timestamp of the current date, ending at the end timestamp of the current date, with state UNKNOWN.
TSS-CTS-022	Otherwise, if the user has no data for the current date, the UDF shall generate one time segment starting from the start timestamp of the current date, ending at the end timestamp of the current date, with state UNKNOWN.
TSS-CTS-023	If the user has event data for the current date, the UDF shall calculate adjusted time pad duration, create an initial time segment, and iterate over events in chronological order.
TSS-CTS-024	The UDF shall calculate the adjusted time pad duration. The time pad duration shall be the minimum between the configuration-specified pad time value and half of the time between the start timestamp of the current date and the timestamp of the first event in the current date.
TSS-CTS-025	The UDF shall create an initial time segment that covers the time from the start timestamp of the current date until the first event of the date.
TSS-CTS-026	If the user has no previous time segments, the initial time segment shall start from the start timestamp of the current date, end at the first event's timestamp minus adjusted time pad duration and have state UNKNOWN.

ID	DEFINITION
TSS-CTS-027	If the user has previous time segments, the UDF shall attempt to continue them. If the previous time segment is of state STAY, MOVE, or ABROAD and the duration between the end timestamp of the previous time segment and the timestamp of the first event of the current date is shorter than the state-corresponding configuration-specified maximum time value, the initial time segment shall start from the start timestamp of the current date, end at the first event's timestamp, and have the same state, cells and PLMN values as the previous time segment.
TSS-CTS-028	If the user has previous time segments but they do not fulfill continuing conditions, the initial time segment shall start from the start timestamp of the current date, end at the first event's timestamp minus adjusted time pad duration, and have state UNKNOWN.
TSS-CTS-029	The UDF shall iterate over user events in chronological order to generate time segments for the current date. The UDF shall use the latest time segment when handling each event.
TSS-CTS-030	When iterating, if the current event is abroad and the latest time segment is not state ABROAD, then the UDF shall create one time segment starting from the end timestamp of the latest time segment, ending at the current event's timestamp, with state ABROAD.
TSS-CTS-031	When iterating, if the current event is abroad and the latest time segment is state ABROAD and it shares the MCC value with the current event and the time gap between the end timestamp of the time segment and the current event's timestamp is below the configuration-specified max time threshold, then the UDF shall extend the existing time segment by changing its end timestamp to the current event's timestamp.
TSS-CTS-032	When iterating, if the current event is abroad and the latest time segment is state ABROAD and it does not share the MCC value with the current event and the time gap between the end timestamp of the time segment and current event's timestamp is below the configuration-specified max time threshold, then the UDF shall create one time segment starting from the end timestamp of the latest segment, ending at the current event's timestamp, with state ABROAD.
TSS-CTS-033	When iterating, if the current event is abroad and none of the previous conditions were met, then the UDF shall create one time segment starting from the end of the latest time segment, ending at the current event's timestamp, with state UNKNOWN.
TSS-CTS-034	When iterating, if the current event is local, the UDF shall determine cell intersection. The latest time segment and the current event shall be considered intersected if each of the cells of the latest time segment are included in the current event's overlapping cell ids list.
TSS-CTS-035	When iterating, if the current event is local, the UDF shall calculate the time gap value. The time gap value shall be the duration between the end timestamp of the latest time segment and the current event's timestamp.
TSS-CTS-036	When iterating, if the current event is local and the latest time segment state is UNKNOWN or ABROAD, the UDF shall create one time segment starting from the end timestamp of the latest time segment, ending at the current event's timestamp, with state UNDETERMINED.
TSS-CTS-037	When iterating, if the current event is local and the current event and latest segment are intersected and the time gap is below the configuration-specified threshold and the latest time segment state is UNDETERMINED or STAY, then the UDF shall extend the existing time segment, setting the end timestamp to the current event's timestamp and adding the event's cell to the time segment's list of cells. Then if the duration of the time segment exceeds the configuration-specified minimum stay duration, the UDF shall set the time segment state to STAY.
TSS-CTS-038	When iterating, if the current event is local and the current event and latest segment are intersected and the time gap is below the configuration-specified threshold and the latest time segment state is MOVE, then the UDF shall create one time segment starting from the end timestamp of the latest time segment, ending at the current event's timestamp, with state UNDETERMINED.
TSS-CTS-039	When iterating, if the current event is local and the current event and the latest time segment are not intersected and the time gap is below the configuration-specified threshold, then the UDF shall create two time segments with state MOVE: one starting from the end of the latest segment ending at the halfway point of the time gap, and the other starting from the halfway point and ending at the current event's timestamp.
TSS-CTS-040	When iterating, if the current event is local and none of the previous conditions were met, then the UDF shall extend the end timestamp of the latest segment by the configuration-specified pad time. Then the UDF shall create a new time segment starting from that time point and ending at current event

ID	DEFINITION
	timestamp minus pad time, with state UNKNOWN. Then the UDF shall create a new time segment starting from the event timestamp minus pad time, ending at the current events timestamp, with state UNDETERMINED.
TSS-CTS-041	The UDF shall set the last time segment of the current date with *is_last*=*True*.
TSS-CTS-042	For each date, the software shall convert the daily segments to the expected schema and write the output.

3.2.13 INSPIREGRIDGENERATOR

ID	DEFINITION
TSS-GG-001	The software shall be able to generate Spatial Reference Grid following INSPIRE Specification.
TSS-GG-002	The software shall have possibility to generate Spatial Reference Grid for extent given in WGS84 coordinate system.
TSS-GG-003	The software shall have possibility to generate Spatial Reference Grid for a country polygon given in WGS84 coordinate system.
TSS-GG-004	The software shall be able to read countries dataset input data with the data type and schema specified in I.29 Countries.
TSS-GG-005	Spatial context option (extent or country) for grid generation shall be defined in configuration file.
TSS-GG-006	If spatial context option is extent, extent has to be provided as a parameter. If spatial context option is country, country iso2 code has to be set in config.
TSS-GG-007	The software shall be able to convert spatial zones dataset coordinate system into internal coordinate system (EPSG: 3035) before grid generation.
TSS-GG-008	The software shall be able to extend country polygon to fixed buffer distance before grid generation. Buffer distance shall be provided in config file.
TSS-GG-009	The software shall write grid data object following schema specified in I.28 INSPIRE Grid.
TSS-GG-010	The software shall be able to partition output grid data object by quadkey.
TSS-GG-011	The software shall be able to assign quadkey to each grid tile.
TSS-GG-012	Quadkey level for partitioning shall be provided in configuration file.

3.2.14 SYNTHETICDIARIES

ID	DEFINITION
TSS-SYN-DI-001	The software shall load all necessary parameters from a configuration file.
TSS-SYN-DI-002	The output of the component shall be I.30 Synthetic Diaries parquet files partitioned by year, month and date.
TSS-SYN-DI-003	The software shall generate N activity trip diaries per specified date, where N is a parameter provided through the configuration file.
TSS-SYN-DI-004	The software shall generate, for each user, an activity trip diary that contains some of the stays specified in the 'stay_sequence_superset' by probabilistically generating (or not) each of the stays according to the specified 'stay_sequence_probabilities'.
TSS-SYN-DI-005	The software shall generate, for each user and date, a home location that is within the bounding box provided through the parameters 'longitude_min', 'longitude_max', 'latitude_min' and 'latitude_max'.
TSS-SYN-DI-006	The software shall generate, for each user and date, a work location that is within the bounding box provided through the parameters 'longitude_min', 'longitude_max', 'latitude_min' and 'latitude_max', and which is at a distance between 'home_work_distance_min' and 'home_work_distance_max' of the home location of the user.
TSS-SYN-DI-007	The software shall locate every user stay that is not of type 'home' or 'work' to a location which is at a distance of between 'other_distance_min' and 'other_distance_max' from the location of the previous stay, and which is within the bounding box.
TSS-SYN-DI-008	The software shall assign a duration for each trip (interval between stays), which is equal to the distance between the locations of the stays divided by the specified standard 'displacement distance'.
TSS-SYN-DI-009	The software shall assign a duration for each stay, which shall be compatible with the 'duration min' and 'duration max' parameters corresponding to the stay type.
TSS-SYN-DI-010	The stays and trips of each diary shall cover the whole day, from 00:00:00 to 23:59:59.

3.2.15 SYNTHETICNETWORK

ID	DEFINITION
TSS-SN-001	The software shall be able to write synthetic generated network topology data to parquet files stored partitioned by year (YYYY), month (MM, and day (DD).
TSS-SN-002	The software shall be able to write synthetic generated network topology data following the schema specified in I.7 Cell Locations with Physical Properties - Raw.
TSS-SN-003	The software shall be able to read from a configuration file the start and end date of the range of dates for which data will be generated.
TSS-SN-004	The software shall be able to read from a configuration file the number of cells to be generated.
TSS-SN-005	The software shall be able to read from a configuration file a seed value that will be applied to all the random processes within the component.
TSS-SN-006	The software shall be able to read from a configuration file the latitudes and longitudes defining a bounding box in which cell coordinates will be generated.
TSS-SN-007	The software shall be able to read from a configuration file the minimum and maximum value for the values of the altitude, power, range, and frequency fields.
TSS-SN-008	The software shall be able to read from a configuration file the maximum, positive value that the antenna height field can take.
TSS-SN-009	The software shall be able to read from a configuration file the value that will be set in the valid date start and valid date end fields of all cells.
TSS-SN-010	The software shall be able to read from a configuration file the list of values that the field cell_type can take.
TSS-SN-011	The software shall be able to read from a configuration file the probabilities of not generating any optional fields, of setting null values in mandatory fields, of generating values outside of the allowed ranges, and of creating erroneous values in the cell_id, valid_date_start and valid_date_end fields.
TSS-SN-012	The software shall be able to create physical network topology data for the number of cells and the range of dates specified via configuration.
TSS-SN-013	The software shall be able to create records where all the non-mandatory columns of I.7 Cell Locations with Physical Properties - Raw have a non-null value with a probability specified via configuration.
TSS-SN-014	The software shall be able to create records where mandatory fields have a null value with a probability specified via configuration.
TSS-SN-015	The software shall be able to create records where fields take values outside of the allowed ranges with a probability specified via configuration.
TSS-SN-016	The software shall be able to create records with erroneous values in the cell_id, valid_date_start and valid_date_end fields with a probability specified via configuration.

3.2.16 SYNTHETICEVENTS

ID	DEFINITION
TSS-EVN-QW-001	The software shall be able to read and process the data objects of I.7 Cell Locations with Physical Properties - Raw and I.30 Synthetic Diaries.
TSS-EVN-QW-002	The output of the component shall be I.1 MNO Event Data - Raw partitioned by year, month and date.
TSS-EVN-QW-003	The software shall generate timestamp, latitude and longitude values for moves (move events without cell_ids) based on Synthetic Diaries, taking into account the following: 1)The total amount of events generated on the line between the current stay point and next stay point (as provided in synthetic diaries), shall be equal to the configuration parameterevent_freq_moves. 1. The time differences between event timestamps for a given move event and user shall be randomly distributed. 2. The generated points shall be randomly distributed on the line from the current stay point and next stay point.
TSS-EVN-QW-004	The software shall perform all spatial calculation operations using the coordinate reference system in the configuration parameter cartesian_crs.
TSS-EVN-QW-005	The software shall generate timestamp, latitude and longitude values for stays (stay events without cell_ids) based on Synthetic Diaries, taking into account the following: 1. The total amount of events generated for the stay location (a single point) between the period of initial and final timestamp of a stay, shall be equal to event_freq_moves. 2. The time differences between event timestamps for a given stay event and user shall be randomly distributed.
TSS-EVN-QW-006	The software shall generate timestamp, latitude and longitude values for stays (stay events without cell_ids) based on Synthetic Diaries, taking into account the following: 1. the total amount of events generated for the stay location (a single point) between the period of initial and final timestamp of a stay, shall be equal to event_freq_moves. 2. The time differences between event timestamps for a given stay event and user shall be randomly distributed.
TSS-EVN-QW-007	From the generated stays and move events, the software shall randomly select, using as seed the configuration parameter seed, the ratio of rows equal to error_location_probability for generating location errors. It shall modify the longitude and latitude values of these rows, taking into account the following: 1. The minimum distance from the existing point to the newly generated erroneous point shall not be below the configuration parameter error_location_distance_min and the maximum distance shall not exceed the configuration parameter error_location_distance_max. 2. The software shall support generating error values in all directions: north, east, south and west of a point. 3. The software shall store the distance from the newly generated point and existing point in the column loc_error.
TSS-EVN-QW-008	From the generated stays and move events, the software shall randomly select, using as seed the configuration parameter seed, the ratio of rows equal to error_cell_id_probability for the generating errors in the cell_id column. It shall create a cell_id column for the selection of these rows, considering the following: 1. The generated cell_id values shall syntactically follow the format of the cell_id column. 2. The generated cell_id shall be such that no cell_id value in the Synthetic Network data matches it.
TSS-EVN-QW-009	The software shall calculate the closest cell_id for each generated event, based on the latitude and longitude values, taking into account the following: 1. For every event, only cells within the distance defined by configuration parameter closest_cell_distance_max are considered. 2. For every event, the cell_id is selected randomly but only as many cells are considered, as defined by the configuration parameter max_n_of_cells.

ID	DEFINITION
TSS-EVN-QW-010	The software shall set the value of mcc and mnc as a single value for all users as defined by configuration parameters mcc and mnc respectively.
TSS-EVN-QW-011	The software shall set the value of plmn as null for all users.
TSS-EVN-QW-012	The software shall generate timestamp values in events that are not within the time boundaries given in synthetic diaries (out of bound timestamps) according to a configuration provided probability value. If the given probability is zero, no such errors are generated.
TSS-EVN-QW-013	The software shall generate syntactically erroneous values in events according to configuration provided probability value. These are values that have the same data type as expected, yet the values are not syntactically correct. For example, for columns longitude and latitude, these may be values outside acceptable ranges (greater than 180), for the cell_id column, values that do not follow the format of cell_ids, etc. If the given probability is zero, no such errors are generated.
TSS-EVN-QW-014	The software shall generate same location duplicates in events based on a given probability value. These are rows that have identical location information as well as timestamp information. If the given probability is zero, no such errors are generated.
TSS-EVN-QW-015	The software shall generate different location duplicates in events based on a given probability value. These are rows that have identical timestamps, but differences in at least one of the location information columns (longitude, latitude, cell_id). If the given probability is zero, no such errors are generated.

3.2.17 PRESENTPOPULATIONESTIMATION

ID	DEFINITION
TSS-PPE-001	The software shall be able to read semantically cleaned event input data from parquet files stored partitioned by year (YYYY), month (MM), day (DD), and user_id_modulo.
TSS-PPE-002	The software shall be able to read cell connection probabilities input data from parquet files stored partitioned by year (YYYY), month (MM), and day (DD).
TSS-PPE-003	The software shall be able to read clean semantically cleaned event input data with the data type scheme specified in I.16 MNO Event Data - Semantically Cleaned.
TSS-PPE-004	The software shall be able to read cell connection probabilities input data with the data type scheme specified in I.15 Cell Connection and Posterior Probabilities.
TSS-PPE-005	The software shall be able to perform computations based on the 100m x 100m INSPIRE grid with the data type scheme specified in I.28 INSPIRE Grid.
TSS-PPE-006	The software shall be able to write the estimated present population output data in parquet format, partitioned by year (YYYY), month (MM), day (DD).
TSS-PPE-007	The software shall be able to write the output estimated present population data following the data scheme specified in I.42 Present Population (at grid level) if so specified via configuration file.
TSS-PPE-008	The software shall be able to read from a configuration file the timestamp for which the present population is to be estimated.
TSS-PPE-009	The software shall be able to read from a configuration file the time gap, in seconds, such that all devices with a register with a time difference to the timestamp no larger than this gap will be included in the estimation of the present population.
TSS-PPE-010	The software shall be able to read from a configuration file the tolerance threshold for the sum of absolute differences between the spatial distribution of devices of the current iteration and the previous iteration over all grid tiles, to stop the iterative procedure of this component.
TSS-PPE-011	The software shall be able to read from a configuration file the maximum number of iterations that the estimation procedure will be allowed to run for.
TSS-PPE-012	The software shall be able to read all registers that are within a distance of the timestamp no larger than the time gap specified via configuration, including registers of the previous or following day if the time gap crosses over midnight.
TSS-PPE-013	The software shall filter out all registers that have a time difference larger than the time gap with respect to the timestamp.
TSS-PPE-014	The software shall consider the remaining devices together with the cell they connected to according to their register closest to the timestamp. In the case that two events are equally close to the timestamp, the earlier event is selected.
TSS-PPE-015	The software shall count, for each cell, the number of devices that have connected to that cell in their register closest to the timestamp.
TSS-PPE-016	The software shall estimate the spatial distribution of devices over the grid tiles that cover the country and its buffer through an iterative Bayesian procedure.
TSS-PPE-017	The software shall use a uniform prior distribution of the devices over the grid tiles equal to the total number of devices divided by the total number of grid tiles of the distribution as the initial value of the spatial distribution of devices.
TSS-PPE-018	The software shall, in each iteration, compute the posterior probability of a device being in grid tile *j* when connected to cell *i* according to Bayes' theorem, multiplying the value of the spatial distribution for tile *j* found in the previous iteration (the prior) by the known cell connection probability of connecting to cell *i* when being in tile *j*, and then normalising over all grid tiles.
TSS-PPE-019	The software shall, in each iteration, compute the new spatial density of devices for a given grid tile *j* as the sum, over all cells *i*, of the product of devices connected to cell *i* and the posterior probability of being in grid tile *j* when connected to cell *i*.
TSS-PPE-020	The software shall stop the iterative estimation if the number of iterations exceeds the maximum number of iterations specified via the configuration file.
TSS-PPE-021	The software shall stop the iterative estimation if the sum of absolute differences between the spatial distribution of devices of the current iteration and the previous over all grid tiles is less than the tolerance threshold specified via configuration file.

ID	DEFINITION
TSS-PPE-022	The software shall take the spatial distribution of devices over the grid tiles obtained in the iterative procedure as the estimation of the present population.

3.2.18 GRIDENRICHMENT

ID	DEFINITION
TSS-GE-001	The software shall be able to read INSPIRE Grid data object partitioned by quadkey with schema specified in I.28 INSPIRE Grid.
TSS-GE-002	The software shall be able to read transportation data in a format and schema specified in I.33 Transportation.
TSS-GE-003	The software shall be able to read landuse data in a format and schema specified in I.32 Landuse.
TSS-GE-004	The software shall ensure that all processing steps are compliant with spatial data processing standards and ensure accurate spatial data manipulation to prevent data integrity issues.
TSS-GE-005	The software shall include error handling mechanisms to manage missing or incomplete data inputs.
TSS-GE-006	The software shall be able to calculate landuse prior probabilities and path loss exponent coefficient for each input grid tile using landuse and transportation data. This shall be optional based on configuration parameter.
TSS-GE-007	If landuse and transportation data are not available or prior probabilities and path loss exponent not used in pipeline application the software shall skip corresponding processing steps and assign value 1 to both variables.
TSS-GE-008	The software shall write grid data object following schema specified in I.31 Enriched Grid partitioned by quadkey.
TSS-GE-009	The software shall be able to convert transportation lines to polygons using predefined buffer widths specific to each transportation class (primary, secondary, tertiary, pedestrian, railroad) as specified in the configuration.
TSS-GE-010	The software shall be able to perform spatial operations to intersect and merge landuse polygons with transportation polygons based on their geographical boundaries in a way that transportation polygons do not overlap with landuse polygons.
TSS-GE-011	The software shall create grid tiles polygons from grid tiles IDs
TSS-GE-012	The software shall intersect grid tiles to calculate the proportion of each landuse category within the boundaries of each grid tile. This includes calculating the area of each landuse category within a tile as a percentage of the total tile area.
TSS-GE-013	If any landuse category is missing in any given grid tile the software shall assign 0.0 as area share value.
TSS-GE-014	If there are no landuse categories in any given grid tile the software shall assign 1.0 as open_area category area share value.
TSS-GE-015	The software shall apply the predefined weights to the proportions of landuse categories within each grid tile to calculate the landuse prior probabilities. The software shall normalize these probabilities so that the sum across the whole grid equals one.
TSS-GE-016	The software shall apply the predefined weights to the proportions of landuse categories within each grid tile to calculate the path loss exponent coefficient for each tile.
TSS-GE-017	The software shall provide functionality to configure the weights for the calculation of both landuse prior probabilities and path loss exponent coefficients. This configuration should allow adjustment of weights for each landuse category.

3.2.19 GEOZONESGRIDMAPPING

ID	DEFINITION
TSS-ZGM-001	The software shall be able to read INSPIRE Grid data object partitioned by quadkey with schema specified in I.28 INSPIRE Grid.
TSS-ZGM-002	The software shall be able to perform mapping of either administrative units data or other geographic zones data to grid. Which zoning type to use shall be defined in config file
TSS-ZGM-003	If 'administrative units' is the selected zoning type, the software shall be able to read administrative zoning data in a format and schema specified in I.34 Administrative Units.
TSS-ZGM-004	If 'other geographic zones' is the selected zoning type, the software shall be able to read other geographic zoning data in a format and schema specified in I.35 Geographic Zones.
TSS-ZGM-005	The software shall be able to perform mapping with any datasets of a given zoning type based on configuration parameter.
TSS-ZGM-006	The software shall perform spatial intersection operation using grid tiles centroids and zone polygons.
TSS-ZGM-007	The software shall extract number of hierarchical levels from zoning dataset. If number of levels is more than 1, so the dataset is hierarchical, mapping shall be performed on the lowest level of hierarchy
TSS-ZGM-008	For each grid tile the software shall extract zone IDs of all levels of hierarchy and combine them into hierarchical id using "|" as a separator between levels.
TSS-ZGM-009	If a grid tile centroid doesn't spatially intersect with any of the given zones' polygons, zone_id and hierarchica_id shall be set to 'undefined'
TSS-ZGM-010	The software shall write grid data object following schema specified in I.36 Zones – Grid Map partitioned by dataset_id.

3.2.20 MIDTERMPERMANENCEESTIMATION

ID	DEFINITION
TSS-MPE-001	The software shall be able to read daily permanence score input data from parquet files stored partitioned by year (YYYY), month (MM), day (DD), id_type, and user_id_modulo.
TSS-MPE-002	The software shall be able to read holiday dates input data from parquet files.
TSS-MPE-003	The software shall be able to read the I.21 Daily Permanence Score and I.40 Holiday Dates Calendar Data Objects.
TSS-MPE-004	The software shall be able to write mid-term permanence score metrics to parquet files stored partitioned by year (YYYY), month (MM), day_type, time_interval, id_type, and user_id_modulo.
TSS-MPE-005	The software shall write results data following schema specified in I.38 Mid-Term Permanence Metrics for all full months provided in the configured processing interval.
TSS-MPE-006	The software shall be able to read from a configuration file the start and end month for interval to process in the format YYYY-MM.
TSS-MPE-007	The software shall be able to read from a configuration file the country of study for which to consider holiday dates.
TSS-MPE-008	The software shall be able to read from a configuration file the number of days (as a positive integer) for which to include data from the previous month. This parameter will determine the number of calendar days, for which the values of the daily permanence score data object are read, prior to the month currently being processed. For instance, if the currently processable month is defined as 05-2024, and the parameter value is 15, rows from the daily permanence data object corresponding to dates between 16-04-2024 and 30-04-2024 are also included in the processing for mean and standard deviation calculation of regularity indices, but not for frequency calculation.
TSS-MPE-009	The software shall be able to read from a configuration file the number of days (as a positive integer) for which to include data from the next month. This parameter will determine the number of calendar days, for which the values of the daily permanence score data object are read, after the month currently being processed. For instance, if the currently processable month is defined as 05-2024, and the parameter value is 15, rows from the daily permanence data object corresponding to dates between 01-06-2024 and 15-06-2024 are also included in the processing for mean and standard deviation calculation of regularity indices, but not for frequency calculation.
TSS-MPE-010	The software shall be able to read from a configuration file the definition of a day based on its start hour. For example, one might want to consider that a day D starts at 4 AM. The definition shall be limited to full hours, and the parameter must be an integer between 0 and 23. All sub-monthly intervals shall be defined using these borders. For example, Monday interval shall be defined from Monday 4 AM until Tuesday 4 AM.
TSS-MPE-011	The software shall be able to read from a configuration file the definition of 'night_time' hours as a list of different start and ending hours, in HH:MM format, for example 18:45 to 08:15. Allowed values of the minutes (MM) are 00, 15, 30, and 45. Following the definition of a day based on its start hour, specified via configuration, the 'night_time' will belong to the date that contains its start hour. It is allowed that the 'night_time' hours cross the limit between two dates. It is not allowed, however, that when the 'night_time' end hour is different from 00:00 and the 'night_time' start hour is earlier than the day start hour, the 'night_time' end hour is earlier than the 'night_time' start hour. Example of non-allowed configuration: day start hour equal to 4, 'night_time' start hour equal to 03:30, 'night_time' end hour equal to 01:00 (01:00 < 03:30 < 04:00).
TSS-MPE-012	The software shall be able to read from a configuration file the definition of 'working_hours' as a list of different start and ending hours, in HH:MM format, for example 08:00 to 17:00. Allowed values of the minutes (MM) are 00, 15, 30, and 45. Following the definition of a day based on its start hour, specified via configuration, the 'working_hours' will belong to the date that contains its start hour. It is not allowed that the 'working_hours' cross the limit between two dates. It is also not allowed that when the 'working_hours' end hour is different from 00:00 and the 'working_hours' start hour is earlier than the day start hour, the 'working_hours' end hour is earlier than the 'working_hours' start hour. Example of non-allowed configuration: day start equal to 4, 'working_hours' start hour equal to 03:30, 'working_hours' end hour equal to 01:00 (01:00 < 03:30 < 04:00).

ID	DEFINITION
TSS-MPE-013	The software shall be able to read from a configuration file the definition of ‘evening_hours’ as a list of different start and ending hours, in HH:MM format, for example 08:00 to 17:00. Allowed values of the minutes (MM) are 00, 15, 30, and 45. Following the definition of a day based on its start hour, specified via configuration, the ‘evening_hours’ will belong to the date that contains its start hour. It is not allowed that the ‘evening_hours’ cross the limit between two dates. It is also not allowed that when the ‘evening_hours’ end hour is different from 00:00 and the ‘evening_hours’ start hour is earlier than the day start hour, the ‘evening_hours’ end hour is earlier than the ‘evening_hours’ start hour. Example of non-allowed configuration: day start equal to 4, ‘evening_hours’ start hour equal to 03:30, ‘evening_hours’ end hour equal to 01:00 (01:00 < 03:30 < 04:00).
TSS-MPE-014	The software shall be able to check that the time slot duration and limits of the daily permanence score input data is compatible with the ‘night_time’, ‘evening_hours’, and ‘working_hours’ time intervals defined in the configuration, and stop the execution and warn the user when one of the required dates has an incompatible time slot duration.
TSS-MPE-015	The software shall be able to read from a configuration file the definition of weekend start and end days by specifying values between 1 and 7, starting from Monday as 1, Tuesday as 2, up to Sunday as 7. For example, if the start day is 6 and the end day is 7, and the start hour of the day was specified as 4 AM, then the weekend starts at 4 AM of the Saturday and ends at 4 AM of the Monday.
TSS-MPE-016	The allowed sub-daily periods are: ‘all’, ‘night_time’, ‘evening_time’, ‘working_hours’, and the sub-monthly periods are: ‘all’, ‘workdays’, ‘holidays’, ‘weekends’, ‘mondays’, ‘tuesdays’, ‘wednesdays’, ‘thursdays’, ‘fridays’, ‘saturdays’, ‘sundays’.
TSS-MPE-017	The software shall be able to calculate metrics for the sub-monthly period ‘all’, defined as all dates within each month being studied.
TSS-MPE-018	The software shall be able to calculate metrics for the sub-monthly period ‘workdays’, defined as those days of the week that do not belong to the weekend and that are not marked as holidays in the country of study within each month being studied.
TSS-MPE-019	The software shall be able to calculate metrics for the sub-monthly period ‘holidays’, defined as those days marked as holidays in the country of study within each month being studied.
TSS-MPE-020	The software shall be able to calculate metrics for the sub-monthly period ‘mondays’, ‘tuesdays’, ‘wednesdays’, ‘thursdays’, ‘fridays’, ‘saturdays’, and ‘sundays’, defined by all of the corresponding days of the week within each month being studied.
TSS-MPE-021	The software shall be able to calculate metrics for the sub-daily period ‘all’, defined by all time slots contained in a date.
TSS-MPE-022	The software shall be able to calculate metrics for the sub-daily period ‘night_time’, defined by all time slots contained between the start and ending ‘night_time’ hours specified via configuration.
TSS-MPE-023	The software shall be able to calculate metrics for the sub-daily period ‘working_hours’, defined by all time slots contained between the start and ending ‘night_time’ hours specified via configuration.
TSS-MPE-024	The software shall be able to calculate metrics for the sub-daily period ‘evening_time’, defined by all time slots contained between the start and ending ‘night_time’ hours specified via configuration.
TSS-MPE-025	The combinations of sub-daily and sub-monthly periods for mid-term metrics calculation shall be provided in configuration file. The input structure has the shape of a dictionary, where the keys are the allowed and non-repeated values of sub-monthly periods, and the values are a list of allowed and non-repeated values of sub-daily periods surrounded by quotes. Example: {'all': ['all', ‘night_time', ‘evening’, ‘working_hours’], ‘workdays’: [‘night_time', 'working_hours']}.
TSS-MPE-026	The software shall read in the daily permanence score data object for the configured month and days in the previous and next month as defined by configuration parameters.
TSS-MPE-027	The software shall be able to calculate mid-term permanence score, mid-term frequency count and mid-term regularity indices per device and grid tile, as well as for the ‘unknown’ location, using permanence score values from Daily Permanence Score Data Object for the combinations of sub-daily and sub-monthly periods over each full month as specified via configuration.
TSS-MPE-028	The software shall be able to calculate the ‘device observation’ mid-term permanence score per device from the daily permanence score data, equal to the number of time slots of the sub-monthly and sub-daily periods over one full month that have a value of the daily permanence score equal to 1 in at least

ID	DEFINITION
	one grid tile; as well as the mid-term frequency count, equal to the number of dates in which at least one time slot of a grid tile the sub-monthly and sub-daily period over one full month has a daily permanence score equal to 1. These shall be done using the permanence score values from the Daily Permanence Score Data Object for the combinations of sub-daily and sub-monthly periods over each full month as specified via configuration.
TSS-MPE-029	The mid-term permanence score of a device in a grid tile or 'unknown' location shall be calculated as the summation of the daily permanence score of the device in that location over all time slots belonging to the corresponding sub-monthly and sub-daily periods and month being considered.
TSS-MPE-030	The mid-term frequency count of a device in a grid tile or 'unknown' location shall be calculated as number of days of the sub-monthly period of the month being studied in which that location has non-zero permanence score, i.e. permanence score values equal to 1, for any of the time slots in the sub-daily period being considered.
TSS-MPE-031	The mid-term regularity indices shall be calculated as the mean and the standard deviation of the temporal distance in number of days between consecutive dates of the sub-monthly period and month being studied with daily permanence score equal to 1 (i.e., greater than zero) in any of the time slots in the sub-daily period being considered. The start date shall be taken as the latest date of the sub-monthly period, daily permanence score equal to one in any time slot of the sub-daily period, and that belongs to the dates considered from the previous month for the calculation of these indices. In the case that none of these dates satisfy these conditions, the start date shall be taken as the earliest date considered. Analogously, the end date shall be taken as the first date among the dates of the following month that satisfies these conditions, and if it does not exist, the latest date is considered.
TSS-MPE-032	The mid-term metrics that refer to a specific grid tile shall have in their 'id_type' field a value equal to 'grid', together with the ID of that grid tile in the 'grid_id' field. If the metrics refer to an unknown location or to the device observation, they shall have the value 'unknown' or 'device_observation' respectively under both 'grid_id' and 'id_type' fields.

3.2.21 LONGTERMPERMANENCEESTIMATION

ID	DEFINITION
TSS-LPE-001	The software shall be able to read the I.38 Mid-Term Permanence Metrics Data Object stored as parquet partitioned by year (YYYY), month (MM), day_type, time_interval, id_type, and user_id_modulo.
TSS-LPE-002	The software shall be able to read from a configuration file the start and end month for interval to process Mid-term Permanence Metrics in the format YYYY-MM.
TSS-LPE-003	The software shall be able to read from a configuration file the definition of a sub-yearly intervals. Potential implementation as a dictionary {'winter':[12,1,2]. 'summer':[5,6,7,8]}, where keys are names of sub-yearly interval and values are lists of months that constitutes this interval.
TSS-LPE-004	The software shall read in the monthly permanence metrics for the configured months.
TSS-LPE-005	The software shall be able to calculate long-term permanence score, long-term frequency count, long-term frequency mean, long-term frequency standard deviation and long-term regularity indices per device, grid tile and 'unknown' location (id_type = 'unknown') using monthly permanence metrics values from Monthly Permanence Score Data Object for all combinations of sub-daily, sub-monthly and sub-yearly periods set in the configuration file over all months in the given time interval.
TSS-LPE-006	The combinations of sub-daily, sub-monthly and sub-yearly periods for long-term metrics calculation shall be provided in configuration file. Potential implementation as a dictionary of dictionaries: {'all':{'all': ['all', 'night_time', 'evening', 'working_hours'], 'working_days': ['night_time', 'working_hours']}, 'summer':{ 'weekends': ['all']}}, where keys are sub-yearly periods and values are dictionaries of sub-monthly periods as keys and and lists of sub-daily periods as values.
TSS-LPE-007	The software shall perform validation that all configured for processing sub-daily and sub-monthly periods are present in Mid-term Permanence Metrics Data Object and notify the user about missing combinations and stop processing.
TSS-LPE-008	Long-term permanence score shall be calculated as the sum of the tile monthly permanence scores ('mps') from Mid-term Permanence Metrics Data Object.
TSS-LPE-009	Long-term frequency count shall be calculated by sum of the monthly frequency counts from Mid-term Permanence Metrics Data Object. Long-term frequency mean shall be calculated as the mean of the monthly frequency count values of months belonging to the period of reference. The Long-term frequency std shall be calculated as the std of the monthly frequency count values of months belonging to the period of reference.
TSS-LPE-010	Long-term regularity indices per tile are calculated by taking the mid-term monthly mean distances between consecutive permanencies in the given tile and by computing the mean and the standard deviation of the mean distances.
TSS-LPE-011	The software shall be able to calculate the long-term 'device observation' metrics: • long-term device observation permanence score per device by summing up 'mps' column values of id_type = 'device_observation' from Mid-term Permanence Metrics Data Object • long-term device observation frequency by summing up 'frequency' column values of id_type = 'device_observation' from Mid-term Permanence Metrics Data Object Metrics shall be calculated for all combinations of sub-daily, sub-monthly and sub-yearly periods set in the configuration file over all months in the given time interval.
TSS-LPE-012	The mid-term metrics that refer to a specific grid tile shall have in their 'id_type' field a value equal to 'grid', together with the ID of that grid tile in the 'grid_id' field. If the metrics refer to an unknown location or to the device observation, they shall have the value 'unknown' or 'device_observation' respectively under both 'grid_id' and 'id_type' fields.
TSS-LPE-013	The software shall write results data following schema specified in I.39 Long-Term Permanence Metrics Object for the whole period provided in the configured processing interval.

3.2.22 USUALENVIRONMENTLABELING

ID	DEFINITION
TSS-UEL-001	The software shall be able to read the I.39 Long-Term Permanence Metrics Data Object stored as parquet partitioned by start_date, end_date and user_id_modulo.
TSS-UEL-002	The software shall be able to read following threshold parameters for labeling from the configuration file: • gap_ps_threshold (integer): the threshold of the difference in long permanence score values between consecutive tiles ordered by long term permanence score in descending order. Used to filter out tiles with long permanence score difference above this value and all the tiles following in descending long term permanence score values order. Default: 1 if only tiles with highest score are to be kept • total_ps_threshold (float): the total device permanence score assigned in reference period below which the user is not assigned a usual environment label, and is flagged as 'rarely observed'. Default: 300 (average PS=5 per day in 60 days, when the default value for the period of reference length is 6 months) • freq_days_treshold (float): the percentage out of total number of days when device has permanence in the reference period below which the user is not assigned a usual environment label and is flagged as 'rarely observed'. Default: 30 (unit: percentage) • ue_gap_ps_threshold (float): same as gap_ps_threshold, but used for filtering in UE labeling. Default: 20 (20 % of the highest permanence score value) • ue_ps_threshold (float): the percentage of permanence scores in top tiles out of the sum of daily device observation values in reference period. Tiles above this threshold are labeled as Usual Environment tiles. Default value: 70 (unit: percentage) • ue_ndays_threshold (float): the percentage of the sum of the number of days with non-zero permanence in top tiles out of total number of non-zero permanence days in reference period. Tiles above this threshold are labeled as Usual Environment tiles. Default value: 70 (unit: percentage) • home_ps_threshold (float): the percentage of permanence scores in top tiles out of the sum of daily device observation values in reference period. If the device has at least this value in top tiles these tiles are labeled as Home Location. Default value: 80 (unit: percentage) • home_ndays_threshold (float): the percentage of the sum of the number of days with non-zero permanence in top tiles out of total number of non-zero permanence days in reference period. If the device was in the first tile or group of tiles at least this value these tiles are labeled as Home Location. Default value: 80 (unit: percentage). • work_ps_threshold (float): minimum percentage of sum of permanence score during working days and daytime in top tiles out of total permanence score during working days and daytime, for a tile to be labelled as a work location tile. Default value: 80 (unit: percentage). • work_ndays_threshold (float): minimum percentage of non-zero permanence score days during working days and daytime in top tiles out of total number of non-zero permanence score days during working days and daytime, for a tile to be labelled as a work location tile. Default value: 80 (unit: percentage).
TSS-UEL-003	The software shall be able to read from a configuration file the start and end month for interval to process Long-term Permanence Metrics in the format YYYY-MM.
TSS-UEL-004	The software shall perform Usual Environment labeling and Home and Work locations labeling of tiles for each device.
TSS-UEL-005	The software shall perform validation that all combinations of periods required for labeling are present in Long-term Permanence Metrics Data Object, notify the user about missing combinations and stop further execution. Currently, the required periods are: • UE labeling - all days: all intervals • Home labeling - all days: all intervals, all days: night-time • Work labeling - work days: working hours
TSS-UEL-006	The software shall filter rarely observed devices using all days: all intervals combination based on the following rules:

ID	DEFINITION
	1. Filter devices for which 'lps' value in id_type = ‘device_observation' row < total_ps_threshold parameter into separate table. Mark such devices as filtered by rule ‘device_filter_1’ (rarely observed). 2. Filter devices for which 'total_frequency' value in id_type = ‘device_observation' row < freq_days_threshold parameter into same as above separate table. Mark such devices as filtered by rule ‘device_filter_2’ (discontinuously observed). Devices filtered during this step shall not be used for any labeling.
TSS-UEL-007	The software shall label tiles as Usual Environment tiles based on following algorithm: 1. For all days : all intervals combination: a. Get the highest value of a long permanence score (‘lps’) of a device over all grid tiles (PS max). b. Calculate the difference in ‘lps’ values between consecutive tiles ordered by ‘lps’ values in descending order. c. Find tiles that have a difference in ‘lps’ value > ue_gap_threshold (default is 20% of PS max), filter out these tiles and all the tiles with ‘lps’ values below. 2. For each tile in the remaining tiles group check if its ‘lps’ value is at least ue_ps_threshold (default is 70% of 'lps' value in id_type = ‘device_observation' row of all days: all intervals combination). Tiles for which this condition is fulfilled are labeled as UE tiles. Labeling rule code: ‘ue_1’. 3. For tiles which have not got UE label in previous step perform the same check for all other combinations of day types and periods. If condition is fulfilled for any of the combinations, label tiles as UE tiles. Labeling rule code: ‘ue_2’. 4. If no UE label being assigned after all of the above steps, add ue labeling rule ‘ue_na’ - label not assigned.
TSS-UEL-008	The software shall save the rule based on which tiles were labeled as UE tiles using predefined rule codes.
TSS-UEL-009	The software shall label tiles as Home location tiles based on following algorithm: 1. For all days: all intervals combination: a. Calculate the difference in long permanence scores (‘lps’) between consecutive tiles ordered by ‘lps’ values in descending order. b. Find first tile that have a difference in ‘lps’ value > gap_ps_threshold (default is 1), filter out this tile and all the tiles with ‘lps’ values below from all period combinations used for home labeling. 2. For each tile in the remaining tiles group check if its ‘lps’ value is at least home_ps_threshold. (default is 80% of 'lps' value in id_type = ‘device_observation' row of all : all periods combination). Such tiles are labeled as Home tiles. Labeling rule code: ‘h_1’. 3. If no home label being assigned, repeat this condition check for all days: night_time combination. Tiles that fulfilled this condition are labeled as Home tiles. Labeling rule code: ‘h_2’. 4. If no home label being assigned, check if the device was in the tiles at least home_ndays_threshold (default is 80% of 'total_frequency' value in id_type = ‘device_observation' row of all days: all intervals combination). Tiles that fulfilled this condition are labeled as Home tiles. Labeling rule code: ‘h_3’. 5. If no Home label being assigned after all of the above steps, add labeling rule ‘loc_na’ - label not assigned.
TSS-UEL-010	The software shall label tiles as Work location tiles based on following algorithm: 1. For working days: working time combination: a. Calculate the difference in long permanence scores (‘lps’) between consecutive tiles ordered by ‘lps’ values in descending order. b. Find first tile that have a difference in ‘lps’ value > gap_ps_threshold (default is 1), filter out this tile and all the tiles with ‘lps’ values below from all period combinations used for work labeling. 2. For each tile in the remaining tiles group check for workdays: working_hours combination if its ‘lps’ value is at least work_ps_threshold. (default is 70% of 'lps' value in id_type =

ID	DEFINITION
	'device_observation' row of all days: all intervals combination). Tiles for which this condition is fulfilled are labeled as Work tiles. Labeling rule code: 'w_1'. 3. If no work label being assigned, for each tile in the remaining tiles group check for workdays : working_hours periods combination if its 'total_frequency' value is at least work_ndays_threshold (default value is 70% of 'total_frequency' value in id_type = 'device_observation' row of all days: all intervals combination). Tiles for which this condition is fulfilled are labeled as Work tiles. Labeling rule code: 'w_2'. 4. If no Work label being assigned after all of the above steps, add labeling rule 'loc_na' - label not assigned.
TSS-UEL-011	The software shall save the rule based on which tiles were labeled as Home or Work tiles using predefined rule codes.
TSS-UEL-012	The software shall perform labeling for each location type individually, so same tile can be labeled multiple times.
TSS-UEL-013	The software shall write results data following schema specified in I.37 UE Labels Data Object for all full months provided in the configured processing interval. Partitioned by year, month, day, user_id_mod.
TSS-UEL-014	The software shall produce following quality metrics: a. Number of tiles in each labeling rule. b. Number of home location tiles which are not labeled as UE. c. Number of work location tiles which are not labeled as UE. d. Number of devices which are filtered out as rarely observed and discontinuously observed.
TSS-UEL-015	The software shall write quality metrics following schema and format specified in I.43 Labeling Quality Metrics.

3.2.23 USUALENVIRONMENTAGGREGATION

ID	DEFINITION
TSS-UEA-001	The software shall be able to read from a configuration file the 'start month' and 'end month' for the interval to select from the I.37 UE Labels input in the format YYYY-MM.
TSS-UEA-002	The software shall be able to read from a configuration file a boolean 'use land use' parameter indicating whether land use information will be used for the usual environment aggregation.
TSS-UEA-003	The software shall be able to read an I.37 UE Labels Data Object from parquet files stored partitioned by start_date, end_date & user_id_modulo.
TSS-UEA-004	The software shall be able to read an I.31 Enriched Grid Data Object from parquet files stored partitioned by quadkey.
TSS-UEA-005	The software shall load all usual environment grid tiles for all devices from the I.37 UE Labels input data for the selected start and end month regardless of the label.
TSS-UEA-006	The software shall load a tile weight (tw) for each grid tile from the 'prior_probabilty' column of the I.31 Enriched Grid Data Object if 'uniform_tile_weights' parameter has been set as False. If this parameter has been set as True, all grid tiles shall be assigned tw = 1.
TSS-UEA-007	The software shall calculate, for each device, its device tile weight value (weight_td) for each of the device's usual environment grid tiles. This is achieved by using the following formula for each tile i: weight_td (grid_i) = tw (grid_i) / Σj(tw (grid_j)) Where: • grid_i: is a target grid tile, i.e., a tile that is included in the current device's usual environment, and for which we are calculating pue. • weight_td (grid_i): is the weight of the device in the target grid tile (grid_1). • tw (grid_i): is the tile weight for target grid tile (grid_1), either 1 or coming from the enriched grid data. • Σj(tw (grid_j)): is the sum of the tile weights of all the grid tiles in the device's usual environment.
TSS-UEA-008	The software shall sum the weight_td values of all devices in each grid tile to obtain the aggregated weighted device counts of each tile.
TSS-UEA-009	The software shall produce an output I.44 Aggregated Usual Environments Data Object with the final usual environment count of each tile in parquet files partitioned by start_date and end_date.

3.2.24 CELLSPROXIMITYESTIMATION

ID	DEFINITION
TSS-CPE-001	The software shall be able to read Cell Footprint data object with schema specified in I.13 Cell Footprints for the given day.
TSS-CPE-002	The software shall perform all processing steps for each day of data period specified in configuration file
TSS-CPE-003	The software shall model coverage areas of the cells by converting grid tiles to polygons using grid tiles centroids and concave hull operation
TSS-CPE-004	The software shall extend coverage areas (buffer) by the number of meters specified in configuration
TSS-CPE-005	The software shall calculate distances between pairs of nearby cells. The search radius for nearby cells shall be defined in configuration
TSS-CPE-006	For each cell, the software shall aggregate all nearby cells where distance = 0 to overlapping cells list
TSS-CPE-007	The software shall write output data object defined in I.45 Cell Distances partitioned by year, month, day
TSS-CPE-008	The software shall write output data object defined in I.14 Cell Intersection Groups partitioned by year, month, day

3.2.25 INTERNALMIGRATION

ID	DEFINITION
TSS-HCD-001	The software shall be able to read the I.37 UE Labels data object for two different long-term periods for which home location changes will be detected following its data schema.
TSS-HCD-002	The software shall be able to read the I.36 Zones - Grid Map data object containing the mapping of grid tiles to geographic zones data following its data schema.
TSS-HCD-003	The software shall be able to read the I.31 Enriched Grid data object containing weights for each grid tile to be used for the distribution of home location.
TSS-HCD-004	The software shall be able to write the resulting estimated home location changes following the schema of the output data object I.46 Internal Migration.
TSS-HCD-005	The software shall be able to write quality metrics of the internal migration process following the schema of the output data object I.47 Internal Migration Quality Metrics.
TSS-HCD-006	The software shall be able to read from a configuration file what two long-term periods to compare for home location change detection.
TSS-HCD-007	The software shall be able to count the number of tiles labelled as home that each device has in both long-term periods, as well as the number of home tiles shared by both periods.
TSS-HCD-008	The software shall be able to compute the overlap proportion of the home location of each device, equal to two times the number of shared home tiles in both periods divided the sum of home tiles in the first and the second period for that device.
TSS-HCD-009	The software shall be able to filter out those devices whose overlap proportion is equal or above a migration threshold for the computation of the output migration indicator, keeping those with an overlap proportion lower than said threshold.
TSS-HCD-010	The software shall be able to map the home tiles of both long-term periods to the specific zone they correspond in according to the input I.36 Zones - Grid Map.
TSS-HCD-011	The software shall be able to compute, for each device and long-term period, a weight for each of its home tiles, either uniform weights or based on the custom weights as per the I.31 Enriched Grid data object.
TSS-HCD-012	The software shall be able to compute, for each device and long-term period, the weight for each geographic zone as the sum of the weights of its home tiles assign to that zone.
TSS-HCD-013	The software shall be able to compute, for each device, a migration weight between two different zones equal to the product of the weight of a zone in the first long-term period and the weight of a zone in the second long-term period, for every pair of distinct zones with non-zero weight.
TSS-HCD-014	The software shall be able to compute the output migration indicator for any pair of zones as the sum of migration weights between those two zones aggregated over all devices.
TSS-HCD-015	The software shall be able to read from a configuration file the migration threshold, a value between 0 and 1, to select what users are considered to have performed a home location change based on their overlap proportion.
TSS-HCD-016	The software shall be able to read from a configuration file the ID of the zoning dataset and list of hierarchical levels to use for mapping the tiles to a set of geographical zones.
TSS-HCD-017	The software shall be able to read from a configuration file the start month, end month and season for both of the usual environment labels datasets that are to be compared to detect home location changes.

3.2.26 TOURISMSTAYSESTIMATION

ID	DEFINITION
TSS-TSE-001	The software shall be able to read Continuous Time Segments data object with schema specified in I.20 Daily Continuous Time Segments.
TSS-TSE-002	The software shall be able to read Cell Footprints with connection probabilities data object with schema specified in I.15 Cell Connection and Posterior Probabilities.
TSS-TSE-003	The software shall be able to read the mapping of grid tiles to geographic zones data object with schema specified in I.36 Zones - Grid Map.
TSS-TSE-004	The software shall be able to read Usual Environment Labels Data Object with schema specified in I.37 UE Labels. This shall be optional.
TSS-TSE-005	The software shall be able to perform all processing steps one day at a time for the given range of dates.
TSS-TSE-006	The software shall select segments relevant for tourism case (inbound) by selecting only foreign MCC.
TSS-TSE-007	The software shall remove inbound residents by checking if a device has usual environment in the country of study. This shall be optional.
TSS-TSE-008	The software shall select segments with state = 'stay'.
TSS-TSE-009	The software shall perform stays mapping from cells to zones using cell footprints and taking into account cell connection probabilities. For every segment, its corresponding cells shall be first mapped to their footprints with posterior probabilities. Then posterior probabilities shall be averaged to the number of cells (Pg * 1/num_cells) so that probabilities of multiple cells in a grid tile can be summed up together (Pg_total = Pg1 * 1/num_cells + Pg2 * 1/num_cells…Pgn * 1/num_cells…) and so total sum of all grid probabilities for a stay is equal to 1. The last step is to map all grids to target geographic zoning and perform aggregation by zone with summing up all probabilities.
TSS-TSE-010	The target zoning dataset shall be determined in configuration by **zoning_dataset_id** parameter.
TSS-TSE-011	In case of hierarchical dataset, mapping shall be done to the lowest level of hierarchy
TSS-TSE-012	The software shall remove all stays of devices which have Usual Environment assigned to them. This shall be done by checking if any UE exists in the UE labels data object for current devices with duration overlapping current date. This step shall be optional. Its execution shall be defined by config parameter and not performed for the cases when usual environment has not been calculated.
TSS-TSE-013	The software shall remove all stays with duration under given threshold. The threshold shall be determined in general configuration by **min_duration_segment_m** parameter with default value 180 minutes.
TSS-TSE-014	The software shall mark overnight stays. Overnight stay shall be defined by following conditions: a) time interval of a stay crosses functional midnight b) duration of a stay is more than a given threshold. Functional midnight shall be determined by config parameter **functional_midnight_h**, default value is 04:00 AM. Duration threshold shall be defined by config parameter **min_duration_segment_night_m**, default value is 5 hours.
TSS-TSE-015	The software shall write output data object defined in I.48 Daily Tourism Stays partitioned by year, month, day and user_id_modulo.

3.2.27 TOURISMSTATISTICSCALCULATION

ID	DEFINITION
TSS-TSC-001	The software shall be able to read Daily Tourism Stays data object with schema specified in I.48 Daily Tourism Stays.
TSS-TSC-002	The software shall be able to read existing Tourism trips data object with schema specified in I.49 Tourism Trips.
TSS-TSC-003	The software shall be able to read MCC to ISO Timezones data object with schema specified in I.50 MCC to ISO Timezones.
TSS-TSC-004	The software shall calculate trips and aggregations for each parameter-specified zoning dataset and for each month in the parameter-specified range of months.
TSS-TSC-005	For each month, the software shall calculate a input data period for tourism stays. The input data period starts from the beginning of the month. The input data period ends with the end of the month plus the lookforward window: max trip gap parameter-specified number of days in the beginning of the next month.
TSS-TSC-006	For each zoning dataset, for each month, the software shall select as input stays all stays which are within the validity period of the current month and which match the current zoning dataset. In addition, the software shall select as input stays all stays that are part of ongoing trips from the previous month.
TSS-TSC-007	The software shall assign a trip id value to each input stay.
TSS-TSC-008	If a stay was part of an ongoing trip in the previous month, it shall keep the existing trip id.
TSS-TSC-009	If a stay does not have an existing trip id and the chronologically preceding stay of the same user is within the parameter-specified max trip gap, the stay shall be assigned the trip id of the previous stay. If not, the stay shall be assigned a newly generated trip id.
TSS-TSC-010	The trip ids shall be unique across the trips of one user.
TSS-TSC-011	Each trip shall be marked unfinished if it includes any stays from the lookforward window, and marked finished otherwise.
TSS-TSC-012	The tourism trips of the month shall be written with the schema specified in I.49 Tourism Trips.
TSS-TSC-013	Each stay shall be joined with the MCC-ISO2 data on the MCC value to assign the ISO2 code to the stay. Stays with no matching MCC value shall be assigned the code XX.
TSS-TSC-014	Each stay shall be unpacked to separate part-stays for each value in its zone_id_list.
TSS-TSC-015	For each zoning dataset, for each month, the statistical aggregations on each parameter-specified hierarchical zoning level shall be calculated.
TSS-TSC-016	For each hierarchical level, the corresponding zone id shall be extracted from the stay's hierarchical_id to be used for aggregation.
TSS-TSC-017	For each part-stay, a visit id shall be calculated. If there does not exist any previous part-stay with the same zone id within the max visit gap-specified, then the part-stay shall be assigned a new visit id. Otherwise, it shall be assigned the same visit id as the previous part-stay.
TSS-TSC-018	Visit ids shall be locally unique. Visit ids may be consecutive numbers, since they are not stored long-term.
TSS-TSC-019	Each visit shall be marked unfinished if it contains any part-stays within the lookforward window, and considered finished otherwise.
TSS-TSC-020	The aggregation of nights spent per zone per country of origin shall be calculated as the sum of the zone_weight values of all part-stays with the same zone_id and country of origin which are both from overnight stays and finished visits.
TSS-TSC-021	The aggregation of number of departures per zone per country of origin shall be calculated as the total number of distinct finished trips that contain any part-stays with the corresponding zone_id and country of origin. For the *is_overnight=True* breakdown, only part-stays from overnight stays are included. For the *is_overnight=False* breakdown, only part-stays from non-overnight stays are included.
TSS-TSC-022	The nights spent and number of departures per zone aggregations shall be combined into one data object and written with the schema I.51 Inbound Tourism Aggregations I.
TSS-TSC-023	The average number of destinations per country of origin shall be calculated as the average number of distinct zone_id values of each trip made by the users from the specified country of origin.

ID	DEFINITION
TSS-TSC-024	For each finished trip, the nights spent per destination are the sums of zone_weight values per zone_id calculated from part-stays of the trip which are from overnight stays. The average number of nights spent per destination per country of origin shall be calculated as the average of that value across the users from the specified country.
TSS-TSC-025	The average number of destinations and the average number of nights spent per destination per country of origin shall be combined into one data object and written with the schema I.52 Inbound Tourism Aggregations II.

3.2.28 TOURISMOUTBOUNDSTATISTICSCALCULATION

ID	DEFINITION
TSS-TOSC-001	The software shall be able to read Continuous Time Segments data object with schema specified in I.20 Continuous Time Segments.
TSS-TOSC-002	The software shall be able to read existing Tourism trips data object with schema specified in I.49 Tourism Trips.
TSS-TOSC-003	The software shall be able to read MCC to ISO Timezones data object with schema specified in I.50 MCC to ISO Timezones.
TSS-TOSC-004	The software shall calculate trips and aggregations for each month in the parameter-specified range of months.
TSS-TOSC-005	For each month, the software shall calculate a validity period for input stays. The validity period starts from the beginning of the month. The validity period ends with the end of the month plus the lookforward window: max trip gap parameter-specified number of hours in the beginning of the next month.
TSS-TOSC-006	The software shall select as input stays all time segments within the validity period of the current month which have the segment state ABROAD. In addition, the software shall select as input stays all time segments that are part of ongoing trips from the previous month.
TSS-TOSC-007	Each stay shall be joined with the MCC-ISO2 data on the MCC value to assign the ISO2 code and local timezone to the stay.
TSS-TOSC-008	The software shall mark overnight stays. A stay shall be marked as overnight if its duration contains the parameter-specified functional midnight hour and its duration is longer than the parameter-specified threshold.
TSS-TOSC-009	The software shall calculate a trip id value for each input stay: • If a stay was part of an ongoing trip in the previous month, it shall keep the existing trip id. • If a stay does not have an existing trip id and the chronologically preceding stay of the same user is within the max trip gap-specified time gap, the stay shall be assigned the trip id of the previous stay. If not, the stay shall be assigned a newly generated trip id.
TSS-TOSC-010	The trip ids shall be unique across the trips of one user.
TSS-TOSC-011	Each trip shall be marked unfinished if it includes any stays from the month following the current processing month and marked finished otherwise.
TSS-TOSC-012	The tourism trips of the month shall be written with the schema specified in I.49 Tourism Trips with dataset_id set to 'abroad'.
TSS-TOSC-013	The software shall calculate the number of overnight stays per country of destination as the number of overnight stays in that country that are part of finished trips in the current month.
TSS-TOSC-014	The overnight stays aggregation of the month shall be written with the schema specified in I.53 Outbound Tourism Aggregations.

3.2.29 OUTPUTINDICATORS

ID	DEFINITION
TSS-OIN-001	The software shall be able to read as input the following data objects related to present population: I.42 Present Population and I.36 Zones - Grid Map, where the latter is required only if spatial aggregation is to be performed using a custom zoning dataset.
TSS-OIN-002	The software shall be able to read as input the following data objects related to usual environment/home location: I.44 Aggregated Usual Environments and I.36 Zones - Grid Map, where the latter is required only if spatial aggregation is to be performed using a custom zoning dataset.
TSS-OIN-003	The software shall be able to read as input the following data object related to internal migration: I.46 Internal Migration.
TSS-OIN-004	The software shall be able to read as input the following data objects related to inbound tourism: I.51 Inbound Tourism Aggregations I: Nights spent and departures per zone, I.52 Inbound Tourism Aggregations II: Average number of destinations and nights spent per country of origin, and optionally I.54 Inbound Estimation Factors.
TSS-OIN-005	The software shall be able to read as input the following data object related to outbound tourism: I.53 Outbound Tourism Aggregations: Nights spent per destination country.
TSS-OIN-006	The software shall be able to process the specific partition or partitions of each data object as specified in a configuration file.
TSS-OIN-007	The software shall be able to perform spatial aggregation of the indicators of both present population and usual environment to the zoning specified in a configuration file: • If the INSPIRE 100 m grid is specified, the data is already at the level of this grid, so only a renaming of columns is to be performed • If the INSPIRE 1 km grid is specified, the data is to be mapped from the 100 m grid to the 1km grid and aggregated. • If other zoning dataset is specified, the data is to be mapped according to the grid to zone mapping data object and aggregated.
TSS-OIN-008	The software shall be able to multiply the following columns of the input data by the local deduplication factor specified in a configuration file: • “population” for present population use case data. • “weighted_device_count” for usual environment/home location use case data. • “migration” for internal migration use case data. • “nights_spent” for outbound tourism use case data.
TSS-OIN-009	The software shall be able to multiply the following columns of the input data of the inbound tourism use case by the deduplication factor specified in the Inbound Estimation Factors data object by taking into account the different factors for each country of origin, or use the default deduplication factor for inbound visitors specified in a configuration file: “nights_spent” and “num_of_departures” of the original I.51 Inbound Tourism Aggregations I: Nights spent and departures per zone data object.
TSS-OIN-010	The software shall be able to multiply the following columns of the input data by the local MNO-to-target-population specified in a configuration file: • “population” for present population use case data. • “weighted_device_count” for usual environment/home location use case data. • “migration” for internal migration use case data. • “nights_spent” for outbound tourism use case data.
TSS-OIN-011	The software shall be able to multiply the following column of the input data of the inbound tourism use case by the MNO-to-target-population factor specified in the Inbound Estimation Factors data object by taking into account the different factors for each country of origin, or use the default MNO-to-target-population factor for inbound visitors specified in a configuration file. “nights_spent” and “num_of_departures” of the original I.51 Inbound Tourism Aggregations I: Nights spent and departures per zone data object.
TSS-OIN-012	The software shall be able to apply k-anonymity by either obfuscating or deleting records, as specified in a configuration file, for each of the input data objects to be processed.

ID	DEFINITION
TSS-OIN-013	The software shall be able to apply the k-anonimity process on the following columns of each of the input datasets: • "population" for present population use case data. • "weighted_device_count" for usual environment/home location use case data. • "migration" for internal migration use case data. • "num_of_departures" of the original I.51 Inbound Tourism Aggregations I: Nights spent and departures per zone data object for inbound tourism use case data.
TSS-OIN-014	The software shall be able to write the following output data objects based on the use case: • I.41 Present Population - Zones for present population • I.55 Aggregated Usual Environments - Zones for usual environment/home location • I.46 Internal Migration for internal migration • I.51 Inbound Tourism Aggregations I: Nights spent and departures per zone and I.52 Inbound Tourism Aggregations II: Average number of destinations and nights spent per country of origin for inbound tourism • I.53 Outbound Tourism Aggregations: Nights spent per destination country for outbound tourism
TSS-OIN-015	The software shall be able to check if the number of fields in the written output data match the expected number of fields and log a warning it they do not.
TSS-OIN-016	The software shall be able to check if the names of fields in the written output data match the expected names of fields, and log a warning it they do not.
TSS-OIN-017	The software shall be able to check if the types of fields in the written output data match the expected types of fields, and log a warning it they do not.
TSS-OIN-018	The software shall be able to check if columns that do not accept null values contain any and log a warning, if they do.
TSS-OIN-019	The software shall be able to read from a configuration file the use case to be processed by the component.
TSS-OIN-020	The software shall be able to read from a configuration file whether to clean the output directory or not.
TSS-OIN-021	The software shall be able to read from a configuration file the local deduplication factor and local MNO-to-target-population factor.
TSS-OIN-022	The software shall be able to read from a configuration file the default values for inbound visitors of the deduplication factor and the MNO-to-target-population factor.
TSS-OIN-023	The software shall be able to read from a configuration file what type of k-anonymity should be applied to the data, either obfuscate or delete.
TSS-OIN-024	The software shall be able to read from a configuration file the value *k* for the k-anonymity process.
TSS-OIN-025	The software shall be able to read from a configuration file, when processing data of the present population use case, the following parameters to determine what part of the data should be processed: the zoning dataset to use for spatial aggregation, the hierarchical levels to consider, and a date range with both dates inclusive.
TSS-OIN-026	The software shall be able to read from a configuration file, when processing data of the usual environment/home location use case, the following parameters to determine what part of the data should be processed: the zoning dataset to use for spatial aggregation, the hierarchical levels to consider, a list of usual environment labels, and the start month, end month, and season.
TSS-OIN-027	The software shall be able to read from a configuration file, when processing data of the internal migration use case, the following parameters to determine what part of the data should be processed: the zoning dataset, the hierarchical levels, the start month, end month, and season of the first long-term period, and the start month, end month, and season of the second long-term period.
TSS-OIN-028	The software shall be able to read from a configuration file, when processing data of the inbound tourism use case, the following parameters to determine what part of the data should be processed: the zoning dataset to use for spatial aggregation, the hierarchical levels, the start month, and the end month.
TSS-OIN-029	The software shall be able to read from a configuration file, when processing data of the present population use case, the following parameters to determine what part of the data should be processed: the start month and the end month.

ID	DEFINITION
TSS-OIN-030	The software shall be able to read from a configuration file, when processing data of the present population use case, the following parameters to determine what part of the data should be processed: the start month and the end month.

3.2.30 MULTIMNOAGGREGATION

ID	DEFINITION
TSS-MMA-001	The software shall be able to read as input the following data object related to present population: I.41 Present Population - Zones.
TSS-MMA-002	The software shall be able to read as input the following data objects related to usual environment/home location: I.55 Aggregated Usual Environments - Zones .
TSS-MMA-003	The software shall be able to read as input the following data objects related to internal migration: I.46 Internal Migration.
TSS-MMA-004	The software shall be able to read as input the following data objects related to inbound tourism: I.51 Inbound Tourism Aggregations I: Nights spent and departures per zone.
TSS-MMA-005	The software shall be able to read as input the following data objects related to inbound outbound tourism: I.53 Outbound Tourism Aggregations: Nights spent per destination country.
TSS-MMA-006	The software shall be able to write an output data object with the same format as the input data read which was specified in configuration: I.41 Present Population - Zones, I.55 Aggregated Usual Environments - Zones, I.46 Internal Migration, I.51 Inbound Tourism Aggregations I: Nights spent and departures per zone, or I.53 Outbound Tourism Aggregations: Nights spent per destination country.
TSS-MMA-007	The software shall be able to process the specific partition or partitions of each data object as specified in a configuration file.
TSS-MMA-008	The software shall be able to read as many input data objects as single MNOs, *n,* have been specified via configuration file.
TSS-MMA-009	The software shall be able to work with the *target columns* that contain the target metrics or values of interest in the input data.
TSS-MMA-010	The software shall be able to aggregate, for each input data object type, the target metric or metrics of each MNO by multiplying it by its respective MNO factor and adding up all values across the single MNOs that have the same identifier columns, that is, the same values in all columns that are not the target column.
TSS-MMA-011	The software shall ignore records obfuscated by k-anonimity, that is, records where the target metric has been flagged to be less than k.
TSS-MMA-012	The software shall be able to read from a configuration file the number of single MNOs, *n,* to be aggregated for the input data object type to be processed.
TSS-MMA-013	The software shall be able to read from a configuration file as many single MNO factors to be used to in the multi-MNO aggregation as the number of single MNOs *n* to be aggregated for each of the input data object types to be processed.
TSS-MMA-014	The software shall be able to read from a configuration file, when processing data of the usual environment/home location use case, the following parameters to determine what part of the data should be processed: the zoning dataset to use for spatial aggregation, the hierarchical levels to consider, a list of usual environment labels, and the start month, end month, and season.
TSS-MMA-015	The software shall be able to read from a configuration file, when processing data of the internal migration use case, the following parameters to determine what part of the data should be processed: the zoning dataset, the hierarchical levels, the start month, end month, and season of the first long-term period, and the start month, end month, and season of the second long-term period.
TSS-MMA-016	The software shall be able to read from a configuration file, when processing data of the inbound tourism use case, the following parameters to determine what part of the data should be processed: the zoning dataset to use for spatial aggregation, the hierarchical levels, the start month, and the end month.
TSS-MMA-017	The software shall be able to read from a configuration file, when processing data of the present population use case, the following parameters to determine what part of the data should be processed: the start month and the end month.
TSS-MMA-018	The software shall be able to read from a configuration file, when processing data of the present population use case, the following parameters to determine what part of the data should be processed: the start month and the end month.

3.2.31 DAILYPERMANENCESCOREQUALITYMETRICS

ID	DEFINITION
TSS-DPSQM-001	The software shall be able to read the daily permanence score data with the data type scheme specified in I.21 Daily Permanence Score.
TSS-DPSQM-002	The software shall be able to write the resulting daily permanence score quality metrics following the schema of the output data object I.56 Daily Permanence Score Quality Metrics.
TSS-DPSQM-003	The software shall be able to count the number of devices with a number of time slots classified as “unknown” equal or higher than a percentage threshold.
TSS-DPSQM-004	The software shall be able to count the number of devices with a high number of “unknown” time slots for each date being processed, and compute its percentage with respect to the total devices in the daily permanence score data of that date.
TSS-DPSQM-005	The software shall raise a critical warning if the percentage of devices with a high number of “unknown” time slots is equal or higher than the critical threshold.
TSS-DPSQM-006	The software shall raise a non-critical warning if the percentage of devices with a high number of “unknown” time slots is strictly higher than a non-critical threshold and strictly lower than the critical threshold.
TSS-DPSQM-007	The software shall be able to read from a configuration file the date range for which to compute daily permanence score quality metrics.
TSS-DPSQM-008	The software shall be able to read from a configuration file the critical and non-critical threshold for the percentage of devices with a high number of “unknown” time slots.

3.2.32 CELLFOOTPRINTQUALITYMETRICS

ID	DEFINITION
TSS-CFQM-001	The software shall be able to read the syntactically clean network data with the data type scheme specified in I.8 Cell locations with Physical Properties - Cleaned.
TSS-CFQM-002	The software shall be able to read the syntactically clean event data with the data type scheme specified in I.2 MNO Event Data - Syntactically Cleaned.
TSS-CFQM-003	The software shall be able to read the cell footprint data with the data type scheme specified in I.13 Cell Footprints.
TSS-CFQM-004	The software shall be able to write the resulting cell footprint quality metrics following the schema of the output data object I.57 Cell Footprint Quality Metrics.
TSS-CFQM-005	The software shall be able to count the number of cells with no cell footprint for each date being processed and compute its percentage with respect to the total number of cells in that date.
TSS-CFQM-006	The software shall be able to count the number of events assigned to each cell with no footprint for each date being processed and compute its percentage with respect to the total number of events in that date.
TSS-CFQM-007	The software shall be able to sum the total percentage of events assigned to cells with no footprints.
TSS-CFQM-008	The software shall raise a critical warning if the percentage of cells with no footprint is equal or higher than the critical threshold.
TSS-CFQM-009	The software shall raise a non-critical warning if the percentage of cells with no footprint is strictly higher than a non-critical threshold and strictly lower than the critical threshold.
TSS-CFQM-010	The software shall raise a critical warning if the percentage of events assigned to cells with no footprint is equal or higher than the critical threshold.
TSS-CFQM-011	The software shall raise a non-critical warning if the percentage of events assigned to cells with no footprint is strictly higher than a non-critical threshold and strictly lower than the critical threshold.
TSS-CFQM-012	The software shall be able to read from a configuration file the date range for which to compute cell footprint quality metrics.
TSS-CFQM-013	The software shall be able to read from a configuration file the critical and non-critical threshold for the percentage of cells with no footprint.
TSS-CFQM-014	The software shall be able to read from a configuration file the critical and non-critical threshold for the percentage of events with no footprint.

4 TECHNOLOGY STACK

Based on the general software requirements (see section 3.1 General requirements), the technology stack of the software has been defined. **Apache Spark** framework has been chosen as it perfectly complies with the requirements. The only aspect not directly addressed by the Apache Spark framework is the 'spatial computations' requirement (TSS-GEN-017), as Spark doesn't natively support geospatial operations. However, **Apache Sedona** is an extension built on Apache Spark whose purpose is to perform efficient spatial computations with Spark. By adding this extension to Spark, a framework that satisfies all the requirements is met. Spark is natively written in the Scala programming language, nonetheless it supports bindings for multiple programming languages such as Java, Python and R. From these languages, the **Python** programming language is chosen since it performs exceptionally the requirements.

A comprehensive list of the technology stack selected for the development of the software together with the rationale behind its selection is presented in Table 5.

Table 5: Software technology stack

TECHNOLOGIES		RATIONALE	REMARKS
Operating System	Linux	Cloud environments and containers usually run Linux as operating system. Most Linux distributions are open-source and free. Linux is a reliable and secure operating system due to its design and open-source nature.	
Development	Software Language: Python 3.7+	Standard data science, data analytics and data engineering software language. It has multiple open-source, state-of-the-art data processing libraries, such as numpy, pandas and pyspark. Most popular software language at the moment, with more than 25% of total share[3]. This increases the probability of external users contributing to the open-source project. Supported by all popular IDEs. Supported by all cloud computing providers.	The Python version may be constrained by the cloud infrastructure of the MNO operator.
	Data processing engine: Spark (Pyspark)	Spark is an open-source data processing framework ideal for big data pipelines. It provides bindings for python with the pyspark library. Spark can be deployed in a single machine or a cluster depending on the data workload. Spark has a machine learning library which allows data scientists to train and deploy models at scale. Spark can be deployed in popular cloud managed clusters (e.g. AWS EMR, GCP Dataproc, Azure Hdinsight).	Due to privacy constraints, MNOs require that the software runs in their closed cloud environment. This restriction may limit the available computing resources for software execution. Based on project team previous experience working with MNOs, most of them usually have deployed a cloud-managed map-reduce cluster, such as AWS EMR or GCP Dataproc. Spark can seamlessly operate on these environments, which

[3] PYPL PopularitY of Programming Language index

TECHNOLOGIES		RATIONALE	REMARKS
		Spark provides native support for local file systems, distributed file systems (HDFS) and blob storage systems.	simplifies the future deployment of the software.
	Geospatial data processing framework: Apache Sedona	Apache Sedona is a framework built on top of Apache Spark for processing high workloads of geospatial data. Apache Sedona provides bindings for the python language. Apache Sedona provides standard spatial operations such as spatial joins, nearest neighbour searches, range queries and spatial indexes. As it is built on top of Apache Spark, geospatial data can be incorporated in machine learning models.	
Code & Components Orchestration	Custom module	An ad-hoc/custom orchestration module has been developed for the pipeline. It is designed as a modular piece that could be replaced in the future by a more complex/sophisticated engine if needed.	
Data	File Format: • Parquet/GeoParquet	It allows the possibility of working with both centralized and distributed computing systems. Standard and recommended file format of the Spark framework.	
	Data storage: • Centralized environment ○ Local file-system • Distributed environment ○ HDFS (Hadoop) • Cloud environment	The data storage should be invisible to the software. If the system has been setup correctly, the software should be able to read data from the given path locations. Spark provides support for local file systems, distributed file systems (HDFS) and blob storage systems.	

TECHNOLOGIES		RATIONALE	REMARKS
	○ Blob storage (AWS S3, GCP Cloud storage, Azure Blob storage)		
Testing	Pytest	Ability to run multiple tests in parallel for optimised test suite execution times. Easy-to-use syntax. Automatic test discovery. Support for HTML reports on coverage and testing results.	
Source Control	GIT	As the use of GitHub is a requirement, the source control engine should be git, as it is the main engine supported by the platform. Git is the most popular source control engine.	
Code Documentation	Code style: • PEP8	PEP8 is the standard coding style for python software. It makes code more maintainable and readable. It is ideal for open-source projects, as it facilitates contribution due to the fact that all the code has a homogeneous and well-known style.	
	Docstring style: • Google Docstring Style	Readable and compact. Ideal for small docstrings. Most popular docstring format. Makes contribution easier. Supports automatic generation deployment of documentation in HTML files.	
	Code Documentation engine: • MkDocs	MkDocs uses Markdown, a lightweight markup language, for content creation, making it easy for users to write and update documentation.	

TECHNOLOGIES	RATIONALE	REMARKS
	MkDocs includes a built-in development server, enabling users to preview their documentation locally before publishing it, facilitating iterative improvements. Multiple plugin support: search-bar, table of contents, versioning, tabs… Code modules automatic documentation generation from python docstrings in Google style.	

5 DESIGN

This chapter describes all the software design decisions considered in the development of the software. First, general design aspects are presented (see section 5.1 General design), providing information about the data design, software design, infrastructure design, version control and software artefacts design. Secondly, the design considerations of each software component are presented (see section 5.2 Component design).

5.1 GENERAL DESIGN

5.1.1 DATA DESIGN

Big Data demands a meticulous and strategic approach to data design decisions within the pipeline architecture. In the realm of processing vast volumes of information, every design choice reverberates across the entire ecosystem, influencing the efficiency, scalability, and ultimately, the success of the data pipeline. The decisions made in the early stages of data design impact considerably the pipeline's ability to handle, analyse, and derive meaningful insights from massive datasets.

5.1.1.1 DATA FORMAT

All data processed by the pipeline components will be in **(geo)parquet** format as it is the ideal format for working with the spark framework. It may be the case that some input data is not presented in (geo)parquet format (e.g. csv, json, etc.). Hence, a format transformation process is needed. In this regard, a data ingestion process is defined which incorporates all data into the system in the desired (geo)parquet format.

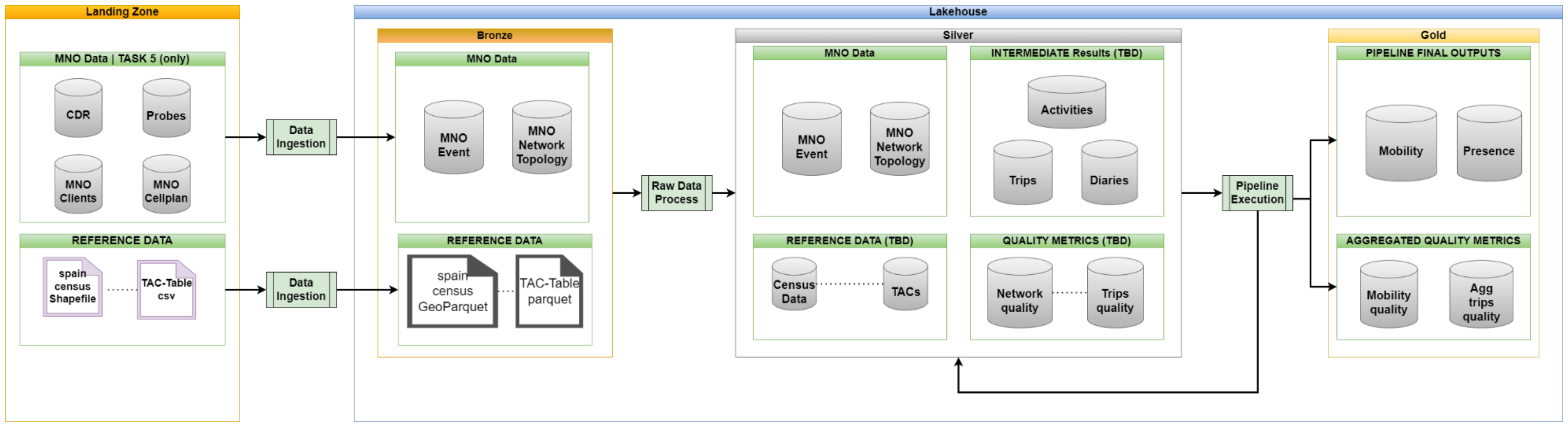
5.1.1.2 DATA STORAGE

As the solution is designed to work in a cloud architecture, its blob storage can be defined as a *Lakehouse* which guarantees that all data in it is accessible by any computing infrastructure deployed within the cloud. When executing locally, the OS filesystem can be used as *Lakehouse*. A medallion architecture is proposed for classifying the data within the *Lakehouse* based in three levels in which each one represents a more advanced level of data processing:

- **Bronze**: almost raw data ingested in the desired format. Mainly MNO data and contextual data.
- **Silver:** data model of the project. Enriched MNO data, intermediate outputs and quality metrics and quality warnings datasets.
- **Gold:** final aggregated outputs (final indicators) of the pipeline.

As previously mentioned, it is expected that not all input datasets will be in the (geo)parquet format, so a **landing zone** has been defined to address this aspect. In this zone all data as it is obtained is centralized so it can be then ingested into the bronze layer of the *Lakehouse*.

Figure 2: Medallion architecture scheme



5.1.1.3 MNO DATA DELIVERY

Event and network topology data for each day will be provided by MNOs at the Bronze level.

This data must be stored with the following folder structure:
bronze/<country>/<mno>/<data_type>/year=<YYYY>/month=<MM>/day=<DD>/*.parquet.

For example: **bronze/es/orange/events/year=2023/month=01/day=01/event_data.parquet.**

Under the day folder multiple parquet files could be stored. However, it is recommended to use parquet files with sizes of 512MB-1GB as defined in the official parquet documentation [1].

References:

[1] Apache parquet file-format configurations. Available: https://parquet.apache.org/docs/file-format/configurations/ [Accessed Nov. 23, 2023]

5.1.2 SOFTWARE DESIGN

The aim of this section is to describe all the software design decisions for the execution of a big data pipeline that processes and generates data in the data model described in section 5.1.1 Data design.

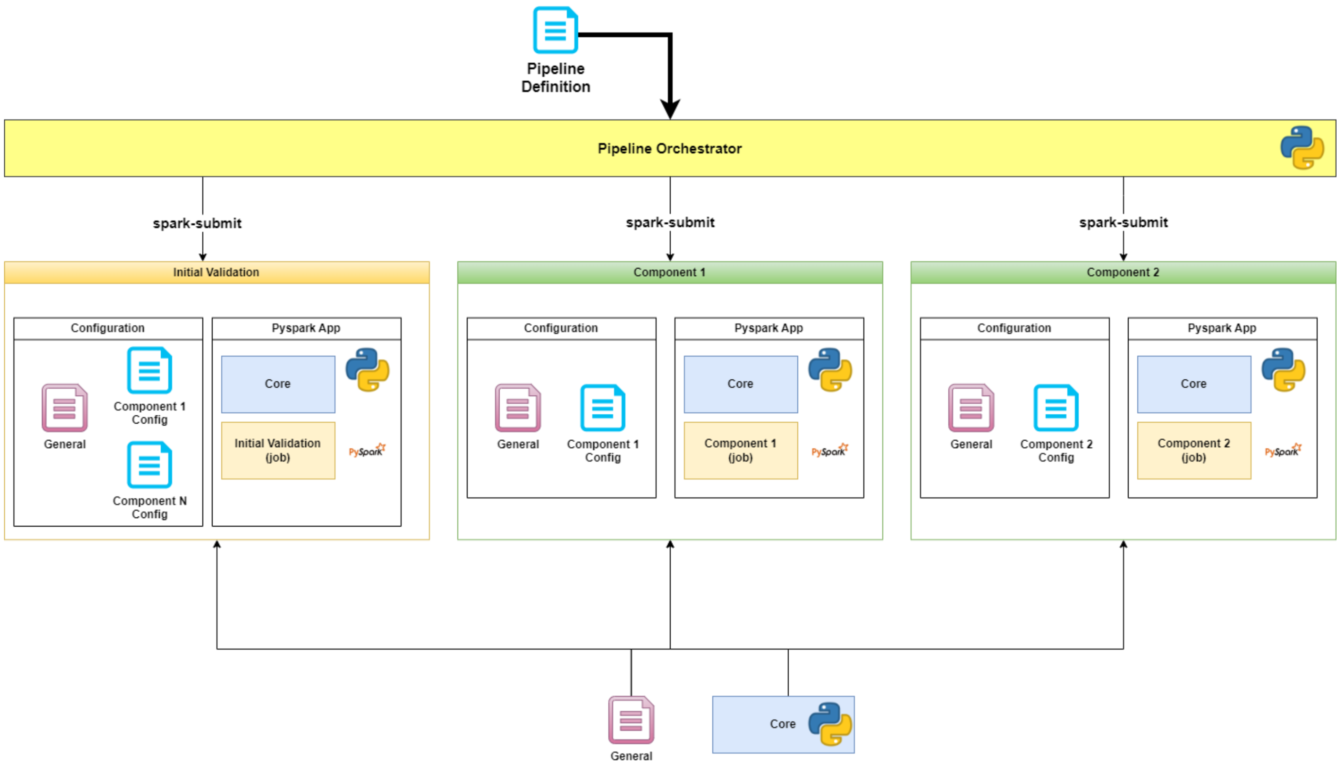
5.1.2.1 PIPELINE DESIGN

Processing multiple Big Data pipelines is the main functionality of the software to be developed. These pipelines can be divided into independent modules/components in which each one performs an ETL process. For this purpose the **isolated components** design principle has been applied which consists on having independent software processing units that do not share in-memory data and that, as long as they have all required input data, they can be executed without any dependency of other components. With this approach, components can be developed independently and will integrate without problems in a pipeline as long as the data objects definitions are adhered to. Furthermore, if the pipeline execution fails, the pipeline execution can be restored from the component that failed as all the previous components will have been executed correctly. Additionally, in the context of a *PySpark* application, using isolated components grants that the temporary and cache data of a Spark session will be completely cleaned after each execution.

Having each component as a single *PySpark* application allows the project to easily integrate with orchestration software. A component is defined as a Python package composed of a '*Core*' sub-package containing common functionalities of all components like logging, configuration, abstract classes and interfaces and a '*Components*' sub-package in which each component will represent a spark job. Besides the code, a spark job submission will include configuration text files. Two or more configuration files will be used for each component which can be categorized into two types:

- **General**: general & common configuration of the pipeline.
- **Component**: specific component configuration file(s) that can override some general configuration parameters.

Figure 3: Pipeline orchestration scheme



5.1.2.2 COMPONENTS DESIGN

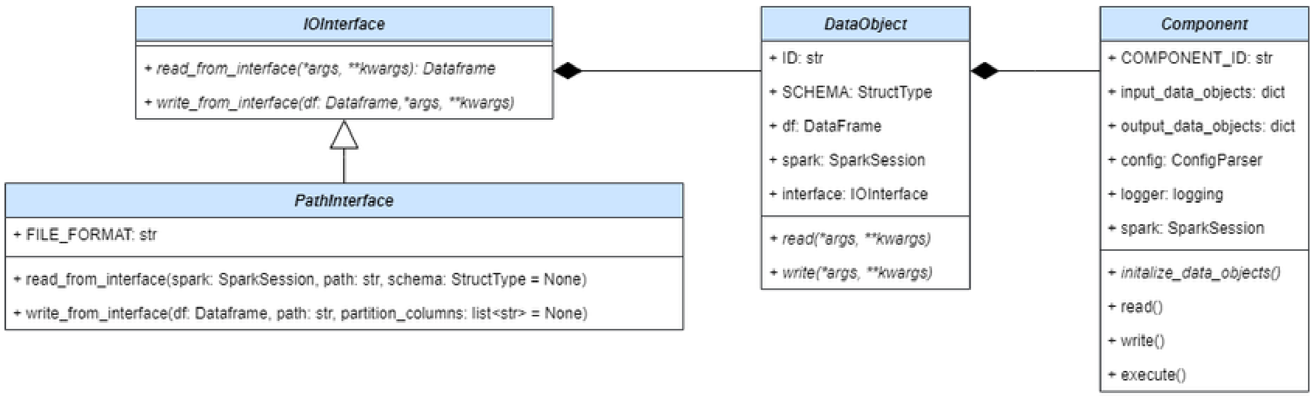
While every component executed in the pipeline corresponds to a single module to be executed as a spark-job, we can define different types of components depending on their purpose.

- **Ingestion:** these components are in charge of getting raw data in different file formats (csv, json, text, shapefile, etc.) and introducing it into the *Lakehouse* in a common file format: parquet & geoparquet. For demonstration/testing purposes, synthetic data is generated to simulate a pipeline execution. The synthetic data generating components is considered as an ingestion component.
- **Initial Validation:** it is a single component that performs pipeline setup verification checks. Its main purpose is to provide a 'fail fast' functionality for preventing small errors that will break the pipeline halfway like missing a configuration file for a component at a later stage of the pipeline. The verifications performed are:
  - Configuration files are valid;
  - Data can be read and written;
  - Component classes can be initialised.
- **Execution:** components that perform the functional logic of the pipeline. Each component performs ETL processes for a single functional step in the pipeline. It is recommended not to include too much functionality in a single component and instead split it up between execution components.
- **Quality:** these components perform validation and quality processes and store these analyses in the *Lakehouse*.

5.1.2.3 CLASS DIAGRAM

While the software will execute each component as a separate spark-job, the whole application can be conceived as a single python program which provides a component selection for single executions. The proposed software architecture is based in a '*Core*' package which contains the abstract classes and interfaces, '*DataObjects*' and common functionalities like the configuration, spark session and logging management.

Figure 4: Component and DataObject class diagram



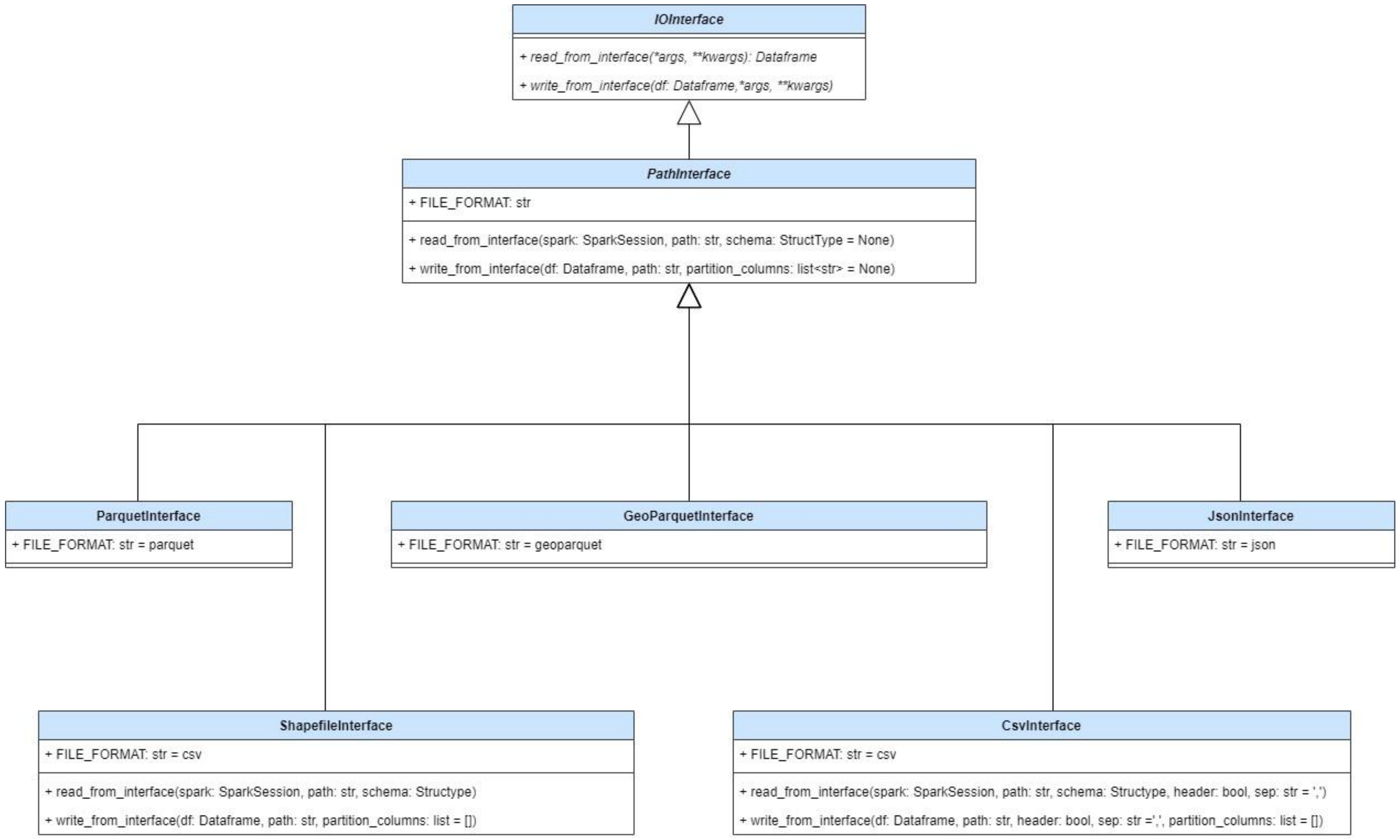
IOInterface
+ read_from_interface(*args, **kwargs): Dataframe
+ write_from_interface(df: Dataframe,*args, **kwargs)
PathInterface
+ FILE_FORMAT: str
+ read_from_interface(spark: SparkSession, path: str, schema: StructType = None)
+ write_from_interface(df: Dataframe, path: str, partition_columns: list<str> = None)
DataObject
+ ID: str
+ SCHEMA: StructType
+ df: DataFrame
+ spark: SparkSession
+ interface: IOInterface
+ read(*args, **kwargs)
+ write(*args, **kwargs)
Component
+ COMPONENT_ID: str
+ input_data_objects: dict
+ output_data_objects: dict
+ config: ConfigParser
+ logger: logging
+ spark: SparkSession
+ initalize_data_objects()
+ read()
+ write()
+ execute()

The most important class of the application is the '*Component*' class which is the abstract class that performs the read, transform and write operations. One of the key aspects of this software architecture is the use of the '*DataObject*' classes. Every data source is accessible for read and write operations through a '*DataObject*' class. This prevents multiple read and write definitions of a data source used in multiple components, eases the scalability of software and guarantees consistency in read and write operations as the same schema is always used. The '*DataObject*' class contains an '*IOInterface*' class which abstracts input and output operations perform on data sources. In the realm of Big Data is common that data can be given through different file types (csv, json, parquet…), databases or APIs; having a class that abstracts this access grants modularity and scalability as the incorporation/change of a data source only implies a modification in the '*IOInterface*' used by the '*DataObject*'. Thanks to the Spark framework, different file formats are read with the same code with minimum changes. An intermediate abstract class, called '*PathInterface*', that inherits from '*IOInterface*' is defined in order to prevent having duplication of code for reading and writing a file. From this class concrete classes for reading different file formats can be defined. The supported file formats are:

- Parquet
- Json
- Csv
- Shapefile
- Geoparquet.

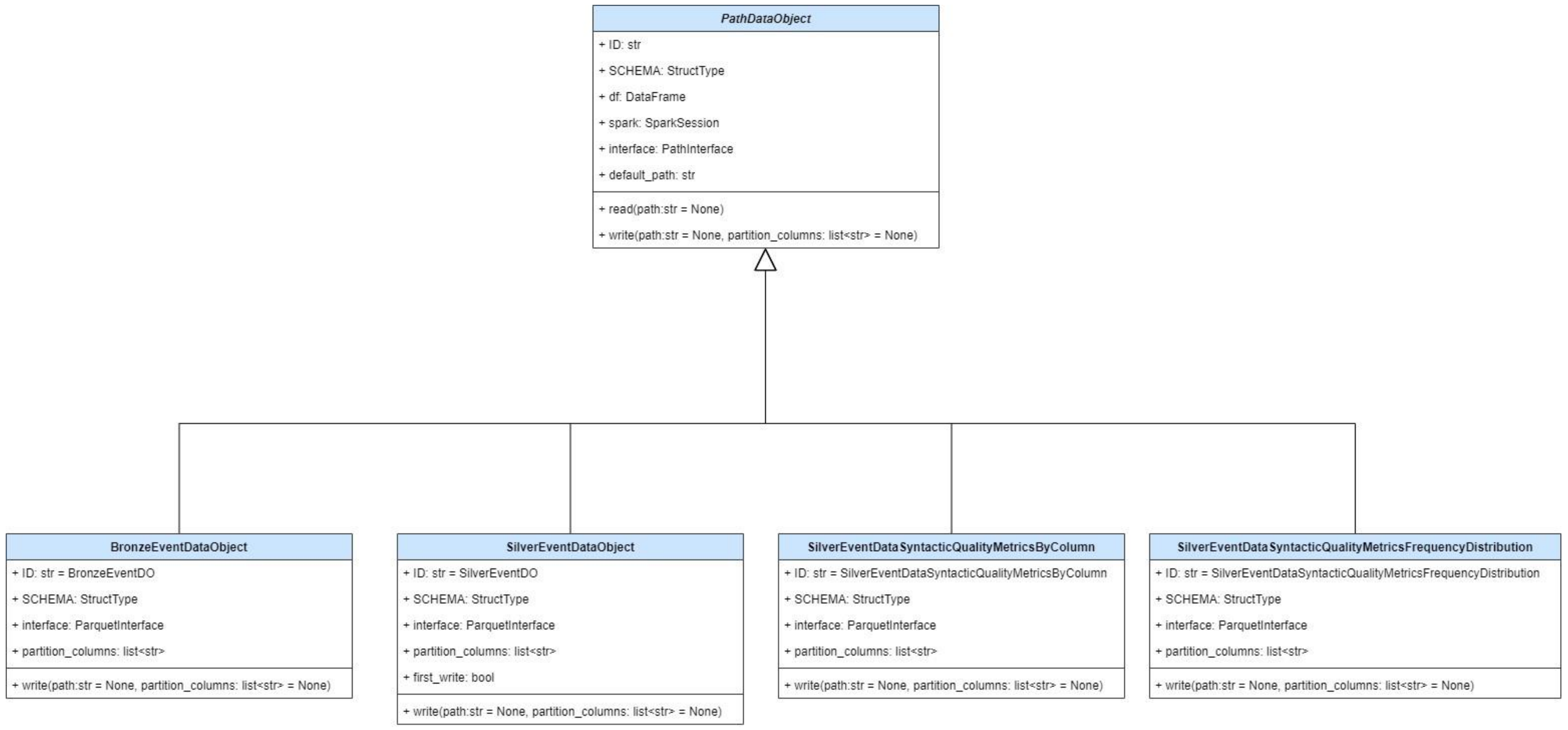
The concrete classes for this file access require only a change to the FILE_FORMAT variable as the main logic is inherited by the parent class reducing code duplication. For special cases, like shapefiles, specific logic for reading a shapefile is needed as the Sedona Framework is used.

Figure 5: IO Interface class diagram


IOInterface
+ read_from_interface(*args, **kwargs): Dataframe
+ write_from_interface(df: Dataframe,*args, **kwargs)
PathInterface
+ FILE_FORMAT: str
+ read_from_interface(spark: SparkSession, path: str, schema: StructType = None)
+ write_from_interface(df: Dataframe, path: str, partition_columns: list<str> = None)
ParquetInterface
+ FILE_FORMAT: str = parquet
GeoParquetInterface
+ FILE_FORMAT: str = geoparquet
JsonInterface
+ FILE_FORMAT: str = json
ShapefileInterface
+ FILE_FORMAT: str = csv
+ read_from_interface(spark: SparkSession, path: str, schema: Structype)
+ write_from_interface(df: Dataframe, path: str, partition_columns: list = [])
CsvInterface
+ FILE_FORMAT: str = csv
+ read_from_interface(spark: SparkSession, path: str, schema: Structype, header: bool, sep: str = ',')
+ write_from_interface(df: Dataframe, path: str, header: bool, sep: str =',', partition_columns: list = [])

After defining all I/O interfaces, the '*DataObjects*' of the application can be defined. A '*DataObject*' class is defined for each '*DataObject*' defined in Annex I. These classes contain information about the data they are modeling, like a unique ID to identify the data, the data schema or the data type. They also hold the spark DataFrame and provide an easy and centralized way for developers to read and write data of a data object. This prevents multiple read and write implementations of a data object that is used in multiple components. Figure 5 shows an example of four different data object class diagrams.

Figure 6: DataObjects example class diagram



PathDataObject
+ ID: str
+ SCHEMA: StructType
+ df: DataFrame
+ spark: SparkSession
+ interface: PathInterface
+ default_path: str
+ read(path:str = None)
+ write(path:str = None, partition_columns: list<str> = None)
BronzeEventDataObject
+ ID: str = BronzeEventDO
+ SCHEMA: StructType
+ interface: ParquetInterface
+ partition_columns: list<str>
+ write(path:str = None, partition_columns: list<str> = None)
SilverEventDataObject
+ ID: str = SilverEventDO
+ SCHEMA: StructType
+ interface: ParquetInterface
+ partition_columns: list<str>
+ first_write: bool
+ write(path:str = None, partition_columns: list<str> = None)
SilverEventDataSyntacticQualityMetricsByColumn
+ ID: str = SilverEventDataSyntacticQualityMetricsByColumn
+ SCHEMA: StructType
+ interface: ParquetInterface
+ partition_columns: list<str>
+ write(path:str = None, partition_columns: list<str> = None)
SilverEventDataSyntacticQualityMetricsFrequencyDistribution
+ ID: str = SilverEventDataSyntacticQualityMetricsFrequencyDistribution
+ SCHEMA: StructType
+ interface: ParquetInterface
+ partition_columns: list<str>
+ write(path:str = None, partition_columns: list<str> = None)

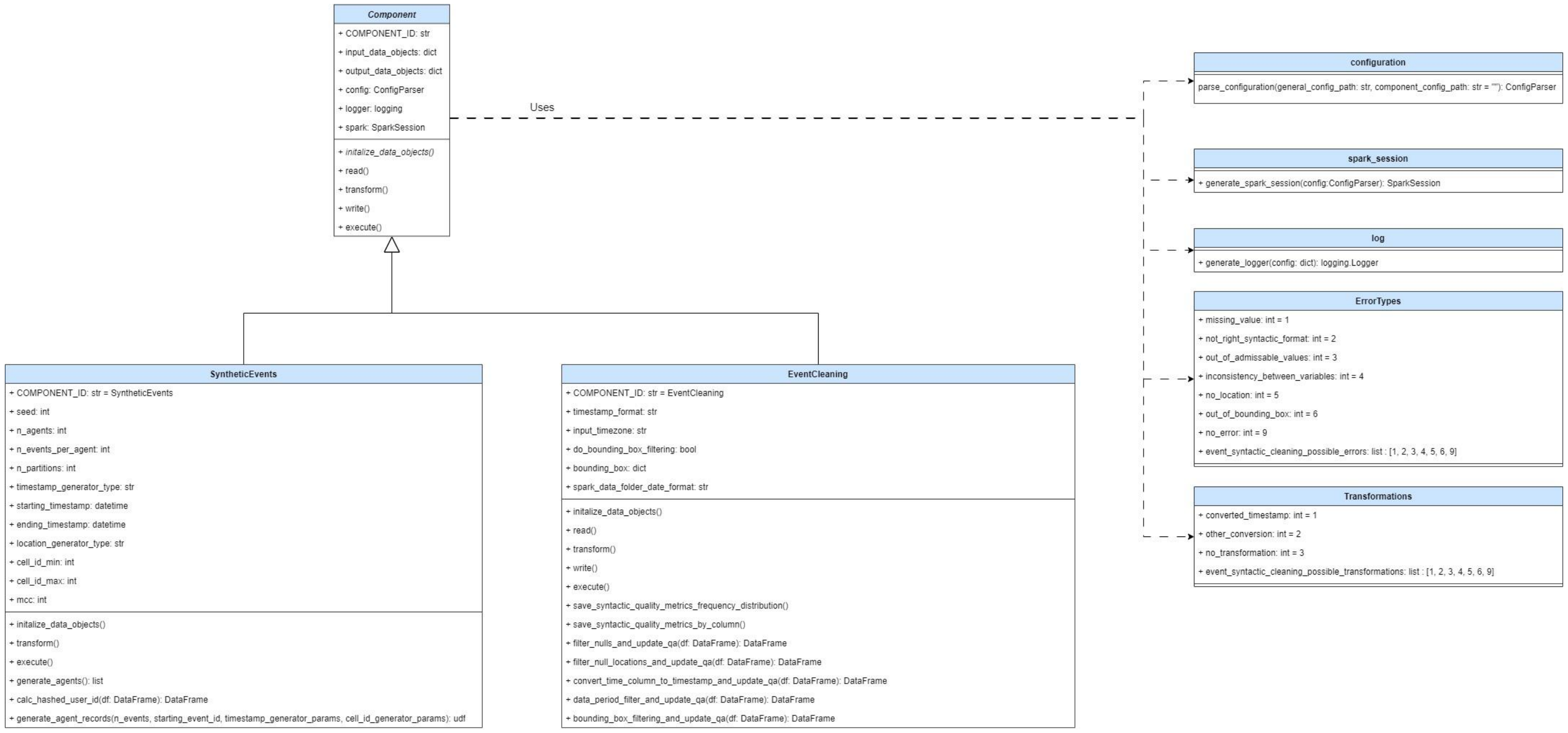
After modeling all the data objects that will be used in the release of the software, the components that make use of this data and perform the transformations are implemented. Each component can be thought as an abstract class which will read data, transform data and write data. They are the main point of execution as each component represents a step of the pipeline. All components also use some common functionalities which consist of:

- Reading configuration files
- Starting a Spark Session
- Initialize a Logger

Component classes will use the '*DataObjects*' associated to them to read and write data. All this logic can be centralised in an abstract class which delegates to its inherited classes the only responsibility to implement the concrete data transformations. This approach keeps codes modular and clean. Furthermore, it eases the development as developers only need to take care of implementing the logic of the transformations of the component.

In Section 5.2 Component design all components of the software are described with a class diagram that represents all the concrete objects that interact in the execution of the component.

Figure 7: Concrete component implementation class diagram


Component
+ COMPONENT_ID: str
+ input_data_objects: dict
+ output_data_objects: dict
+ config: ConfigParser
+ logger: logging
+ spark: SparkSession
+ initalize_data_objects()
+ read()
+ transform()
+ write()
+ execute()
Uses
configuration
parse_configuration(general_config_path: str, component_config_path: str = ""): ConfigParser
spark_session
+ generate_spark_session(config:ConfigParser): SparkSession
log
+ generate_logger(config: dict): logging.Logger
ErrorTypes
+ missing_value: int = 1
+ not_right_syntactic_format: int = 2
+ out_of_admissable_values: int = 3
+ inconsistency_between_variables: int = 4
+ no_location: int = 5
+ out_of_bounding_box: int = 6
+ no_error: int = 9
+ event_syntactic_cleaning_possible_errors: list : [1, 2, 3, 4, 5, 6, 9]
Transformations
+ converted_timestamp: int = 1
+ other_conversion: int = 2
+ no_transformation: int = 3
+ event_syntactic_cleaning_possible_transformations: list : [1, 2, 3, 4, 5, 6, 9]
SyntheticEvents
+ COMPONENT_ID: str = SyntheticEvents
+ seed: int
+ n_agents: int
+ n_events_per_agent: int
+ n_partitions: int
+ timestamp_generator_type: str
+ starting_timestamp: datetime
+ ending_timestamp: datetime
+ location_generator_type: str
+ cell_id_min: int
+ cell_id_max: int
+ mcc: int
+ initalize_data_objects()
+ transform()
+ execute()
+ generate_agents(): list
+ calc_hashed_user_id(df: DataFrame): DataFrame
+ generate_agent_records(n_events, starting_event_id, timestamp_generator_params, cell_id_generator_params): udf
EventCleaning
+ COMPONENT_ID: str = EventCleaning
+ timestamp_format: str
+ input_timezone: str
+ do_bounding_box_filtering: bool
+ bounding_box: dict
+ spark_data_folder_date_format: str
+ initalize_data_objects()
+ read()
+ transform()
+ write()
+ execute()
+ save_syntactic_quality_metrics_frequency_distribution()
+ save_syntactic_quality_metrics_by_column()
+ filter_nulls_and_update_qa(df: DataFrame): DataFrame
+ filter_null_locations_and_update_qa(df: DataFrame): DataFrame
+ convert_time_column_to_timestamp_and_update_qa(df: DataFrame): DataFrame
+ data_period_filter_and_update_qa(df: DataFrame): DataFrame
+ bounding_box_filtering_and_update_qa(df: DataFrame): DataFrame

5.1.2.4 CONFIGURATION DESIGN

One critical aspect of building robust big data pipelines is the management of configuration settings. To achieve enhanced flexibility, maintainability, and scalability, a prudent approach is to utilise a combination of a general configuration file and component-specific configuration files.

\ GENERAL CONFIGURATION FILE

The general configuration file serves as the overarching blueprint for the entire big data pipeline. It encapsulates settings that are applicable across multiple components, providing a centralised and standardised approach to configuration management. This file contains global execution settings, like logger settings, path values and spark-session settings. By consolidating these shared settings in a single file, the pipeline gains consistency and becomes more adaptable to changes in the overall infrastructure.

\ COMPONENT-SPECIFIC CONFIGURATION FILES

Complementing the general configuration file, each individual component within the big data pipeline is associated with its own specific configuration file. These files contain parameters tailored to the unique requirements and characteristics of each component. For instance, a data ingestion component might have settings related to data sources, formats, and ingestion frequencies, while an execution component may have parameters governing data transformation logic.

ADVANTAGES OF USING SEPARATED CONFIGURATION FILES

\ **a. Modularity and maintainability:** separating configurations into distinct files promotes a modular design, allowing developers to focus on the specific requirements of each component. This modularity not only simplifies development but also streamlines maintenance efforts. When modifications or updates are necessary, developers can address specific components without the need to navigate through an extensive monolithic configuration file.

\ **b. Ease of collaboration:** in collaborative development environments, multiple teams or individuals may be responsible for different components of a big data pipeline. Using separated configuration files facilitates parallel development and reduces the risk of conflicts. Each team can work on their respective configurations independently, minimising the chances of unintentional interference.

\ **c. Scalability:** as big data pipelines evolve and expand, the addition of new components or the modification of existing ones is inevitable. Separated configuration files accommodate this scalability seamlessly. Developers can introduce new configurations for new components without disrupting the settings of existing ones, promoting a scalable and extensible architecture. Furthermore, developers can override general settings parameters in the component specific settings for testing purposes.

\ **d. Version control:** by organising configurations in a modular fashion, version control becomes more effective. Changes to specific components can be tracked independently, providing a clear audit trail of configuration modifications over time. This enhances traceability, simplifies debugging, and facilitates the rollback to previous configurations, if needed.

5.1.2.5 LOGGING DESIGN

The logger is initialised after reading the configuration file. A single python logging object is created logging into the standard out (*stdout)* file descriptor. Furthermore, the software can also create a log file in the local filesystem of the master machine besides the writing to *stdout*. This functionality is activated via configuration and is recommended for local mono-cluster deployments. In cloud environments, like AWS EMR and GCP *Dataproc,* the logs written in *stdout* file descriptor can be saved into their respective blob storage.

Each component shall log the configuration that will use at the start of its execution in the log file.

5.1.2.6 CRITICAL QUALITY WARNINGS

In a Big Data pipeline, for ensuring its reliable orchestration, it is crucial to differentiate between controlled exits due to quality warnings and unexpected failures. Our pipeline includes specific Quality Warnings components designed to exit in a controlled manner with a predefined process **exit status 2**. This mechanism signals to the implemented *multimno* orchestrator, or any other orchestration layer that the user may use, that the component has not encountered an unhandled error but has, instead, terminated due to a detected quality issue. By distinguishing between controlled warnings and failures, the pipeline can enable intelligent decision-making, allowing downstream processes to react accordingly - whether by triggering alerts, proceeding with caution, or halting execution based on predefined rules.

The implemented **Multimno Orchestrator** will halt pipeline execution upon encountering a **Critical Quality Warning**, ensuring that data integrity issues are properly addressed. When a component exits with **status 2**, the orchestrator will log the corresponding message, mark the event as a controlled warning, and terminate the orchestration also with **exit status 2**. This guarantees that quality issues are clearly identified and propagated while preventing further execution in cases where continuing the pipeline could compromise data reliability.

This modular design enhances flexibility for future custom orchestrators while maintaining consistency in handling quality warnings. By clearly differentiating controlled exits from failures, it prevents false positives and ensures that operational responses are aligned with the severity of detected issues.

5.1.3 INFRASTRUCTURE DESIGN

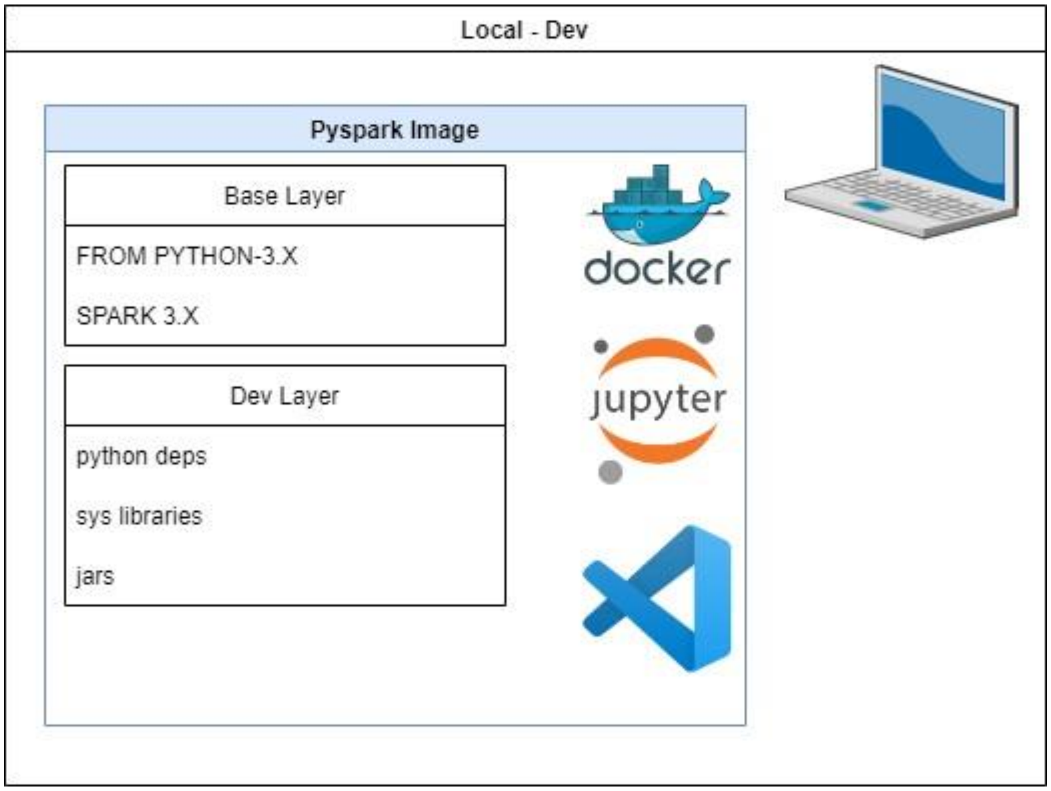
The software developed in the project processes big data pipelines which, due to the expected large volume of the data, distributed computing and distributed file systems frameworks will be used. Spark & HDFS, respectively, are the proposed open-source frameworks. They can be executed in centralised environments and distributed environments.

5.1.3.1 DEVELOPMENT/TESTING ENVIRONMENT

When developing the software, it is important that it can be executed locally so developers can perform an agile developing cycle. Thankfully both Spark & HDFS frameworks can be deployed locally in a centralised system of a single computer. However, in the case of a local execution, the OS filesystem can be used instead of HDFS for simplicity as the data used in this case should not be large.

For a local execution, docker technology is proposed as it allows to completely isolate software dependencies from the host machine inside the container. Containers can be conceived as virtual machines that only have the indispensable libraries for executing the software. With this approach, users only need to have docker installed in their system to execute the application. Furthermore, it allows to test different versions of libraries in an agile manner as multiple containers with different environments can be created in order to verify the software execution across multiple library versioning combination.

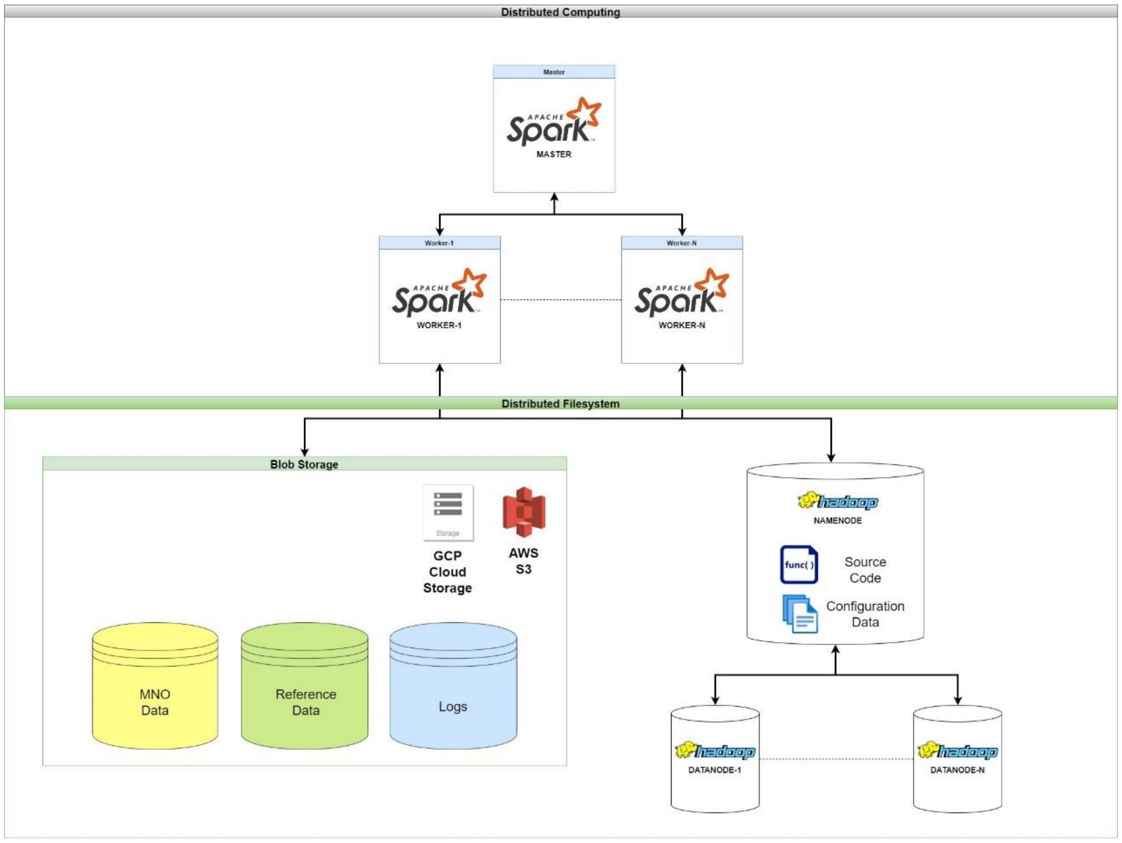
Figure 8: Standalone docker deployment



5.1.3.2 PRODUCTION ENVIRONMENT

Thanks to cloud providers like AWS and GCP, computing environments that easily scale can be deployed. Furthermore, the software needs to be executed in the MNO cloud environments due to data privacy constraints. Based on the project team previous experience working with MNOs, many of them usually provide a cloud-managed map-reduce cluster, such as AWS EMR or GCP Dataproc. These clusters follow a driver-executor architecture ideal for the Spark and Hadoop frameworks. In Figure 8, a representation of a distributed computing deployment in the MNO-Cloud is represented.

Figure 9: Distributed computing deployment



5.1.4 VERSION CONTROL

The code shall be maintained and released following the semantic versioning strategy. It consists on using three numeric levels for code versioning classified as **Major.Minor.Patch.** For example: 1.2.4.

Each level classifies the changes in the source code:

\ **Major:** changes that are not backward compatible.
\ **Minor:** changes that are backward compatible. Example: performance improvements or new functionalities.
\ **Patches:** bug fixes.

Levels are increased sequentially by one. When a level increases it resets the value for levels to its right to zero (example: increasing the minor version for version 1.2.4. will result in 1.3.0.)

Generally, when the software is in development before its official first release (beta stage) the major version is set to zero (example: version 0.7.3.)

Pre-release metadata can be added to the version by appending a hyphen to the end (example: version 1.0.0-alpha1)

5.1.5 SOFTWARE ARTEFACTS DESIGN

5.1.5.1 SOURCE CODE

\ CODING STYLE

PEP 8, which stands for Python Enhancement Proposal 8, is the coding style proposed for writing clean, readable, and maintainable Python code. It was created to promote consistency in Python code and make it easier for developers to collaborate on projects. PEP 8 provides the following **advantages**:

1. **Readability**: PEP 8 enforces a consistent and easy-to-read coding style. This makes it easier for developers to understand and maintain the code, which is especially important for collaborative projects or when revisiting your own code in the future.
2. **Consistency**: PEP 8 helps ensure that Python code looks and feels consistent across different projects and teams. This consistency simplifies code reviews and reduces the learning curve when working on new projects.
3. **Collaboration**: when multiple developers work on a project, using PEP 8 ensures that everyone follows the same coding conventions. This can prevent misunderstandings and disagreements about coding style and improves code quality and maintainability.
4. **Tooling and automation**: many code editors and integrated development environments (IDEs) provide built-in or third-party tools for checking and formatting code according to PEP 8. These tools can automatically highlight or fix violations, making it easy to follow the style guide.
5. **Debugging**: code that follows PEP 8 is often easier to debug, as it has a consistent structure and naming conventions. This can save you time when troubleshooting issues.
6. **Community standards**: PEP 8 is widely accepted in the Python community, and most Python developers are familiar with its conventions. Adhering to PEP 8 makes it easier for you to collaborate with other developers and participate in open-source projects.
7. **Future-proofing**: following PEP 8 helps future-proof your code. As Python evolves, adhering to established coding standards makes it easier to update your code to newer Python versions and libraries.

PEP 8 official guide is available at the following link: https://peps.python.org/pep-0008/

\ DOCSTRING STYLE

Adhering to a unique docstring style guarantees consistency within software development in a project. Google Docstrings are the most popular convention for docstrings which facilitates readability and collaboration in open-source projects. Furthermore, Google Docstrings provide the following **benefits**:

1. **Clarity and readability:** Google Docstrings provide a structured format that includes sections for a function's description, parameters, return values, and examples. This format enhances the clarity and readability of your code documentation, making it easier for both developers and automated documentation tools to understand your code.
2. **Consistency:** Google Docstrings provide a consistent way to document your code. When multiple developers work on a project, using a standardized docstring format ensures that all functions and classes are documented in a similar and predictable way.
3. **Auto-generation:** many documentation tools and IDEs can parse Google Docstrings and automatically generate documentation from them. For example, tools like Sphinx and Doxygen can create HTML or PDF documentation from the source code docstrings.
4. **IDE support:** several Python Integrated Development Environments (IDEs), such as PyCharm and VSCode, can use Google Docstrings to provide code suggestions, autocompletion, and inline documentation. This can be a significant productivity boost for developers.

5. **API documentation:** Google Docstrings are suitable for generating API documentation. This makes it easier to extract and publish the project's API documentation for others to use.
6. **Help for code review:** when reviewing code, especially in a collaborative setting, well-documented functions with Google Docstrings can provide reviewers with a clear understanding of the purpose of each function and its expected inputs and outputs. This can lead to more effective code reviews.
7. **Self-documentation:** Google Docstrings serve as a form of self-documentation for your code. They provide valuable information about how to use the functions and classes without needing to dig into the implementation details.

Google Docstrings official guide is available in the following link:
https://google.github.io/styleguide/pyguide.html#38-comments-and-docstrings

5.1.5.2 TESTING

\ EXECUTION ARTEFACTS

\ **Testing code**: code written in Python containing the unit-tests of the project. Each module should have, at least, a testing file with a battery of tests. Both 'happy path' and error cases should be tested. Tests should evolve as code evolves.

\ **Testing resources:** files needed to execute all the unit-tests of the project. They can be divided in the following categories:

- **Configuration:** configuration data needed for the execution of tests.
- **Testing Data:** small input data and output expected data needed by tests.
- **Automation scripts (optional):** scripts that execute the tests and generate the testing reports.

\ TESTING REPORT

Report containing the results of the testing execution. This report is automatically generated with the *automation scripts* mentioned in the previous section. It is defined as:

\ **Test execution report:** file indicating which tests have been passed, failed or skipped. It should also include the version of the software used, test logs and execution time.

5.2 COMPONENT DESIGN

*[**Remark** - This section contains the design for the components available in the release 0.3 of the software.]*

5.2.1 EVENTCLEANING

5.2.1.1 MODULE DESCRIPTION

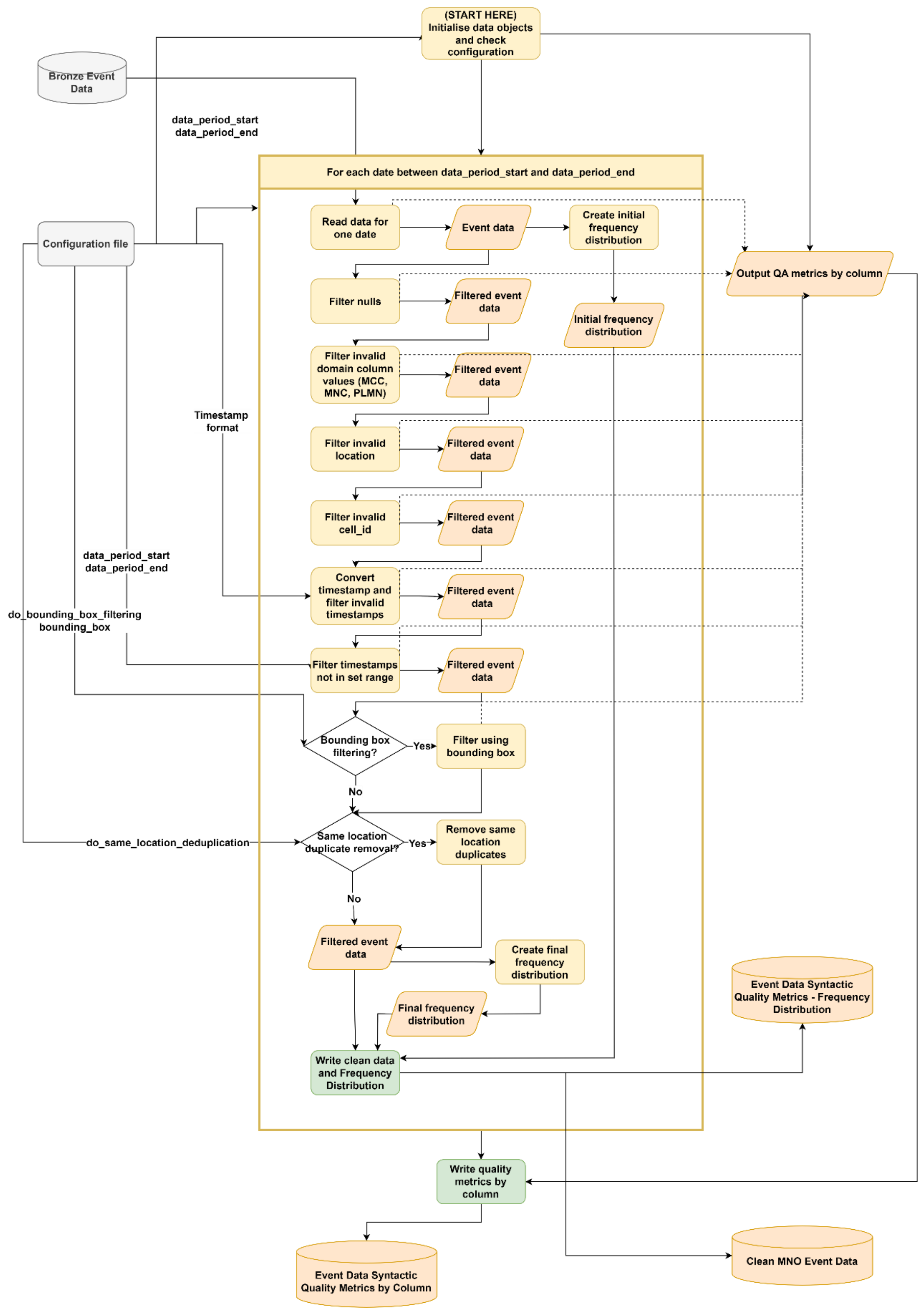
- **Module Name:** EventCleaning
- **Objectives:** the objective of this method is to perform syntactic checks on the raw event data from the MNO. Data not matching the expected syntax will be removed. Based on the removed records, quality metrics will be created.
- **Functionality:**
  EventCleaning Requirements Specification
- **Data Inputs and Outputs:**
  - Input:
    I.1 MNO Event Data – Raw

- Outputs:
  I.2 MNO Event Data – Syntactically Cleaned
  I.4 MNO Event Data Syntactic Quality Metrics – frequency distribution
  I.3 MNO Event Data Syntactic Quality Metrics – by column

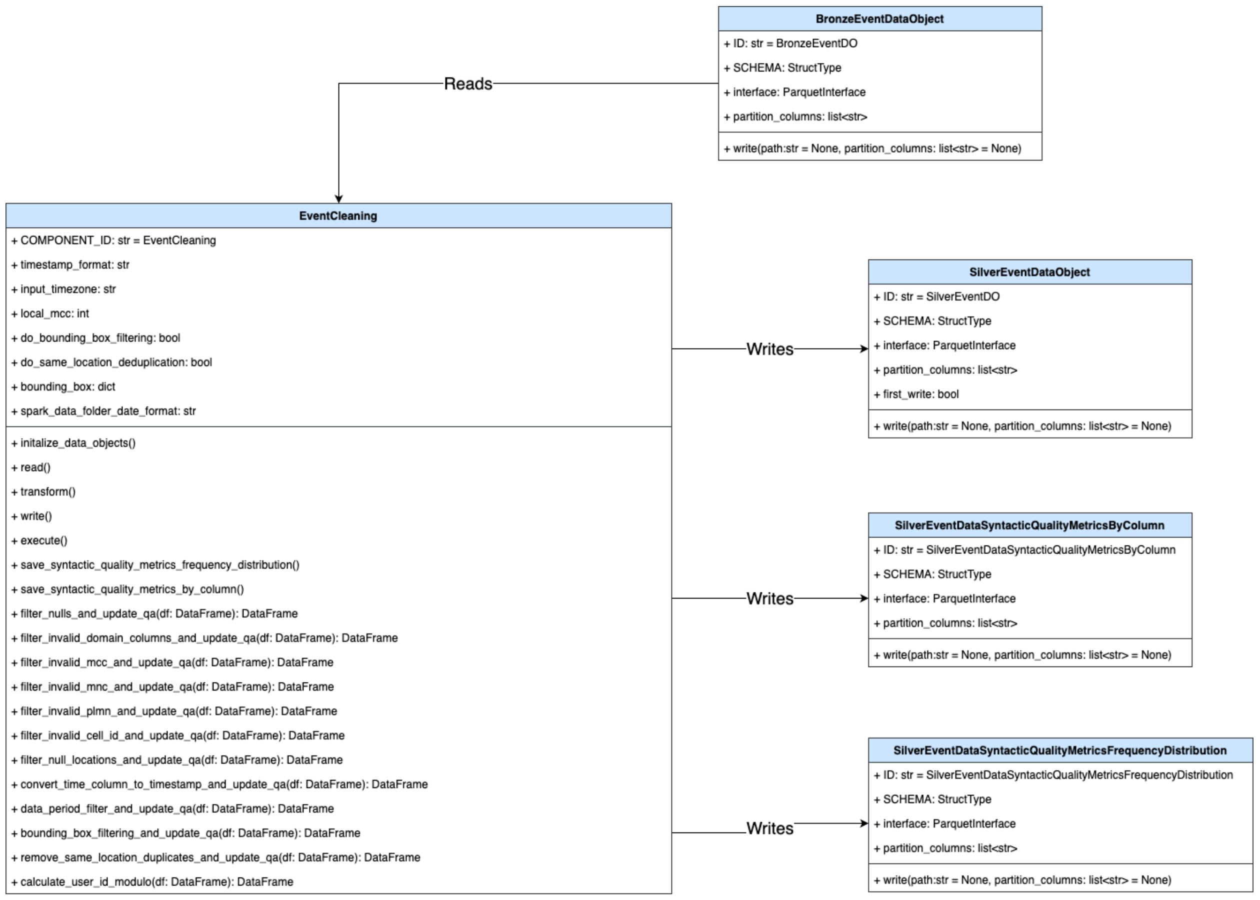
5.2.1.2 DEVELOPMENT DESIGN

- **Key Algorithms/Processes:**
  The data is processed in one-day chunks. It is expected that the MNOs will provide data that is already separated by date. All the following steps are run for each date in the data:
  - Create quality metrics data objects.
  - Filter out rows that contain nulls in user_id or timestamp columns and update quality metrics.
  - Filter out rows that do not have valid domain columns (each row must have mcc and mnc, or plmn).
  - Infer the domain of each row:
    - If plmn is not null - domain is outbound
    - If mcc is equal to local_mcc from configuration - domain is domestic
    - Otherwise - domain is inbound.
  - Filter out domestic and inbound rows that have an invalid MCC code (has to be a number between 100 and 999) and update quality metrics.
  - Filter out domestic and inbound rows that have an invalid MNC code (has to be a numerical number with 2 or 3 digits; n.b. can also be 00) and update quality metrics.
  - Filter out outbound rows that have an invalid PLMN code (has to be a number between 10000 and 99900) and update quality metrics.
  - Filter out domestic and inbound rows that do not have a valid location. A row has to have a cell_id or both latitude and longitude columns as not nulls to be considered valid. Update quality metrics.
  - Filter out domestic and inboundrows with invalid cell_id. A valid cell_id contains 14 or 15 numerical digits. Update quality metrics.
  - Convert timestamp column to internal timestamp type according to timestamp_format from configuration and filter out rows where timestamp does not match the given format. Update quality metrics.
  - Filter out rows, where the timestamp is not between data_period_start and data_period_end. Update quality metrics.
  - If do_bounding_box_filtering is set to True in configuration,
    - For rows with latitude and longitude: filter out rows where value is out of bounds for bounding box defined by bounding_box in configuration. Update quality metrics.
  - If do_same_location_duplicate_removal is set to True in configuration,
    - Remove all rows that have identical values in the columns: timestamp, user_id, cell_id, latitude, longitude, plmn.
    - For rows with latitude and longitude: Filter out rows where value is out of bounds for bounding box defined by bounding_box in configuration. Update quality metrics
  - Calculate the modulo of the user_id column, to be used for partitioning the data, so that each partition would contain a similar number of users.
  - Write silver event data object and quality metrics

- **Data flow diagram:**


(START HERE) Initialise data objects and check configuration
Bronze Event Data
data_period_start data_period_end
For each date between data_period_start and data_period_end
Read data for one date
Event data
Create initial frequency distribution
Output QA metrics by column
Configuration file
Filter nulls
Filtered event data
Initial frequency distribution
Filter invalid domain column values (MCC, MNC, PLMN)
Filtered event data
Timestamp format
Filter invalid location
Filtered event data
Filter invalid cell_id
Filtered event data
data_period_start data_period_end
Convert timestamp and filter invalid timestamps
Filtered event data
do_bounding_box_filtering bounding_box
Filter timestamps not in set range
Filtered event data
Bounding box filtering?
Yes
Filter using bounding box
No
do_same_location_deduplication
Same location duplicate removal?
Yes
Remove same location duplicates
No
Filtered event data
Create final frequency distribution
Event Data Syntactic Quality Metrics - Frequency Distribution
Final frequency distribution
Write clean data and Frequency Distribution
Write quality metrics by column
Event Data Syntactic Quality Metrics by Column
Clean MNO Event Data

- **Class diagram:**


BronzeEventDataObject
+ ID: str = BronzeEventDO
+ SCHEMA: StructType
+ interface: ParquetInterface
+ partition_columns: list<str>
+ write(path:str = None, partition_columns: list<str> = None)
Reads
EventCleaning
+ COMPONENT_ID: str = EventCleaning
+ timestamp_format: str
+ input_timezone: str
+ local_mcc: int
+ do_bounding_box_filtering: bool
+ do_same_location_deduplication: bool
+ bounding_box: dict
+ spark_data_folder_date_format: str
+ initalize_data_objects()
+ read()
+ transform()
+ write()
+ execute()
+ save_syntactic_quality_metrics_frequency_distribution()
+ save_syntactic_quality_metrics_by_column()
+ filter_nulls_and_update_qa(df: DataFrame): DataFrame
+ filter_invalid_domain_columns_and_update_qa(df: DataFrame): DataFrame
+ filter_invalid_mcc_and_update_qa(df: DataFrame): DataFrame
+ filter_invalid_mnc_and_update_qa(df: DataFrame): DataFrame
+ filter_invalid_plmn_and_update_qa(df: DataFrame): DataFrame
+ filter_invalid_cell_id_and_update_qa(df: DataFrame): DataFrame
+ filter_null_locations_and_update_qa(df: DataFrame): DataFrame
+ convert_time_column_to_timestamp_and_update_qa(df: DataFrame): DataFrame
+ data_period_filter_and_update_qa(df: DataFrame): DataFrame
+ bounding_box_filtering_and_update_qa(df: DataFrame): DataFrame
+ remove_same_location_duplicates_and_update_qa(df: DataFrame): DataFrame
+ calculate_user_id_modulo(df: DataFrame): DataFrame
Writes
SilverEventDataObject
+ ID: str = SilverEventDO
+ SCHEMA: StructType
+ interface: ParquetInterface
+ partition_columns: list<str>
+ first_write: bool
+ write(path:str = None, partition_columns: list<str> = None)
Writes
SilverEventDataSyntacticQualityMetricsByColumn
+ ID: str = SilverEventDataSyntacticQualityMetricsByColumn
+ SCHEMA: StructType
+ interface: ParquetInterface
+ partition_columns: list<str>
+ write(path:str = None, partition_columns: list<str> = None)
Writes
SilverEventDataSyntacticQualityMetricsFrequencyDistribution
+ ID: str = SilverEventDataSyntacticQualityMetricsFrequencyDistribution
+ SCHEMA: StructType
+ interface: ParquetInterface
+ partition_columns: list<str>
+ write(path:str = None, partition_columns: list<str> = None)

- **Code Structure:**

The code structure follows the format set by the core package, and the general repository structure.

The location of the module script in the repository is as follows:

```
/multimno_internal/
 └─── multimno
    └─── components
       └─── execution
          └─── event_cleaning
             └─── event_cleaning.py
```

event_cleaning.py contains one class named EventCleaning which is a subclass of Component.

The EventCleaning class overrides all methods in the Component class:

- __init__ method initialises the data objects and reads the necessary values from config file.
- read method is responsible for reading the data from one date into memory.
- write method is responsible for writing event data and frequency distribution quality metrics for the date currently being processed.

- transform performs all necessary filtering and transformations for daily data and updates the quality metrics data objects. transform contains calls to many other smaller functions that perform the actual data manipulation.
- execute is responsible for calling read, write and transform for each unique date in the dataset. The processing is done date-by-date. Only the data from one date is being processed at any given time.

5.2.2 EVENTQUALITYWARNINGS

5.2.2.1 MODULE DESCRIPTION

- **Module Name:** EventQualityWarnings
- **Objectives:** the objective of this method is to create a flexible/dynamic tool that will compute Quality Warnings checks based on two outputs - Quality Metrics Frequency Distribution and Quality Metrics By Column. The flexibility is provided by the option of specifying what group of QWs to compute, what value for different thresholds to choose and most importantly it is able to compute Quality Warnings after both MNO Event Cleaning and Event Deduplication stages meaning that this component does the job of Event Data Syntactic Quality Warnings and Event Deduplication Quality Warnings. The component is supposed to write two Data Objects - Log Table with unified structure of representing errors' information and For Plots which stores data needed to create graphs of three variables' distribution along with some other statistical measures - initial frequency, total frequency, and error rate by date.
- **Functionality:**
  the process of managing Quality Warnings is segmented into three major categories: QWs related to the daily sizes of data (both raw and preprocessed); the error rate of event data across various granularity levels (by date, by date and cell_id, by date and user_id, by date and cell_id and user_id); and quality assessments of error types (missing values, values out-of-range, deduplication of identical locations, and etc.).
  Functionality details may be found in the software requirements: 3.2.7 EventQualityWarnings
- **Data Inputs and Outputs:**
  - Input:
    In both Quality Warnings cases the Component expects two inputs: Event Data Quality Metrics Frequency Distribution and Event Data Quality Metrics By Column
    - I.3 MNO Event Data Syntactic Quality Metrics – by column
    - I.4 MNO Event Data Syntactic Quality Metrics – frequency distribution
  - Output:
    - I.5 MNO Event Data Quality Warnings – log table
    - I.22 MNO Event Data Quality Warnings – for plots

5.2.2.2 DEVELOPMENT DESIGN

- **Key Algorithms/Processes:**
  The whole Component heavily relies on the input Quality Metrics. It is important to specify the correct time period for Quality Warnings taking into account the lookback period timeline, in order to have covered enough previous data for the calculation of the Quality Warnings. For example, if the Quality Metrics were computed for the period of [2023-01-01, 2023-01-15] and a lookback period is set to be a week (7 days) then the first date of the time reference/period for Quality Warnings would be 2023-01-08, and the end date should be any date later than the start date and earlier than or the same as the last date of the calculated Quality Metrics (i.e. 2023-01-15 in the given example).

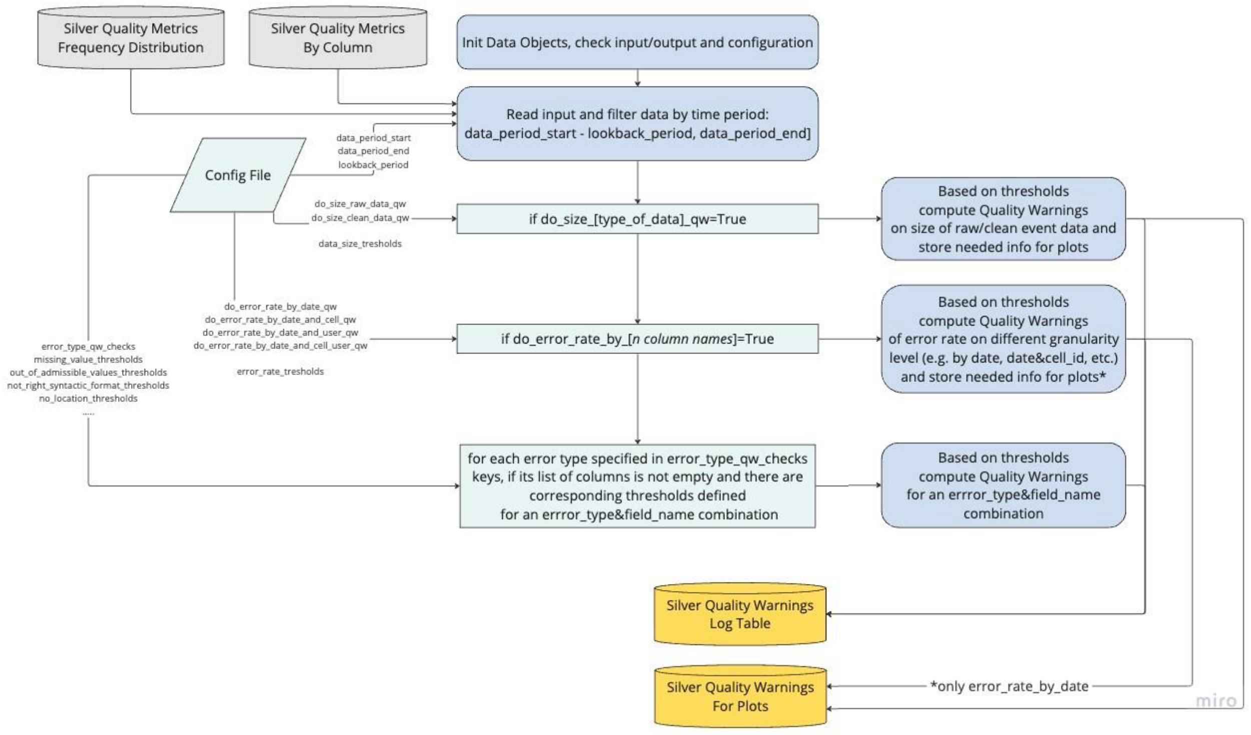
The whole process of execution of Quality Warnings is divided into three large groups: Quality Warnings regarding daily size of data; error rate of event data on different granularity levels; and quality checks of error types (e.g. missing value, out-of-range, deduplication same locations). The first two groups (size and error rate) solely use Silver Event Data Syntactic Quality Metrics - Frequency Distribution object and each sub-Quality-Warning within the mentioned sets is invoked by boolean value (basically, if True do something). The last group requires two inputs Frequency Distribution and Silver Event Data Syntactic Quality Metrics - By Column although the later holds the most important information. Also, the logic of this group differs; namely, the algorithm loops through each unique combination of error_type&field_name and performs same types of Quality Warnings, meaning the input is changing (e.g. number of errors for combination missing_value&user_id, or out_of_range&mcc), while the Quality Warnings process stays the same. The Component description step-by-step is presented below:

- Initialise EventQualityWarnings Component. Create attributes based on corresponding config (cleaning and deduplication have their own, separate config), check existence of input, initialise corresponding output Data Objects, if clear_destination_directory clear all Component's output
- Read Quality Metrics for the period: [data_period_start - lookback_period, data_period_end]. In config lookback_period is specified as string but in component it gets numerical representation.
- **Perform Quality Warning regarding data size (regards only Event Cleaning Quality Warnings)**, it could be either raw size (initial frequency) or clean size (final frequency), both are run if their corresponding config boolean params (do_size_raw_data_qw and do_size_clean_data_qw) are set to True. The QW involved: checking if a size within a range of two absolute numbers (upper and lower limit) and between [mean+X*std, mean-X*std] boundaries, average and standard deviation are calculated based on previous data of lookback_period length. Correspondingly three configurable thresholds (for each type of size) are involved: absolute upper/lower limits and the number of stds appropriate to deviate from mean. The information of wrong entries (please refer to its structure in Methodology Section) is stored in Log Table and apart from that data to plot graphs is being calculated. Important to mention that for Log Table the period would be as specified in config [data_period_start, data_period_end], while For Plots it should be [data_period_start - lookback_period, data_period_end].
- **Perform error rate Quality Warnings (regards only MNO Event Cleaning Quality Warnings)** which is computed by formula: **Error rate** = (Total initial frequency - Total final frequency) / Total initial frequency*100. The error rate is then checked on three warnings: should not be higher than some absolute number; should not be higher than average of previous error rates by some X%, should not be higher than mean + X*std. Again, for average and standard deviation information of previous days is used. The error rate Quality Warnings are computed on different granularity level (by date, by date and cell_id, by date and user_id, by date and cell_id and user_id). Each warning for each granularity level has their own configurable thresholds. The decision on running error rate Quality Warnings on each level is decided by its own boolean config param (e.g. do_error_rate_by_date_qw, do_error_rate_by_date_and_cell_qw, and so on). The information of wrong entries is stored in Log Table and apart from that data to plot graphs is being calculated but only for error rate by date.
- Perform final set of QWs - **error type Quality Warnings (regards both MNO Event Cleaning Quality Warnings and Event Deduplication Quality Warnings)**. They have the same checks as for error rate Quality Warnings - absolute upper limit, not over the average by X%, and mean+X*std limit (and under the hood uses the same function as for error rate QWs). However, the logic of invoking these checks is different instead of using boolean value, the code does it dynamically looping through unique combination of error_type&field_name (one error type can

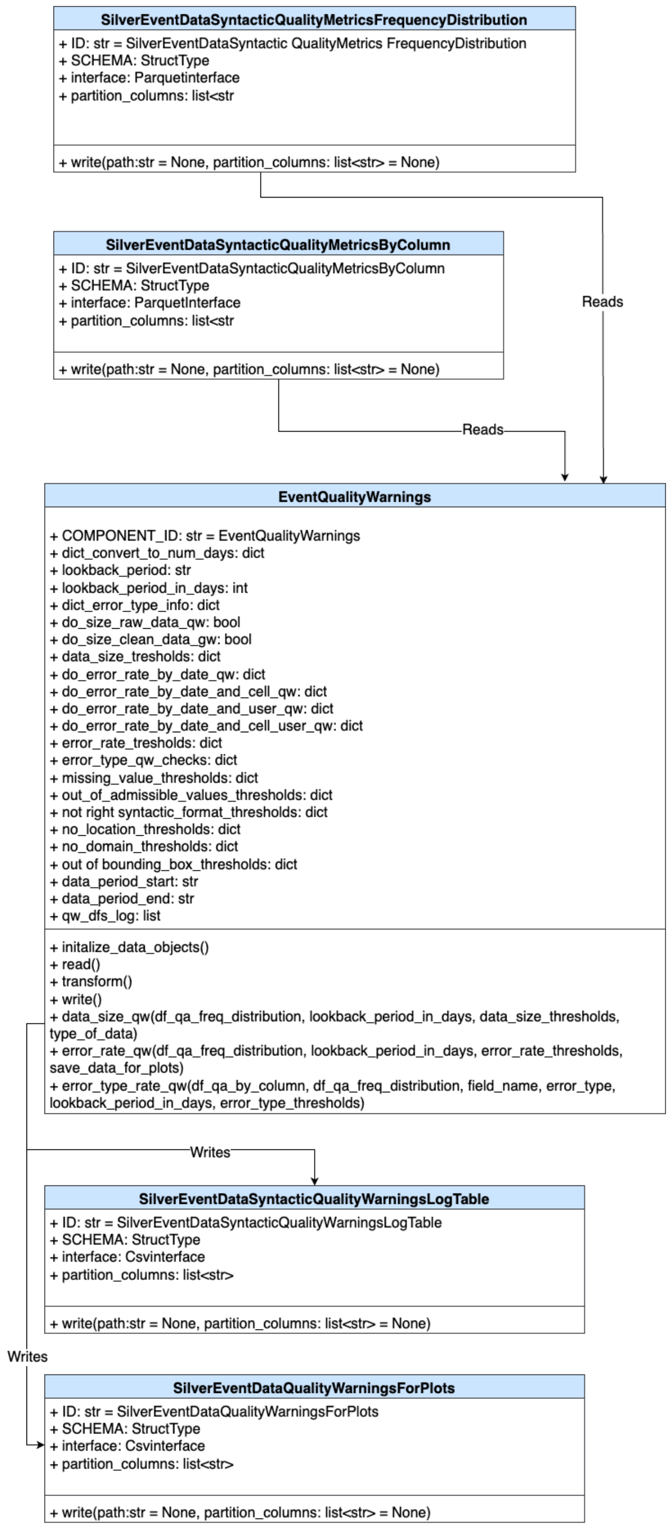
have many field names) which is specified in a config param: error_type_qw_checks . Each stated error_type should have another config param to define thresholds for its field_names (e.g. missing_value_thresholds), for a more detailed description please refer to configuration. The information of wrong entries is stored in Log Table, no data for plots is saved.

- Write silver output data objects of the Component: SilverEventDataSyntacticQualityWarningsLogTable and SilverEventDataSyntacticQualityWarningsForPlots as CSVs partitioned by date

- **Data flow diagram:**


Silver Quality Metrics Frequency Distribution
Silver Quality Metrics By Column
Init Data Objects, check input/output and configuration
Read input and filter data by time period: data_period_start - lookback_period, data_period_end]
Config File
data_period_start
data_period_end
lookback_period
do_size_raw_data_qw
do_size_clean_data_qw
data_size_tresholds
if do_size_[type_of_data]_qw=True
Based on thresholds compute Quality Warnings on size of raw/clean event data and store needed info for plots
do_error_rate_by_date_qw
do_error_rate_by_date_and_cell_qw
do_error_rate_by_date_and_user_qw
do_error_rate_by_date_and_cell_user_qw
error_rate_tresholds
if do_error_rate_by_[n column names]=True
Based on thresholds compute Quality Warnings of error rate on different granularity level (e.g. by date, date&cell_id, etc.) and store needed info for plots*
error_type_qw_checks
missing_value_thresholds
out_of_admissible_values_thresholds
not_right_syntactic_format_thresholds
no_location_thresholds
.....
for each error type specified in error_type_qw_checks keys, if its list of columns is not empty and there are corresponding thresholds defined for an errror_type&field_name combination
Based on thresholds compute Quality Warnings for an errror_type&field_name combination
Silver Quality Warnings Log Table
Silver Quality Warnings For Plots
*only error_rate_by_date
miro

- **Class diagram:**


SilverEventDataSyntacticQualityMetricsFrequencyDistribution
+ ID: str = SilverEventDataSyntactic QualityMetrics FrequencyDistribution
+ SCHEMA: StructType
+ interface: Parquetinterface
+ partition_columns: list<str
+ write(path:str = None, partition_columns: list<str> = None)
SilverEventDataSyntacticQualityMetricsByColumn
+ ID: str = SilverEventDataSyntacticQualityMetricsByColumn
+ SCHEMA: StructType
+ interface: ParquetInterface
+ partition_columns: list<str
+ write(path:str = None, partition_columns: list<str> = None)
Reads
Reads
EventQualityWarnings
+ COMPONENT_ID: str = EventQualityWarnings
+ dict_convert_to_num_days: dict
+ lookback_period: str
+ lookback_period_in_days: int
+ dict_error_type_info: dict
+ do_size_raw_data_qw: bool
+ do_size_clean_data_gw: bool
+ data_size_tresholds: dict
+ do_error_rate_by_date_qw: dict
+ do_error_rate_by_date_and_cell_qw: dict
+ do_error_rate_by_date_and_user_qw: dict
+ do_error_rate_by_date_and_cell_user_qw: dict
+ error_rate_tresholds: dict
+ error_type_qw_checks: dict
+ missing_value_thresholds: dict
+ out_of_admissible_values_thresholds: dict
+ not right syntactic_format_thresholds: dict
+ no_location_thresholds: dict
+ no_domain_thresholds: dict
+ out of bounding_box_thresholds: dict
+ data_period_start: str
+ data_period_end: str
+ qw_dfs_log: list
+ initalize_data_objects()
+ read()
+ transform()
+ write()
+ data_size_qw(df_qa_freq_distribution, lookback_period_in_days, data_size_thresholds, type_of_data)
+ error_rate_qw(df_qa_freq_distribution, lookback_period_in_days, error_rate_thresholds, save_data_for_plots)
+ error_type_rate_qw(df_qa_by_column, df_qa_freq_distribution, field_name, error_type, lookback_period_in_days, error_type_thresholds)
Writes
SilverEventDataSyntacticQualityWarningsLogTable
+ ID: str = SilverEventDataSyntacticQualityWarningsLogTable
+ SCHEMA: StructType
+ interface: Csvinterface
+ partition_columns: list<str>
+ write(path:str = None, partition_columns: list<str> = None)
Writes
SilverEventDataQualityWarningsForPlots
+ ID: str = SilverEventDataQualityWarningsForPlots
+ SCHEMA: StructType
+ interface: Csvinterface
+ partition_columns: list<str>
+ write(path:str = None, partition_columns: list<str> = None)

- **Code Structure:**
  The code structure follows the format set by the core package, and the general repository structure.

  The location of the module script in the repository is as follows:

```
multimno
    └── components
        └── quality
            └── event_quality_warnings
                └── event_quality_warnings.py
```

`event_quality_warnings.py` contains one class named `EventQualityWarnings` which is a subclass of `Component`.

The `EventQualityWarnings` class overwrites all methods in the `Component` class:

`__init__` method initialises the data objects and reads the necessary values from config file.
`read` method is responsible for reading the data from Event Quality Metrics
`write` method is responsible for writing outputs of the component.

`transform` performs all specified Quality Warning checks
`execute` is responsible for calling `read`, `write` and `transform`

5.2.3 EVENTDEDUPLICATION

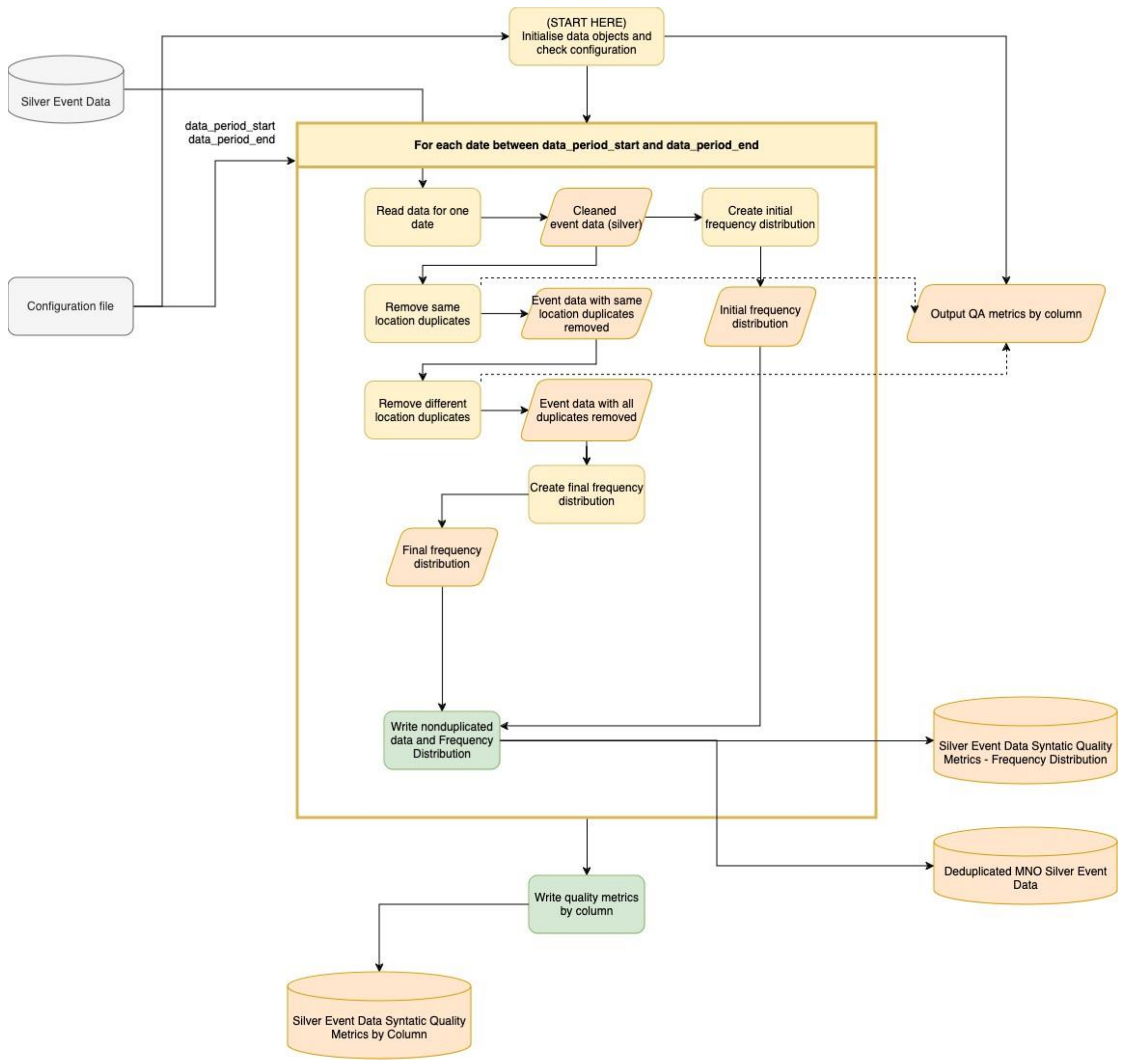
5.2.3.1 MODULE DESCRIPTION

- **Module Name:** EventDeduplication
- **Objectives:** the objective of the method is to process event data, so that duplicate records are removed, and to create quality metrics based on detected duplicated rows.
  These quality metrics follow the standard structure of syntactic quality metrics, and include variables such as initial frequency, total frequency, and error rate by date.
- **Functionality:** the Event Deduplication module retrieves and removes the duplicated records in the device level event data. It distinguishes between same and different location duplicates. It produces frequency and column-wise statistics for removed duplicates. Quality metrics produced per column are produces for each date in the configured period.
  Functionality details may be found in the software requirements: 3.2.8 EventDeduplication
- **Data Inputs and Outputs:**
  - Input:
    - I.2 MNO Event Data – Syntactically Cleaned
  - Output:
    - I.3 MNO Event Data Syntactic Quality Metrics – by column
    - I.4 MNO Event Data Syntactic Quality Metrics – frequency distribution
    - I.6 MNO Event Data – Deduplicated

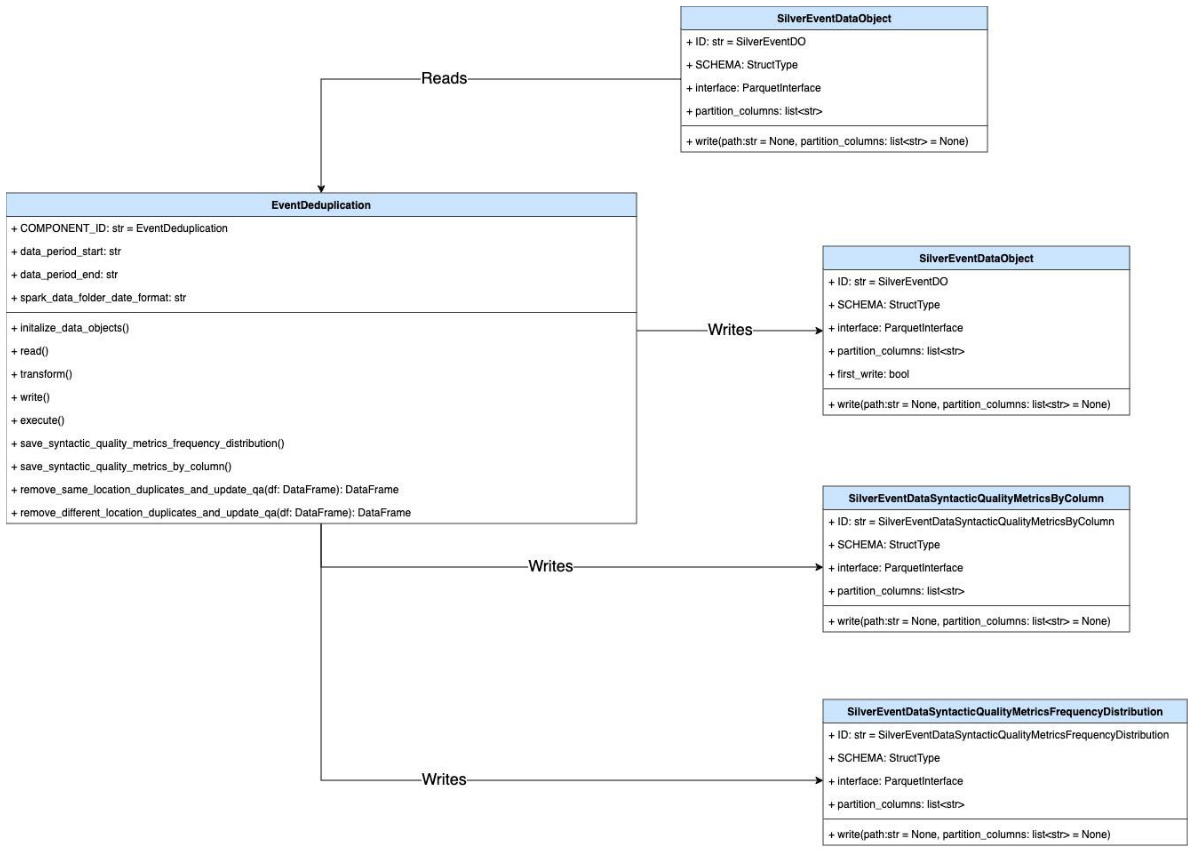
5.2.3.2 DEVELOPMENT DESIGN

- **Key Algorithms/Processes:**
  - Iteration over selected dates. All the processes described below are performed on a date bases, at each level of iteration.
  - Reading in event data for all subscribers for a given date.
  - Processing the data.
  - Selection of one row in cases of same location duplicates. These are duplicate rows that have identical location information (cell_id, longitude and latitude) and timestamp information. As the rows are identical, only one row is kept.
  - Removal of different location duplicates from the data. These are duplicate rows that have identical location information timestamp information but may have different location information. All rows in cases of these duplicates are removed.
  - Counting the number of rows that have been changed by either of the two duplicate removal techniques.
  - Calculating the initial frequency before and after duplicate removal.
  - Writing deduplicated quality metrics per column.
  - Writing deduplicated records.
  - Writing silver output data objects of the Component: SilverEventDataSyntacticQualityMetricsByColumn considering the error codes for deduplication.

- **Data flow diagram:**


(START HERE) Initialise data objects and check configuration
Silver Event Data
data_period_start
data_period_end
Configuration file
For each date between data_period_start and data_period_end
Read data for one date
Cleaned event data (silver)
Create initial frequency distribution
Remove same location duplicates
Event data with same location duplicates removed
Initial frequency distribution
Output QA metrics by column
Remove different location duplicates
Event data with all duplicates removed
Create final frequency distribution
Final frequency distribution
Write nonduplicated data and Frequency Distribution
Silver Event Data Syntatic Quality Metrics - Frequency Distribution
Deduplicated MNO Silver Event Data
Write quality metrics by column
Silver Event Data Syntatic Quality Metrics by Column

- **Class diagram:**


SilverEventDataObject
+ ID: str = SilverEventDO
+ SCHEMA: StructType
+ interface: ParquetInterface
+ partition_columns: list<str>
+ write(path:str = None, partition_columns: list<str> = None)
Reads
EventDeduplication
+ COMPONENT_ID: str = EventDeduplication
+ data_period_start: str
+ data_period_end: str
+ spark_data_folder_date_format: str
+ initalize_data_objects()
+ read()
+ transform()
+ write()
+ execute()
+ save_syntactic_quality_metrics_frequency_distribution()
+ save_syntactic_quality_metrics_by_column()
+ remove_same_location_duplicates_and_update_qa(df: DataFrame): DataFrame
+ remove_different_location_duplicates_and_update_qa(df: DataFrame): DataFrame
Writes
SilverEventDataObject
+ ID: str = SilverEventDO
+ SCHEMA: StructType
+ interface: ParquetInterface
+ partition_columns: list<str>
+ first_write: bool
+ write(path:str = None, partition_columns: list<str> = None)
Writes
SilverEventDataSyntacticQualityMetricsByColumn
+ ID: str = SilverEventDataSyntacticQualityMetricsByColumn
+ SCHEMA: StructType
+ interface: ParquetInterface
+ partition_columns: list<str>
+ write(path:str = None, partition_columns: list<str> = None)
Writes
SilverEventDataSyntacticQualityMetricsFrequencyDistribution
+ ID: str = SilverEventDataSyntacticQualityMetricsFrequencyDistribution
+ SCHEMA: StructType
+ interface: ParquetInterface
+ partition_columns: list<str>
+ write(path:str = None, partition_columns: list<str> = None)

- **Code Structure:**
  The code structure follows the format set by the core package, and the general repository structure.

  The location of the module script in the repository is as follows:

```
/multimno_internal/
└── multimno
    └── components
        └── execution
            └── event_deduplication
                └── event_deduplication.py
```

`event_deduplication.py` contains one class named `EventDeduplication` which is a subclass of `Component`.

The `EventDeduplication` class overwrites all methods in the `Component` class:

`__init__` method initialises the data objects and reads the necessary values from config file.
`read` method is responsible for reading the data from Event Quality Metrics
`write` method is responsible for writing outputs of the component.

`transform` performs all specified Quality Warning checks
`execute` is responsible for calling `read`, `write` and `transform`

5.2.4 NETWORKCLEANING

5.2.4.1 MODULE DESCRIPTION

- **Module Name:** NetworkCleaning
- **Objectives:** this module is responsible for performing syntax checks on Network Topology Data to remove erroneous entries and to produce corresponding syntax quality metrics.
- **Functionality:** this module finds and removes entries where one field presents one of the following errors (when applicable): missing or null value, cannot be parsed, and out-of-range value. It also counts the number of errors before and after performing these checks, as well as the number of times each type of error appeared in each field.
  Functionality details may be found in the software requirements: 3.2.1 NetworkCleaning
  At this moment in time, only the processing of cell locations with physical properties is implemented.
- **Data Inputs and Outputs:**
  - Input:
    - I.7 Cell Locations with Physical Properties - Raw
  - Output
    - I.8 Cell Locations with Physical Properties – Cleaned
    - I.9 MNO Network Topology Data Quality Metrics
    - I.26 MNO Network Topology Top Frequent Erros
    - I.27 MNO Network Topology Row Error Metrics

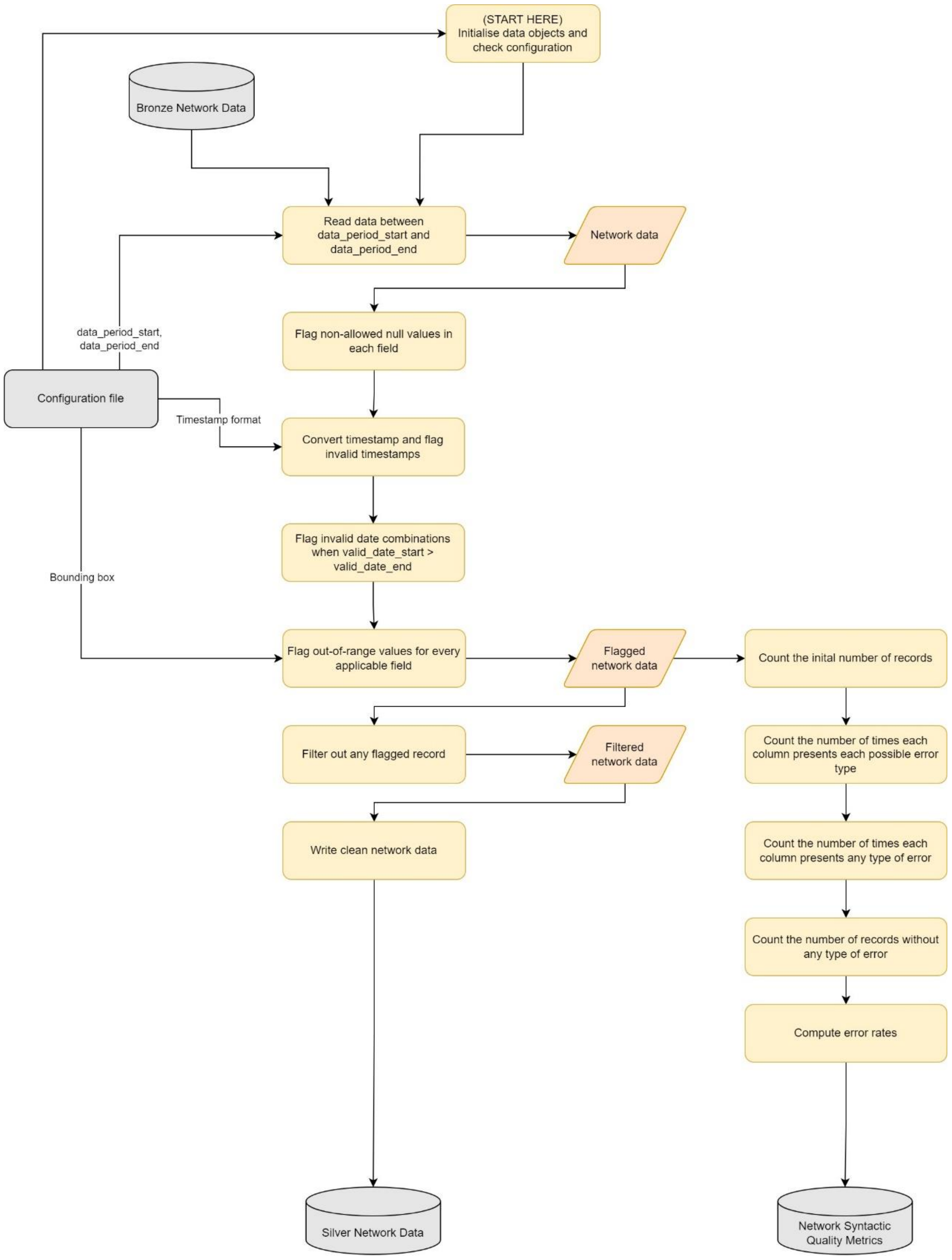
5.2.4.2 DEVELOPMENT DESIGN

- **Key Algorithms/Processes:** The raw data is processed for the set of dates within an date interval specified via configuration file. It is assumed that the raw input data is partitioned by *year, month, day* columns, and the processes below work separately on each date's data.
  - Create quality metrics data object.
  - Filter out rows outside of the date interval.
  - Create an empty list `auxiliar_columns` that will contain the names of auxiliar columns that will keep track of each possible type of error in each field of a row.
  - <u>Missing values</u>:
    - Create one boolean column per field name, and set it to True if, for a given row, the value in a specific field is null.
      - Exception: `azimuth_angle` is expected to be null when `directionality` is equal to 0 – this is not computed as a 'mising'-null value and will not be computed as such for the corresponding quality metric later on.
      - Note that `valid_date_end` is allowed to be null. Nevertheless, the null values of this column will be checked and reflected in the corresponding boolean column.
    - Add all these columns names to `auxiliar_columns`.
  - <u>Parsing errors</u>:
    - Only `valid_date_start` and `valid_date_end` can have this type of error.
    - Parse the above-mentioned columns from string type to timestamp type.

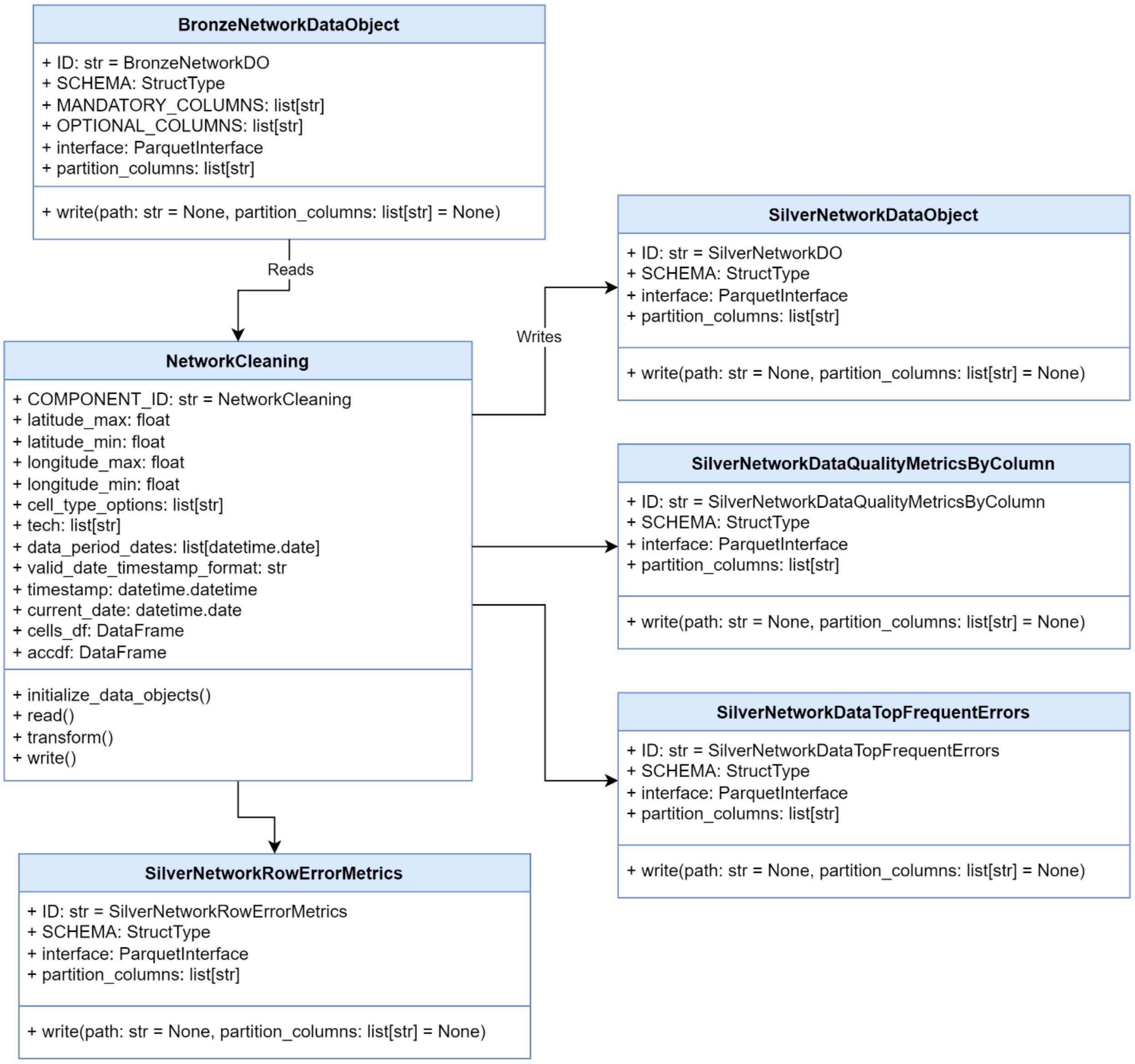
        - When a non-null value cannot be parsed with the specified timestamp format, the function employed, `pyspark.sql.functions.to_timestamp`, returns a null value.
        - Create one boolean column for each of these two fields and set it to True if the original value is non-null and the parsing failed.
        - Add the two column names to `auxiliar_columns`.
    - <u>Out-of-range/out-of-bounds values</u>:
        - First, check for incoherent dates: this occurs when `valid_date_start` is a later point in time than `valid_date_end`.
            - Create a new boolean column equal to True when both `valid_date_start` and `valid_date_end` are not null, and `valid_date_start > valid_date_end`.
            - Add the new column's name to `auxiliar_columns`.
        - Now, check of out-of-range values for the rest of the variables. A new boolean column will be created for each of them, True when the value is out-of-range, and their names are added to `auxiliar_columns`.
            - `cell_id`: check if the string has a length different from 14 or 15 characters (to be improved to check for CGI/eCGI rules).
            - `latitude`: check if the value is outside a configuration-specified interval.
            - `longitude`: check if the value is outside a configuration-specified interval.
            - `antenna_height`: check if the value is less or equal to 0 (i.e., non-positive).
            - `directionality`: check if the value is not equal to 0 or to 1.
            - `azimuth_angle`: whenever directionality is equal to 1, check if the value is lower than 0 or higher than 360.
            - `elevation_angle`: check if the value is lower than -90 or higher than 90.
            - `horizontal_beam_width`: check if the value is lower than 0 or higher than 360.
            - `vertical_beam_width`: check if the value is lower than 0 or higher than 360.
            - `power`: check if the value is lower than 0.
            - `range`: check if the value is lower than 0.
            - `frequency`: check if the value is lower than 0.
            - `technology`: check if the value is not one of '5G', 'LTE', 'UMTS', and 'GSM'.
            - `cell_type`: check if the value is not one of the possible admitted values specified via configuration file.
    - For each field, create a new boolean column and set it to True if, for a given row, the field does not have any type of error. Add these column names to `auxiliar_columns`.
        - Exception: the column `valid_date_end` is allowed to have null values. Thus, the null-boolean-column corresponding to `valid_date_end` is not considered for the computation of this boolean column.
    - Create a new boolean column to_preserve and set it to True if a given row does not have any type of error in any of its fields.
        - Exception: the column `valid_date_end` is allowed to have null values. Thus, the null-boolean-column corresponding to `valid_date_end` is not considered for the computation of this boolean column.
    - Compute quality metrics:

        - Count the number of True values in each of the columns whose names are stored in `auxiliar_columns`. These are the error-related quality metrics for each date considered.
        - For each date, count the number of rows present in the raw input data.
        - Count the number of times that the True value appears in the `to_preserve` column for each date considered. These are the number of rows present after the syntactic checks are performed.
    - Compute row error metrics:
        - Count the total number of rows that are going to be deleted, that is, any row that has any type of error in any of its mandatory fields.
        - Count the total number of rows that have at least one type of error in any of its fields, irrespective of whether that field is mandatory or optional.
    - Compute top frequent invalid values: the absolute frequency of each invalid value in a given field is computed. Ordered from most to least frequent, the accumulated sum of percentage of each error with respect to the total number of errors is calculated. Based on what is requested via configuration file, this information is saved in two different ways:
        - If the top *k* most frequent invalid values were requested as an absolute number, the *k* most frequent combinations of field and invalid value are saved.
        - If the topmost frequent invalid values were requested as a percentage number *k*, the most frequent combinations of field and invalid value that cover at least *k* percentage of all invalid values are saved.
    - Filter out rows with the column `to_preserve` as a mask, select only the original columns (so no `auxiliar_column` or `to_preserve` is kept), and save the result. This is the clean dataset after syntactic checks.

- **Data flow diagram:**


(START HERE) Initialise data objects and check configuration
Bronze Network Data
Read data between data_period_start and data_period_end
Network data
data_period_start, data_period_end
Flag non-allowed null values in each field
Configuration file
Timestamp format
Convert timestamp and flag invalid timestamps
Flag invalid date combinations when valid_date_start > valid_date_end
Bounding box
Flag out-of-range values for every applicable field
Flagged network data
Count the inital number of records
Filter out any flagged record
Filtered network data
Count the number of times each column presents each possible error type
Write clean network data
Count the number of times each column presents any type of error
Count the number of records without any type of error
Compute error rates
Silver Network Data
Network Syntactic Quality Metrics

- **Class diagram:**


BronzeNetworkDataObject
+ ID: str = BronzeNetworkDO
+ SCHEMA: StructType
+ MANDATORY_COLUMNS: list[str]
+ OPTIONAL_COLUMNS: list[str]
+ interface: ParquetInterface
+ partition_columns: list[str]
+ write(path: str = None, partition_columns: list[str] = None)
Reads
NetworkCleaning
+ COMPONENT_ID: str = NetworkCleaning
+ latitude_max: float
+ latitude_min: float
+ longitude_max: float
+ longitude_min: float
+ cell_type_options: list[str]
+ tech: list[str]
+ data_period_dates: list[datetime.date]
+ valid_date_timestamp_format: str
+ timestamp: datetime.datetime
+ current_date: datetime.date
+ cells_df: DataFrame
+ accdf: DataFrame
+ initialize_data_objects()
+ read()
+ transform()
+ write()
Writes
SilverNetworkDataObject
+ ID: str = SilverNetworkDO
+ SCHEMA: StructType
+ interface: ParquetInterface
+ partition_columns: list[str]
+ write(path: str = None, partition_columns: list[str] = None)
SilverNetworkDataQualityMetricsByColumn
+ ID: str = SilverNetworkDataQualityMetricsByColumn
+ SCHEMA: StructType
+ interface: ParquetInterface
+ partition_columns: list[str]
+ write(path: str = None, partition_columns: list[str] = None)
SilverNetworkDataTopFrequentErrors
+ ID: str = SilverNetworkDataTopFrequentErrors
+ SCHEMA: StructType
+ interface: ParquetInterface
+ partition_columns: list[str]
+ write(path: str = None, partition_columns: list[str] = None)
SilverNetworkRowErrorMetrics
+ ID: str = SilverNetworkRowErrorMetrics
+ SCHEMA: StructType
+ interface: ParquetInterface
+ partition_columns: list[str]
+ write(path: str = None, partition_columns: list[str] = None)

- **Code Structure:** The code structure follows the format set by the core package, and the general repository structure. The location of the module script in the repository is as follows:

```
/multimno/
└── components
    └── execution
        └── network_cleaning
            └── network_cleaning.py
```

    - network_cleaning.py contains one class named NetworkCleaning which is a subclass of Component. The NetworkCleaning class overrides some of the methods of Component:
        - The __init__ method first call its parent's __init__ method, which sets up the Spark session, initialises data objects and reads the configuration file.
        - Transform performs all necessary filtering and transformations pertaining to the syntactic checks for daily raw network data and computes the associated updates the quality metrics data objects.

5.2.5 NETWORKQUALITYWARNINGS

5.2.5.1 MODULE DESCRIPTION

- **Module Name:** NetworkQualityWarnings
- **Objectives:** the task of this module is to analyse the quality metrics resulting from the network syntacitc checks process and identify anomalous situations that may require further investigation.
- **Functionality:** the module computes statistics on the quality metrics over a specified lookback period and compares them with present values. When anomalous situations are identified, warnings are produced, as well as data to easily create plots that summarise the evolution of metrics over time and the frequency of each type of error.
  Functionality details may be found in the software requirements: 3.2.2 NetworkQualityWarnings
- **Data Inputs and Outputs:**
    - Input:
        - I.9 MNO Network Topology Data Quality Metrics
    - Output:
        - I.10 MNO Network Topology Data Quality Warnings – log table
        - I.23 MNO Network Syntactic Quality Warnings Line Plot Data
        - I.24 MNO Network Syntactic Quality Warnings Pie Plot Data

5.2.5.2 DEVELOPMENT DESIGN

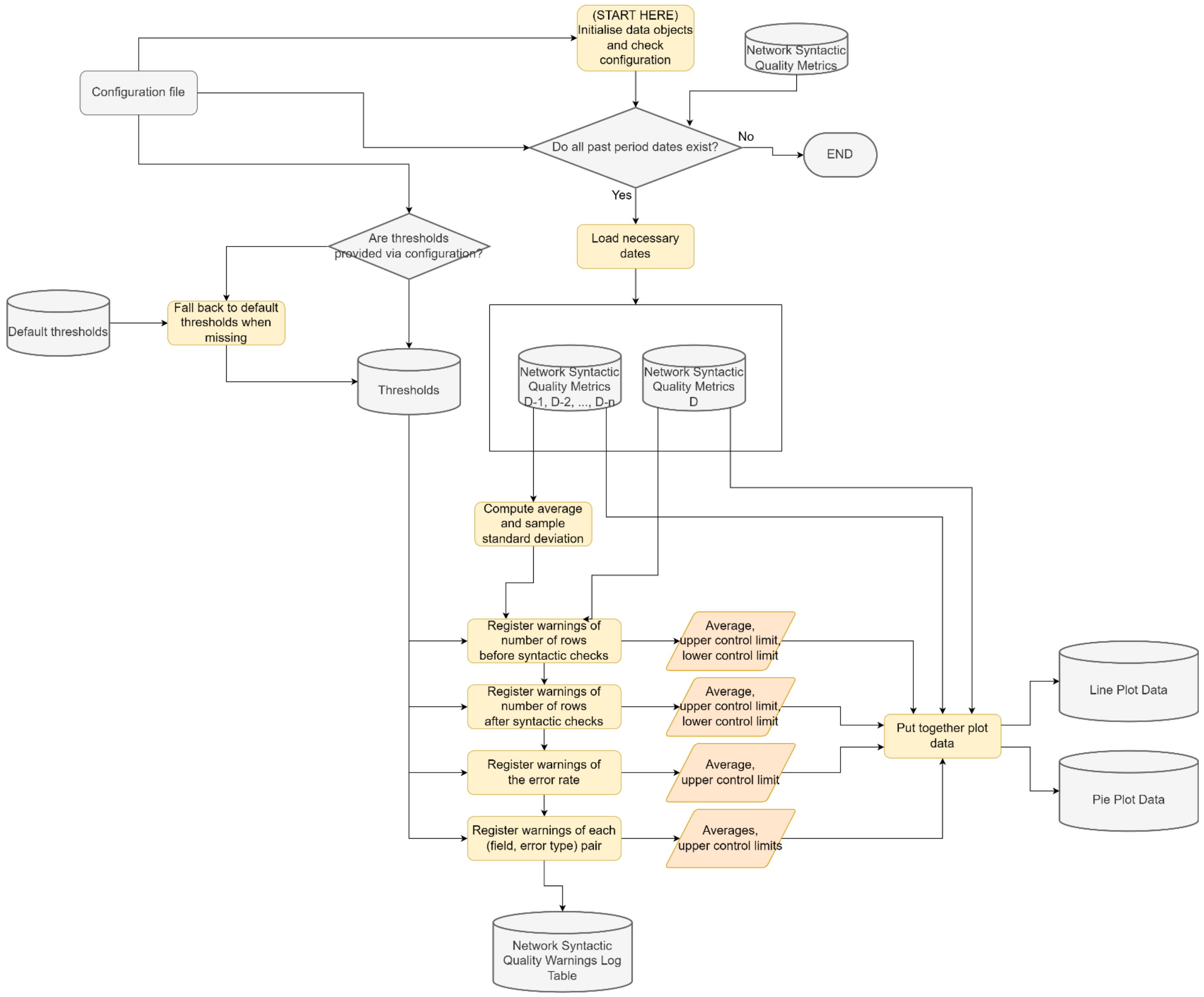
- **Key Algorithms/Processes:**
    - Create the data objects.
    - The thresholds to be used for raising warnings that are specified via configuration file are read and their types and values are validated. In the case that a specific threshold is not present, its default value is used instead.
    - Read the length of the lookback period from the configuration file, as well as the date to be studied. If the study date is not present, or any of the lookback dates are not present, an exception is raised and the execution stops.
    - Compute the necessary statistics, namely the average and the sample standard deviation, of each quality metric over the lookback period.
    - Load the values of the quality metrics for the study date.
    - Register warnings regarding the number of rows before the syntactic checks when:
        - The study date's number of rows is greater than the average number of rows over the previous period by more than a specified threshold percentage.
        - The study date's number of rows is smaller than the average number of rows over the previous period by more than a specified threshold percentage.

    - The study date's number of rows is greater than the average number of rows over the previous period by a specified number of standard deviations – that is, greater than the *upper control limit*.
    - The study date's number of rows is smaller than the average number of rows over the previous period by a specified number of standard deviations – that is, smaller than the *lower control limit*.
    - The study date's number of rows is greater than a specified absolute threshold.
    - The study date's number of rows is smaller than a specified absolute threshold.
  - Register warnings regarding the number of rows after the syntactic checks when:
    - The study date's number of rows is greater than the average number of rows over the previous period by more than a specified threshold percentage.
    - The study date's number of rows is smaller than the average number of rows over the previous period by more than a specified threshold percentage.
    - The study date's number of rows is greater than the average number of rows over the previous period by a specified number of standard deviations – that is, greater than the *upper control limit*.
    - The study date's number of rows is smaller than the average number of rows over the previous period by a specified number of standard deviations – that is, smaller than the *lower control limit*.
    - The study date's number of rows is greater than a specified absolute threshold.
    - The study date's number of rows is smaller than a specified absolute threshold.
  - Register warnings regarding the overall error rate in the syntactic checks process when:
    - The study date's error rate is greater than the average error rate over the previous period by more than a specified threshold percentage.
    - The study date's error rate is greater than the average error rate over the previous period by a specified number of standard deviations – that is, greater than the *upper control limit*.
    - The study date's error rate is greater than a specified absolute threshold.
  - Register warning regarding the number of errors that each field presented in each error type (separately):
    - The study date's number of errors of a given error type in a given field is greater than the average number of errors of that error type in that field over the previous period by more than a specified threshold percentage.
    - The study date's number of errors of a given error type in a given field is greater than the average number of errors of that error type in that field over the previous period by a specified number of standard deviations – that is, greater than the *upper control limit*.
    - The study date's number of errors of a given error type in a given field is greater than a specified absolute threshold.
  - Write every registered warning into a log table, specifying:
    - the study date,
    - the date in which the quality warnings component is being executed,
    - the value of the metric that raised the warning,
    - the condition that had to be fulfilled to raise the warning,
    - the threshold with which the metric was compared, and
    - a warning text giving context to the warning.
  - Using the statistics computed previously, prepare the data needed to plot the required graphs:
    - Line plot showing the evolution of the number of rows before the syntactic checks over the lookback period and the study date, together with the average over the previous

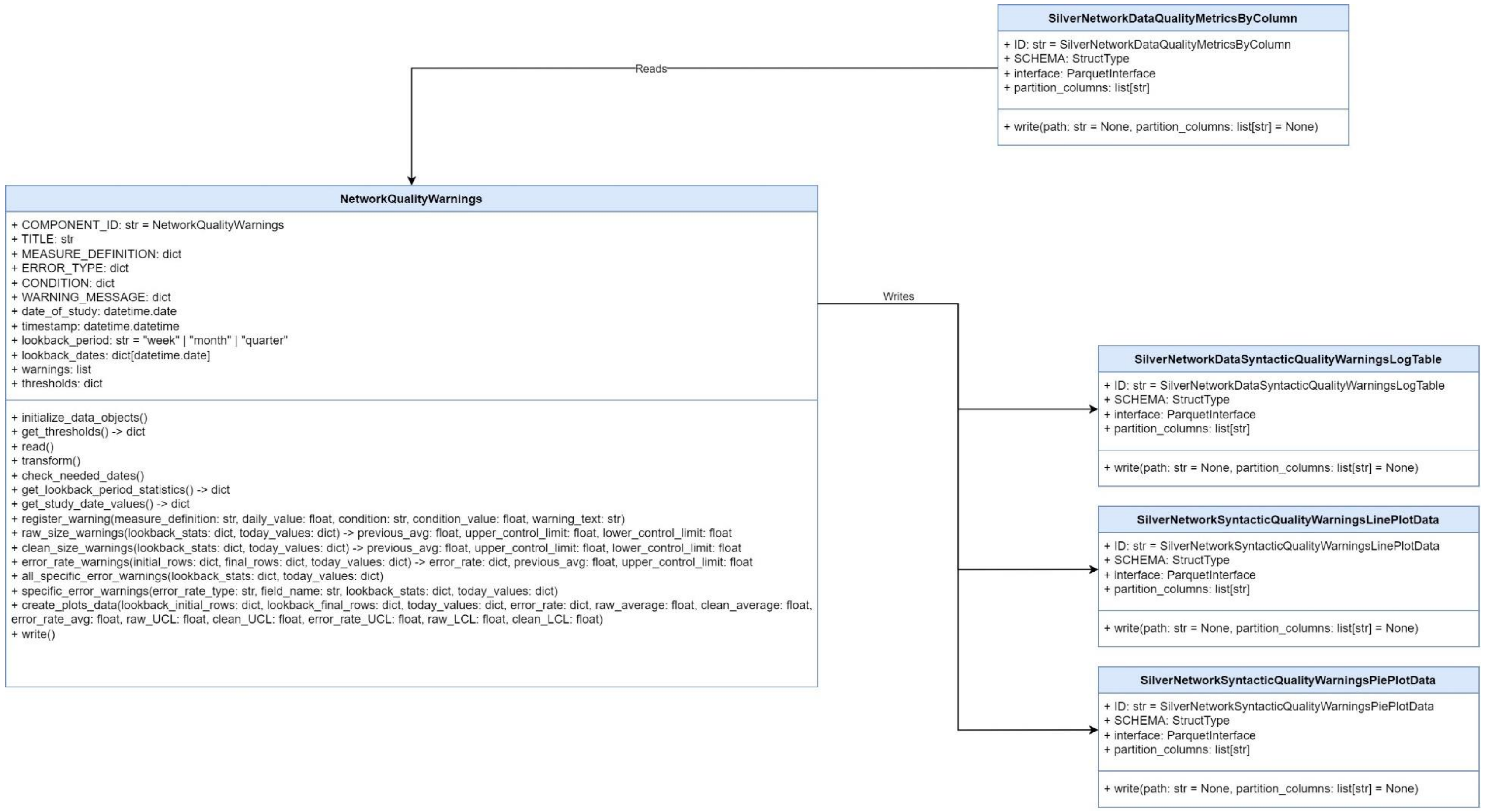
period, the upper control limit, and the lower control limit. Save the data needed to make this graph into parquet format.

- Line plot showing the evolution of the number of rows after the syntactic checks over the lookback period and the study date, together with the average over the previous period, the upper control limit, and the lower control limit. Save the data needed to make this graph into a parquet file.
- Line plot showing the evolution of the error rate over the lookback period and the study date, together with the average over the previous period and the upper control limit. Save the data needed to make this graph into a parquet file.
- For each field, a pie chart showing the percentage distribution of each type of error present in that field for the study date. Save the data needed to make this graph into respective parquet files.

- **Data flow diagram:**


(START HERE) Initialise data objects and check configuration
Network Syntactic Quality Metrics
Configuration file
Do all past period dates exist?
No
END
Yes
Are thresholds provided via configuration?
Load necessary dates
Default thresholds
Fall back to default thresholds when missing
Thresholds
Network Syntactic Quality Metrics D-1, D-2, ..., D-n
Network Syntactic Quality Metrics D
Compute average and sample standard deviation
Register warnings of number of rows before syntactic checks
Average, upper control limit, lower control limit
Register warnings of number of rows after syntactic checks
Average, upper control limit, lower control limit
Register warnings of the error rate
Average, upper control limit
Register warnings of each (field, error type) pair
Averages, upper control limits
Put together plot data
Line Plot Data
Pie Plot Data
Network Syntactic Quality Warnings Log Table

- **Class diagram:**


SilverNetworkDataQualityMetricsByColumn
+ ID: str = SilverNetworkDataQualityMetricsByColumn
+ SCHEMA: StructType
+ interface: ParquetInterface
+ partition_columns: list[str]
+ write(path: str = None, partition_columns: list[str] = None)
Reads
NetworkQualityWarnings
+ COMPONENT_ID: str = NetworkQualityWarnings
+ TITLE: str
+ MEASURE_DEFINITION: dict
+ ERROR_TYPE: dict
+ CONDITION: dict
+ WARNING_MESSAGE: dict
+ date_of_study: datetime.date
+ timestamp: datetime.datetime
+ lookback_period: str = "week" | "month" | "quarter"
+ lookback_dates: dict[datetime.date]
+ warnings: list
+ thresholds: dict
+ initialize_data_objects()
+ get_thresholds() -> dict
+ read()
+ transform()
+ check_needed_dates()
+ get_lookback_period_statistics() -> dict
+ get_study_date_values() -> dict
+ register_warning(measure_definition: str, daily_value: float, condition: str, condition_value: float, warning_text: str)
+ raw_size_warnings(lookback_stats: dict, today_values: dict) -> previous_avg: float, upper_control_limit: float, lower_control_limit: float
+ clean_size_warnings(lookback_stats: dict, today_values: dict) -> previous_avg: float, upper_control_limit: float, lower_control_limit: float
+ error_rate_warnings(initial_rows: dict, final_rows: dict, today_values: dict) -> error_rate: dict, previous_avg: float, upper_control_limit: float
+ all_specific_error_warnings(lookback_stats: dict, today_values: dict)
+ specific_error_warnings(error_rate_type: str, field_name: str, lookback_stats: dict, today_values: dict)
+ create_plots_data(lookback_initial_rows: dict, lookback_final_rows: dict, today_values: dict, error_rate: dict, raw_average: float, clean_average: float, error_rate_avg: float, raw_UCL: float, clean_UCL: float, error_rate_UCL: float, raw_LCL: float, clean_LCL: float)
+ write()
Writes
SilverNetworkDataSyntacticQualityWarningsLogTable
+ ID: str = SilverNetworkDataSyntacticQualityWarningsLogTable
+ SCHEMA: StructType
+ interface: ParquetInterface
+ partition_columns: list[str]
+ write(path: str = None, partition_columns: list[str] = None)
SilverNetworkSyntacticQualityWarningsLinePlotData
+ ID: str = SilverNetworkSyntacticQualityWarningsLinePlotData
+ SCHEMA: StructType
+ interface: ParquetInterface
+ partition_columns: list[str]
+ write(path: str = None, partition_columns: list[str] = None)
SilverNetworkSyntacticQualityWarningsPiePlotData
+ ID: str = SilverNetworkSyntacticQualityWarningsPiePlotData
+ SCHEMA: StructType
+ interface: ParquetInterface
+ partition_columns: list[str]
+ write(path: str = None, partition_columns: list[str] = None)

- **Code Structure:** The code structure follows the format set by the core package, and the general repository structure. The location of the module script in the repository is as follows:

```
/multimno/
└── src
    └── components
        └── quality
            └── network_quality_warnings
                └── network_quality_warnings.py
```

  - network_quality_warnings.py contains one class named NetworkQualityWarnings which is a subclass of Component. It overrides the following methods:
    - The __init__ method first call its parent's __init__ method, which sets up the Spark session, initialises data objects and reads the configuration file.
    - The transform method handles all the logic behind the component.
    - The write method writes the quality warnings log table containing the computed warnings. It also writes into parquet files the data required to produce the defined plots.
  - The NetworkCleaning component also has the following methods:
    - get_thresholds handles the logic of reading configuration-specified thresholds and the usage of default threshold whenever a specific threshold value is not specified.
    - check_needed_dates verifies that both the study date and the dates in the lookback period are all present in the metrics data and throws an exception when some date is missing.
    - get_lookback_period_statistics computes the average and sample standard deviation of the quality metrics over the lookback period
    - get_study_date_values retrieves and computes the metric values of the study date.
    - register_warning is a method that abstracts away the creation of a warning in the log table, taking as arguments all necessary information and putting it in the correct format.
    - raw_size_warnings contains the logic behind the warning computation regarding the number of rows before the syntactic checks.
    - clean_size_warnings contains the logic behind the warning computation regarding the number of rows after the syntactic checks.
    - error_rate_warnings contains the logic behind the warning computation regarding the error rate detected in the syntactic checks process.
    - all_specific_error_warnings loops over all field and error type specific errors in order to compute their warnings.
    - specific_error_warning contains the logic behind the warning computation regarding a specific (field, error type) pair determined in the all_specific_error_warnings method.
    - create_plots_data gathers and formats the data required to produce the necessary plots of the component.
  - NetworkCleaning also contains as attributes different sets of formattable strings used in the generation of the log table. These include MEASURE_DEFINITION, CONDITION, TITLE, WARNING_MESSAGE.

5.2.6 SIGNALSTRENGTHMODELING

5.2.6.1 MODULE DESCRIPTION

- **Module Name:** SignalStrengthModeling
- **Objectives:** responsible for modeling the signal strength propagation in a cellular network.
- **Functionality:** takes as input a configuration file and a set of data representing the network's cells and their physical properties. The component then calculates the signal strength at various points of a reference grid, taking into account factors such as the distance to the cell, physical properties of the cell, the azimuth and elevation angles of the cell, the directionality of the cell and physical environment. Functionality details may be found in the software requirements: 3.2.3 SignalStrengthModeling
- **Data Inputs and Outputs:**
    - Inputs:
        - I.8 Cell Locations with Physical Properties – Cleaned
        - I.11 Reference Grid
    - Outputs:
        - I.12 Cells Signal Strengths

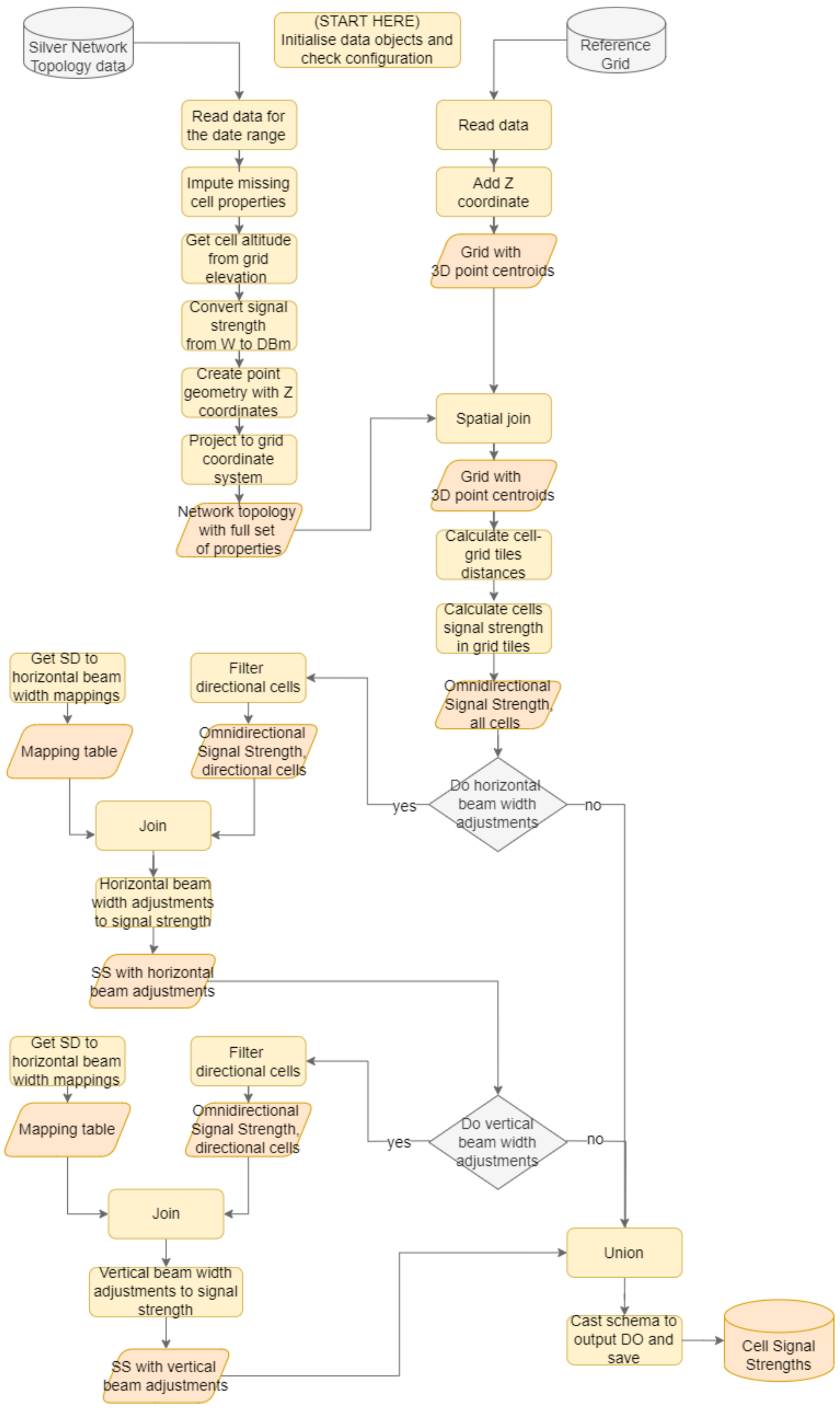
5.2.6.2 DEVELOPMENT DESIGN

- **Key Algorithms/Processes:**

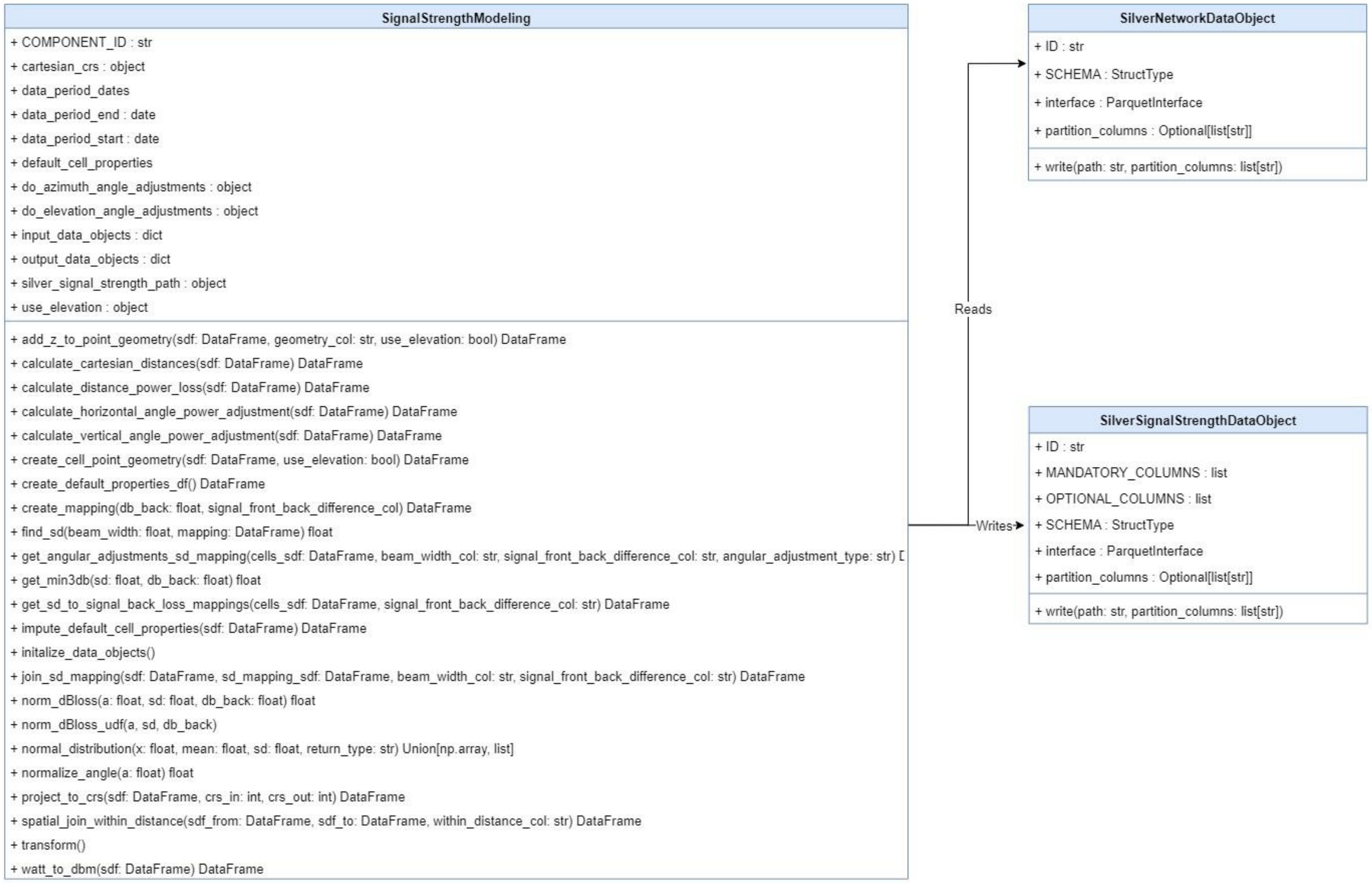
1. Initialisation. Read all necessary config parameters, check the availability of input data, read it in data objects.
2. Prepare input datasets:
    1. Filter input network data to include only date range specified in config.
    2. Add Z coordinate to grid centroids. If elevation is used Z coordinate is assigned based on a grid elevation property. If elevation is not used assign Z = 0.
    3. Check that all necessary cells' physical properties are present and impute missing properties. Based on a cell type, missing properties are filled in by taking default values for this cell type defined in config file. If cell type is not defined or not present in config file default cell properties are assigned.
    4. Convert signal strength values from W to DBm.
    5. Create cell point geometries. If elevation is used, set Z coordinate as altitude + antenna height. If elevation is not used, set Z coordinate as 0 + antenna height.
    6. Project coordinate system of cell geometries to coordinate system of the reference grid.
3. Spatial join of cells to grid centroids. Join is done based on spatial intersection of a buffer polygons around cell points of a radius equal to the maximum cell range with grid centroids.
4. Calculate planar and 3D cartesian distances between cell point and all joined grid centroids.
5. Calculate signal strength in grid tiles. Using power and Path Loss Exponent cell properties and distances to joined grid tiles within cell range calculate signal strength in every grid tile with signal strength propagation equation.
6. Perform horizontal beam width adjustments to signal strength for directional cells. Optional depending on config parameter.
    1. Get mapping table with standard deviations in signal strength in all horizontal angles for all combinations of horizontal beam widths and signal strength differences between front and back of antennas.
    2. Filter only directional cells from cell-grid dataset.
    3. Join mapping table with standard deviations to cell-grid dataset.

    4. Calculate signal strength adjustments based on relative azimuth angle and the distance between grid tiles and a cell using joined standard deviation value for a cell horizontal beam width.
7. Perform vertical beam width adjustments to signal strength for directional cells. Optional depending on config parameter.
    1. Get mapping table with standard deviations in signal strength in all vertical angles for all combinations of vertical beam widths and signal strength differences between front and back of antennas.
    2. Filter only directional cells from cell-grid dataset.
    3. Join mapping table with standard deviations to cell-grid dataset.
    4. Calculate signal strength adjustments based on elevation angle and the distance between grid tiles and a cell using joined standard deviation value for a cell vertical beam width.
8. Union directional and non-directional cell-grid datasets.
9. Convert cell-grid dataset schema to match the output data object schema and save to storage.

- **Data flow diagram:**


Silver Network Topology data
(START HERE) Initialise data objects and check configuration
Reference Grid
Read data for the date range
Impute missing cell properties
Get cell altitude from grid elevation
Convert signal strength from W to DBm
Create point geometry with Z coordinates
Project to grid coordinate system
Network topology with full set of properties
Read data
Add Z coordinate
Grid with 3D point centroids
Spatial join
Grid with 3D point centroids
Calculate cell-grid tiles distances
Calculate cells signal strength in grid tiles
Omnidirectional Signal Strength, all cells
Do horizontal beam width adjustments
yes
no
Get SD to horizontal beam width mappings
Mapping table
Filter directional cells
Omnidirectional Signal Strength, directional cells
Join
Horizontal beam width adjustments to signal strength
SS with horizontal beam adjustments
Get SD to horizontal beam width mappings
Mapping table
Filter directional cells
Omnidirectional Signal Strength, directional cells
Do vertical beam width adjustments
yes
no
Join
Vertical beam width adjustments to signal strength
SS with vertical beam adjustments
Union
Cast schema to output DO and save
Cell Signal Strengths

- **Class diagram:**


SignalStrengthModeling
+ COMPONENT_ID : str
+ cartesian_crs : object
+ data_period_dates
+ data_period_end : date
+ data_period_start : date
+ default_cell_properties
+ do_azimuth_angle_adjustments : object
+ do_elevation_angle_adjustments : object
+ input_data_objects : dict
+ output_data_objects : dict
+ silver_signal_strength_path : object
+ use_elevation : object
+ add_z_to_point_geometry(sdf: DataFrame, geometry_col: str, use_elevation: bool) DataFrame
+ calculate_cartesian_distances(sdf: DataFrame) DataFrame
+ calculate_distance_power_loss(sdf: DataFrame) DataFrame
+ calculate_horizontal_angle_power_adjustment(sdf: DataFrame) DataFrame
+ calculate_vertical_angle_power_adjustment(sdf: DataFrame) DataFrame
+ create_cell_point_geometry(sdf: DataFrame, use_elevation: bool) DataFrame
+ create_default_properties_df() DataFrame
+ create_mapping(db_back: float, signal_front_back_difference_col) DataFrame
+ find_sd(beam_width: float, mapping: DataFrame) float
+ get_angular_adjustments_sd_mapping(cells_sdf: DataFrame, beam_width_col: str, signal_front_back_difference_col: str, angular_adjustment_type: str) D
+ get_min3db(sd: float, db_back: float) float
+ get_sd_to_signal_back_loss_mappings(cells_sdf: DataFrame, signal_front_back_difference_col: str) DataFrame
+ impute_default_cell_properties(sdf: DataFrame) DataFrame
+ initalize_data_objects()
+ join_sd_mapping(sdf: DataFrame, sd_mapping_sdf: DataFrame, beam_width_col: str, signal_front_back_difference_col: str) DataFrame
+ norm_dBloss(a: float, sd: float, db_back: float) float
+ norm_dBloss_udf(a, sd, db_back)
+ normal_distribution(x: float, mean: float, sd: float, return_type: str) Union[np.array, list]
+ normalize_angle(a: float) float
+ project_to_crs(sdf: DataFrame, crs_in: int, crs_out: int) DataFrame
+ spatial_join_within_distance(sdf_from: DataFrame, sdf_to: DataFrame, within_distance_col: str) DataFrame
+ transform()
+ watt_to_dbm(sdf: DataFrame) DataFrame
Reads
Writes
SilverNetworkDataObject
+ ID : str
+ SCHEMA : StructType
+ interface : ParquetInterface
+ partition_columns : Optional[list[str]]
+ write(path: str, partition_columns: list[str])
SilverSignalStrengthDataObject
+ ID : str
+ MANDATORY_COLUMNS : list
+ OPTIONAL_COLUMNS : list
+ SCHEMA : StructType
+ interface : ParquetInterface
+ partition_columns : Optional[list[str]]
+ write(path: str, partition_columns: list[str])

-

- **Code Structure:**

The code structure follows the format set by the core package, and the general repository structure.

The location of the module script in the repository is as follows:

```
multimno
    └── components
        └── execution
            └── signal_strength
                └── signal_stength_modeling.py
```

signal_stength_modeling.py contains one class named SignalStrengthModelingwhich is a subclass of Component.

The SignalStrengthModelingclass overrides transform method of base Component class.
transform method performs all necessary filtering and transformations of network topology data for signal strengths modeling by sequentially calling other methods that perform the actual data manipulation.

5.2.7 CELLFOOTPRINTESTIMATION

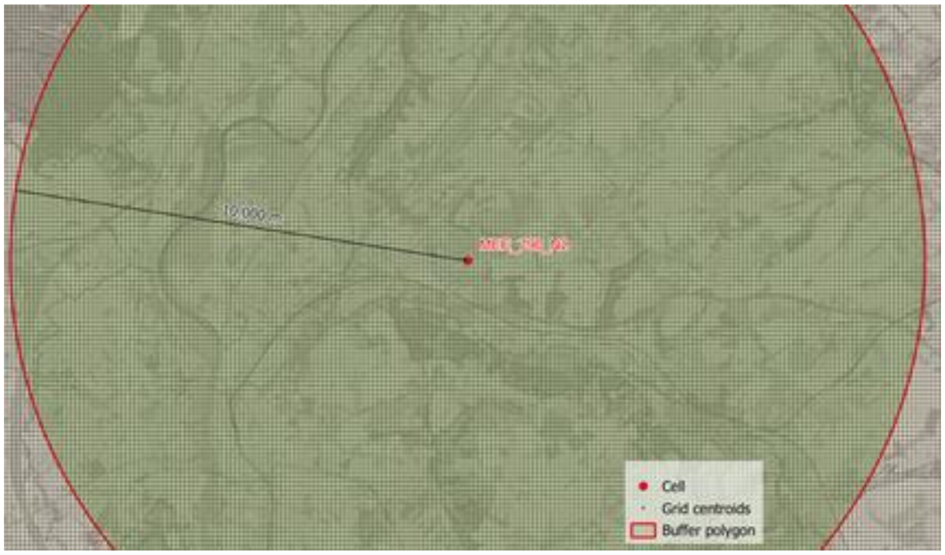
5.2.7.1 MODULE DESCRIPTION

- **Module Name:** CellFootprintEstimation
- **Objectives:** The component models signal strength propagation based on physical properties of cellular antennas on reference spatial grid and then converts signal strengths to signal dominance (cell footprint).
- **Functionality:** takes as input a configuration file and a set of data representing the network's cells and their physical properties. The component then calculates the signal strength at various points of a reference grid, taking into account factors such as the distance to the cell, physical properties of the cell, the azimuth and elevation angles of the cell, the directionality of the cell and physical environment. Then component then calculates the signal dominance per grid tile and applies any combination out of 3 pruning methods depending on config parameters.
  Functionality is outlined in the software requirement specifications: 3.2.4 CellFootprintEstimation
- **Data Inputs and Outputs:**
  - Input:
    - I.8 Cell Locations with Physical Properties - Cleaned
    - I.28 INSPIRE Grid
  - Outputs:
    - I.13 Cell Footprints

5.2.7.2 DEVELOPMENT DESIGN

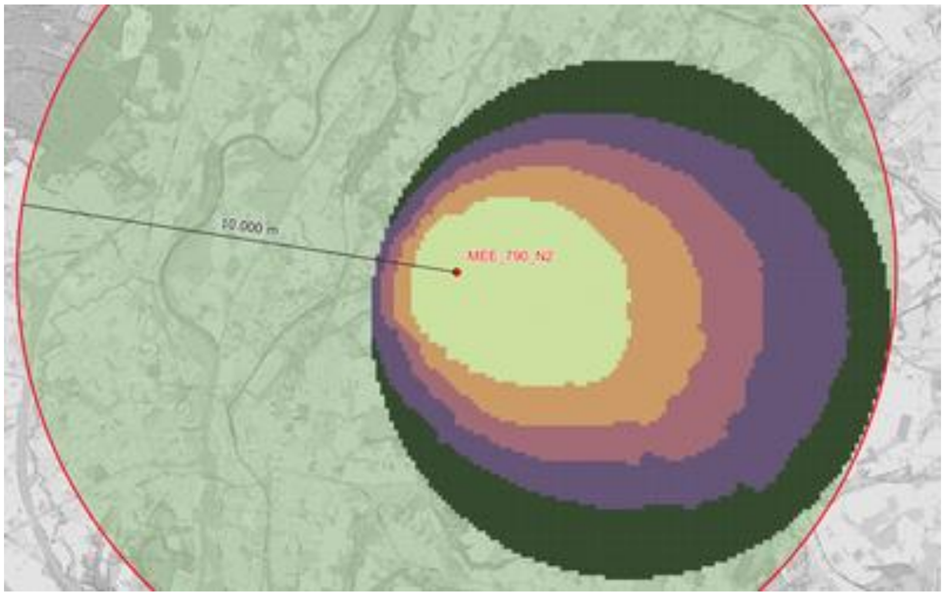
- **Key Algorithms/Processes:**

1. Initialisation. Read all necessary config parameters, check the availability of input data, read it in data objects
2. Prepare input datasets:
    1. Filter input network data to include only date range specified in config.
    2. add Z coordinate to grid centroids. If elevation is used Z coordinate is assigned based on a grid elevation property. If elevation is not used assign Z = 0.
    3. Check that all necessary cells' physical properties are present and impute missing properties. Based on a cell type, missing properties are filled in by taking default values for this cell type defined in config file. If cell type is not defined or not present in config file default cell properties are assigned.
    4. Convert signal strength values from W to DBm.
    5. Create cell point geometries. If elevation is used, set Z coordinate as altitude + antenna height. If elevation is not used, set Z coordinate as 0 + antenna height.
    6. Project coordinate system of cell geometries to coordinate system of the reference grid
3. Spatial join of cells to grid centroids. Join is done based on spatial intersection of a buffer polygons around cell points of a radius = maximum cell range with grid centroids.



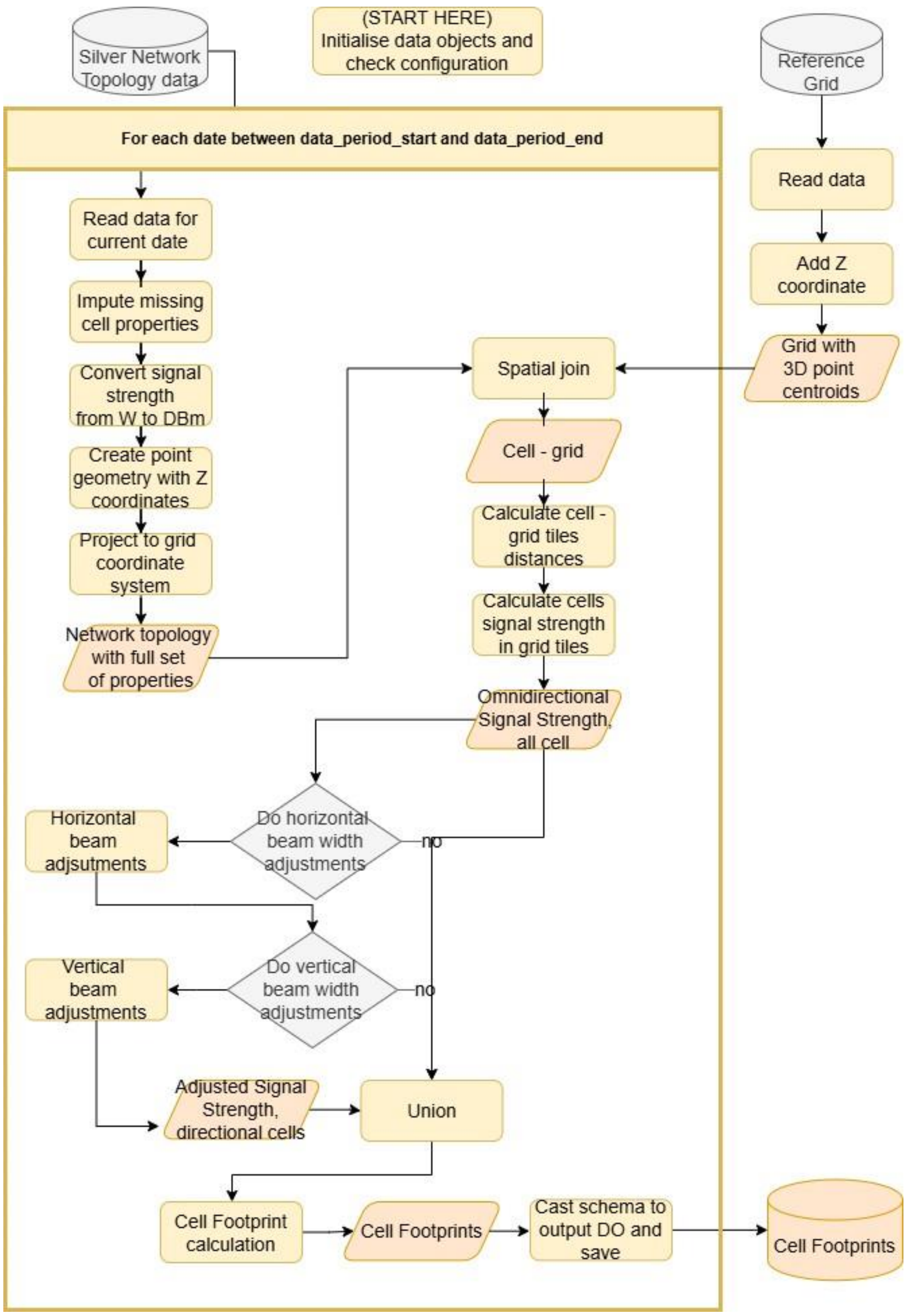
4. Calculate planar and 3D cartesian distances between cell point and all joined grid centroids.
5. Calculate signal strength in grid tiles. Using power and Path Loss Exponent cell properties and distances to joined grid tiles within cell range calculate signal strength in every grid tile with signal strength propagation equation.
6. Perform horizontal beam width adjustments to signal strength for directional cells. Optional depending on config parameter.
    1. Get mapping table with standard deviations in signal strength in all horizontal angles for all combinations of horizontal beam widths and signal strength differences between front and back of antennas.
    2. Filter only directional cells from cell-grid dataset.
    3. Join mapping table with standard deviations to cell-grid dataset.

    4. Calculate signal strength adjustments based on relative azimuth angle and the distance between grid tiles and a cell using joined standard deviation value for a cell horizontal beam width
7. Perform vertical beam width adjustments to signal strength for directional cells. Optional depending on config parameter.
    1. Get mapping table with standard deviations in signal strength in all vertical angles for all combinations of vertical beam widths and signal strength differences between front and back of antennas.
    2. Filter only directional cells from cell-grid dataset.
    3. Join mapping table with standard deviations to cell-grid dataset.
    4. Calculate signal strength adjustments based on elevation angle and the distance between grid tiles and a cell using joined standard deviation value for a cell vertical beam width.

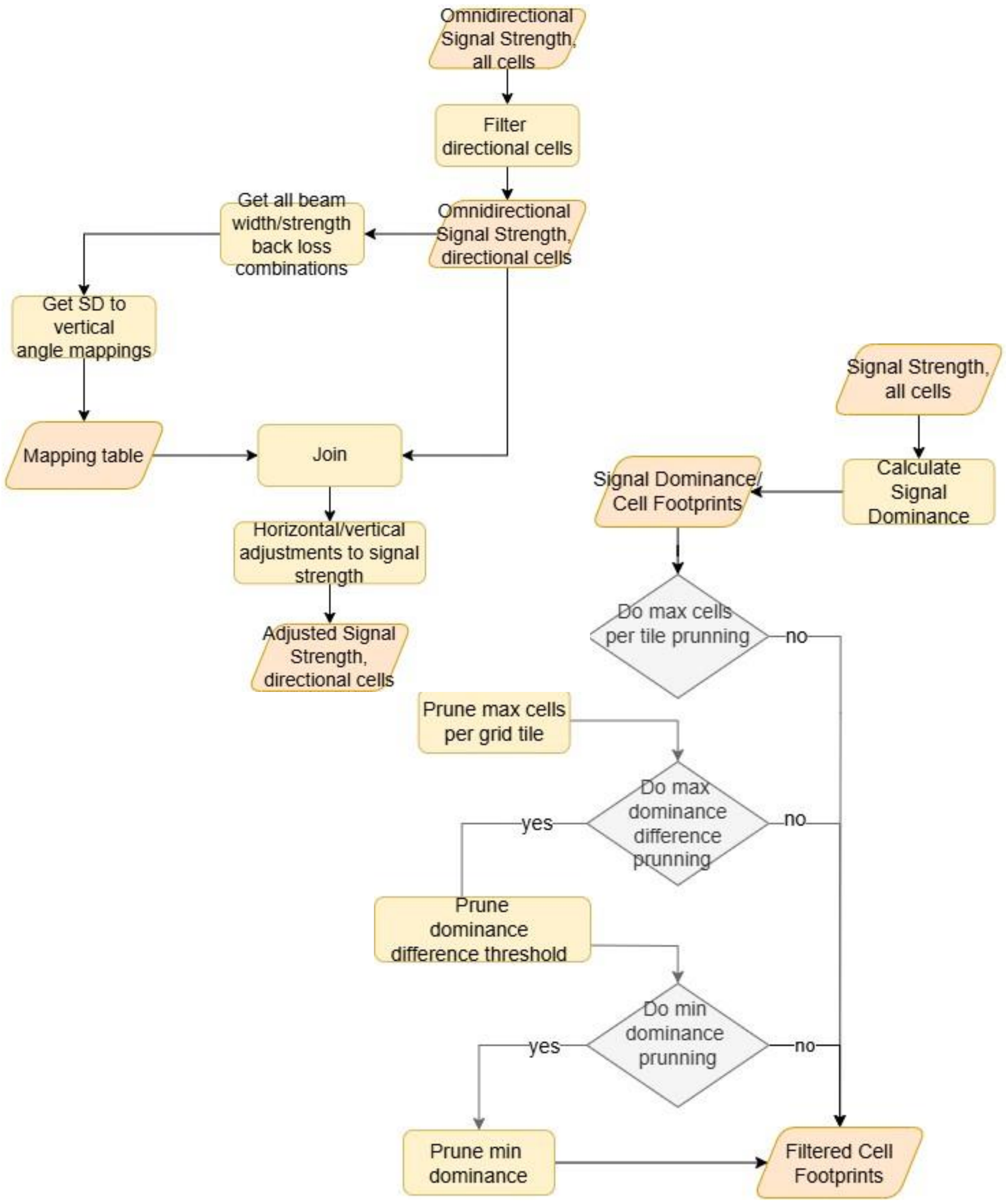


8. Union directional and non-directional cell-grid datasets.
9. Calculate signal dominance (cell footprint) from signal strength values.
10. Apply set of pruning methods depending on configuration:
    1. Maximum cells per grid tile. Keep predefined number of contributing to overall tile's signal dominance cells per grid tile. Optional step depending on configuration.
    2. Threshold difference from the best signal dominance. Always keep best signal dominance cell per grid tile. Then calculate the difference of all other cells in this tile from the best and prune cells under predefined difference threshold. Optional step depending on configuration.
    3. Threshold signal dominance. Prune all cells with signal dominance value under threshold. Optional step depending on configuration.
11. Convert output datasets schema to match the output data objects schemas and save to storage.

- **Data flow diagram:**

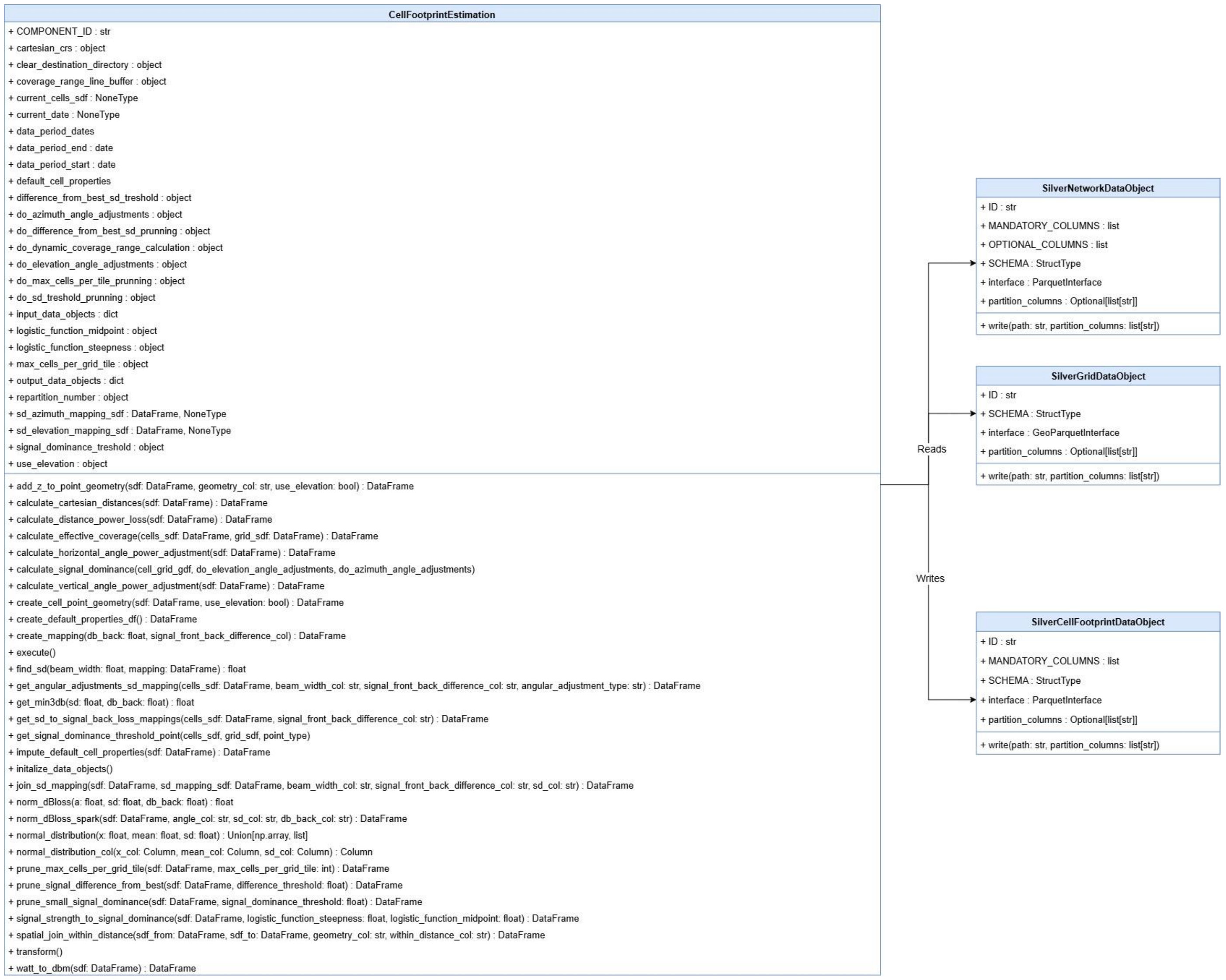


Silver Network Topology data
(START HERE) Initialise data objects and check configuration
Reference Grid
For each date between data_period_start and data_period_end
Read data for current date
Impute missing cell properties
Convert signal strength from W to DBm
Create point geometry with Z coordinates
Project to grid coordinate system
Network topology with full set of properties
Read data
Add Z coordinate
Grid with 3D point centroids
Spatial join
Cell - grid
Calculate cell - grid tiles distances
Calculate cells signal strength in grid tiles
Omnidirectional Signal Strength, all cell
Horizontal beam adjsutments
Do horizontal beam width adjustments
no
Vertical beam adjustments
Do vertical beam width adjustments
no
Adjusted Signal Strength, directional cells
Union
Cell Footprint calculation
Cell Footprints
Cast schema to output DO and save
Cell Footprints



Omnidirectional Signal Strength, all cells
Filter directional cells
Omnidirectional Signal Strength, directional cells
Get all beam width/strength back loss combinations
Get SD to vertical angle mappings
Mapping table
Join
Horizontal/vertical adjustments to signal strength
Adjusted Signal Strength, directional cells
Signal Strength, all cells
Calculate Signal Dominance
Signal Dominance/ Cell Footprints
Do max cells per tile prunning
no
Prune max cells per grid tile
Do max dominance difference prunning
yes
no
Prune dominance difference threshold
Do min dominance prunning
yes
no
Prune min dominance
Filtered Cell Footprints

- **Class diagram:**


CellFootprintEstimation
+ COMPONENT_ID : str
+ cartesian_crs : object
+ clear_destination_directory : object
+ coverage_range_line_buffer : object
+ current_cells_sdf : NoneType
+ current_date : NoneType
+ data_period_dates
+ data_period_end : date
+ data_period_start : date
+ default_cell_properties
+ difference_from_best_sd_treshold : object
+ do_azimuth_angle_adjustments : object
+ do_difference_from_best_sd_prunning : object
+ do_dynamic_coverage_range_calculation : object
+ do_elevation_angle_adjustments : object
+ do_max_cells_per_tile_prunning : object
+ do_sd_treshold_prunning : object
+ input_data_objects : dict
+ logistic_function_midpoint : object
+ logistic_function_steepness : object
+ max_cells_per_grid_tile : object
+ output_data_objects : dict
+ repartition_number : object
+ sd_azimuth_mapping_sdf : DataFrame, NoneType
+ sd_elevation_mapping_sdf : DataFrame, NoneType
+ signal_dominance_treshold : object
+ use_elevation : object
+ add_z_to_point_geometry(sdf: DataFrame, geometry_col: str, use_elevation: bool) : DataFrame
+ calculate_cartesian_distances(sdf: DataFrame) : DataFrame
+ calculate_distance_power_loss(sdf: DataFrame) : DataFrame
+ calculate_effective_coverage(cells_sdf: DataFrame, grid_sdf: DataFrame) : DataFrame
+ calculate_horizontal_angle_power_adjustment(sdf: DataFrame) : DataFrame
+ calculate_signal_dominance(cell_grid_gdf, do_elevation_angle_adjustments, do_azimuth_angle_adjustments)
+ calculate_vertical_angle_power_adjustment(sdf: DataFrame) : DataFrame
+ create_cell_point_geometry(sdf: DataFrame, use_elevation: bool) : DataFrame
+ create_default_properties_df() : DataFrame
+ create_mapping(db_back: float, signal_front_back_difference_col) : DataFrame
+ execute()
+ find_sd(beam_width: float, mapping: DataFrame) : float
+ get_angular_adjustments_sd_mapping(cells_sdf: DataFrame, beam_width_col: str, signal_front_back_difference_col: str, angular_adjustment_type: str) : DataFrame
+ get_min3db(sd: float, db_back: float) : float
+ get_sd_to_signal_back_loss_mappings(cells_sdf: DataFrame, signal_front_back_difference_col: str) : DataFrame
+ get_signal_dominance_threshold_point(cells_sdf, grid_sdf, point_type)
+ impute_default_cell_properties(sdf: DataFrame) : DataFrame
+ initalize_data_objects()
+ join_sd_mapping(sdf: DataFrame, sd_mapping_sdf: DataFrame, beam_width_col: str, signal_front_back_difference_col: str, sd_col: str) : DataFrame
+ norm_dBloss(a: float, sd: float, db_back: float) : float
+ norm_dBloss_spark(sdf: DataFrame, angle_col: str, sd_col: str, db_back_col: str) : DataFrame
+ normal_distribution(x: float, mean: float, sd: float) : Union[np.array, list]
+ normal_distribution_col(x_col: Column, mean_col: Column, sd_col: Column) : Column
+ prune_max_cells_per_grid_tile(sdf: DataFrame, max_cells_per_grid_tile: int) : DataFrame
+ prune_signal_difference_from_best(sdf: DataFrame, difference_threshold: float) : DataFrame
+ prune_small_signal_dominance(sdf: DataFrame, signal_dominance_threshold: float) : DataFrame
+ signal_strength_to_signal_dominance(sdf: DataFrame, logistic_function_steepness: float, logistic_function_midpoint: float) : DataFrame
+ spatial_join_within_distance(sdf_from: DataFrame, sdf_to: DataFrame, geometry_col: str, within_distance_col: str) : DataFrame
+ transform()
+ watt_to_dbm(sdf: DataFrame) : DataFrame
Reads
Writes
SilverNetworkDataObject
+ ID : str
+ MANDATORY_COLUMNS : list
+ OPTIONAL_COLUMNS : list
+ SCHEMA : StructType
+ interface : ParquetInterface
+ partition_columns : Optional[list[str]]
+ write(path: str, partition_columns: list[str])
SilverGridDataObject
+ ID : str
+ SCHEMA : StructType
+ interface : GeoParquetInterface
+ partition_columns : Optional[list[str]]
+ write(path: str, partition_columns: list[str])
SilverCellFootprintDataObject
+ ID : str
+ MANDATORY_COLUMNS : list
+ SCHEMA : StructType
+ interface : ParquetInterface
+ partition_columns : Optional[list[str]]
+ write(path: str, partition_columns: list[str])

- **Code Structure:**

The code structure follows the format set by the core package, and the general repository structure.

The location of the module script in the repository is as follows:

```
multimno
  └──── components
     └──── execution
        └──── cell_footprint
           └──── cell_footprint_estimation.py
```

cell_footprint_estimation.py contains one class named CellFootprintEstimation which is a subclass of Component.

- CellFootprintEstimation which class overrides transform method of base Component class.
- transform method performs all necessary filtering and transformation for Signal Strength data modeling and its conversion to signal dominance (cell footprint) by sequentially calling other methods that perform the actual data manipulation.

5.2.8 CELLCONNECTIONPROBABILITYESTIMATION

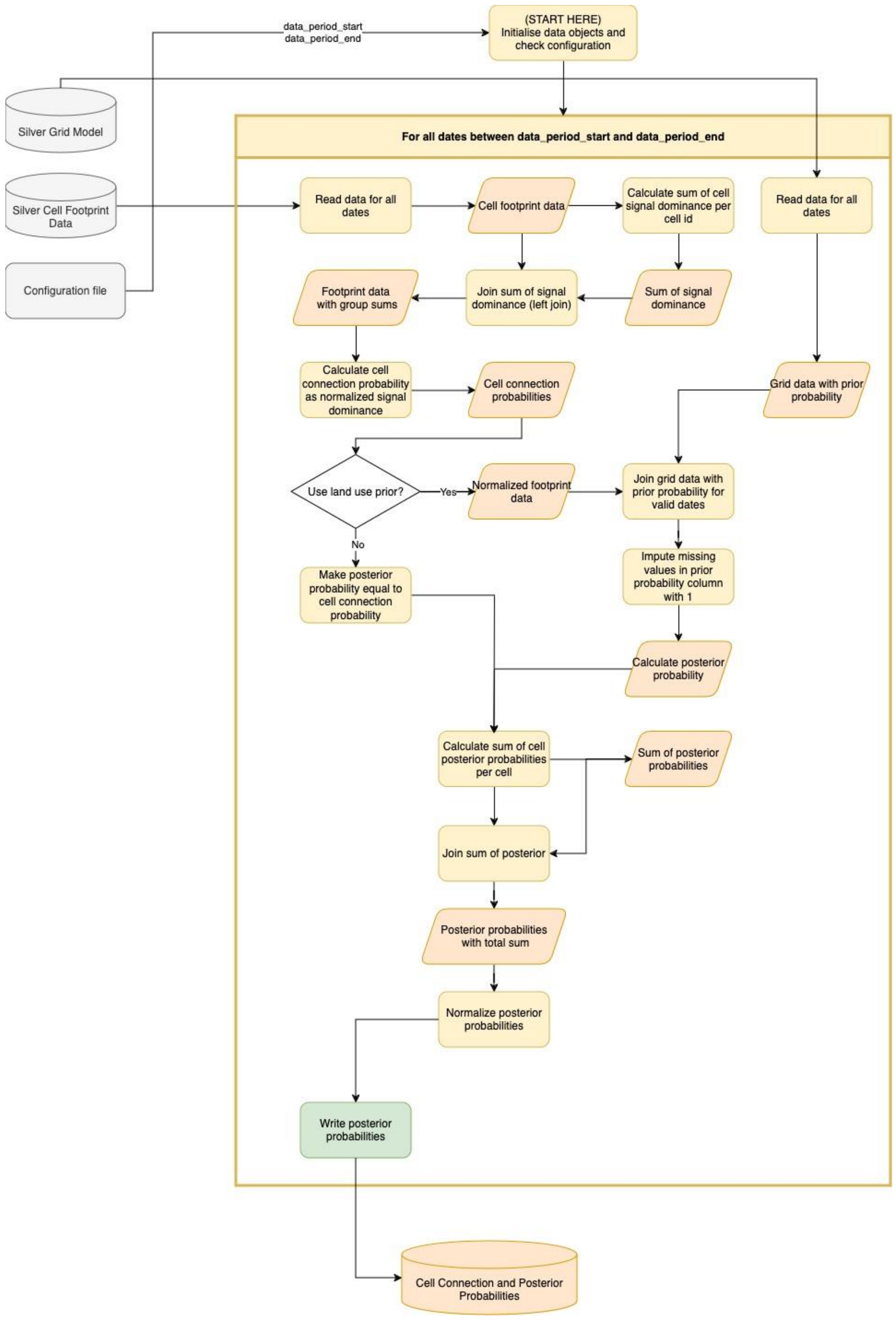
5.2.8.1 MODULE DESCRIPTION

- **Module Name:** CellConnectionProbabilityEstimation
- **Objectives:** this module calculates cell connection probabilities based on the cell footprint values, and optionally applies the land use prior probabilities, to get the posterior probabilities for each cell id and grid id.
- **Functionality:**
  the component reads in cell footprint data, calculates cell connection probabilities for each grid, and then performs posterior calculation , using prior probability values from the reference grid, when so specified in the configuration.
  Functionality is outlined in the software requirement specifications:
  3.2.5 CellConnectionProbabilityEstimation
- **Data Inputs and Outputs:**
  - Input:
    - I.13 Cell Footprints
    - I.11 Reference Grid
  - Outputs:
    - I.15 Cell Connection and Posterior Probabilities

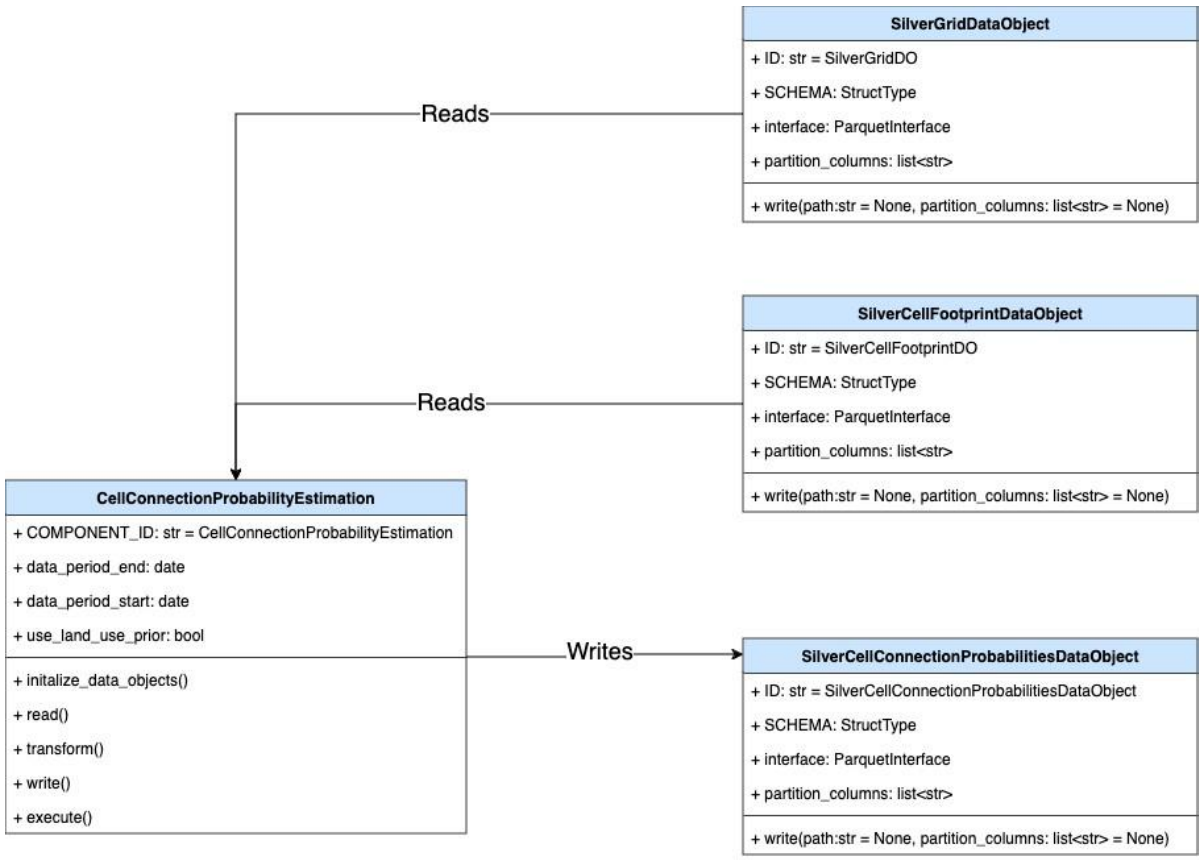
5.2.8.2 DEVELOPMENT DESIGN

- **Key Algorithms/Processes:**
  The data is processed for the selected dates range. All following steps are run for each date:
  - Calculate sum of cell footprint for each grid_id.
  - Calculate cell connection probability as ratio of cell footprint to sum of footprint for grid_id.
  - If so set in configuration, join the grid data with prior probabilities to the result of previous step
  - If so set in configuration, calculate posterior probabilities by multiplying prior probabilities and cell connection probabilities. Otherwise make posterior probabilities equal with cell connection probabilities.
  - Calculate sum of cell connection probabilities for cell id.
  - Normalise posterior probabilities using sum of previous step.

- **Data flow diagram:**


data_period_start
data_period_end
(START HERE) Initialise data objects and check configuration
Silver Grid Model
Silver Cell Footprint Data
Configuration file
For all dates between data_period_start and data_period_end
Read data for all dates
Cell footprint data
Calculate sum of cell signal dominance per cell id
Read data for all dates
Footprint data with group sums
Join sum of signal dominance (left join)
Sum of signal dominance
Calculate cell connection probability as normalized signal dominance
Cell connection probabilities
Grid data with prior probability
Use land use prior?
Yes
Normalized footprint data
Join grid data with prior probability for valid dates
No
Make posterior probability equal to cell connection probability
Impute missing values in prior probability column with 1
Calculate posterior probability
Calculate sum of cell posterior probabilities per cell
Sum of posterior probabilities
Join sum of posterior
Posterior probabilities with total sum
Normalize posterior probabilities
Write posterior probabilities
Cell Connection and Posterior Probabilities

- **Class diagram:**


SilverGridDataObject
+ ID: str = SilverGridDO
+ SCHEMA: StructType
+ interface: ParquetInterface
+ partition_columns: list<str>
+ write(path:str = None, partition_columns: list<str> = None)
Reads
SilverCellFootprintDataObject
+ ID: str = SilverCellFootprintDO
+ SCHEMA: StructType
+ interface: ParquetInterface
+ partition_columns: list<str>
+ write(path:str = None, partition_columns: list<str> = None)
Reads
CellConnectionProbabilityEstimation
+ COMPONENT_ID: str = CellConnectionProbabilityEstimation
+ data_period_end: date
+ data_period_start: date
+ use_land_use_prior: bool
+ initalize_data_objects()
+ read()
+ transform()
+ write()
+ execute()
Writes
SilverCellConnectionProbabilitiesDataObject
+ ID: str = SilverCellConnectionProbabilitiesDataObject
+ SCHEMA: StructType
+ interface: ParquetInterface
+ partition_columns: list<str>
+ write(path:str = None, partition_columns: list<str> = None)

- **Code Structure:**
  The code structure follows the format set by the core package, and the general repository structure.

  The location of the module script in the repository is as follows:

```
/multimno_internal/
└── multimno
    └── components
        └── execution
            └── cell_connection_probability
                └── cell_connection_probability.py
```

  - cell_connection_probability.py contains one class named CellConnectionProbabilityEstimation which is a subclass of Component.

The CellConnectionProbabilityEstimation class overwrites __init__ andtransform in the Component class.

__init__ method initialises the data objects and reads the necessary values from config file.
transform performs all necessary transformations and calculation of cell probability estimation for the

entire period. transform does not contain any calls to smaller functions, but holds the entire processing flow.

5.2.9 SEMANTICCLEANING

5.2.9.1 MODULE DESCRIPTION

- **Module Name:** SemanticCleaning
- **Objectives:** the objective of this module is to perform checks to identify and flag semantically erroneous events of devices.
- **Functionality:** The semantic checks include the following:
    - Valid reference to a cell identifier: whether an event makes a reference to an existent cell that is operative at the event's timestamp and, if the cell exists, whether it was operative or not. This check does not apply to outbound data.
    - Illogical change of location of the device based on time and distance difference between consecutive events: some events are flagged as incorrect and others are flagged as suspicious. This check does not apply to outbound data.
    - Duplicates (record with identical timestamps for a user) that have different location information in cell_id or longitude and latitude columns. For outbound data, the PLMN column is used.

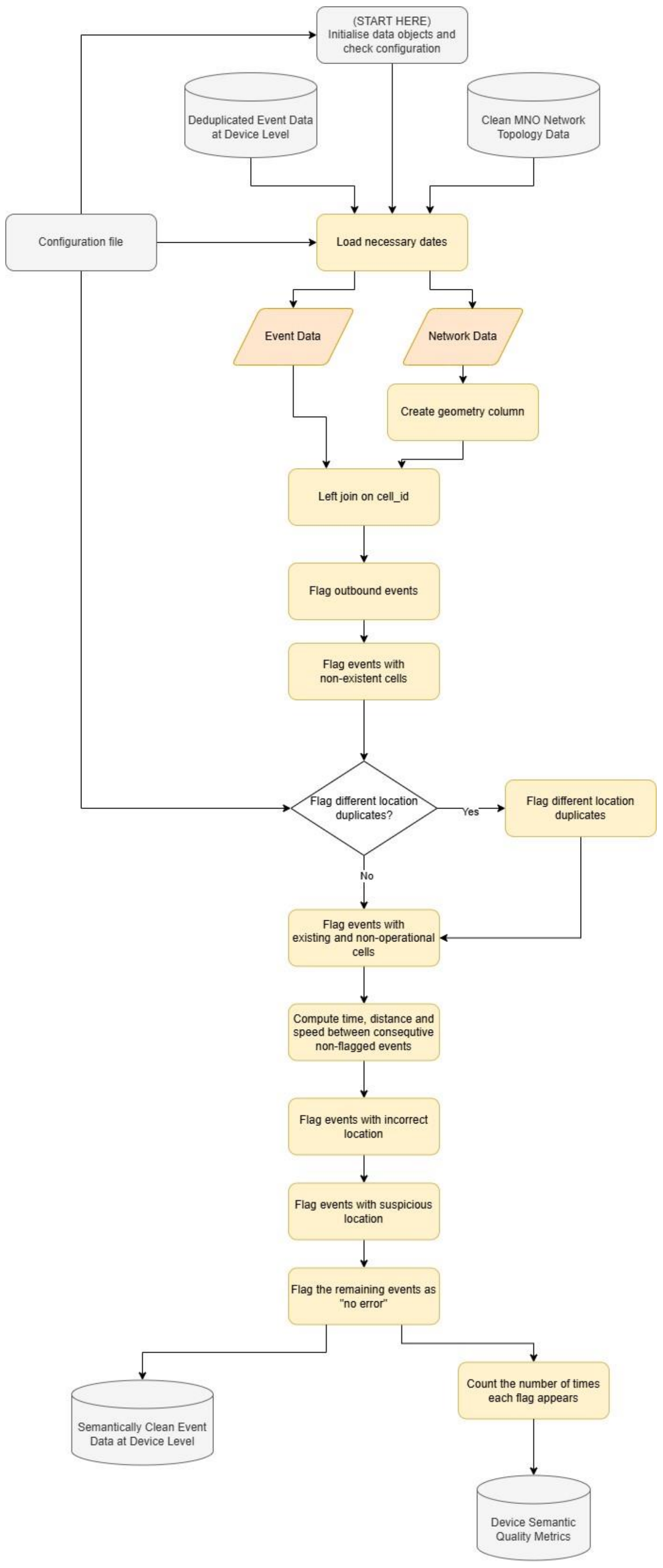
  Functionality is outlined in the software requirement specifications: 3.2.9 SemanticCleaning
  At this moment in time, only the processing of cell locations with physical properties is implemented.
- **Data Inputs and Outputs:**
    - Input:
        - I.1 MNO Event Data - Raw
        - I.8 Cell Locations with Physical Properties – Cleaned
    - Output:
        - I.16 MNO Event Data – Semantically Cleaned
        - I.17 MNO Device Semantic Quality Metrics

5.2.9.2 DEVELOPMENT DESIGN

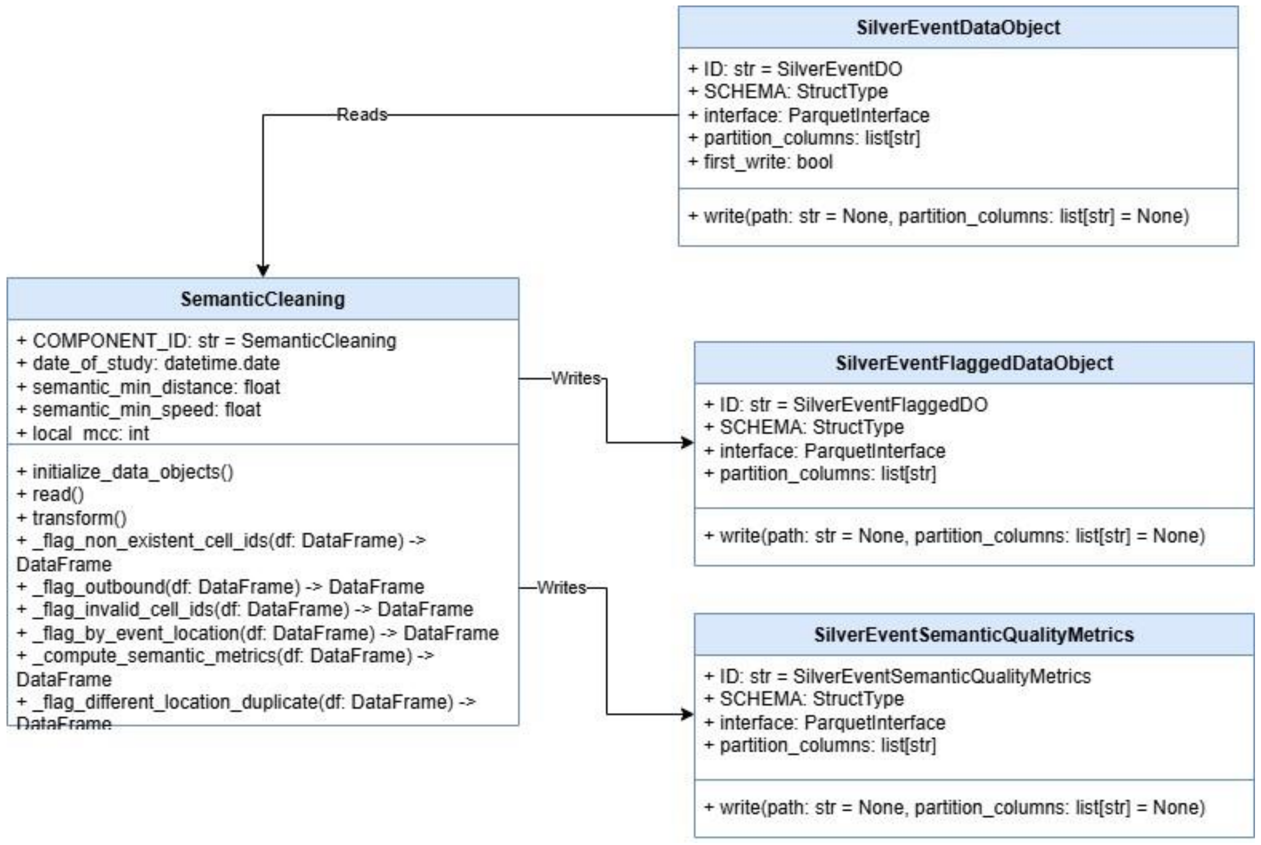
- **Key Algorithms/Processes:**
    - Create the data objects: events and cells.
    - Read from the configuration file the minimum distance and speed for which an event might be classified as semantically erroneous.
    - Mark outbound records. A record is outbound if the MCC component of the PLMN value differs from the configuration-provided MCC value of the local country. Outbound records are omitted from further error checks other than the different location duplicates check.
    - Create a geometry column with the latitude-longitude point of each cell.
    - Perform a left join between events and cells by the cell ID field. In this way, non-existent cell IDs appearing in the events data will be matched with null values.
    - Whenever the geometry column is null, flag these events with the flag corresponding to a non-existent cell.
    - Then, flag different location duplicates. Different location duplicates are cases where timestamp and user_id columns have identical values for more than two rows, but the combination of values for longitude, latitude and cell_id is not identical for the same selection of rows. For outbound records, PLMN values are compared instead.

- Then, flag events that make reference to an existent cell that was not operative when the event was registered with the corresponding flag. The geometry column created above, which is just an auxiliary column, is set to null for these flagged events for convenience later on.
- Next, semantically erroneous events regarding location will be flagged. For this it is necessary to compute the estimated distance and speed between two consecutive events *which have not been flagged*. This is achieved as follows:
    - Create two windows, both partitioned by year, month, day, user_id_modulo (these four are the partition variables of event data) and user_id, and ordered by timestamp. One window will comprise all events following the current position (from the current position plus one, to unbounded following), and the other will comprise all events preceding the current position (from unbounded preceding, to the current position minus one).
    - Using these two windows *and "skipping" all events previously flagged*, four auxiliary columns are created, containing the time difference to the next event, the time difference from the previous event, the distance to the following event, and the distance to the previous event, respectively.
    - Then, two additional columns are created with the estimated mean speed with respect to next and previous events respectively.
    - With all the necessary information already computed, events are now flagged:
        - Whenever the distance and speed to <u>both</u> the next and previous events surpass their thresholds specified via configuration, the event is flagged as an event with an incorrect location.
        - Whenever the distance and speed to <u>either, but not both</u>, the next or previous events surpass the thresholds specified via configuration, the event is flagged as an event with a suspicious location.
        - The first and last events of the day for a given device are compared with the second and second-to-last events of the day respectively. If the distance and speed thresholds are surpassed, they are flagged with a suspicious location.
- The rest of the events that have not been flagged until now are given the "no error" flag.
- All auxiliary columns are removed and only those fields in the output event data object are left.
- The dataframe is cached or persisted into memory.
- Semantic metrics are computed: the now flagged event data is grouped by error flag and the number of occurrences of each flagged is counted.
- The output event data and semantic metrics are saved.

- **Data flow diagram:**


(START HERE) Initialise data objects and check configuration
Deduplicated Event Data at Device Level
Clean MNO Network Topology Data
Configuration file
Load necessary dates
Event Data
Network Data
Create geometry column
Left join on cell_id
Flag outbound events
Flag events with non-existent cells
Flag different location duplicates?
Yes
Flag different location duplicates
No
Flag events with existing and non-operational cells
Compute time, distance and speed between consequtive non-flagged events
Flag events with incorrect location
Flag events with suspicious location
Flag the remaining events as "no error"
Semantically Clean Event Data at Device Level
Count the number of times each flag appears
Device Semantic Quality Metrics

- **Class diagram:**


SilverEventDataObject
+ ID: str = SilverEventDO
+ SCHEMA: StructType
+ interface: ParquetInterface
+ partition_columns: list[str]
+ first_write: bool
+ write(path: str = None, partition_columns: list[str] = None)
Reads
SemanticCleaning
+ COMPONENT_ID: str = SemanticCleaning
+ date_of_study: datetime.date
+ semantic_min_distance: float
+ semantic_min_speed: float
+ local_mcc: int
+ initialize_data_objects()
+ read()
+ transform()
+ _flag_non_existent_cell_ids(df: DataFrame) -> DataFrame
+ _flag_outbound(df: DataFrame) -> DataFrame
+ _flag_invalid_cell_ids(df: DataFrame) -> DataFrame
+ _flag_by_event_location(df: DataFrame) -> DataFrame
+ _compute_semantic_metrics(df: DataFrame) -> DataFrame
+ _flag_different_location_duplicate(df: DataFrame) -> DataFrame
Writes
SilverEventFlaggedDataObject
+ ID: str = SilverEventFlaggedDO
+ SCHEMA: StructType
+ interface: ParquetInterface
+ partition_columns: list[str]
+ write(path: str = None, partition_columns: list[str] = None)
Writes
SilverEventSemanticQualityMetrics
+ ID: str = SilverEventSemanticQualityMetrics
+ SCHEMA: StructType
+ interface: ParquetInterface
+ partition_columns: list[str]
+ write(path: str = None, partition_columns: list[str] = None)

- **Code Structure:**

The code structure follows the format set by the core package, and the general repository structure. The location of the module script in the repository is as follows:

```
/multimno/
└──── src
   └──── components
      └──── execution
         └──── event_semantic_cleaning
            └──── event_semantic_cleaning.py
```

- event_semantic_cleaning.py contains one class named SemanticCleaning which is a subclass of Component. It overrides the following methods:
  - The __init__ method first call its parent's __init__ method, which sets up the Spark session, initialises data objects and reads the configuration file.
  - The transform method handles all the logic behind the component.
- The SemanticCleaning component also has the following methods:
  - _flag_non_existent_cell_ids handles the check and flagging of references to non-existent cell IDs.

        - _flag_outbound handles the flagging of outbound events.
        - _flag_invalid_cell_ids handles the check and flagging of references to existent cell IDs that were not operative in the moment an event was registered.
        - _flag_by_event_location handles the check and flagging of events with an incorrect or suspicious location.
        - _compute_semantic_metrics handles the counting of occurences of each flag and formatting them as the quality metrics.
        - _flag_different_location_duplicate handles the detection and flagging of different location duplicates.

5.2.10 SEMANTICQUALITYWARNINGS

5.2.10.1 MODULE DESCRIPTION

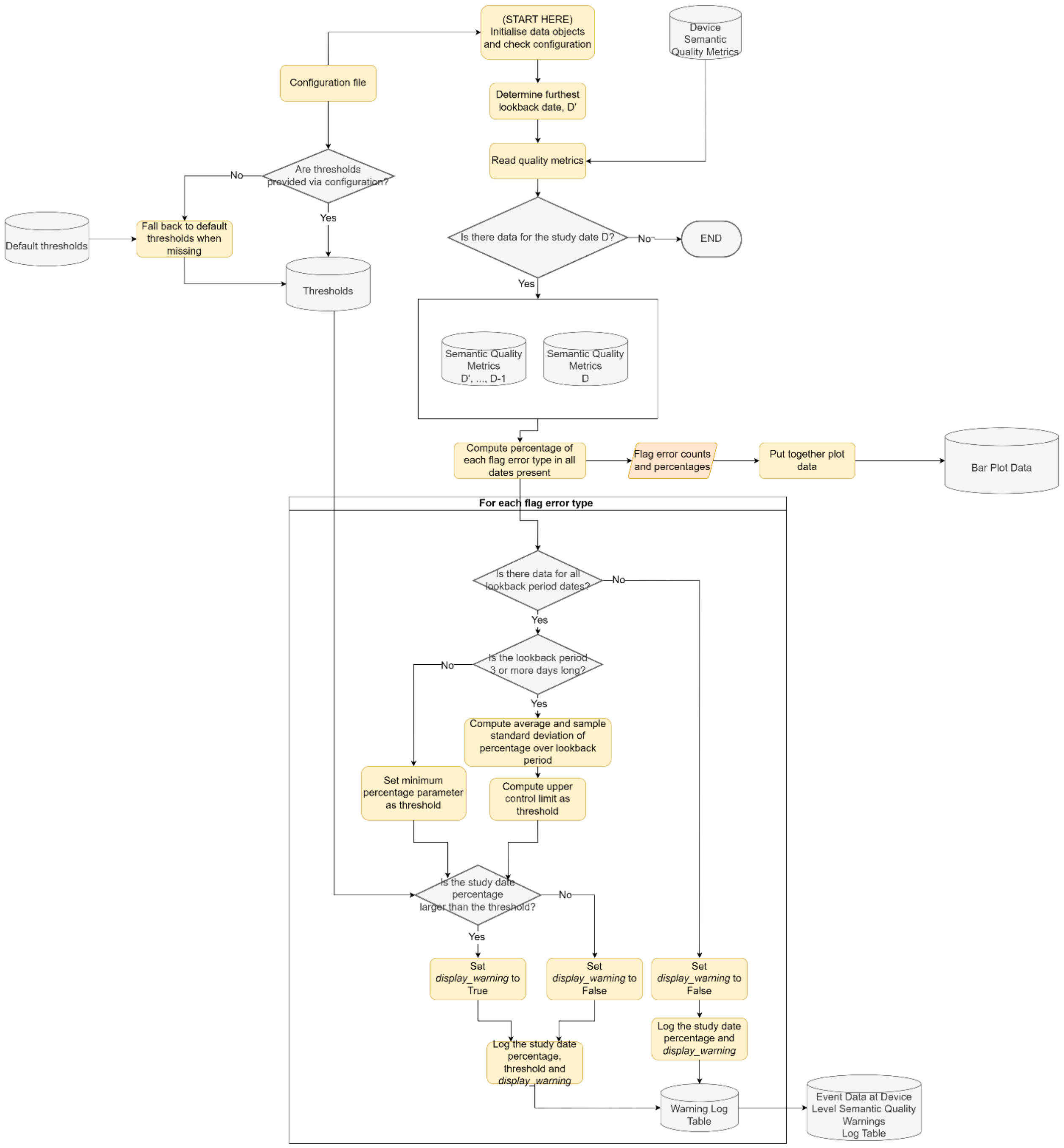
- **Module Name:** SemanticQualityWarnings
- **Objectives:** this module analyses the semantic quality metrics produced in the event semantic checks at device level process in order to identify anomalous situations that may need to be investigated further.
- **Functionality:** the module computes statistics on the semantic event quality metrics over a specified lookback period and compares them with present values. When anomalous situations are identified, warnings are produced, as well as data to easily create plots that summarise the evolution of metrics over time and the frequency of each type of error.
  Functionality is outlined in the software requirement specifications: 3.2.10 SemanticQualityWarnings
- **Data Inputs and Outputs:**
    - Input:
        - I.17 MNO Device Semantic Quality Metrics
    - Output:
        - I.18 MNO Event Data at device Level Semantic Quality Warnings – log table
        - I.25 Event Data at Device Level Semantic Quality Warnings Bar Plot Data

5.2.10.2 DEVELOPMENT DESIGN

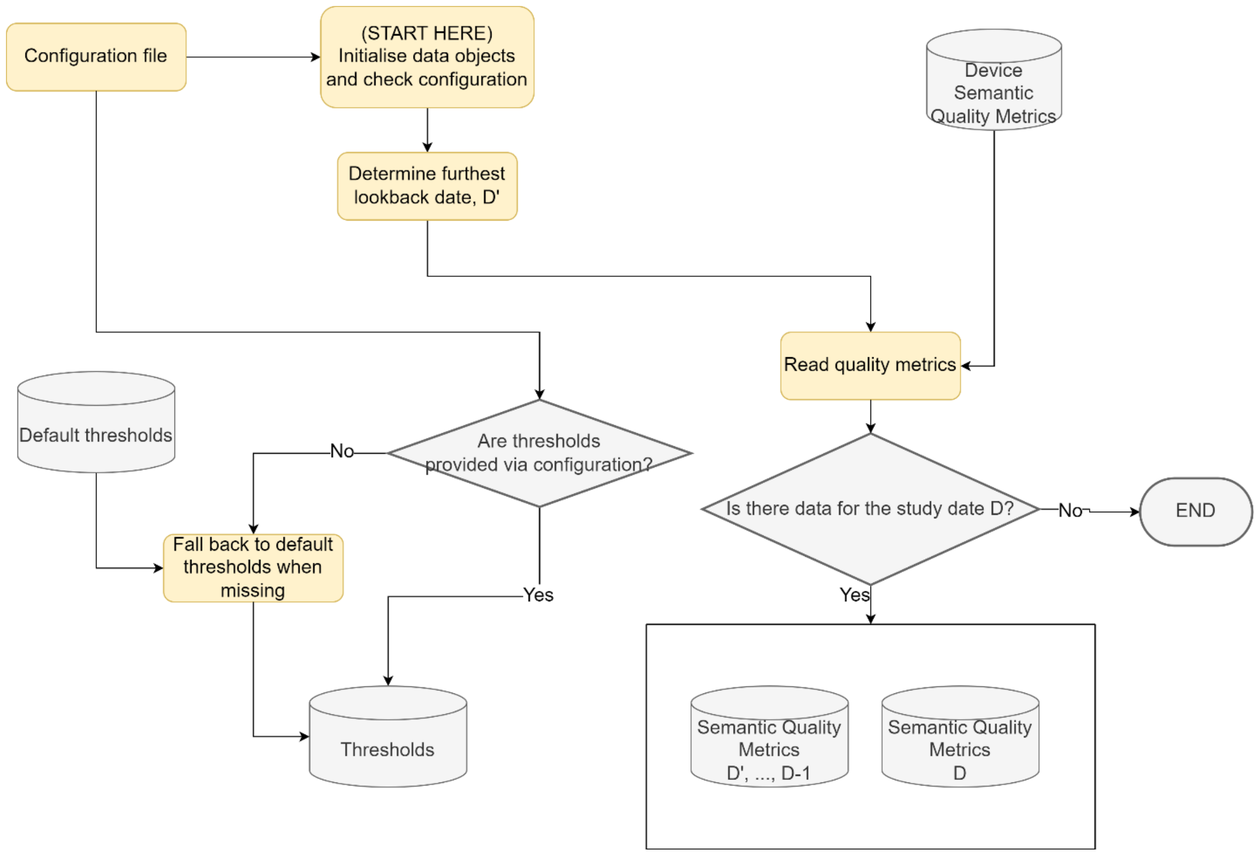
- **Key Algorithms/Processes:**
    - Create the data objects.
    - The thresholds to be used for raising warnings that are specified via configuration file are read and their types and values are validated. In the case that a specific threshold is not present, its default value is used instead.
    - Since each metric might have a different lookback period, the date furthest into the past is found, and data is read between this date and the study date.
    - If there are no metrics for the study date, an exception is raised.
    - Compute the percentage of each type of flag error, including the 'no error' flag, for each date read.
    - For each error flag (excluding 'no error' flag) do:
        - Check that the corresponding metric is present for all the lookback period dates of this error:
            - If one of them is missing, no warning is to be raised.
            - If they are all present, but the lookback period is lower than 3, use the 'min_percentage' parameter as the threshold for the warning raising condition.

    - If they are all present and the lookback period is equal or greater than 3, compute the average and sample standard deviation of the percentage of this flag error over its lookback period. Then, compute the threshold to raise a warning as the upper control limit (i.e. average plus the standard deviation multiplied by the 'min_sd' parameter).
    - If the percentage of the study date is greater than the threshold, raise a warning.
  - Log the percentage value of the present day. In the case that a threshold was computed, log it as well. If a warning is to be raised, log a True value, or False otherwise.
- Format all logged data in the required format and write it to file.
- Using the statistics computed previously, prepare the data needed to plot the required graphs:
  - Bar plot showing the absolute count of each flag error type for each date over the longest lookback period plus the study date considered in the process. Save the data needed to make this graph into a parquet file.
  - Bar plot showing the percentage of each flag error type for each date over the longest lookback period plus the study date considered in the process. Save the data needed to make this graph into a parquet file.

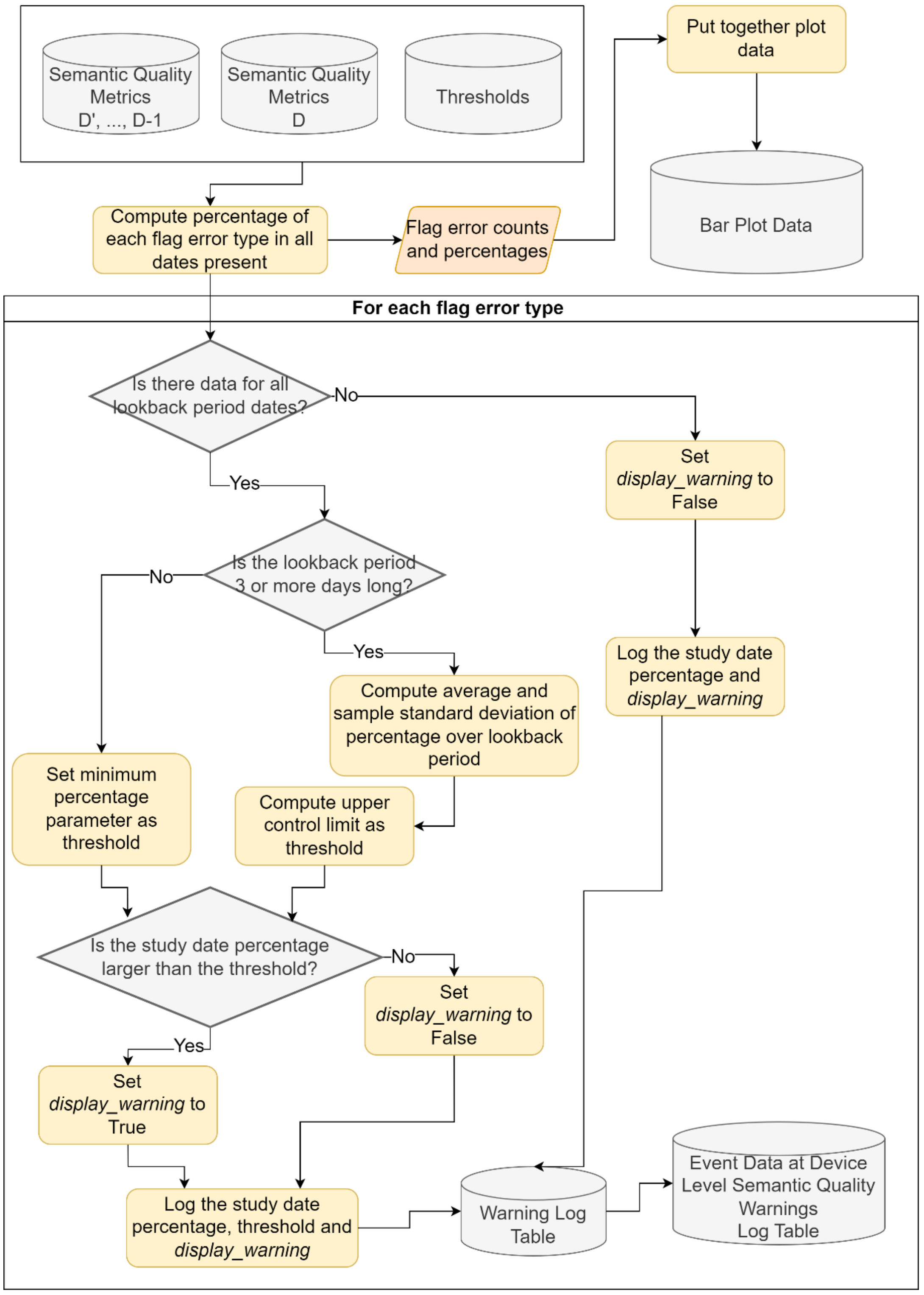
- **Data flow diagram (full view):**


(START HERE) Initialise data objects and check configuration
Device Semantic Quality Metrics
Configuration file
Determine furthest lookback date, D'
Read quality metrics
Are thresholds provided via configuration?
No
Yes
Default thresholds
Fall back to default thresholds when missing
Thresholds
Is there data for the study date D?
No
END
Yes
Semantic Quality Metrics D', ..., D-1
Semantic Quality Metrics D
Compute percentage of each flag error type in all dates present
Flag error counts and percentages
Put together plot data
Bar Plot Data
For each flag error type
Is there data for all lookback period dates?
No
Yes
Is the lookback period 3 or more days long?
No
Yes
Compute average and sample standard deviation of percentage over lookback period
Set minimum percentage parameter as threshold
Compute upper control limit as threshold
Is the study date percentage larger than the threshold?
No
Yes
Set display_warning to True
Set display_warning to False
Set display_warning to False
Log the study date percentage and display_warning
Log the study date percentage, threshold and display_warning
Warning Log Table
Event Data at Device Level Semantic Quality Warnings Log Table

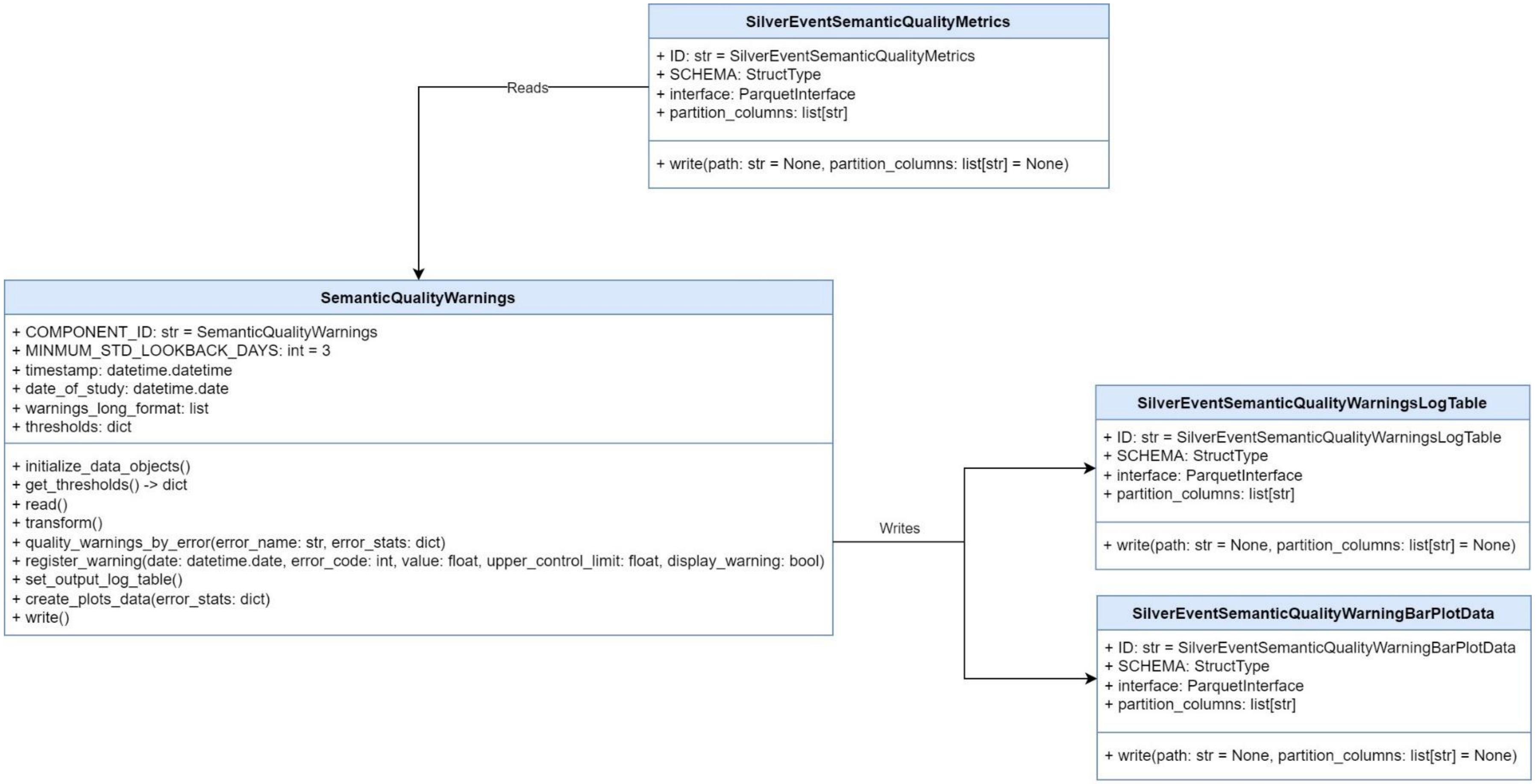
- **Data flow diagram (part I):**


Configuration file
(START HERE) Initialise data objects and check configuration
Device Semantic Quality Metrics
Determine furthest lookback date, D'
Read quality metrics
Default thresholds
Are thresholds provided via configuration?
No
Yes
Is there data for the study date D?
No
END
Yes
Fall back to default thresholds when missing
Thresholds
Semantic Quality Metrics D', ..., D-1
Semantic Quality Metrics D

- **Data flow diagram (part II):**


Semantic Quality Metrics D', ..., D-1
Semantic Quality Metrics D
Thresholds
Put together plot data
Bar Plot Data
Compute percentage of each flag error type in all dates present
Flag error counts and percentages
For each flag error type
Is there data for all lookback period dates?
No
Yes
Set *display_warning* to False
Is the lookback period 3 or more days long?
No
Yes
Compute average and sample standard deviation of percentage over lookback period
Log the study date percentage and *display_warning*
Set minimum percentage parameter as threshold
Compute upper control limit as threshold
Is the study date percentage larger than the threshold?
No
Set *display_warning* to False
Yes
Set *display_warning* to True
Log the study date percentage, threshold and *display_warning*
Warning Log Table
Event Data at Device Level Semantic Quality Warnings Log Table

- **Class diagram:**


SilverEventSemanticQualityMetrics
+ ID: str = SilverEventSemanticQualityMetrics
+ SCHEMA: StructType
+ interface: ParquetInterface
+ partition_columns: list[str]
+ write(path: str = None, partition_columns: list[str] = None)
Reads
SemanticQualityWarnings
+ COMPONENT_ID: str = SemanticQualityWarnings
+ MINMUM_STD_LOOKBACK_DAYS: int = 3
+ timestamp: datetime.datetime
+ date_of_study: datetime.date
+ warnings_long_format: list
+ thresholds: dict
+ initialize_data_objects()
+ get_thresholds() -> dict
+ read()
+ transform()
+ quality_warnings_by_error(error_name: str, error_stats: dict)
+ register_warning(date: datetime.date, error_code: int, value: float, upper_control_limit: float, display_warning: bool)
+ set_output_log_table()
+ create_plots_data(error_stats: dict)
+ write()
Writes
SilverEventSemanticQualityWarningsLogTable
+ ID: str = SilverEventSemanticQualityWarningsLogTable
+ SCHEMA: StructType
+ interface: ParquetInterface
+ partition_columns: list[str]
+ write(path: str = None, partition_columns: list[str] = None)
SilverEventSemanticQualityWarningBarPlotData
+ ID: str = SilverEventSemanticQualityWarningBarPlotData
+ SCHEMA: StructType
+ interface: ParquetInterface
+ partition_columns: list[str]
+ write(path: str = None, partition_columns: list[str] = None)

- **Code Structure:** The code structure follows the format set by the core package, and the general repository structure. The location of the module script in the repository is as follows:

```
/multimno/
└── src
    └── components
        └── quality
            └── semantic_quality_warnings
                └── semantic_quality_warnings.py
```

  - semantic_quality_warnings.py contains one class named SemanticQualityWarnings which is a subclass of Component. It overrides the following methods:
    - The __init__ method first call its parent's __init__ method, which sets up the Spark session, initialises data objects and reads the configuration file.
    - The transform method handles all the logic behind the component.
    - The write method writes the quality warnings log table containing the computed warnings. It also writes into parquet files the data required to produce the defined plots.
  - The SemanticQualityWarnings also has the following methods:
    - get_thresholds handles the logic of reading configuration-specified thresholds and the usage of default threshold whenever a specific threshold value is not specified.
    - quality_warnings_by_error: method that handles the logic for computing the necessary statistics and raising a warning for a specific error flag in the study date.
    - register_warning is a method that abstracts away the creation of a warning in the log table, taking as arguments all necessary information and putting it in the correct format.
    - set_output_log_table formats the warnings into the expected table format.
    - create_plots_data gathers and formats the data required to produce the necessary plots of the component.

5.2.11 DEVICEACTIVITYSTATISTICS

5.2.11.1 MODULE DESCRIPTION

- **Module Name:** DeviceActivityStatistics
- **Objectives:** This module uses data on individual devices after and produces metrics to assess the usability of the devices for specific procedures or use cases based on the activity statistics.
- **Functionality:**
- **Data Inputs and Outputs:**
  - Input:
    I.16 MNO Event Data – Semantically Cleaned
    I.8 Cell Locations with Physical Properties – Cleaned
  - Outputs:
    I.19 Device Activity Statistics

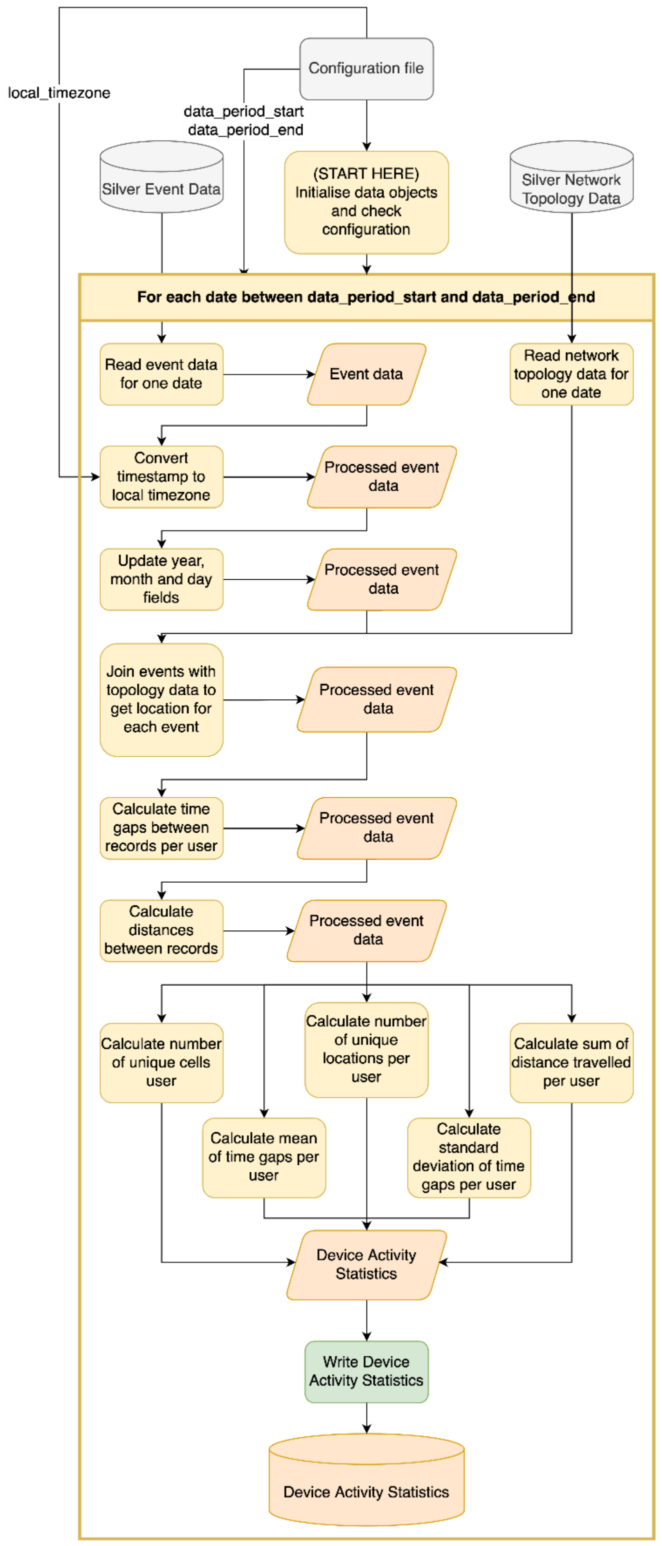
5.2.11.2 DEVELOPMENT DESIGN

- **Key Algorithms/Processes:**
  The data is processed in one-day chunks in the local timezone. As the data is saved in UTC, the first

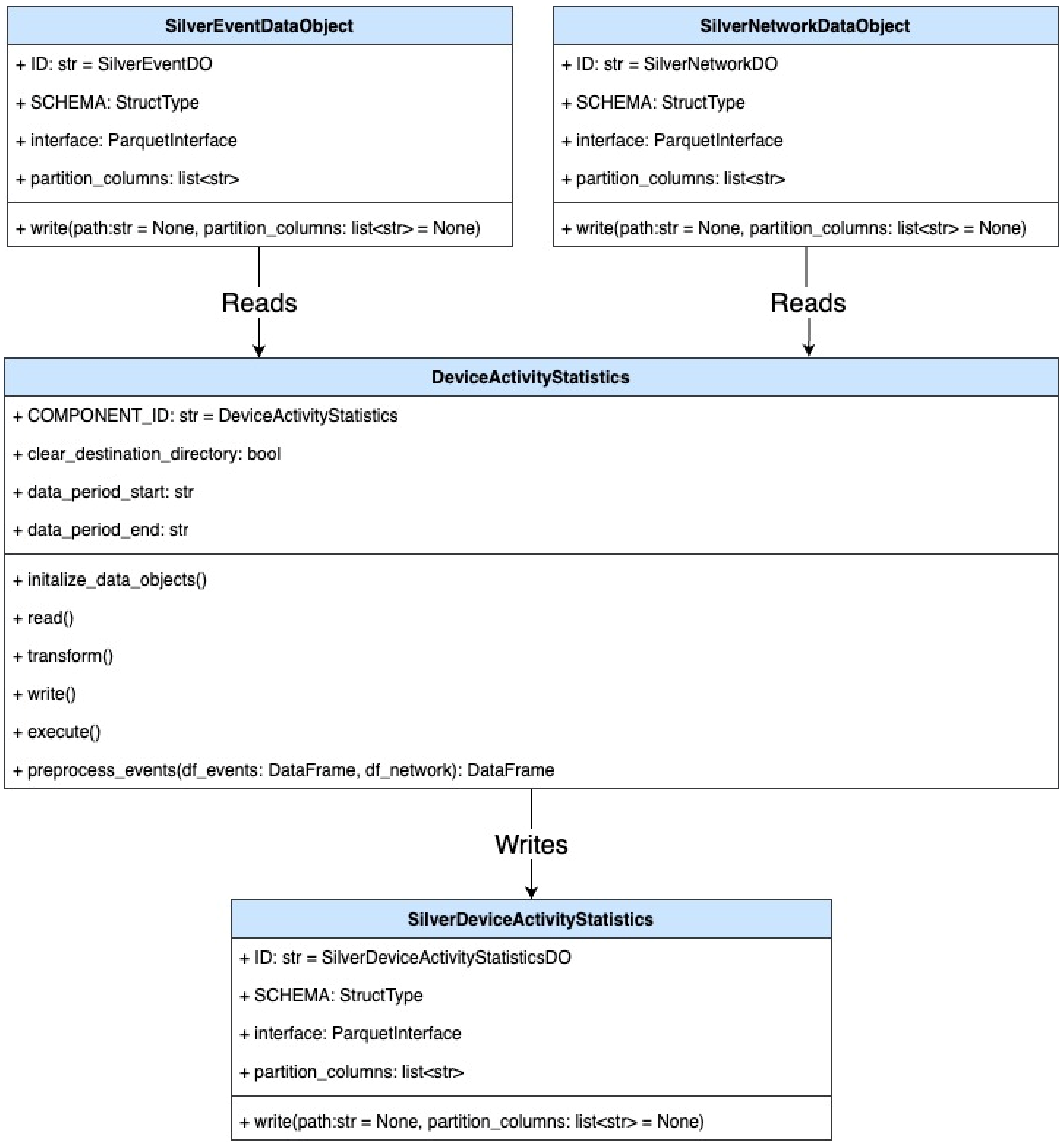
step is to calculate the times in UTC that need to be read. All of the following steps are run for each date in the data:

- Preprocess events data:
  - Timestamp is converted to local time.
  - Year, month and day fields are updated according to new timestamp.
  - Events data is joined with topology data to get locations of cells where the events happened.
  - The data is ordered by user and timestamp.
  - The time gaps between records are calculated per user.
  - Geometry (point) columns are created for the current cell location and location of next cell.
  - The distance between these two geometries is calculated.
- Calculate number of unique cells per user.
- Calculate number of unique locations per user (based on cell locations or lat/lon of event if cell_id not available).
- Calculate distance between records per user (based on cell locations or lat/lon of event if cell_id not available).
- Calculate number of unique hours present in data per user.
- Calculate mean and standard deviation of time gaps per user.

- **Data flow diagram:**


Configuration file
local_timezone
data_period_start
data_period_end
Silver Event Data
(START HERE) Initialise data objects and check configuration
Silver Network Topology Data
For each date between data_period_start and data_period_end
Read event data for one date
Event data
Read network topology data for one date
Convert timestamp to local timezone
Processed event data
Update year, month and day fields
Processed event data
Join events with topology data to get location for each event
Processed event data
Calculate time gaps between records per user
Processed event data
Calculate distances between records
Processed event data
Calculate number of unique cells user
Calculate number of unique locations per user
Calculate sum of distance travelled per user
Calculate mean of time gaps per user
Calculate standard deviation of time gaps per user
Device Activity Statistics
Write Device Activity Statistics
Device Activity Statistics

- **Class diagram:**


SilverEventDataObject
+ ID: str = SilverEventDO
+ SCHEMA: StructType
+ interface: ParquetInterface
+ partition_columns: list<str>
+ write(path:str = None, partition_columns: list<str> = None)
SilverNetworkDataObject
+ ID: str = SilverNetworkDO
+ SCHEMA: StructType
+ interface: ParquetInterface
+ partition_columns: list<str>
+ write(path:str = None, partition_columns: list<str> = None)
Reads
Reads
DeviceActivityStatistics
+ COMPONENT_ID: str = DeviceActivityStatistics
+ clear_destination_directory: bool
+ data_period_start: str
+ data_period_end: str
+ initalize_data_objects()
+ read()
+ transform()
+ write()
+ execute()
+ preprocess_events(df_events: DataFrame, df_network): DataFrame
Writes
SilverDeviceActivityStatistics
+ ID: str = SilverDeviceActivityStatisticsDO
+ SCHEMA: StructType
+ interface: ParquetInterface
+ partition_columns: list<str>
+ write(path:str = None, partition_columns: list<str> = None)

- **Code Structure:**
  The code structure follows the format set by the core package, and the general repository structure.

  The location of the module script in the repository is as follows:

```
/multimno_internal/
└── multimno
    └── components
        └── execution
            └── device_activity_statistics
                └── device_activity_statistics.py
```

device_activity_statistics.py contains one class named DeviceActivityStatistics which is a subclass of Component.

The EventCleaning class overwrites __init__, transform and execute in the Component class.

> __init__ method initialises the data objects and reads the necessary values from config file. transform performs all necessary transformations and calculation of activity statistics for daily data. transform contains calls to many other smaller functions that perform the actual data manipulation. execute is responsible for calling read, write and transform for each unique date in the dataset. The processing is done date-by-date. Only the data from one date is being processed at any given time.

5.2.12 CONTINUOUSTIMESEGMENTATION

5.2.12.1 MODULE DESCRIPTION

- **Module Name:** ContinuousTimeSegmentation
- **Objectives:** responsible for aggregating event data for each user into continuous time segments based on certain spatio-temporal conditions.
- **Functionality:** takes as input a configuration file, semantically cleaned event data, cell intersection groups and previously calculated time segments (only when available from executions from previous dates; if not available, the process calculates this information). It then processes user events for each date in the chosen data period and aggregates them into continuous time segments using cell intersection groups to determine events which are happening in nearby cells with overlapping coverage areas and so can belong to the same time segment. Segments are assigned with different states:
    - stay - the location of the device is known and the device is staying in one location for a certain period of time. Period of time is configuration parameter.
    - move - the device is moving from one location to the next; the location of the device is somewhere in between the two locations.
    - undetermined - the location of the device is known, but it is unclear whether or not the device is moving.
    - unknown - the location of the device is unknown: there are no events for a certain (longer) period of time.

  Functionality is outlined in the software requirement specifications:
  3.2.12 ContinuousTimeSegmentation
- **Data Inputs and Outputs:**
    - Inputs:
        - I.16 MNO Event Data – Semantically Cleaned
        - I.14 Cell Intersection Groups
        - I.20 Daily Continuous Time Segments (optional)
    - Outputs:
        - I.20 Daily Continuous Time Segments

5.2.12.2 DEVELOPMENT DESIGN

- **Key Algorithms/Processes:**

1. Initialisation. Read all necessary config parameters, check the availability of input data.
2. If the clearing of output directories parameter is enabled, delete all existing output directories.
3. For each date in the configuration-specified data period:
    - A. Read input event data which is from the current date and has the error flag value as one of the configuration-specified accepted values.
    - B. Read input cell intersection groups data which is from the current date.
    - C. If the configuration parameter *is_first_run=False*, previous Daily CTS data is expected to exist. Read input Daily CTS data which is from the current date and has the flag *is_last=True*.
    - D. Add overlapping cell ids to event data by joining event data to cell intersection groups data on cell id.
    - E. If previous Daily CTS data does not exist, set event data CTS columns to null values.
    - F. If previous Daily CTS data does exist, outer join event data to previous Daily CTS data on user_id and set event data CTS columns to existing values.
    - G. Convert user_id column to String for Pandas processing.
    - H. For each user's data, perform segments aggregation using a Pandas UDF:
        - a. Retrieve user id, partition modulo, MCC and MNC values from data.
        - b. Determine date start and end timestamp boundaries.
        - c. If the user has no data for the current date, handle the entire date at once:
            - i. If the user has no previous time segments, create one time segment for the current date from the start to the end timestamp with state UNKNOWN.
            - ii. If the user has previous time segments, inspect the last time segment:
                - If the previous segment state is ABROAD and the time gap between the previous segment and the end of the current date is below a configuration-specified maximum time threshold, create one time segment for the current date from the start to the end timestamp with state UNKNOWN.
                - Otherwise, create one time segment for the current date from the start to the end timestamp with state UNKNOWN.
            - iii. Set the segment *is_last=True*.
        - d. If the user has data for the current date, iterate over the events:
            - i. Calculate adjusted time pad duration. The time pad duration is the minimum between the configuration-specified pad time value, and half of the time between start of the day and the first event's timestamp.
            - ii. Create initial time segment that covers the time until the first event:
                - If the user has no previous time segments, create one time segment from the start of the day to the first event's timestamp minus adjusted time pad duration with state UNKNOWN.

                - If the user has previous time segments, attempt to continue them. If the previous time segment is of state STAY, MOVE, or ABROAD and the duration between the end of the previous time segment and the first event is shorter than the appropriate configuration-specified maximum time, create one time segment from the start of the day to the first event's timestamp with the same state, cells and PLMN as the previous time segment.

- If the previous time segment could not be continued, create one time segment from the start of the day to the first event's timestamp minus adjusted time pad duration with state UNKNOWN.

iii. Iterate over events to generate new time segments from events, using the latest time segment:

- If the current event is abroad:
    1. If the latest time segment is not state ABROAD, then create one time segment from the end of the latest segment to the current event's timestamp with state ABROAD.
    2. If the latest time segment is state ABROAD and it shares the MCC value with the current event and the time gap between time segment end and event is below the configuration-specified max time threshold, then extend the existing time segment up to the current event's timestamp.
    3. If the latest time segment is state ABROAD and it does not share the MCC value with the current event and the time gap between time segment end and event is below the configuration-specified max time threshold, then create one time segment from the end of the latest segment to the current event's timestamp with state ABROAD.
    4. Otherwise the time gap is too large. Create one time segment from the end of the latest segment to the current event's timestamp with state UNKNOWN.
- If the event is local:
    1. Determine intersection. We consider the latest time segment and the current event to be intersected if each of the cells of the latest time segment are included in the current event's overlapping cell ids list.
    2. Determine time gap. The time gap is the duration between the end of the latest time segment and the current event's timestamp.
    3. If the latest time segment state is UNKNOWN or ABROAD, create one time segment from the end of the latest segment to the current event's timestamp with state UNDETERMINED.
    4. If the event and latest segment are intersected and the time gap is below the configuration-specified threshold and the latest time segment state is UNDETERMINED or STAY, then extend the existing time segment up to the current event and add its cell to the time segment's list of cells. Then if the duration of the time segment exceeds the configuration-specified minimum stay duration, set the time segment state to STAY.
    5. If the event and latest segment are intersected and the time gap is below the configuration-specified threshold and the latest time segment state is MOVE, then create one time

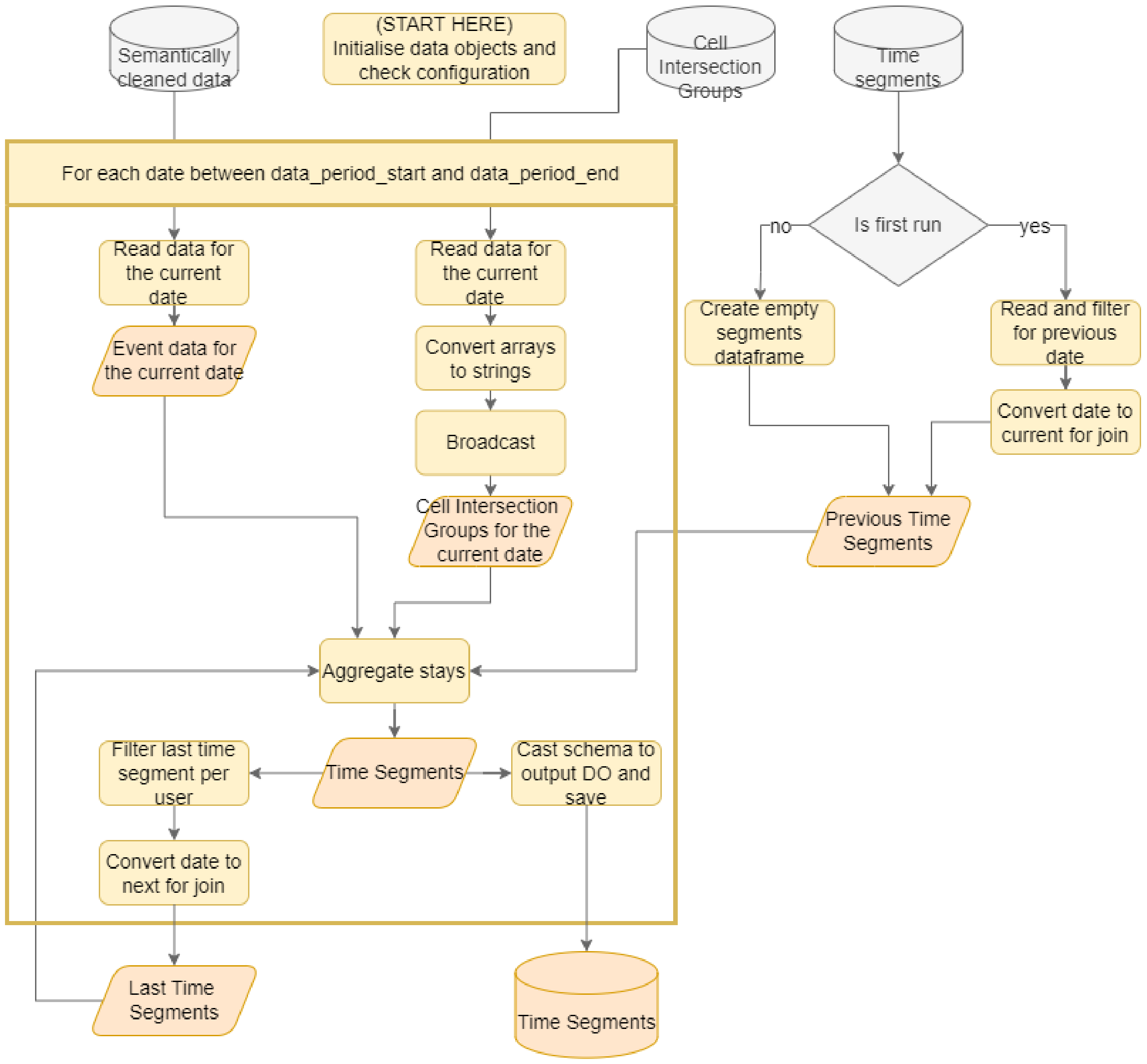
segment from the end of the latest segment to the current event's timestamp with state UNDETERMINED.

6. If the event and latest segment are not intersected and the time gap is below the configuration-specified threshold, then create two time segments with state MOVE: one from the end of the latest segment to the halfway point of the time gap and the other from the halfway point to the event's timestamp.
7. Otherwise, the time gap is too long. Extend the duration of the latest segment by the configuration-specified pad time. Create one new time segment with state UNKNOWN from that point to event timestamp minus pad time. Create one new time segment with state UNDETERMINED from event timestamp minus pad time to event timestamp.

iv. Mark the last time segment *is_last=True*.

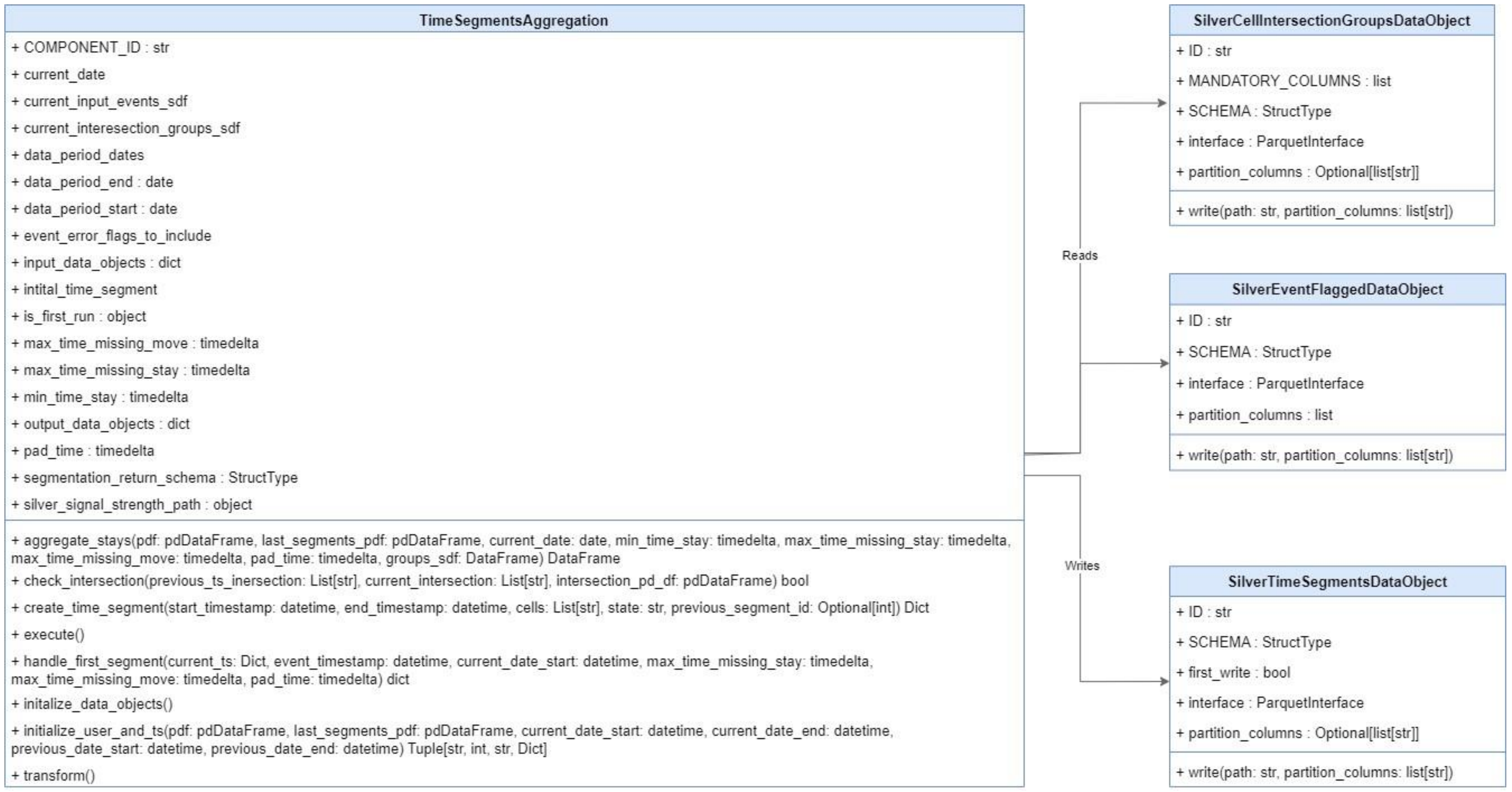
l. Convert data to expected schema and write the current date's Daily CTS output.

- **Data flow diagram:**



Semantically cleaned data
(START HERE) Initialise data objects and check configuration
Cell Intersection Groups
Time segments
For each date between data_period_start and data_period_end
Is first run
no
yes
Read data for the current date
Read data for the current date
Create empty segments dataframe
Read and filter for previous date
Event data for the current date
Convert arrays to strings
Convert date to current for join
Broadcast
Cell Intersection Groups for the current date
Previous Time Segments
Aggregate stays
Filter last time segment per user
Time Segments
Cast schema to output DO and save
Convert date to next for join
Last Time Segments
Time Segments

- **Class diagram:**


TimeSegmentsAggregation
+ COMPONENT_ID : str
+ current_date
+ current_input_events_sdf
+ current_interesection_groups_sdf
+ data_period_dates
+ data_period_end : date
+ data_period_start : date
+ event_error_flags_to_include
+ input_data_objects : dict
+ intital_time_segment
+ is_first_run : object
+ max_time_missing_move : timedelta
+ max_time_missing_stay : timedelta
+ min_time_stay : timedelta
+ output_data_objects : dict
+ pad_time : timedelta
+ segmentation_return_schema : StructType
+ silver_signal_strength_path : object
+ aggregate_stays(pdf: pdDataFrame, last_segments_pdf: pdDataFrame, current_date: date, min_time_stay: timedelta, max_time_missing_stay: timedelta, max_time_missing_move: timedelta, pad_time: timedelta, groups_sdf: DataFrame) DataFrame
+ check_intersection(previous_ts_inersection: List[str], current_intersection: List[str], intersection_pd_df: pdDataFrame) bool
+ create_time_segment(start_timestamp: datetime, end_timestamp: datetime, cells: List[str], state: str, previous_segment_id: Optional[int]) Dict
+ execute()
+ handle_first_segment(current_ts: Dict, event_timestamp: datetime, current_date_start: datetime, max_time_missing_stay: timedelta, max_time_missing_move: timedelta, pad_time: timedelta) dict
+ initalize_data_objects()
+ initialize_user_and_ts(pdf: pdDataFrame, last_segments_pdf: pdDataFrame, current_date_start: datetime, current_date_end: datetime, previous_date_start: datetime, previous_date_end: datetime) Tuple[str, int, str, Dict]
+ transform()
Reads
Writes
SilverCellIntersectionGroupsDataObject
+ ID : str
+ MANDATORY_COLUMNS : list
+ SCHEMA : StructType
+ interface : ParquetInterface
+ partition_columns : Optional[list[str]]
+ write(path: str, partition_columns: list[str])
SilverEventFlaggedDataObject
+ ID : str
+ SCHEMA : StructType
+ interface : ParquetInterface
+ partition_columns : list
+ write(path: str, partition_columns: list[str])
SilverTimeSegmentsDataObject
+ ID : str
+ SCHEMA : StructType
+ first_write : bool
+ interface : ParquetInterface
+ partition_columns : Optional[list[str]]
+ write(path: str, partition_columns: list[str])

- **Code Structure:**

The code structure follows the format set by the core package, and the general repository structure.

The location of the module script in the repository is as follows:

```
multimno
    └── components
        └── execution
            └── time_segments
                └── time_segments_aggregation.py
```

- time_segments_aggregation.py contains one class named CellFootprintEstimationwhich is a subclass of Component.
- The CellFootprintEstimationwhich class overrides transform and execute method of base Component class.
- execute method facilitates iteration over list of processing dates to manage all processing on daily batches.
- transform method performs all necessary filtering and transformations of MNO event data to aggregate it to Time Segments by sequentially calling other methods that perform the actual data manipulation. The main method for Time Segments aggregation is aggregate_stays which is a Pandas UDF called on grouped Spark DataFrame.

5.2.13 DAILYPERMANENCESCORE

5.2.13.1 MODULE DESCRIPTION

- **Module Name:** DailyPermanenceScore
- **Objectives:** Given a definition of time intervals of the day, use events data to estimate each user's permanence time at each grid tile during each of the intervals.
- **Functionality:** needed functionalities are outlined in the software requirement specifications: 3.2.11 DailyPermanenceScore
- **Data Inputs and Outputs:**
  - Input:
    - I.13 Cell Footprints
    - I.16 MNO Event Data – Semantically Cleaned
  - Output:
    - I.21 Daily Permanence Score

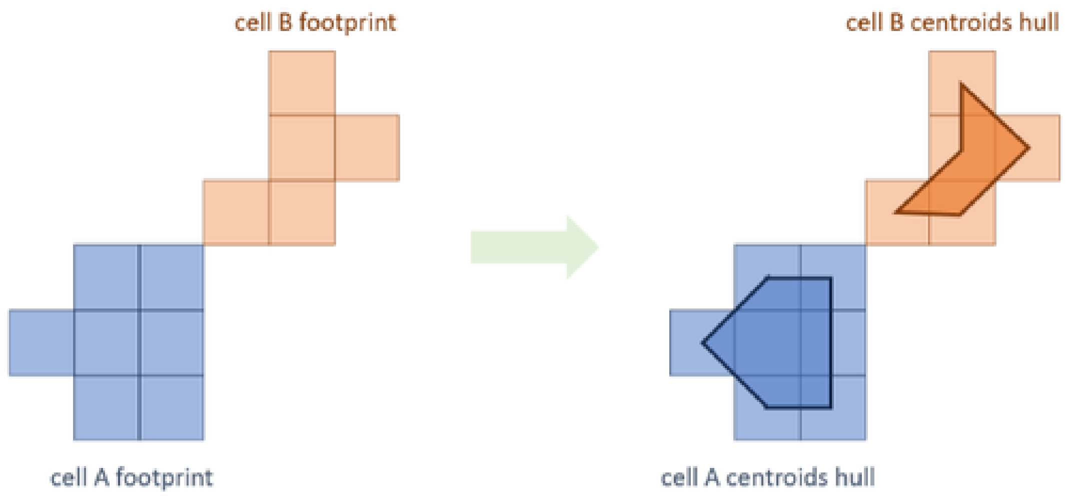
5.2.13.2 DEVELOPMENT DESIGN

- **Key Algorithms/Processes:** The raw data is processed for the set of dates within a date interval specified via configuration file. It is assumed that the raw input data is partitioned by year, month, day columns. The key processes are described below:

0) Check available data, load input data objects and prepare them for further execution

- Check existence of input files for the dates within the date interval specified via configuration file, plus the previous (D-1) and posterior date (D+1) to each of these (D).

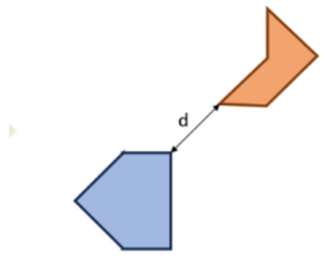
- Exit process if one or more input files are not found at their corresponding path.
- Iterate over dates within the date interval specified via configuration file. Each calculation after this will be performed once for each of the dates.
- Load semantically Cleaned Event Data Objects for the current date (D), last event for the immediately previous date (D-1) and first event for the date after (D+1).
- Remove unneeded columns from Semantically Cleaned Event Data Objects.
- Filter out events with semantic flag warnings from Semantically Cleaned Event Data Objects.
- Combine current events with last and first events.
- Load Cell Footprint Data Objects for current date (D), and for relevant cells for D-1 and D+1 dates.
- Create Cell Footprints polygons by calculating Convex Hull geometry of all the tiles centroids in a cell footprint. Aggregate a footprint's grid tile ids into array.



- Add is_abroad = True flag to events by comparing first 3 digits of 'plmn' column with local_mcc config parameter.
- For abroad events, set cell_id to foreign mcc value.
- Join events with cell footprints polygons geometry using left join.
- For each event, create columns with previous and next events' timestamps and cell_id values.

1) Differentiate events associated to 'permanence' and events associated to 'moves'

- Add new 'is_move' boolean column to user events table. Initialise with False values.
- Generate 3-row window containing first 3 rows of the user events table.
- Calculate distance between cells in the 3-row window. If previous or next cell_id is null, set distance to 0 so that outbound events are always associated with permanence.



- Calculate time difference (Δt) between 1st and last (3rd) event in the 3-row window.
- Calculate the maximum value of the distance from the 1st event's cell and the 2nd event's cell and the summation of distances from 1st to 2nd and from 2nd to 3rd: **d_max** = **max(d(1,3), d(1,2) + d(2,3))**
- Calculate the speed (s) resulting from dividing d_max by Δt.
- If the speed (s) is higher than 'max_vel_thresh', assign 'True' value to the intermediate 3-row window event for the 'is_move' column.
- Move the 3-row window to the next position and repeat until the end of the user events table is reached.

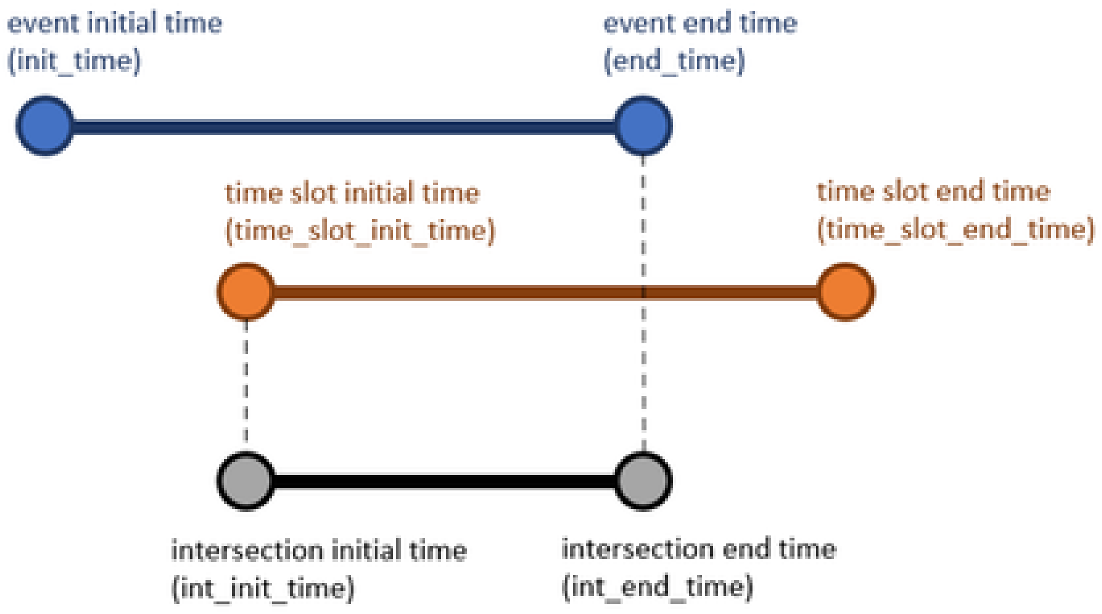
2) Assign initial and end times to each 'permanence' event

- Filter out moves: keep only those rows for which 'is_move' = False in the user events table.
- Calculate time difference (Δt) between the event in the centre of the 3-row window and the previous event (with 'timestamp' column).
- If the previous event and the current event happen in a different cell ('cell_id' column has different values the respective rows), then check if the time difference (Δt) is higher than "max_time_thresh":
  - If Δt ≤ "max_time_thresh": 'init_time' value for the middle event is equal to the average between the 'timestamp' value of the previous row and the 'timestamp' value of the current row.
  - If Δt > 'max_time_thresh': 'init_time' value for the middle event is equal to the 'timestamp' value of the current row minus 'max_time_thresh' / 2.
- If the previous event and the current event happen in the same cell ('cell_id' column has the same value for both rows), then check if the time interval between the 'timestamp' of the previous event and the 'timestamp' of the current event intesects with the night interval. If the interval intersects with the night interval: "time_threshold" = "max_time_thresh_night". Else, "time_threshold" = "max_time_thresh_day":
  - If Δt ≤ "time_threshold": 'init_time' value for the middle event is equal to the average between the 'timestamp' value of the previous row and the 'timestamp' value of the current row.
  - If Δt > "time_threshold": 'init_time' value for the middle event is equal to the 'timestamp' value of the current row minus 'time_threshold' / 2.
- If the current event is **abroad** event and the previous event timestamp is NULL, 'init_time' of the current event is equal to current event timestamp - 'max_time_abroad_thresh' parameter.
- Calculate time difference (Δt) between the event in the centre of the 3-row window and the next event (with 'timestamp' column), and follow the analogous process to the one described just above for the previous event (in this case, filling in the 'end_time' values).
- Move the 3-row window to the next position and repeat until the end of the user events table is reached.

3) Intersect 'permanence' times with specified intervals

- Define a list of equal intervals in which the day is split based on the "time_slot_number" field from the configuration file. This number can only take values 24, 48, or 96, which result in equal intervals of 60, 30, and 15 minutes respectively. Create a table with these time slots.
- Cross join distinct users table with time slots to have all time slots per user for the current date.
- For each row of the crossed table, calculate the maximum value of "init_time" and "time_slot_init_time" columns and the minimum value of "end_time" and "time_slot_end_time" columns. If the maximum init time is lower than the minimum end time, there is intersection.
- Calculate subtraction to obtain duration of the permanence.
- For each user and time slot, calculate the total time the user has performed a permanence.

* Discard time intervals with permanence in a single cell where duration of a permanence is less than half of the time interval and hence resulted permanence score will be 0.

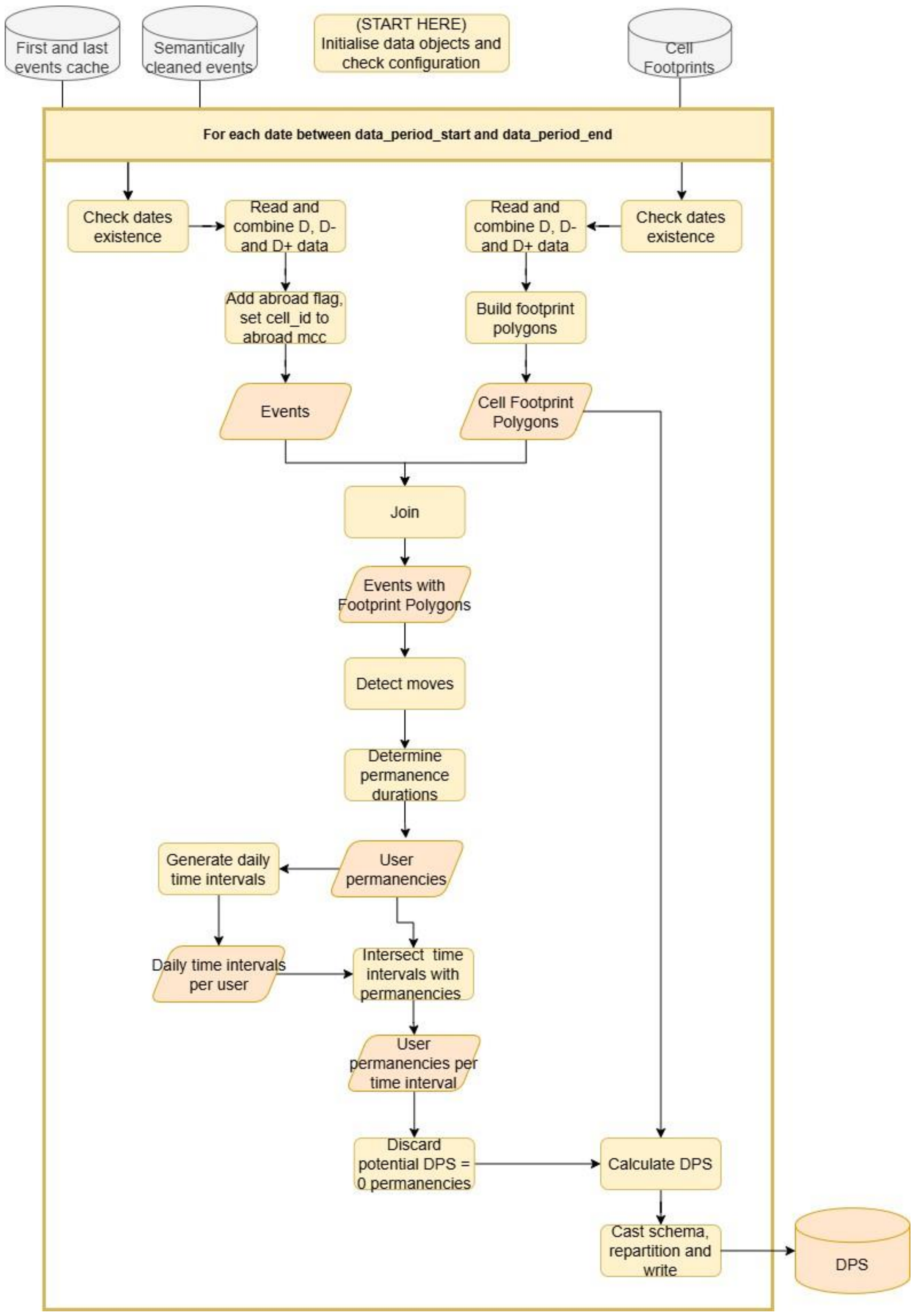


4) Calculate 'permanence' times at each cell in each specified interval for each user

* For intervals with permanence in multiple cells:
    * Join grid tiles arrays from prepared cell footprints table and explode it, repeating each row as many times as tiles in the 'grid_ids' array.
    * Group table by 'grid_id' and sum the 'duration' column values.
    * Remove durations which will be resulted in permanence score = 0.
    * Group table by 'time_slot_initial_time' and 'time_slot_end_time' and aggregate remained grid tiles ids into array.
    * Rename array column to 'dps'.
* For intervals with permanence in single cell:
    * Join grid tiles arrays from prepared cell footprints table. All grids in a footprint of this single cell will get permanence score = 1.
    * Rename array column to 'dps'.
* For intervals without cell id information set 'dps' column to unknown.
* For abroad intervals set 'dps' column to mcc of a foreign country.
* Concatenate 4 different cases intervals into single table.

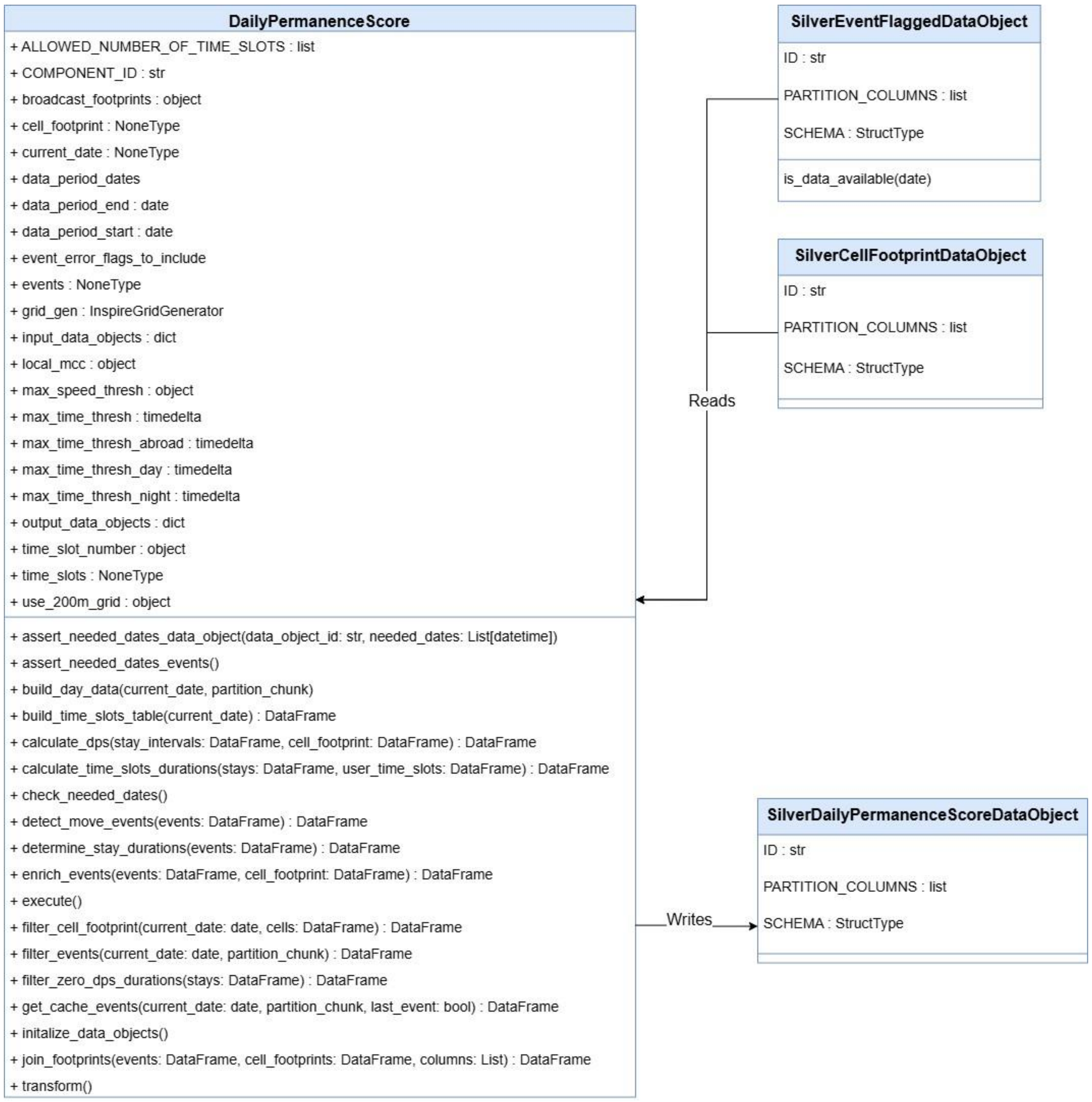
5) Convert to output data object schema, repartition and write to storage

- **Data flow diagram:**



First and last events cache
Semantically cleaned events
(START HERE) Initialise data objects and check configuration
Cell Footprints
For each date between data_period_start and data_period_end
Check dates existence
Read and combine D, D- and D+ data
Read and combine D, D- and D+ data
Check dates existence
Add abroad flag, set cell_id to abroad mcc
Build footprint polygons
Events
Cell Footprint Polygons
Join
Events with Footprint Polygons
Detect moves
Determine permanence durations
Generate daily time intervals
User permanencies
Daily time intervals per user
Intersect time intervals with permanencies
User permanencies per time interval
Discard potential DPS = 0 permanencies
Calculate DPS
Cast schema, repartition and write
DPS

- **Class diagram:**


DailyPermanenceScore
+ ALLOWED_NUMBER_OF_TIME_SLOTS : list
+ COMPONENT_ID : str
+ broadcast_footprints : object
+ cell_footprint : NoneType
+ current_date : NoneType
+ data_period_dates
+ data_period_end : date
+ data_period_start : date
+ event_error_flags_to_include
+ events : NoneType
+ grid_gen : InspireGridGenerator
+ input_data_objects : dict
+ local_mcc : object
+ max_speed_thresh : object
+ max_time_thresh : timedelta
+ max_time_thresh_abroad : timedelta
+ max_time_thresh_day : timedelta
+ max_time_thresh_night : timedelta
+ output_data_objects : dict
+ time_slot_number : object
+ time_slots : NoneType
+ use_200m_grid : object
+ assert_needed_dates_data_object(data_object_id: str, needed_dates: List[datetime])
+ assert_needed_dates_events()
+ build_day_data(current_date, partition_chunk)
+ build_time_slots_table(current_date) : DataFrame
+ calculate_dps(stay_intervals: DataFrame, cell_footprint: DataFrame) : DataFrame
+ calculate_time_slots_durations(stays: DataFrame, user_time_slots: DataFrame) : DataFrame
+ check_needed_dates()
+ detect_move_events(events: DataFrame) : DataFrame
+ determine_stay_durations(events: DataFrame) : DataFrame
+ enrich_events(events: DataFrame, cell_footprint: DataFrame) : DataFrame
+ execute()
+ filter_cell_footprint(current_date: date, cells: DataFrame) : DataFrame
+ filter_events(current_date: date, partition_chunk) : DataFrame
+ filter_zero_dps_durations(stays: DataFrame) : DataFrame
+ get_cache_events(current_date: date, partition_chunk, last_event: bool) : DataFrame
+ initalize_data_objects()
+ join_footprints(events: DataFrame, cell_footprints: DataFrame, columns: List) : DataFrame
+ transform()
SilverEventFlaggedDataObject
ID : str
PARTITION_COLUMNS : list
SCHEMA : StructType
is_data_available(date)
SilverCellFootprintDataObject
ID : str
PARTITION_COLUMNS : list
SCHEMA : StructType
Reads
Writes
SilverDailyPermanenceScoreDataObject
ID : str
PARTITION_COLUMNS : list
SCHEMA : StructType

- **Code Structure:** The code structure follows the format set by the core package, and the general repository structure. The location of the module script in the repository is as follows:

```
/multimno_internal/
└── src
    └── components
        └── execution
            └── daily_permanence_score
                └── daily_permanence_score.py
```

- daily_permanence_score.py contains one class named DailyPermanenceScore which is a subclass of Component. The DailyPermanenceScore class overrides some of the methods of Component:
- The __init__ method first call its parent's __init__ method, which sets up the Spark session, initialises data objects and reads the configuration file.
- transform method performs all necessary filtering and transformations pertaining to the daily permanence score calculation.

5.2.14 INSPIREReferenceGridGeneration

5.2.14.1 MODULE DESCRIPTION

- **Module Name:** InspireGridGeneration
- **Objectives:** Create Reference Grid in INSPIRE format.
- **Functionality:** Generates 100 by 100 meters rectangular grid following INSPIRE specification for the given extent or given country polygon. For a country polygon, a buffer distance can be defined to extend grid beyond the country polygon borders.
  Functionality specification:
  - 3.2.13 INSPIRE Grid Generation
- **Data Inputs and Outputs:**
  - Inputs:
    - I.29 Countries
  - Outputs:
    - I.11 Reference Grid

5.2.14.2 DEVELOPMENT DESIGN

- **Key Algorithms/Processes:**

Initialisation:

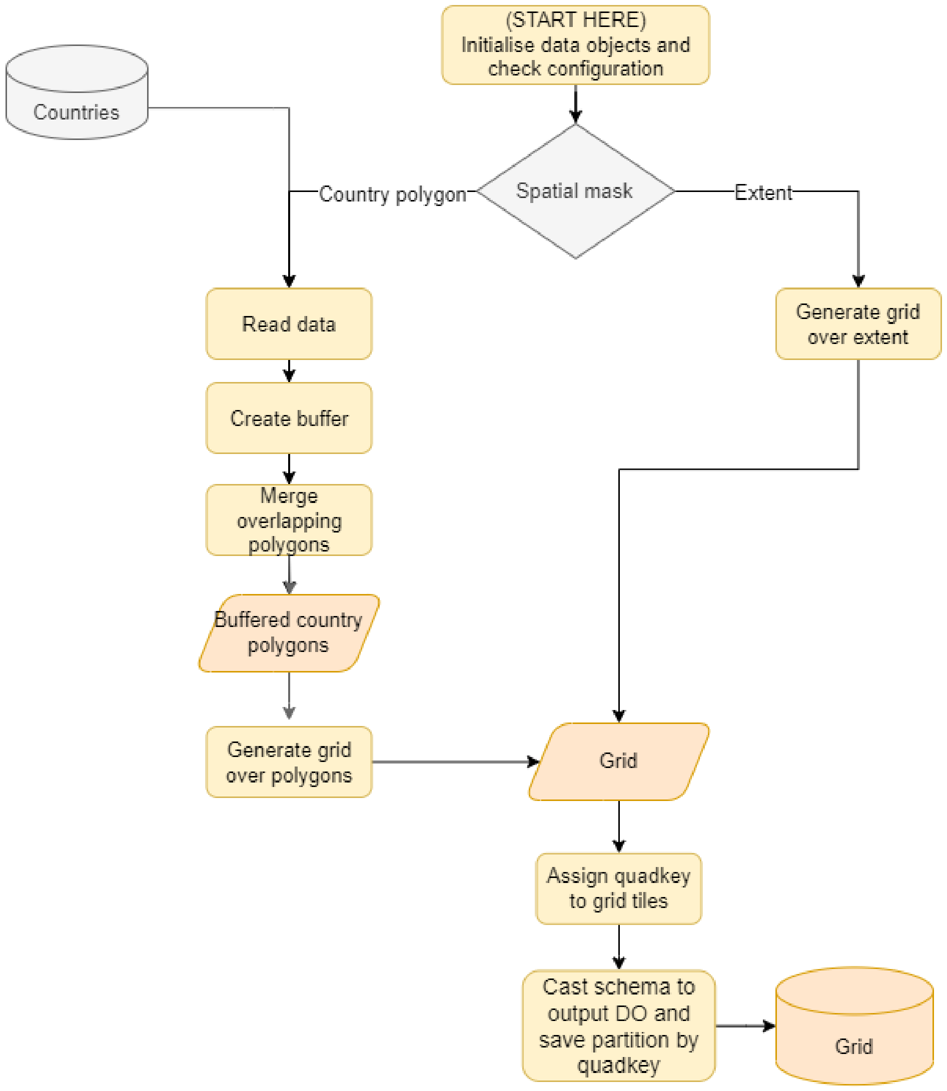
1. Read configurations parameters: type of grid mask, extent, reference country, buffer around country borders, quadkey level for spatial partitioning.
2. Clear the destination directory if configured.
3. Load input data objects for grid, transportation, and land use data.
4. Initialize the output data object for the enriched grid.

Processing:

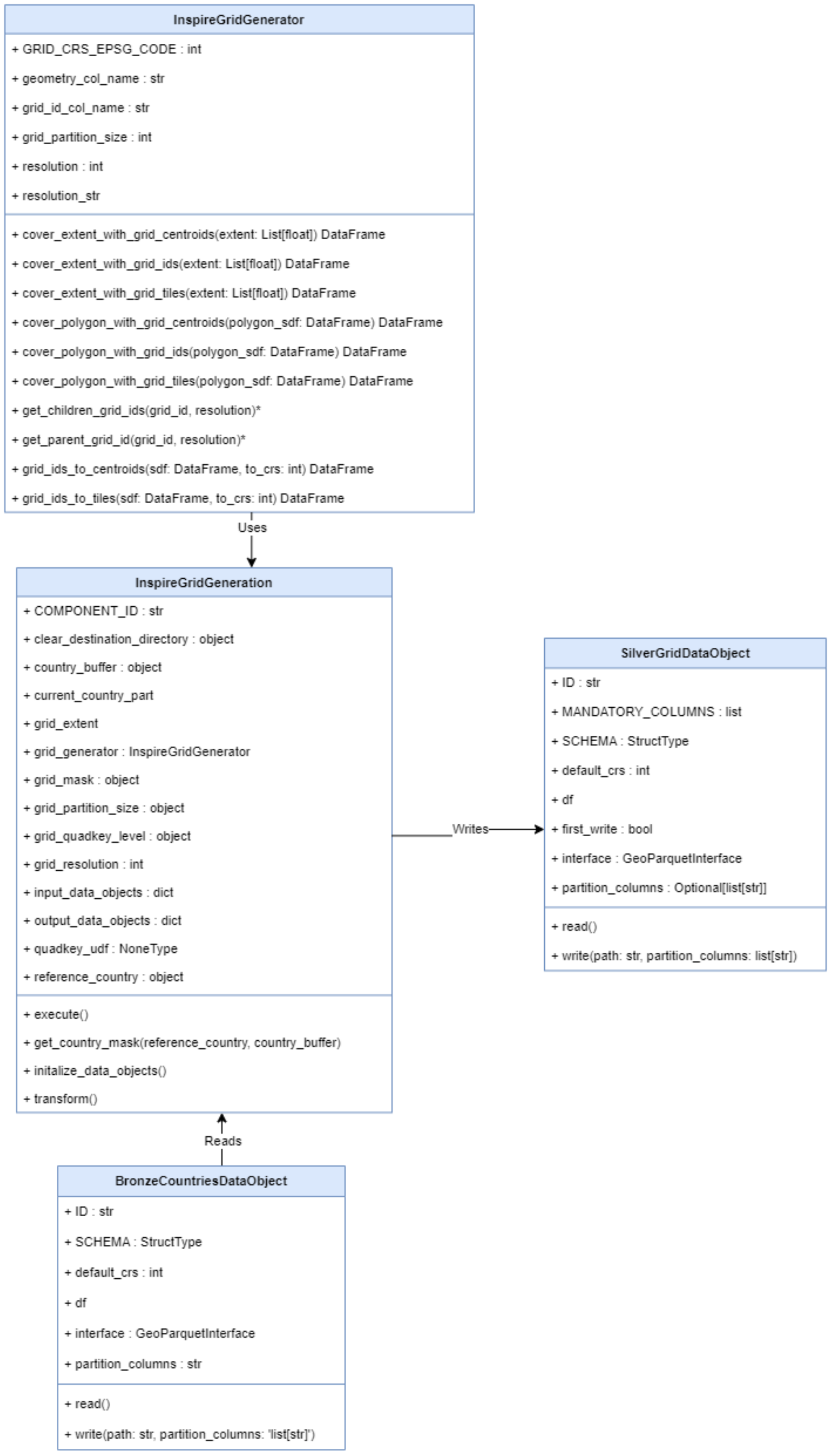
1. Generate INSPIRE grid centroids.
   1. If grid mask parameter is 'extent', generate grid for given extent.
   2. If grid mask parameter 'polygon':
      1. Filter reference country polygon from countries dataset using given iso2 code.
      2. Create a buffer of a given distance around country polygons.

    3. Country may consist of multiple polygons, so it is necessary to merge overlapping resulted polygons together.
    4. Generate grid for each polygon.
2. Assign quadkey of a given level for each grid tile based on tile's centroid latitude and longitude.
3. Convert dataset schema to match the output data object schema and save to storage partitioned by quadkey.

- **Data flow diagram:**


(START HERE) Initialise data objects and check configuration
Countries
Country polygon
Spatial mask
Extent
Read data
Generate grid over extent
Create buffer
Merge overlapping polygons
Buffered country polygons
Generate grid over polygons
Grid
Assign quadkey to grid tiles
Cast schema to output DO and save partition by quadkey
Grid

- **Class diagram:**


InspireGridGenerator
+ GRID_CRS_EPSG_CODE : int
+ geometry_col_name : str
+ grid_id_col_name : str
+ grid_partition_size : int
+ resolution : int
+ resolution_str
+ cover_extent_with_grid_centroids(extent: List[float]) DataFrame
+ cover_extent_with_grid_ids(extent: List[float]) DataFrame
+ cover_extent_with_grid_tiles(extent: List[float]) DataFrame
+ cover_polygon_with_grid_centroids(polygon_sdf: DataFrame) DataFrame
+ cover_polygon_with_grid_ids(polygon_sdf: DataFrame) DataFrame
+ cover_polygon_with_grid_tiles(polygon_sdf: DataFrame) DataFrame
+ get_children_grid_ids(grid_id, resolution)*
+ get_parent_grid_id(grid_id, resolution)*
+ grid_ids_to_centroids(sdf: DataFrame, to_crs: int) DataFrame
+ grid_ids_to_tiles(sdf: DataFrame, to_crs: int) DataFrame
Uses
InspireGridGeneration
+ COMPONENT_ID : str
+ clear_destination_directory : object
+ country_buffer : object
+ current_country_part
+ grid_extent
+ grid_generator : InspireGridGenerator
+ grid_mask : object
+ grid_partition_size : object
+ grid_quadkey_level : object
+ grid_resolution : int
+ input_data_objects : dict
+ output_data_objects : dict
+ quadkey_udf : NoneType
+ reference_country : object
+ execute()
+ get_country_mask(reference_country, country_buffer)
+ initalize_data_objects()
+ transform()
Writes
SilverGridDataObject
+ ID : str
+ MANDATORY_COLUMNS : list
+ SCHEMA : StructType
+ default_crs : int
+ df
+ first_write : bool
+ interface : GeoParquetInterface
+ partition_columns : Optional[list[str]]
+ read()
+ write(path: str, partition_columns: list[str])
Reads
BronzeCountriesDataObject
+ ID : str
+ SCHEMA : StructType
+ default_crs : int
+ df
+ interface : GeoParquetInterface
+ partition_columns : str
+ read()
+ write(path: str, partition_columns: 'list[str]')

- **Code Structure:**

The code structure follows the format set by the core package, and the general repository structure.
The location of the module script in the repository is as follows:

```
multimno
    └── components
        └── ingestion
            └── grid_generation
                └── inspire_grid_generation.py
```

inspire_grid_generation.py contains one class named InspireGridGeneration which is a subclass of Component.
The InspireGridGeneration class is rely on InspireGridGenerator utility class to perform actual grid generation.
The InspireGridGeneration class overrides transform method of base Component class.
transform method instantiates InspireGridGenerator class and uses its method to generate INPSIRE grid centroids for the given spatial extent or country polygon.

5.2.15 SYNTHETICDIARIES

5.2.15.1 MODULE DESCRIPTION

- **Module Name:** SyntheticDiaries
- **Objectives:** the objective of this module is to generate a given number of synthetic user activity-trip diaries.
- **Functionality:** the module includes the following functionalities:
    - Synthetically generating users with random but compatible home and work locations.
    - Synthetically generating compatible sequences of stays for each user (e.g. home-work-other-home).
    - Synthetically assigning a location (exact coordinates) to each of the activities of the user.
    - Synthetically assigning a start time and an end time to each of the activities of the user.
- **Data Inputs and Outputs:**
    - Input:
        - No input datasets are used by this method
    - Output:
        - I.30 Synthetic Diaries

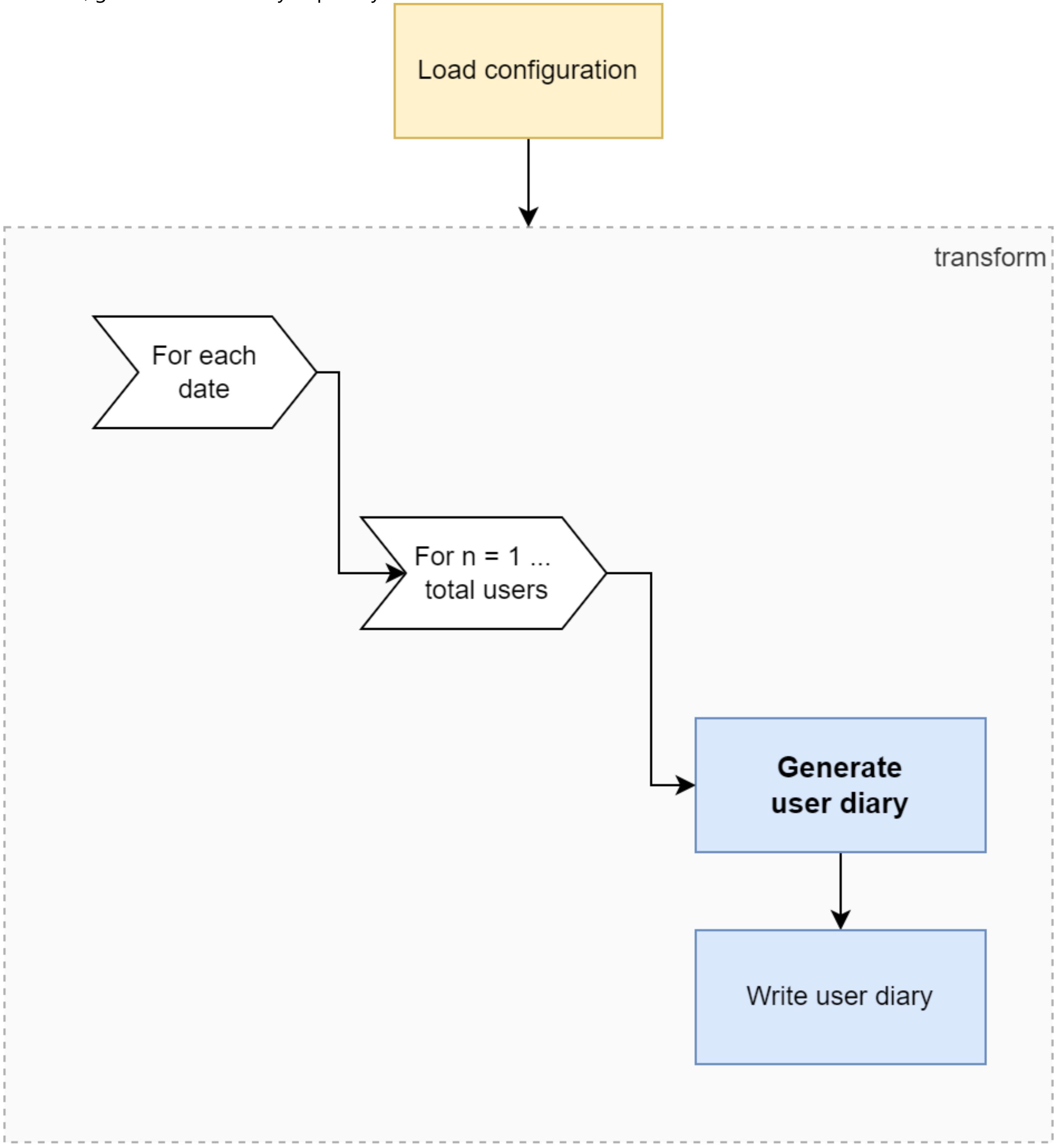
5.2.15.2 DEVELOPMENT DESIGN

- **Key Algorithms/Processes:**
    - Read from the configuration file the number of users for which to generate diaries.
    - Read from the configuration file the date format for the output diaries.
    - Read from the configuration file the initial date for the diary generation.
    - Read from the configuration file the number of dates for the diary generation.
    - Read from the configuration file the maximum longitude and latitude for activity generation (bounding box top right corner limit).
    - Read from the configuration file the minimum longitude and latitude for activity generation (bounding box bottom left corner limit).

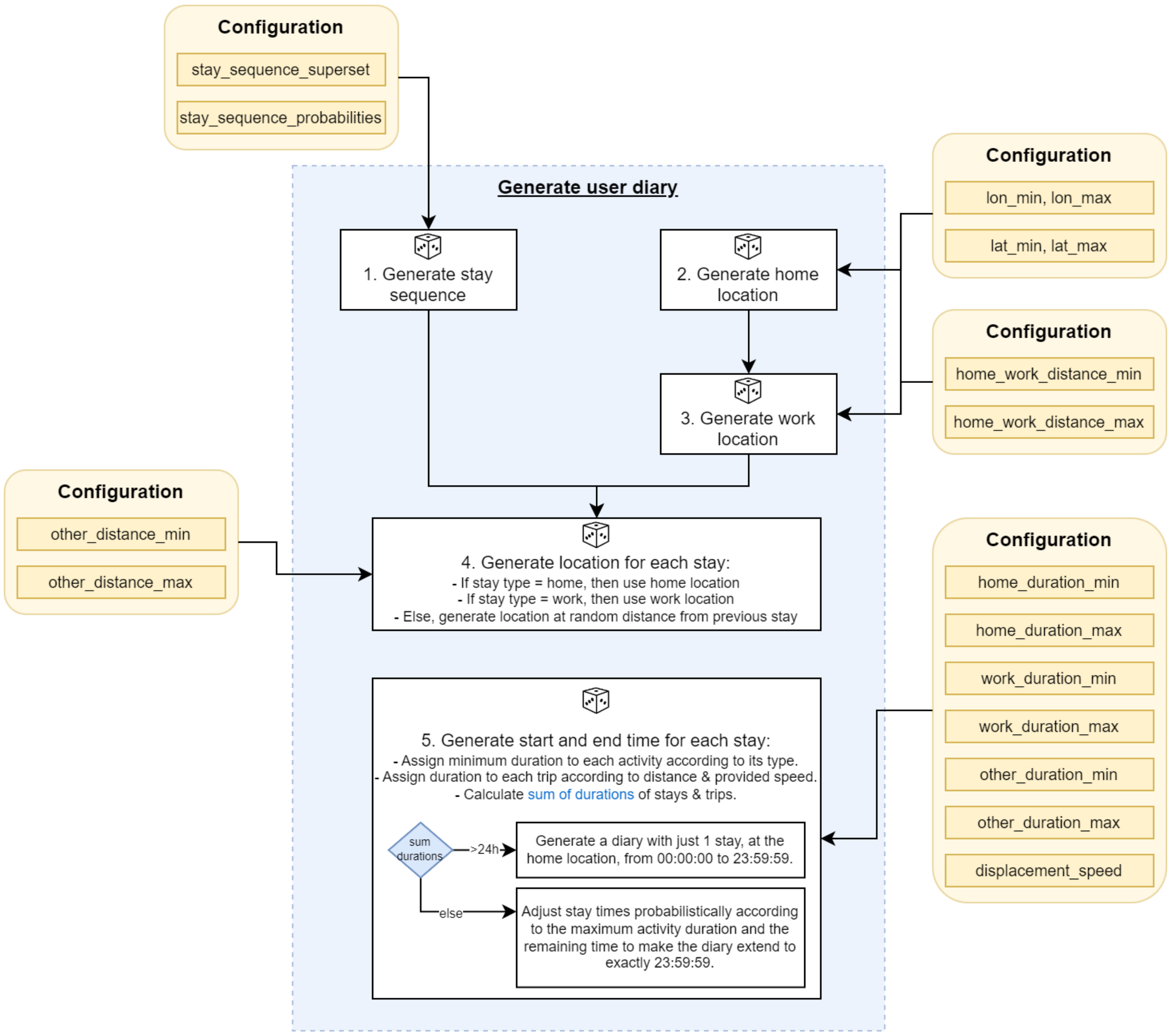
- Read from the configuration file the minimum and maximum distance between home and work for synthetic generation.
- Read from the configuration file the minimum and maximum distance for the assignment of the location of other activities with respect to the location of the previous activity.
- Read from the configuration file the minimum and maximum home activity duration.
- Read from the configuration file the minimum and maximum work activity duration.
- Read from the configuration file the minimum and maximum other activity duration.
- Read from the configuration file the displacement speed which will be considered for assignment of the start activity time of the next activity.
- Read from the configuration file the stay sequence superset in which all synthetically generated diaries will be based.
- Read from the configuration file the sequence of probabilities of the stays in the stay sequence superset of being generated in each synthetically generated diary.
- For each date, starting in the initial date and ending in initial date + number of dates:
    - Create one agent, from 0 to the provided number of users, and for each agent:
        1. Generate a stay sequence for an agent probabilistically based on the provided stay sequence and weights (e.g. home-work-other-other-home).
        2. Generate home location coordinates for the agent based on the bounding limits.
        3. Generate work location coordinates for the agent based on the bounding limits and minimum and maximum distance to home.
        4. Generate activity locations for each of the activities in the generated stay sequence for this agent:
            1. For 'home' activities, assign home location of the agent.
            2. For 'work' activities, assign work location of the agent.
            3. For 'other', reach previous activity, and assign a random location that is at a distance to the previous activity location that is between the provided thresholds.
        5. Generate activity times according to generated stay sequence for this agent:
            1. Firstly, assign to each of these activities the minimum duration considered for that activity type. Trip times are based on Pythagorean distance and a specified average speed.
                1. If the sum of all minimum duration of the activities and the duration of the trips is higher than the 24h of the day, then assign just one "home" activity to the agent from 00:00:00 to 23:59:59.
                2. Else, there will be a remaining time. E.g., the diary of an agent, after adding up all trip durations and minimum activity durations may end at 20:34:57. There is a remaining time to complete the full diary (23:59:59 - 20:34:57). Adjust activity times probabilistically according to the maximum activity duration and this remaining time, making the diary end at exactly 23:59:59.
        6. Write diaries to output file.

- **Data flow diagram:**
  Initialising the SyntheticDiaries component launches a process that loads all necessary parameters from the configuration path.

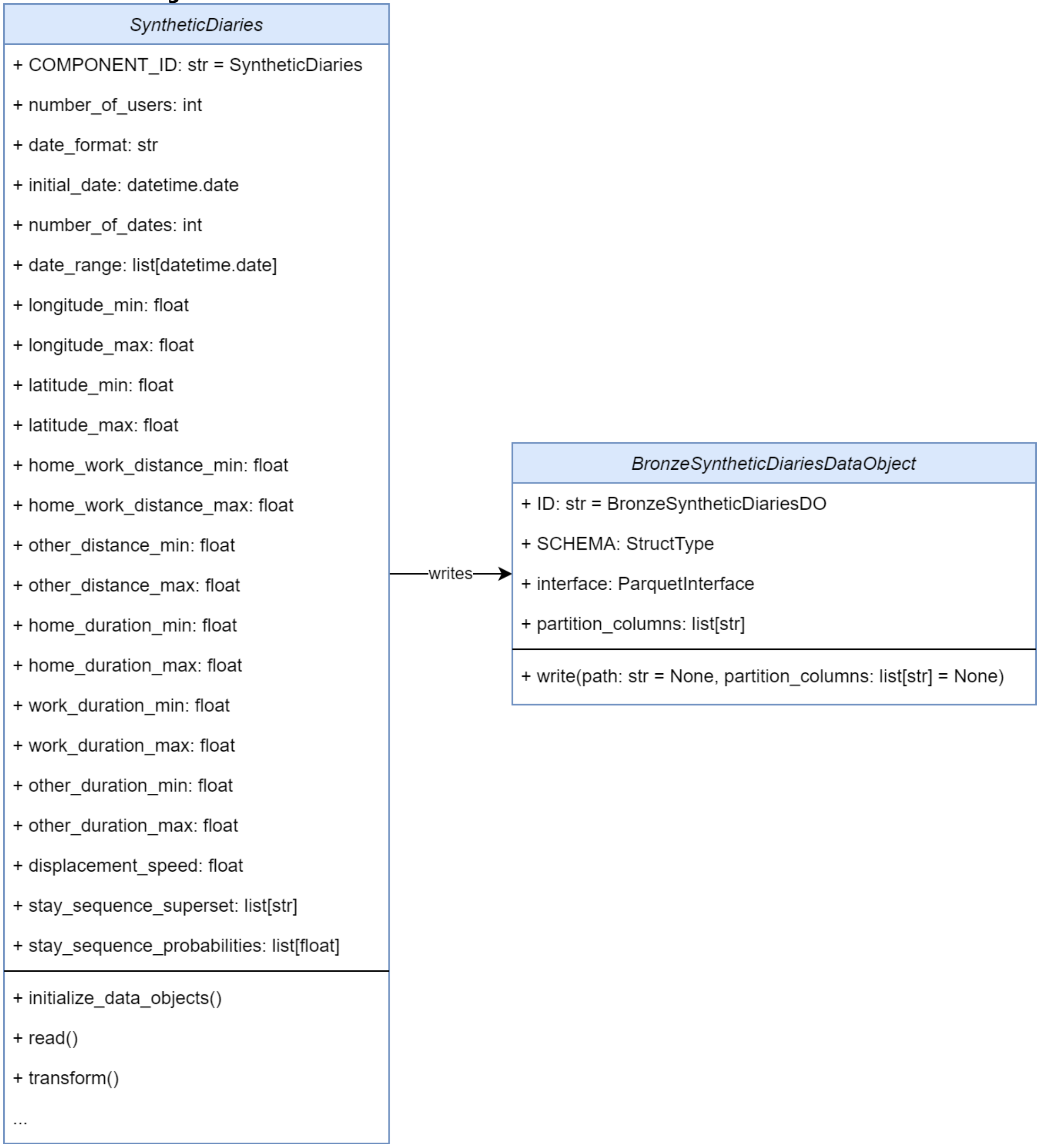
Then, the transform method is applied, triggering the processing of the rest of the method, which, for each date and user, generates an activity-trip diary:



The generation of each user's diary is described in the graph below:


Configuration
stay_sequence_superset
stay_sequence_probabilities
Generate user diary
1. Generate stay sequence
2. Generate home location
3. Generate work location
Configuration
lon_min, lon_max
lat_min, lat_max
Configuration
home_work_distance_min
home_work_distance_max
Configuration
other_distance_min
other_distance_max
4. Generate location for each stay:
- If stay type = home, then use home location
- If stay type = work, then use work location
- Else, generate location at random distance from previous stay
5. Generate start and end time for each stay:
- Assign minimum duration to each activity according to its type.
- Assign duration to each trip according to distance & provided speed.
- Calculate sum of durations of stays & trips.
sum durations
>24h
else
Generate a diary with just 1 stay, at the home location, from 00:00:00 to 23:59:59.
Adjust stay times probabilistically according to the maximum activity duration and the remaining time to make the diary extend to exactly 23:59:59.
Configuration
home_duration_min
home_duration_max
work_duration_min
work_duration_max
other_duration_min
other_duration_max
displacement_speed

- **Class diagram:**


SyntheticDiaries
+ COMPONENT_ID: str = SyntheticDiaries
+ number_of_users: int
+ date_format: str
+ initial_date: datetime.date
+ number_of_dates: int
+ date_range: list[datetime.date]
+ longitude_min: float
+ longitude_max: float
+ latitude_min: float
+ latitude_max: float
+ home_work_distance_min: float
+ home_work_distance_max: float
+ other_distance_min: float
+ other_distance_max: float
+ home_duration_min: float
+ home_duration_max: float
+ work_duration_min: float
+ work_duration_max: float
+ other_duration_min: float
+ other_duration_max: float
+ displacement_speed: float
+ stay_sequence_superset: list[str]
+ stay_sequence_probabilities: list[float]
+ initialize_data_objects()
+ read()
+ transform()
...
writes
BronzeSyntheticDiariesDataObject
+ ID: str = BronzeSyntheticDiariesDO
+ SCHEMA: StructType
+ interface: ParquetInterface
+ partition_columns: list[str]
+ write(path: str = None, partition_columns: list[str] = None)

- **Code Structure:** The code structure follows the format set by the core package, and the general repository structure. The location of the module script in the repository is as follows:

  -
    ```
    /multimno/
    └── src
        └── components
            └── ingestion
                └── synthetic
                    └── synthetic_diaries.py
    ```
  - synthetic_diaries.py contains one class named SyntheticDiaries which is a subclass of Component. It overrides the following methods:
    - The __init__ method first call its parent's __init__ method, which sets up the Spark session, initialises data objects and reads the configuration file.
    - The transform method handles all the logic behind the component.
  - The SyntheticDiaries component also has the following methods:
    - initalize_data_objects loads the output data object schema.
    - haversine calculates haversine distance between 2 points in lat-lon.
    - random_seed_number_generator generates random seed based on several arguments.
    - calculate_trip_time calculates trip time given an origin location and a destination location, according to the specified trip speed.
    - calculate_trip_final_time calculates end time of a trip given an origin time, an origin location, a destination location and a speed.
    - generate_stay_location generates a random activity location within the bounding box limits based on the activity type and previous activity locations.
    - create_agent_activities_min_duration generates activities of the minimum duration following the specified agent activity sequence for this agent and date.
    - adjust_activity_times modifies the "date_activities" list, changing the initial and final timestamps of both stays and moves probablilistically in order to generate stay durations different from the minimum and adjust the durations of the activities to the 24h of the day.
    - add_agent_date_activities for a specific date and user, generate a sequence of activities probabilistically according to the specified activity superset and the activity probabilities. Firstly, assign to each of these activities the minimum duration considered for that activity type. Trip times are based on Pythagorean distance and a specified average speed. If the sum of all minimum duration of the activities and the duration of the trips is higher than the 24h of the day, then assign just one "home" activity to the agent from 00:00:00 to 23:59:59. Else, there will be a remaining time. E.g., the diary of an agent, after adding up all trip durations and minimum activity durations may end at 20:34:57. There is a remaining time to complete the full diary (23:59:59 - 20:34:57). Adjust activity times probabilistically according to the maximum activity duration and this remaining time, making the diary end at exactly 23:59:59.
    - add_date_activities generates activity (stays and moves) rows for a specific date according to parameters.
    - generate_activities generates activity and trip rows according to parameters.
    - generate_lonlat_at_distance given a point (lon, lat) and a distance, in meters, calculates a new random point that is exactly at the specified distance of the provided lon, lat.
    - generate_home_location generates a random home location based on bounding box limits.

        - generate_work_location generates random work location based on home location and maximum distance to home. If the work location falls outside of bounding box limits, try again.
        - generate_other_location generates other activity location based on previous location and maximum distance to previous location. If there is no previous location (this is the first activity of the day), then the home location is considered as previous location. If the location falls outside of bounding box limits, try again.
        - generate_stay_duration generates stay duration probabilistically based on activity type and remaining time.
        - generate_min_stay_duration generates minimum stay duration based on stay type specifications.
        - remove_consecutive_stay_types generates new list replacing consecutive stays of the same type by a unique stay as long as the stay type is contained in the "stay_types_to_group" list.
        - generate_stay_type_sequence generates the sequence of stay types for an agent for a specific date probabilistically based on the superset sequence and specified probabilities. Replace 'home'-'home' and 'work'-'work' sequences by just 'home

5.2.16 SYNTHETICNETWORK

5.2.16.1 MODULE DESCRIPTION

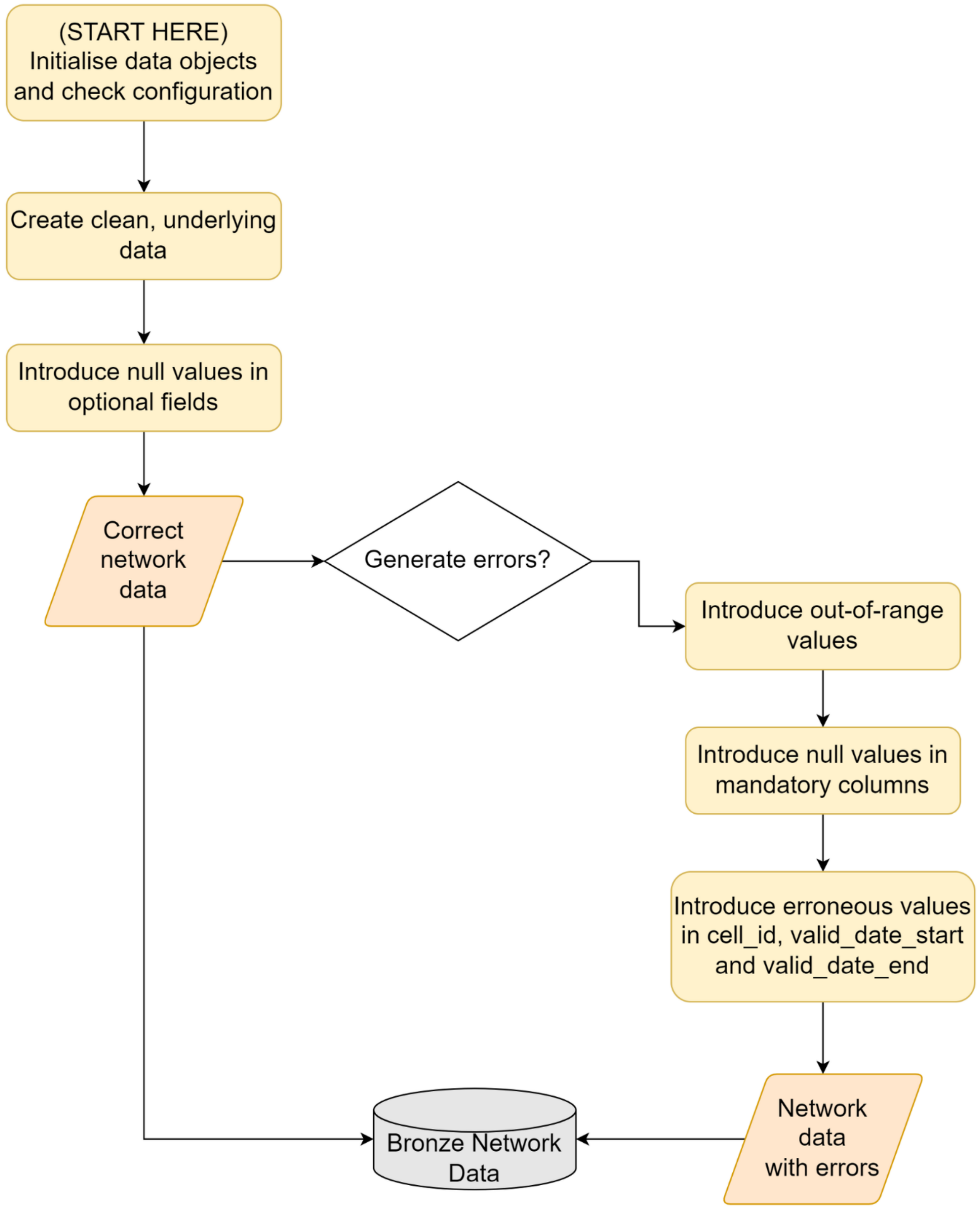
- **Module Name:** SyntheticNetwork.
- **Objectives:** The main goal of the service is to generate synthetic MNO network topology data to simulate real network data provided by the MNO, and allowing the testing and execution of the pipeline. The development of this service will be incremental, iteratively adding more features and characteristics of the real data as the different steps of the pipeline will require them.
- **Functionality:** The SRS documentation sums up the functionality of this service: 3.2.15 SyntheticNetwork.
- **Data Inputs and Outputs:**
    - There are no input objects.
    - The current output data object is I.7 Cell Locations with Physical Properties - Raw.

5.2.16.2 DEVELOPMENT DESIGN

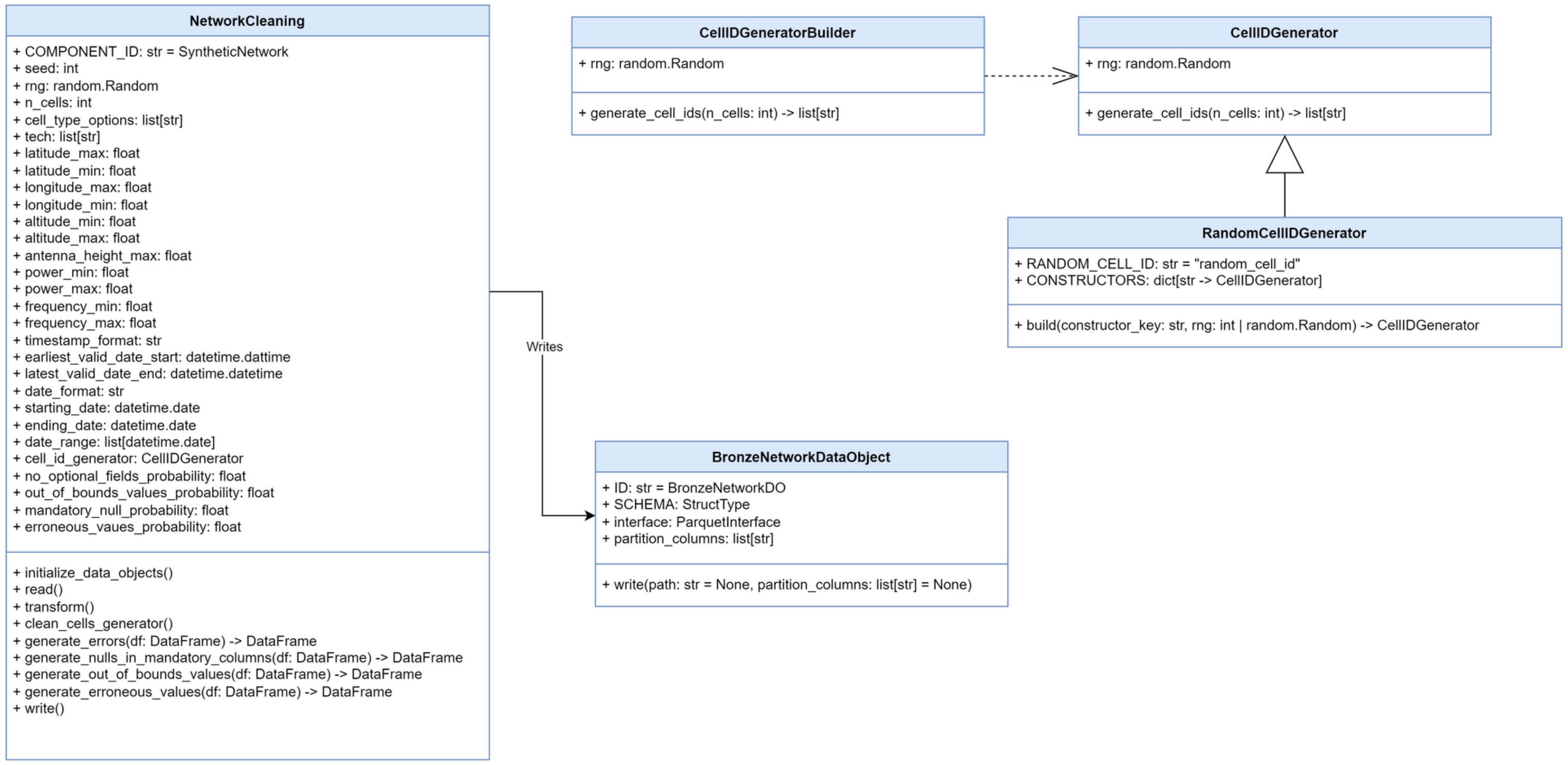
- **Key Algorithms/Processes:** an underlying set of all cells is initially generated. In the clean, no error version, each cell will have a constant value of each of its properties across all dates (e.g., the altitude will be the same for every day). It is supposed that cell data will be available at a daily rate, thus, a parquet partition will be created for every day between starting_date and ending_date.
    - Clean, underlying data generation:
        - The ID of the cell is generated as a 14- or 15-digit string (for now, not following CGI/eCGI standards).
        - The latitude and longitude of the cell are randomly generated with uniform probability in the rectangle defined by latitude_min, latitude_max, longitude_min and longitude_max.
        - The altitude is randomly sampled with uniform probability in the interval defined by altitude_min and altitude_max.
        - The antenna height is randomly sampled with uniform probability in the interval defined by 0and antenna_height_max.

        - The directionality is randomly sampled from the set *{0, 1}* with uniform probability.
        - The azimuth angle is equal to None if the directionality is equal to 0, or is randomly sampled with uniform probability in the interval *[0, 360]*.
        - The elevation angle is randomly sampled with uniform probability in the interval *[-90, 90]*.
        - The horizontal and vertical beam widths are each randomly sampled with uniform probability in the interval *[0, 360]*.
        - The power is randomly sampled with uniform probability in the interval defined by power_minand power_max.
        - The range is randomly sampled with uniform probability in the interval defined by range_min and range_max.
        - The power is randomly sampled with uniform probability in the interval defined by frequency_min and frequency_max.
        - The technology is randomly sampled with uniform probability from the four options 5G, LTE, UMTS, GSM.
        - The valid date start is set to earlist_valid_date_start.
        - The valid date end is set to latest_valid_date_end.
        - The cell type is randomly sampled with uniform probability from a set of options defined via configuration in cell_type_options. Example: macrocell, microcell, picocell, femtocell.
    - Null values: with a probability specified via configuration, all optional fields of a row are set to null.
    - If the user decides to generate synthetic data with errors, then the following steps are followed:
        - Out of bound values: with a probability specified via configuration, for each appropriate field a subset of records is selected and that field's values are changed by value outside the admitted range of values.
        - Nulls in mandatory columns: with a probability specified via configuration, for each mandatory field a subset of records is selected and that field's values are changed to null.
        - Erroneous values:
            - With a probability specified via configuration, a subset of records is selected and the cell_id value is changed by an erroneous one.
            - With a probability specified via configuration, a subset of records is selected: the valid_date_start and valid_date_end are swapped for one half, and for the other half the timestamps are changed for invalid ones.

- **Data flow diagram:**


(START HERE) Initialise data objects and check configuration
Create clean, underlying data
Introduce null values in optional fields
Correct network data
Generate errors?
Introduce out-of-range values
Introduce null values in mandatory columns
Introduce erroneous values in cell_id, valid_date_start and valid_date_end
Network data with errors
Bronze Network Data

- **Class diagram:**



NetworkCleaning
+ COMPONENT_ID: str = SyntheticNetwork
+ seed: int
+ rng: random.Random
+ n_cells: int
+ cell_type_options: list[str]
+ tech: list[str]
+ latitude_max: float
+ latitude_min: float
+ longitude_max: float
+ longitude_min: float
+ altitude_min: float
+ altitude_max: float
+ antenna_height_max: float
+ power_min: float
+ power_max: float
+ frequency_min: float
+ frequency_max: float
+ timestamp_format: str
+ earliest_valid_date_start: datetime.dattime
+ latest_valid_date_end: datetime.datetime
+ date_format: str
+ starting_date: datetime.date
+ ending_date: datetime.date
+ date_range: list[datetime.date]
+ cell_id_generator: CellIDGenerator
+ no_optional_fields_probability: float
+ out_of_bounds_values_probability: float
+ mandatory_null_probability: float
+ erroneous_vaues_probability: float
+ initialize_data_objects()
+ read()
+ transform()
+ clean_cells_generator()
+ generate_errors(df: DataFrame) -> DataFrame
+ generate_nulls_in_mandatory_columns(df: DataFrame) -> DataFrame
+ generate_out_of_bounds_values(df: DataFrame) -> DataFrame
+ generate_erroneous_values(df: DataFrame) -> DataFrame
+ write()
Writes
CellIDGeneratorBuilder
+ rng: random.Random
+ generate_cell_ids(n_cells: int) -> list[str]
CellIDGenerator
+ rng: random.Random
+ generate_cell_ids(n_cells: int) -> list[str]
RandomCellIDGenerator
+ RANDOM_CELL_ID: str = "random_cell_id"
+ CONSTRUCTORS: dict[str -> CellIDGenerator]
+ build(constructor_key: str, rng: int | random.Random) -> CellIDGenerator
BronzeNetworkDataObject
+ ID: str = BronzeNetworkDO
+ SCHEMA: StructType
+ interface: ParquetInterface
+ partition_columns: list[str]
+ write(path: str = None, partition_columns: list[str] = None)

- **Code Structure:** The code structure follows the format set by the core package, and the general repository structure. The location of the module script in the repository is as follows:

```
/multimno/
└── components
    └── ingestion
        └── synthetic
            └── synthetic_network.py
```

  - synthetic_network.py contains one class named SyntheticNetwork which is a subclass of Component. The SyntheticNetwork class overrides some of the methods of Component:
    - The __init__ method first call its parent's __init__ method, which sets up the Spark session, initialises data objects and reads the configuration file.
    - transform performs handles the main logic of the execution.
  - The SyntheticNetwork class also has the following methods:
    - clean_cells_generator creates the clean synthetic network topology data according to the different parameters specified via configuration.
    - generate_errors handles the error generation logic whenever any of the probabilities of generating null values in mandatory columns, creating out-of-bound values or other erroneous values is greater than zero.
    - generate_nulls_in_mandatory_columns handles the changing of valid values in mandatory columns by null values.
    - generate_out_of_bounds_values handles the logic of creating values outside accepted ranges for each applicable field.
    - generate_erroneous_values is handles the creation of invalid cell_id values, swapping valid_date_start and valid_date_end values, and creating invalid timestamps for these two fields as well.

5.2.17 SYNTHETICEVENTS

5.2.17.1 MODULE DESCRIPTION

- **Module Name:** SyntheticEvents
- **Objectives:** the objective of this module is to generate synthetic data on the event level.
- **Functionality:** the module includes the following functionalities:
  - Generating event data that corresponds to stay and move information from synthetic diaries data object and and cell_ids and their locations from the synthetic network data object.
  - Generating event data given with a given set of stay and move frequency parameters and distance measure parameters.
  - Generating location errors and records with nonexistent cell_ids (cell_ids that are not present in synthetic network).
  - Generating null values in any of the columns that are not used for partitioning.
  - Generating timestamp values that are not within the time boundaries given in synthetic diaries (out of bound timestamps).
  - Generating syntactically erroneous values, such as longitude and latitude values greater than 180 and cell_id values that do not follow the format of cell_ids.

    - Generating same location and different location duplicates. The amount of duplicate rows will depend on the probability values given for the duplicate types separately. Only two-row duplicates are generated, meaning that the maximum number of rows that will share the same timestamp for the same user is 2, when generating either type of duplicate rows.
- **Data Inputs and Outputs:**
    - Input:
        - I.30 Synthetic Diaries
        - I.7 Cell Locations with Physical Properties - Raw
    - Output:
        - I.1 MNO Event Data – Raw

5.2.17.2 DEVELOPMENT DESIGN

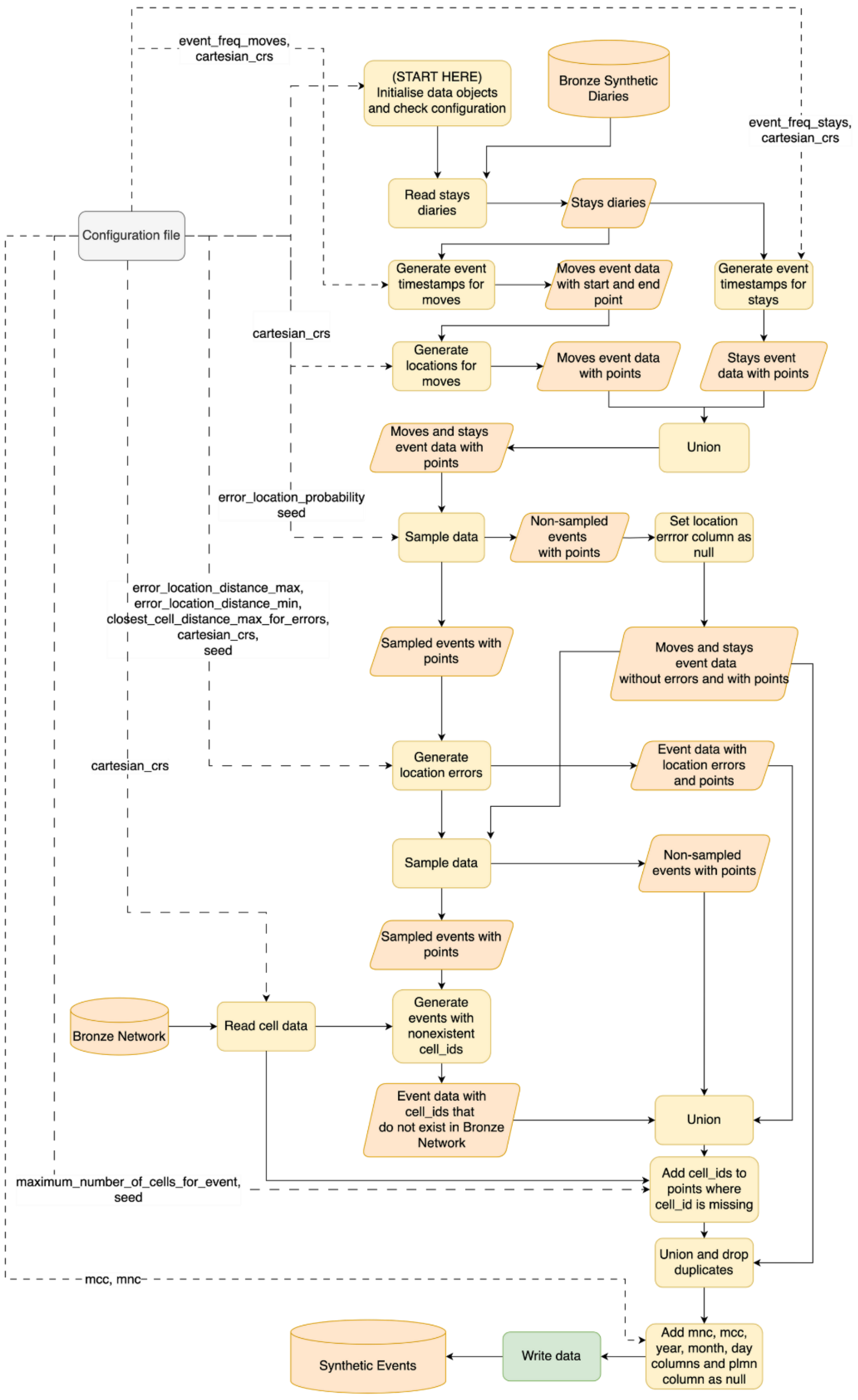
- **Key Algorithms/Processes:**
    - Create the data objects: diaries, network and event data.
    - Read from the configuration file the frequency of events to be generated for all stays.
    - Read from the configuration file the frequency of events to be generated for all moves.
    - Read from the configuration file the maximum distance for a cell to be allowed to be linked to generated point.
    - Read from the configuration file the maximum distance for a cell to be considered as the closest cell when generating events that have erroneous locations.
    - Read from the configuration file the ratio of generated stays and moves to sample, for the generating events that have nonexistent cell ids.
    - Read from the configuration file, the maximum number of cells to consider when generating an event.
    - Generate event timestamps for moves. From synthetic diaries, read in stays, and proceed as follows:
        1. Define window according to initial timestamp
        2. Define geometry column based on the longitude and latitude of next stay
        3. Calculate the time difference between the initial timestamp of next stay and the final timestamp of the current stay
        4. Calculate the total amount of events to be generated for a move event as time_difference_in_seconds / event_freq_moves.
        5. Generate as many random random values in the range of 0 and 1 as was the result of (4) on seperate rows - i.e., explode the dataframe so each random value is assigned to a separate row for a given combination of the timestamp column values
        6. Calculate the offset in seconds as random_float*time_difference_in_seconds
        7. Add the offset in seconds to the final timestamp, which results in random event timestamps between the two stays, and label these rows with the activity type “move”
    - Generate event timestamps for stays. Follow the same logic as for moves generation, but instead use the final and initial timestamp columns for the same row to calculate time difference. Then follow the same sampling idea and generate (or explode to) as many rows as time_difference_in_seconds / event_freq_moves results in.
    - Generate locations for moves. Calculate a line between the geometry of column of current stay, and the next stay. Interpolate on the point, random float values that have been calculated in step 5 of event timestamp generation for moves.
    - Sampling records for which to generate location errors. The parameter “error_location_probability” determines how many rows are sampled, according to the seed value given in the configuration.

- Generating location errors for sampled records. Location errors are generated using the following steps:
    1. Generated longitude and latitude values from the sample are projected from EPSG:4326 to a configured coordinate reference system.
    2. The location error column (loc_error) is calculated as (random_float*(error_location_distance_max - error_location_distance_min)) + error_location_distance_min
       where random_float is generated from a uniform distribution, with paramers (0, 1), using the seed value from configuration.
       The result is a random value within the range of configured parameters, that is be used to offset x and y values (the result of projection in step I).
    3. For each sampled x and y coordinate, randomly determine if the offset is applied by summing loc_error or subtracting it. The probability for either case is equal (0.5).
    4. Existing generated points are replaced with the new points, that have been applied the offset value in the loc_error column with the sign generated in step III.
- Sampling records for which to generate nonexistent cell ids. Nonexistent here refers to cell ids that are not present in the input network data object. This is done by using the parameter error_cell_id_probability, which determines how many rows are sampled, according to the seed value given in the configuration.
- Generating records with nonexistent cell ids for sampled records. This is done by:
    1. Generate random values to match the cell_id field length requirements
    2. Using a left anti join, select from generated cell ids, only those that are not present in the existing network data.
    3. Join those selected in II to the sampled records, using a generated id. The generated id is equal to the row number in the result of II, whereas in the generated records, the id is achieved as row_number() % number_of_unique_cell_ids_in_network_data_object.
- Add cell ids to all previously generated latitude and longitude values. This is done by:
    1. Creating a buffer around each event location and finding cells that intersect with this buffer
    2. Calculating the distance from each event location to the cell and ranking the cells based on this distance.
    3. Keeping only the top 'max_n_of_cells' closest cells for each event
- Add the mcc column value for all users, as the value given in the configuration parameter "mcc"
- Add the mnc column value for all users, as the value given in the configuration parameter "mnc"
- Add the plmn column value for all users as null.
- Add year, month and day columns based on generated timestamps
- Generating errors, if set by the parameter do_error_generation. These are done by the following steps:
- Generating null values in columns that are not used for partitioning. This is done by:
    1. Sampling the rows according to the ratio provided by null_row_probability from the previously generated events.
    2. Selecting randomly a column from that selection of rows to be set as null, to ensure that at least one column is set as null on the sampled rows
    3. Randomly selecting some column values to be null, according to the parameter max_ratio_of_mandatory_columns_to_generate_as_null. This ratio value that describes the maximum number of columns that can be assigned as null, for rows that are selected to include nulls. If set to 1.0, this means that for all rows that are selected to have nulls, all mandatory columns contain nulls. To decide, which columns are

generated a null, the following process is done: 1) a random column is selected 2) a random value between 0 and 1 is generated with the seed parameter given in config 3) If this random value is below max_ratio_of_mandatory_columns_to_generate_as_null, the selected column value is selected to be null for all of the sampled rows. Therefore, the number of columns selected is random, but this parameter can be used to define a maximum limit to it in terms of ratio. For example 0.5 means that it is highly unlikely that the output data will contain rows with 70% of mandatory supported columns being nulls.

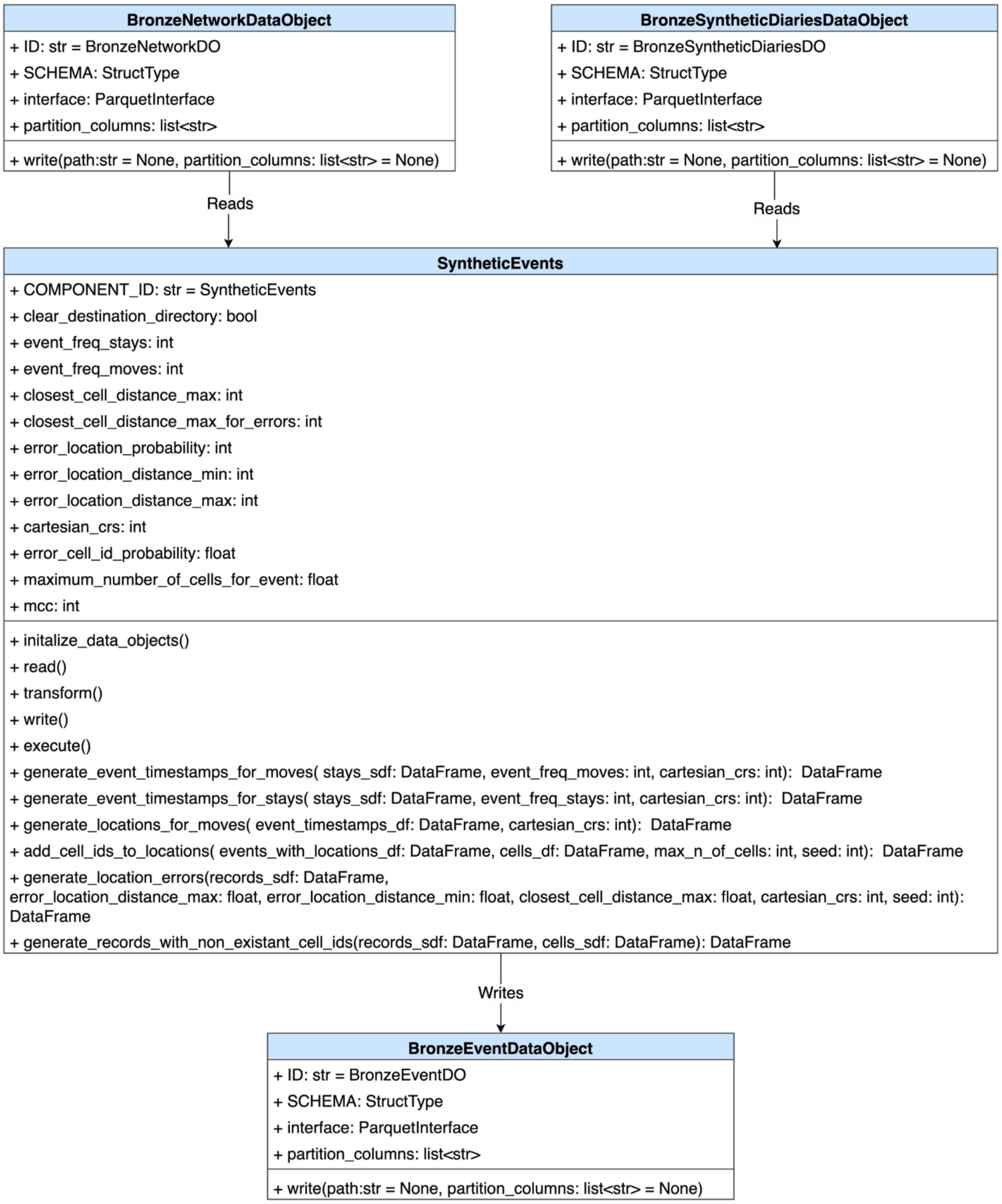
- Generating out of bounds timestamps. This is done by:
    1. Sampling the rows according to the ratio provided by out_of_bounds_probability from the previously generated events that have not been selected for nulls generation.
    2. Modifying the sampled rows in the following way: 1) The maximum and minimum timestamp of the entire previously generated data is extracted 2) A random float value is generated between 2 and 3 from a uniform distribution 3) The span of the data in terms of months is multiplied with the generated value, and the resulting additional months are added to the timestamp so that the new timestamp exceeds the span at least by a factor of 2.
- Generating erroneous values in columns. This is done by:
    1. Sampling the rows according to the ratio provided by out_of_bounds_probability from the previously generated events that have not been selected for nulls generation.
    2. Modifying the columns according to their type. 1) Timestamp columns are replaced with a corrupted format, such as 2023-01-01T07:27:06 2) Float and integer type columns are replaced with a random float value with a minimum of 180 and maximum of 1 800 000. 3) String type columns are replaced with a random string similar to this format: F854IU_62 4) Binary columns (user_id) is replaced with the md5 function result of the original value
- Generating same location duplicates. This is done by:
    1. Sampling the rows that do not involve syntactic errors according to the ratio provided by same_location_duplicates_probability and selecting a maximum number of even rows from the sample subset.
    2. Replacing latitude, longitude, cell_id and timestamp columns for every second row with those of the previous row. This means that every row in the subset selection is a same location duplicate.
- Generating different location duplicates. This is done by:
    1. Sampling the rows that do not involve syntactic errors according to the ratio provided by different_location_duplicates_probability and selecting a maximum number of even rows from the sample subset. Selecting only rows that do not share the same consecutive location information.
    2. Replacing timestamp columns for every second row with those of the previous row. After that, the latitude and longitude columns of every second row are multiplied by 0.95 so that they would not be the same as on the previous row. This means that every row in the subset selection is a different location duplicate.

- **Data flow diagram:**



event_freq_moves, cartesian_crs
(START HERE) Initialise data objects and check configuration
Bronze Synthetic Diaries
event_freq_stays, cartesian_crs
Read stays diaries
Stays diaries
Configuration file
Generate event timestamps for moves
Moves event data with start and end point
Generate event timestamps for stays
cartesian_crs
Generate locations for moves
Moves event data with points
Stays event data with points
Moves and stays event data with points
Union
error_location_probability seed
Sample data
Non-sampled events with points
Set location errror column as null
error_location_distance_max, error_location_distance_min, closest_cell_distance_max_for_errors, cartesian_crs, seed
Sampled events with points
Moves and stays event data without errors and with points
cartesian_crs
Generate location errors
Event data with location errors and points
Sample data
Non-sampled events with points
Sampled events with points
Bronze Network
Read cell data
Generate events with nonexistent cell_ids
Event data with cell_ids that do not exist in Bronze Network
Union
maximum_number_of_cells_for_event, seed
Add cell_ids to points where cell_id is missing
Union and drop duplicates
mcc, mnc
Synthetic Events
Write data
Add mnc, mcc, year, month, day columns and plmn column as null

- **Class diagram:**


BronzeNetworkDataObject
+ ID: str = BronzeNetworkDO
+ SCHEMA: StructType
+ interface: ParquetInterface
+ partition_columns: list<str>
+ write(path:str = None, partition_columns: list<str> = None)
BronzeSyntheticDiariesDataObject
+ ID: str = BronzeSyntheticDiariesDO
+ SCHEMA: StructType
+ interface: ParquetInterface
+ partition_columns: list<str>
+ write(path:str = None, partition_columns: list<str> = None)
Reads
Reads
SyntheticEvents
+ COMPONENT_ID: str = SyntheticEvents
+ clear_destination_directory: bool
+ event_freq_stays: int
+ event_freq_moves: int
+ closest_cell_distance_max: int
+ closest_cell_distance_max_for_errors: int
+ error_location_probability: int
+ error_location_distance_min: int
+ error_location_distance_max: int
+ cartesian_crs: int
+ error_cell_id_probability: float
+ maximum_number_of_cells_for_event: float
+ mcc: int
+ initalize_data_objects()
+ read()
+ transform()
+ write()
+ execute()
+ generate_event_timestamps_for_moves(stays_sdf: DataFrame, event_freq_moves: int, cartesian_crs: int): DataFrame
+ generate_event_timestamps_for_stays(stays_sdf: DataFrame, event_freq_stays: int, cartesian_crs: int): DataFrame
+ generate_locations_for_moves(event_timestamps_df: DataFrame, cartesian_crs: int): DataFrame
+ add_cell_ids_to_locations(events_with_locations_df: DataFrame, cells_df: DataFrame, max_n_of_cells: int, seed: int): DataFrame
+ generate_location_errors(records_sdf: DataFrame, error_location_distance_max: float, error_location_distance_min: float, closest_cell_distance_max: float, cartesian_crs: int, seed: int): DataFrame
+ generate_records_with_non_existant_cell_ids(records_sdf: DataFrame, cells_sdf: DataFrame): DataFrame
Writes
BronzeEventDataObject
+ ID: str = BronzeEventDO
+ SCHEMA: StructType
+ interface: ParquetInterface
+ partition_columns: list<str>
+ write(path:str = None, partition_columns: list<str> = None)

- **Code Structure:** The code structure follows the format set by the core package, and the general repository structure. The location of the module script in the repository is as follows:

```
/multimno/
└─── src
    └─── components
        └─── ingestion
            └─── synthetic
                └─── synthetic_events.py
```

  - synthetic_events.py contains one class named SyntheticEvents which is a subclass of Component. It overrides the following methods:
    - The __init__ method first call its parent's __init__ method, which sets up the Spark session, initialises data objects and reads the configuration file.
    - The transform method handles all the logic behind the component.
  - The SyntheticEvents component also has the following methods:
    - generate_event_timestamps_for_moves handles generation of event timestamps for moves.
    - generate_event_timestamps_for_stays handles generation of event timestamps for stays
    - generate_locations_for_moves handles generation of point geometry for moves.
    - add_cell_ids_to_locations handles joining cell ids to generated longitude and latitude values, given the parameter closest_cell_distance_max.
    - generate_location_errors handles the generation of point geometry, using the given seed parameter for randomized processes (such as exact range of distance, and direction of offset), and the parameters error_location_distance_max and error_location_distance_min.
    - generate_records_with_non_existant_cell_ids handles the generation of records with cell_ids that do not exist in the synthetic network data object, yet follow the format of a cell id syntactically.
    - generate_nulls_in_mandatory_fields handles the generation of null values for rows according to two given probability parameters in the configuration. Previously generated values in the randomly selected columns and rows are replaced with NULL.
    - generate_out_of_bounds_dates handles the generation of timestamps that are out of bounds of the previously generated data according to the corresponding probability parameter in the configuration. This means that timestamps that have been generated up until this point, according to the input of synthetic diaries, are replaced by a monthly offset to be later than the limits set in synthetic diaries.
    - generate_erroneous_type_values handles the generation of error records. Existing values are replaced with erroneous values, that are not syntactically correct, or illogical, given the corresponding probability parameter in the configuration.
    - generate_same_location_duplicates handles the generation of same location duplicates, based on the given respective probability value in configuration.
    - generate_different_location_duplicates handles the generation of different location duplicates, based on the given respective probability value in configuration.

5.2.18 GRIDENRICHMENT

5.2.18.1 MODULE DESCRIPTION

- **Module Name:** GridEnrichment
- **Objectives:** Add additional attributes to reference grid.
- **Functionality:** The component uses landuse and transportation data objects to calculate following metrics for each grid tile:
    - Landuse prior probabilities of the distribution of mobile devices.
    - Environment coefficient for dynamic path loss exponent calculation for cell signal strength modeling.

  Functionality specification: 3.2.18 Grid Enrichment
- **Data Inputs and Outputs:**
    - Inputs:
        - I.32 Landuse
        - I.33 Transportation
        - I.11 Reference Grid
    - Outputs:
        - I.31 Enriched Grid

5.2.18.2 DEVELOPMENT DESIGN

- **Key Algorithms/Processes:**

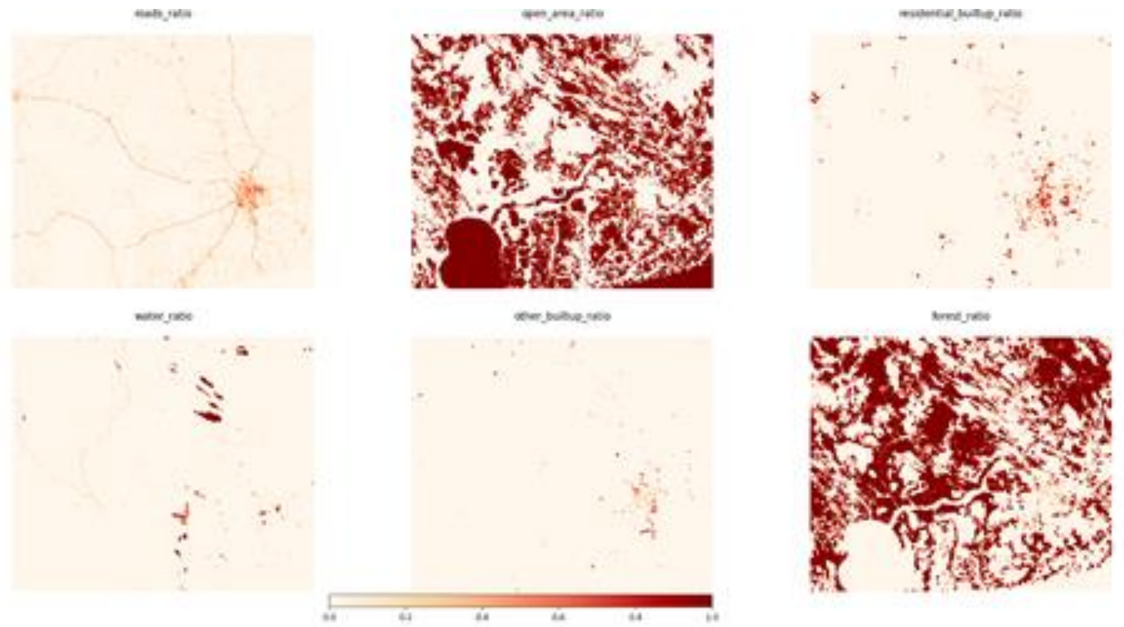
Initialisation:

1. Read configurations parameters for performing land cover enrichment, transportation category buffers, landuse types weights for prior calculation, landuse types weights for environment coefficient calculation and Spark checkpoint directory.
2. Clear the destination directory if configured.
3. Load input data objects for grid, transportation, and land use data.
4. Initialise the output data object for the enriched grid.

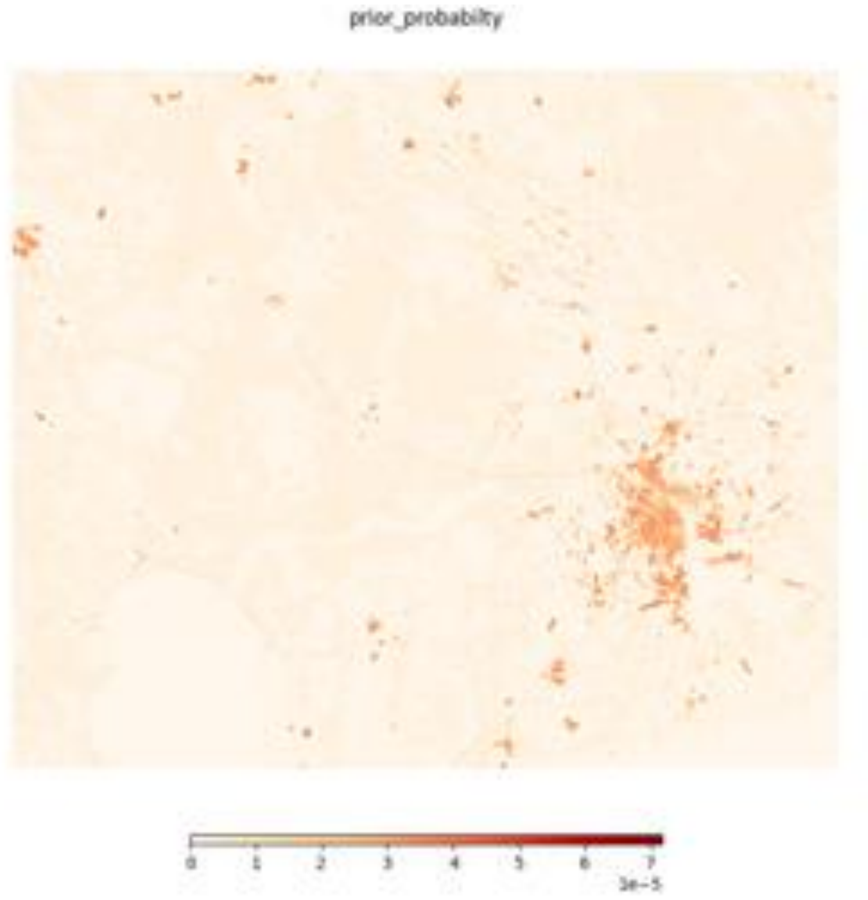
Processing:

For each quadkey partition in input grid data object:

1. Prepare input data.
    1. Filter transportation data to the extent of the current quadkey.
    2. Perform buffer operation using different buffer distances for different road types based on configuration to convert transportation lines to polygons.
    3. Filter landuse data to the extent of the current quadkey.
    4. Cut landuse polygons with transportation polygons and merge them together so that transportation polygons do not overlap landuse polygons.
2. Intersect grid tiles geometry with combined landuse polygons and calculate ratios of landuse classes which are intersected with a grid tile to the total area of a grid tile.

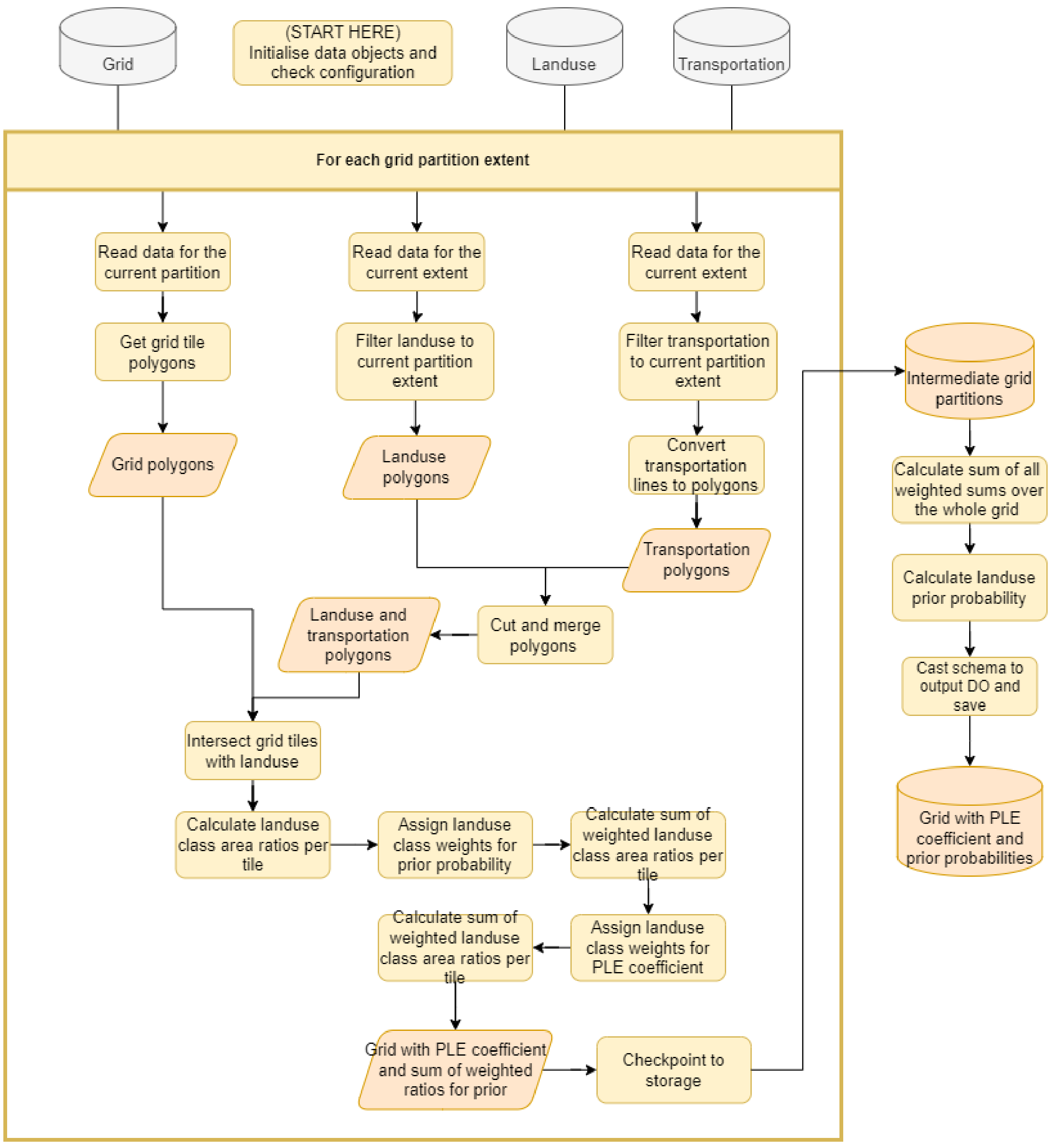


   a. Assign weights for prior probability to each landuse category based on configuration parameter and calculate weighed sum of landuse categories per grid tile.
   b. Assign weights for path loss exponent coefficient to each landuse category based on configuration parameter an calculate weighed sums of landuse category ratios per grid tile to get environment Path Loss Exponent coefficient
   c. Persists the current results with a checkpoint and clear cache to reduce memory footprint.
3. Combine all persisted result parts and remove potential duplicates.
4. Calculate total sum of weighed sums of landuse categories over all grid tiles.
5. Divide weighed sums of landuse categories in grid tiles by total sum to get landuse prior probability values



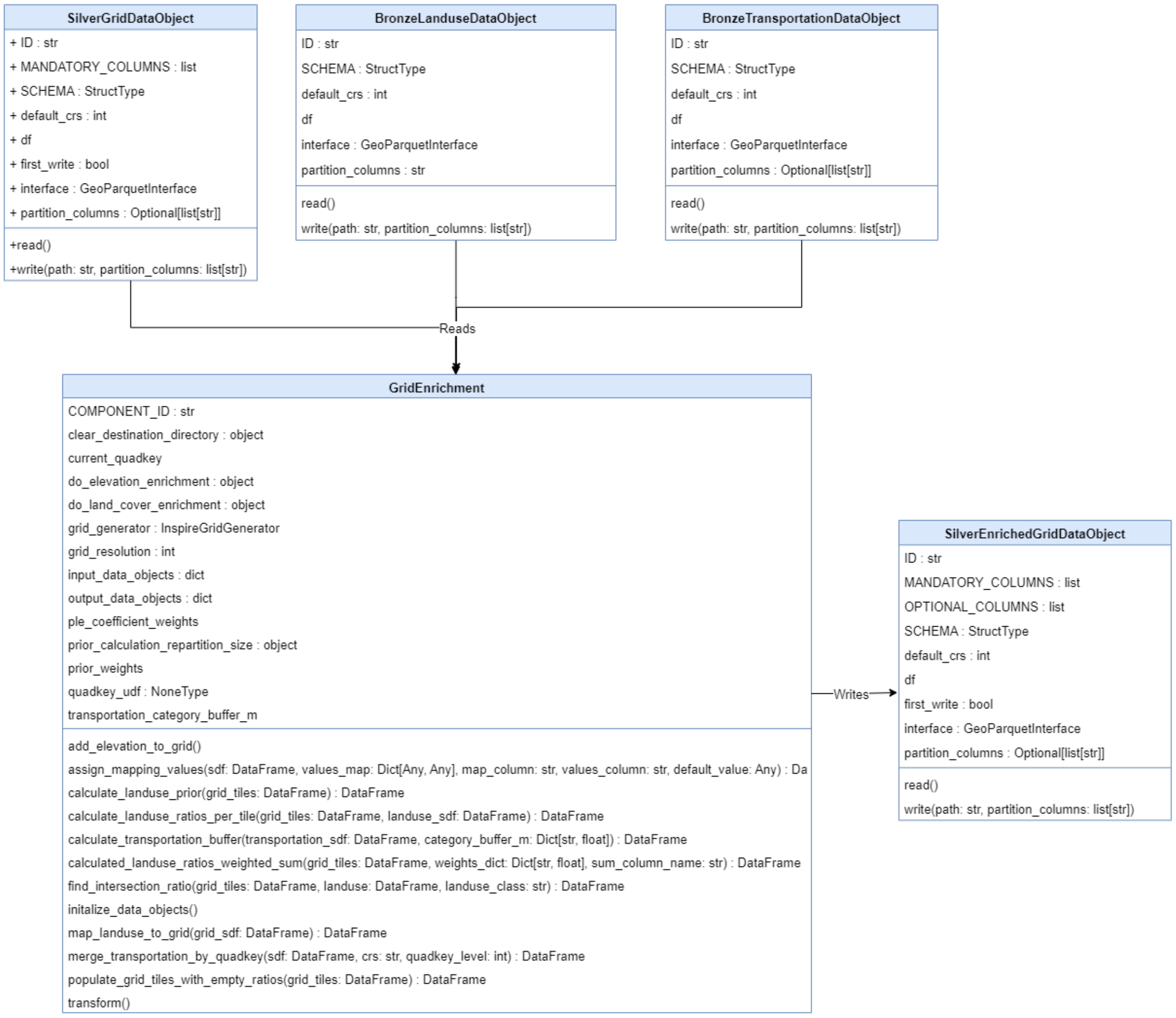
6. Order and repartition resulted grid by quadkey.
7. Apply schema casting and add missing columns to match the output data object's schema.
8. Save to storage partition by quadkey.

- **Data flow diagram:**



Grid
(START HERE) Initialise data objects and check configuration
Landuse
Transportation
For each grid partition extent
Read data for the current partition
Read data for the current extent
Read data for the current extent
Get grid tile polygons
Filter landuse to current partition extent
Filter transportation to current partition extent
Grid polygons
Landuse polygons
Convert transportation lines to polygons
Transportation polygons
Landuse and transportation polygons
Cut and merge polygons
Intersect grid tiles with landuse
Calculate landuse class area ratios per tile
Assign landuse class weights for prior probability
Calculate sum of weighted landuse class area ratios per tile
Assign landuse class weights for PLE coefficient
Calculate sum of weighted landuse class area ratios per tile
Grid with PLE coefficient and sum of weighted ratios for prior
Checkpoint to storage
Intermediate grid partitions
Calculate sum of all weighted sums over the whole grid
Calculate landuse prior probability
Cast schema to output DO and save
Grid with PLE coefficient and prior probabilities

- **Class diagram:**


SilverGridDataObject
+ ID : str
+ MANDATORY_COLUMNS : list
+ SCHEMA : StructType
+ default_crs : int
+ df
+ first_write : bool
+ interface : GeoParquetInterface
+ partition_columns : Optional[list[str]]
+read()
+write(path: str, partition_columns: list[str])
BronzeLanduseDataObject
ID : str
SCHEMA : StructType
default_crs : int
df
interface : GeoParquetInterface
partition_columns : str
read()
write(path: str, partition_columns: list[str])
BronzeTransportationDataObject
ID : str
SCHEMA : StructType
default_crs : int
df
interface : GeoParquetInterface
partition_columns : Optional[list[str]]
read()
write(path: str, partition_columns: list[str])
Reads
GridEnrichment
COMPONENT_ID : str
clear_destination_directory : object
current_quadkey
do_elevation_enrichment : object
do_land_cover_enrichment : object
grid_generator : InspireGridGenerator
grid_resolution : int
input_data_objects : dict
output_data_objects : dict
ple_coefficient_weights
prior_calculation_repartition_size : object
prior_weights
quadkey_udf : NoneType
transportation_category_buffer_m
add_elevation_to_grid()
assign_mapping_values(sdf: DataFrame, values_map: Dict[Any, Any], map_column: str, values_column: str, default_value: Any) : Da
calculate_landuse_prior(grid_tiles: DataFrame) : DataFrame
calculate_landuse_ratios_per_tile(grid_tiles: DataFrame, landuse_sdf: DataFrame) : DataFrame
calculate_transportation_buffer(transportation_sdf: DataFrame, category_buffer_m: Dict[str, float]) : DataFrame
calculated_landuse_ratios_weighted_sum(grid_tiles: DataFrame, weights_dict: Dict[str, float], sum_column_name: str) : DataFrame
find_intersection_ratio(grid_tiles: DataFrame, landuse: DataFrame, landuse_class: str) : DataFrame
initalize_data_objects()
map_landuse_to_grid(grid_sdf: DataFrame) : DataFrame
merge_transportation_by_quadkey(sdf: DataFrame, crs: str, quadkey_level: int) : DataFrame
populate_grid_tiles_with_empty_ratios(grid_tiles: DataFrame) : DataFrame
transform()
Writes
SilverEnrichedGridDataObject
ID : str
MANDATORY_COLUMNS : list
OPTIONAL_COLUMNS : list
SCHEMA : StructType
default_crs : int
df
first_write : bool
interface : GeoParquetInterface
partition_columns : Optional[list[str]]
read()
write(path: str, partition_columns: list[str])

- **Code Structure:**

The code structure follows the format set by the core package, and the general repository structure.
The location of the module script in the repository is as follows:

```
multimno
    └── components
        └── execution
            └── grid_enrichment
                └── grid_enrichment.py
```

grid_enrichment.py contains one class named GridEnrichmentwhich is a subclass of Component.
The GridEnrichment class overrides transform method of base Component class.

5.2.19 GEOZONESGRIDMAPPING

5.2.19.1 MODULE DESCRIPTION

- **Module Name:** GeozonesGridMapping
- **Objectives:** Map given geographic zone datasets to reference grid tile centroids.
- **Functionality:** For each given zoning dataset the component enriches grid tiles with information about zoning unit which they are intersecting by performing spatial join of zoning polygons to grid centroids. In case of hierarchical zoning system, spatial join is performed on the lowest level of hierarchy. Higher level zone IDs are then derived from parent_id column of a zoning dataset and combined into hierarchical id. Functionality specification:
    - 3.2.19 GeozonesGridMapping
- **Data Inputs and Outputs:**
    - Inputs:
        - I.11 Reference Grid
        - I.35 Geographic Zones
        - I.34 Administrative Units
    - Outputs:
        - I.36 Zones – Grid Map

5.2.19.2 DEVELOPMENT DESIGN:

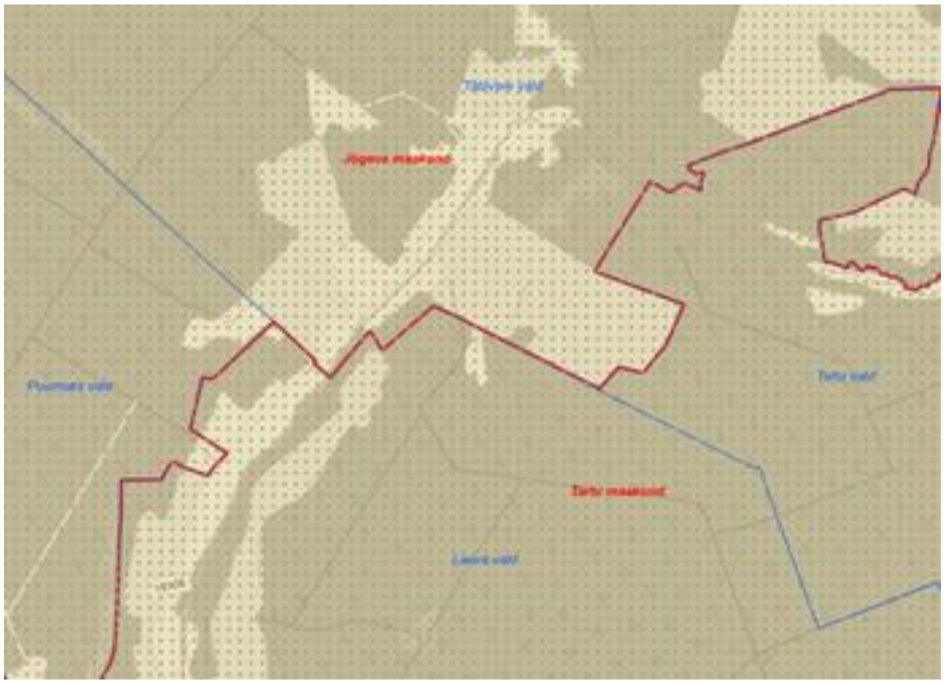
- **Key Algorithms/Processes:**

Initialisation:

1. Read configuration parameters for selecting zoning dataset IDs to perform mapping, zoning type (e.g., administrative units or other geographic zones).
2. Clear the destination directory if configured.
3. Load input data objects for grid, other geographic zones or administrative units based on the selected zoning type.
4. Initialize the output data object for the geozones grid map.

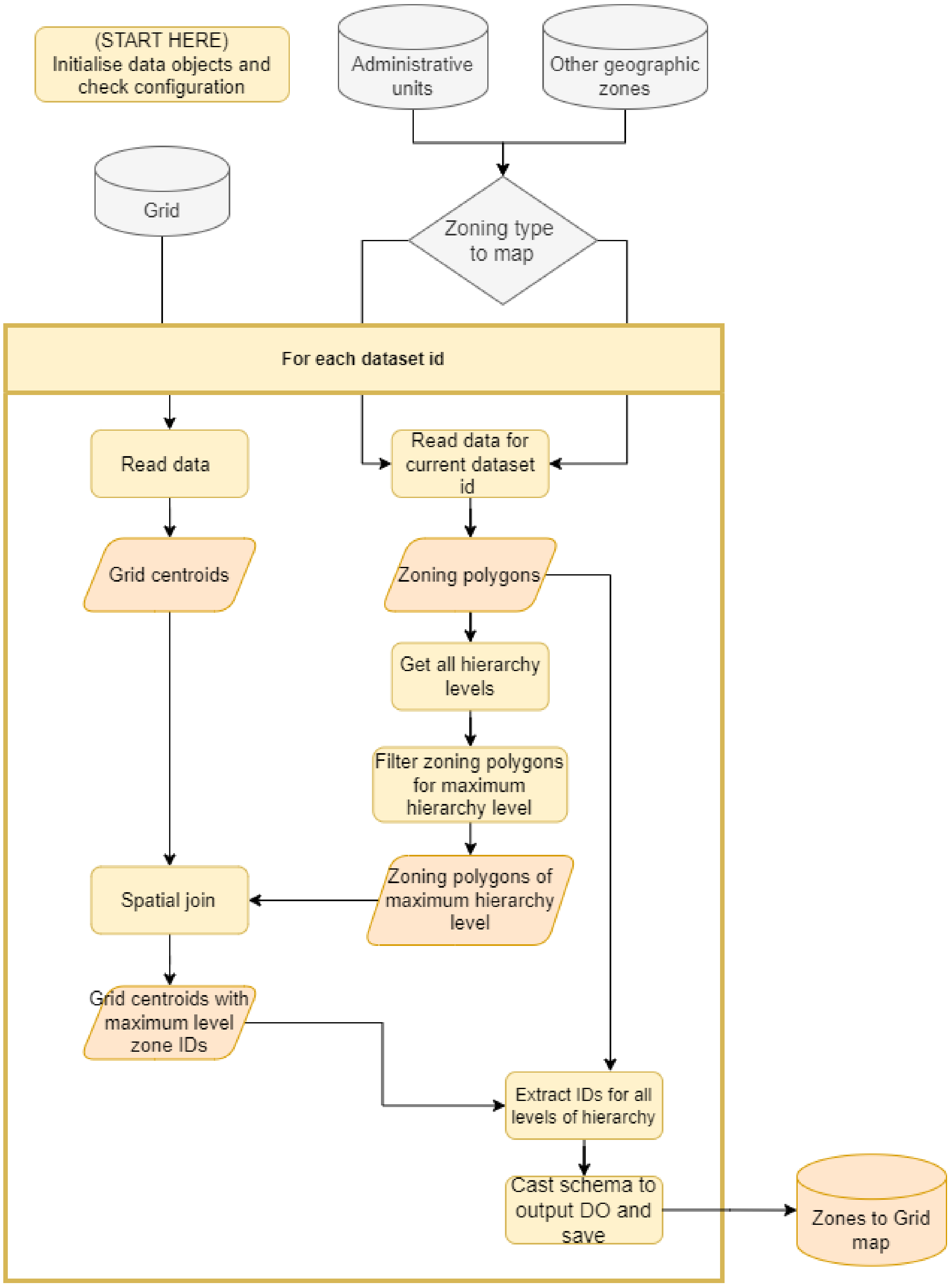
Processing:

1. For each dataset ID following steps are performed:
    1. Filter the current zoning dataset by the dataset ID from corresponding data object.
    2. Retrieve the hierarchy levels of zoning units.
    3. Map zoning units on the maximum level of hierarchy to the grid by performing spatial join of grid centroids to zoning polygons.

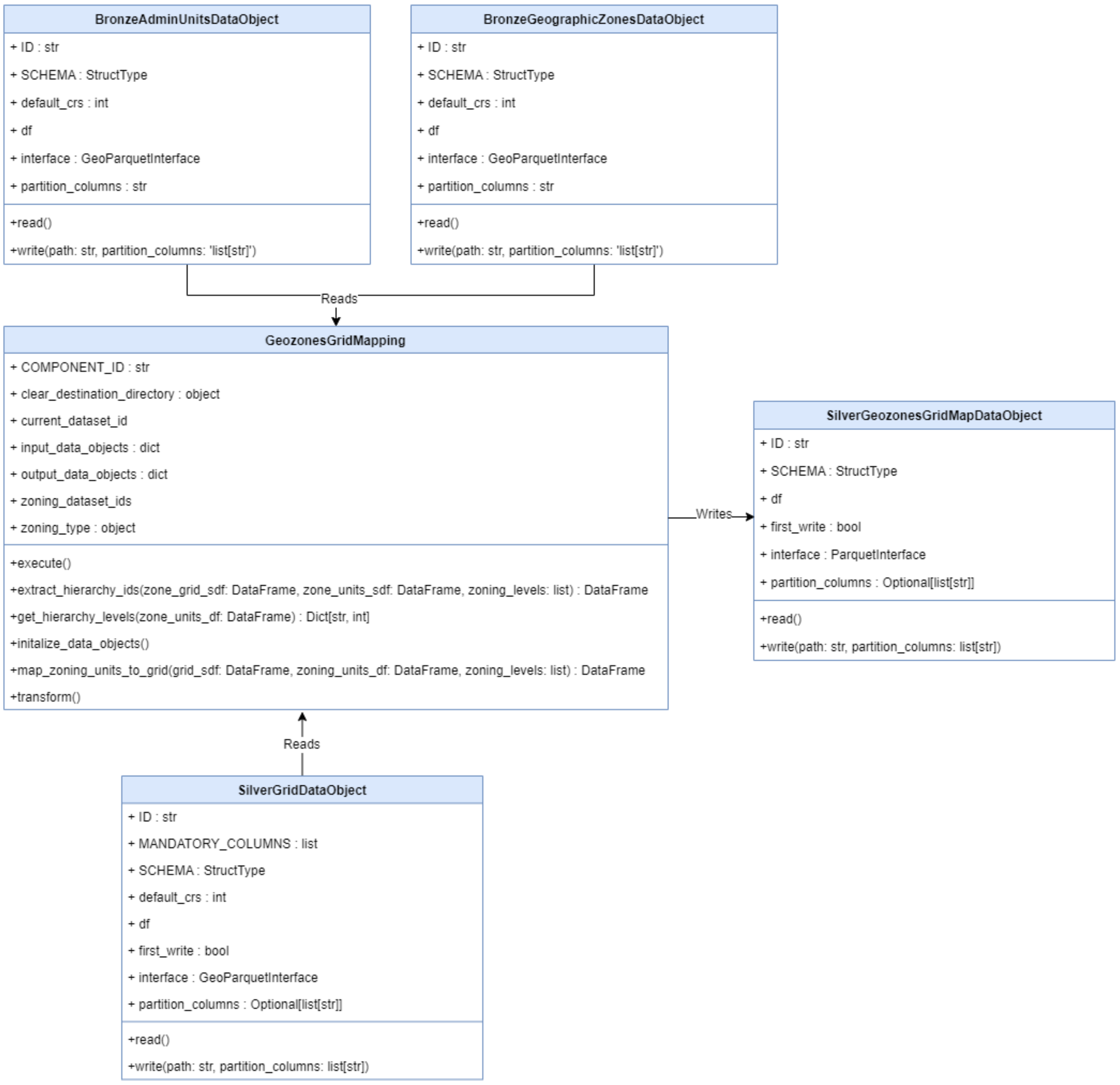


4. Extract IDs for all levels of zoning hierarchy and combine them into hierarchical ID.
5. Assign year, month, and day columns from the zoning dataset to the grid.
6. Apply schema casting to match the output data object's schema and write to storage partitioned by quadkey.

- **Data flow diagram:**


(START HERE) Initialise data objects and check configuration
Administrative units
Other geographic zones
Grid
Zoning type to map
For each dataset id
Read data
Read data for current dataset id
Grid centroids
Zoning polygons
Get all hierarchy levels
Filter zoning polygons for maximum hierarchy level
Spatial join
Zoning polygons of maximum hierarchy level
Grid centroids with maximum level zone IDs
Extract IDs for all levels of hierarchy
Cast schema to output DO and save
Zones to Grid map

- **Class diagram:**


BronzeAdminUnitsDataObject
+ ID : str
+ SCHEMA : StructType
+ default_crs : int
+ df
+ interface : GeoParquetInterface
+ partition_columns : str
+read()
+write(path: str, partition_columns: 'list[str]')
BronzeGeographicZonesDataObject
+ ID : str
+ SCHEMA : StructType
+ default_crs : int
+ df
+ interface : GeoParquetInterface
+ partition_columns : str
+read()
+write(path: str, partition_columns: 'list[str]')
Reads
GeozonesGridMapping
+ COMPONENT_ID : str
+ clear_destination_directory : object
+ current_dataset_id
+ input_data_objects : dict
+ output_data_objects : dict
+ zoning_dataset_ids
+ zoning_type : object
+execute()
+extract_hierarchy_ids(zone_grid_sdf: DataFrame, zone_units_sdf: DataFrame, zoning_levels: list) : DataFrame
+get_hierarchy_levels(zone_units_df: DataFrame) : Dict[str, int]
+initalize_data_objects()
+map_zoning_units_to_grid(grid_sdf: DataFrame, zoning_units_df: DataFrame, zoning_levels: list) : DataFrame
+transform()
Writes
SilverGeozonesGridMapDataObject
+ ID : str
+ SCHEMA : StructType
+ df
+ first_write : bool
+ interface : ParquetInterface
+ partition_columns : Optional[list[str]]
+read()
+write(path: str, partition_columns: list[str])
Reads
SilverGridDataObject
+ ID : str
+ MANDATORY_COLUMNS : list
+ SCHEMA : StructType
+ default_crs : int
+ df
+ first_write : bool
+ interface : GeoParquetInterface
+ partition_columns : Optional[list[str]]
+read()
+write(path: str, partition_columns: list[str])

- **Code Structure:**

The code structure follows the format set by the core package, and the general repository structure.
The location of the module script in the repository is as follows:

```
multimno
    └── components
        └── execution
            └── geozones_grid_mapping
                └── geozones_grid_mapping.py
```

geozones_grid_mapping.py contains one class named GeozonesGridMappingwhich is a subclass of Component.
The GeozonesGridMappingclass overrides transform method of base Component class.

5.2.20 PRESENTPOPULATIONESTIMATION

5.2.20.1 MODULE DESCRIPTION

- **Module Name:** PresentPopulationEstimation
- **Objectives:** This module estimates the present population (number of actual people) in each spatial unit at each time point (fixed timestamp). The spatial unit is either a grid tile or a zone/municipality (collection of grid tiles).
- **Functionality:** This module implements the methodology described in D2.2 method 14.1, variant 1.
- **Data Inputs and Outputs:**
  - Inputs:
    - I.16 MNO Event Data – Semantically Cleaned
    - I.15 Cell Connection and Posterior Probabilities
    - I.28 INSPIRE Grid
  - Outputs:
    - I.42 Present Population
- Configuration parameters
  - *tolerance_period_s*: Maximum allowed time difference for an event to be included in a time point.
  - *data_period_start*: Starting bound when to start time point generation. The first time point is created at this timestamp.
  - *data_period_end*: Ending bound when to end time point generation. No time points are generated later than this timestamp. A time point can be generated on this exact timestamp.
  - *time_point_gap_s*: Number of seconds between two generated time points.
  - *max_iterations*: Maximum number of iterations allowed for the Bayesian process.
  - *min_difference_threshold*: Minimum total difference between Bayesian process prior and posterior values needed to continue iterations of the process.

5.2.20.2 DEVELOPMENT DESIGN

\ TIMELINE QUANTIZATION

Starting from *data_period_start* generate one timestamp after each *time_point_gap_s* until *data_period_end* is reached. A time point can be generated at exactly *data_period_end*, but not later.

timestamp
2023-07-14 10:00:00
2023-07-14 11:00:00
2023-07-14 12:00:00
2023-07-14 13:00:00
2023-07-14 14:00:00

\ DETERMINING RELEVANT EVENT DATA FOR THE TIME POINT

For each time point at timestamp *t*, the events included in its calculation are all events within the window *[t-tolerance_period_s, t+tolerance_period_s]*.

When selecting the data, first date-level filtering is applied to make use of date-partitioned storage of event data. Then timestamp-level filtering is applied to select the exact events.

\ ESTIMATION OF DEVICE COUNT PER CELL FOR TIME POINT

For each time point, for each cell, calculate the number of unique devices present. Both domestic and inbound data should be included (if available).

cell_id	count	timestamp
1	25436	2023-07-14 14:00:00
2	5342	2023-07-14 14:00:00
3	304334	2023-07-14 14:00:00
4	145755	2023-07-14 14:00:00

\ ITERATIVE PROCESS FOR THE ESTIMATION OF POPULATION PER GRID TILE

For each time point, for each grid tile, estimate the present population using cell weighted counts and cell connection probabilities. This is an iterative Bayesian procedure.
Determine grid to cell probabilities by selecting the cell to grid connection probability data that matches the current time point. Then for each grid tile, sum and normalize the cell to grid probabilities to determine the grid to cell probability.
For the iterative process, first initialise the population values of each grid tile: calculate the sum of *weighted_count* of all cells, then for each grid tile, set the initial *population* value to *weighted_counts_sum/n_grid*, where *n_grid* is the total number of grid tiles.
In each iteration:

1. For each (*cell_id*, *grid_id*) pair, calculate the value *a* as *population*grid_prob*, where *population* is this cell's population value and *grid_prob* is the grid to cell connection probability of this grid_id.

2. For each *cell_id*, calculate the sum *sum_a* across all of its (*cell_id*, *grid_id, a*) rows. Get (*cell_id, sum_a)* rows.
3. Normalize *a*: for each (*cell_id*, *grid_id, a*) row, join with (*cell_id, sum_a)* on cell_id. Divide *a* by *sum_a* and replace *a* with the new value.
4. Apply weighting by count: for each (*cell_id*, *grid_id, a*) row, join with device count per cell data (*cell_id, count*) on cell_id. Multiply *a* with *count* and replace *a* with the new value.
5. For each *grid_id*, calculate value *new_population* as the sum of *a* across all matching (*cell_id*, *grid_id, a*) rows.
6. Determine difference: for each *grid_id*, calculate the absolute difference between *population* and *new_population*. Calculate *sum_diff* as the sum of absolute differences across all *grid_id*s.
7. Replace *population* with *new_population*.
8. Check for iteration conditions. Repeat the loop if *sum_diff* is above threshold **and** iteration count is below threshold.

grid_id	population	timestamp
1	654	2023-07-14 14:00:00
2	234	2023-07-14 14:00:00
3	1654	2023-07-14 14:00:00

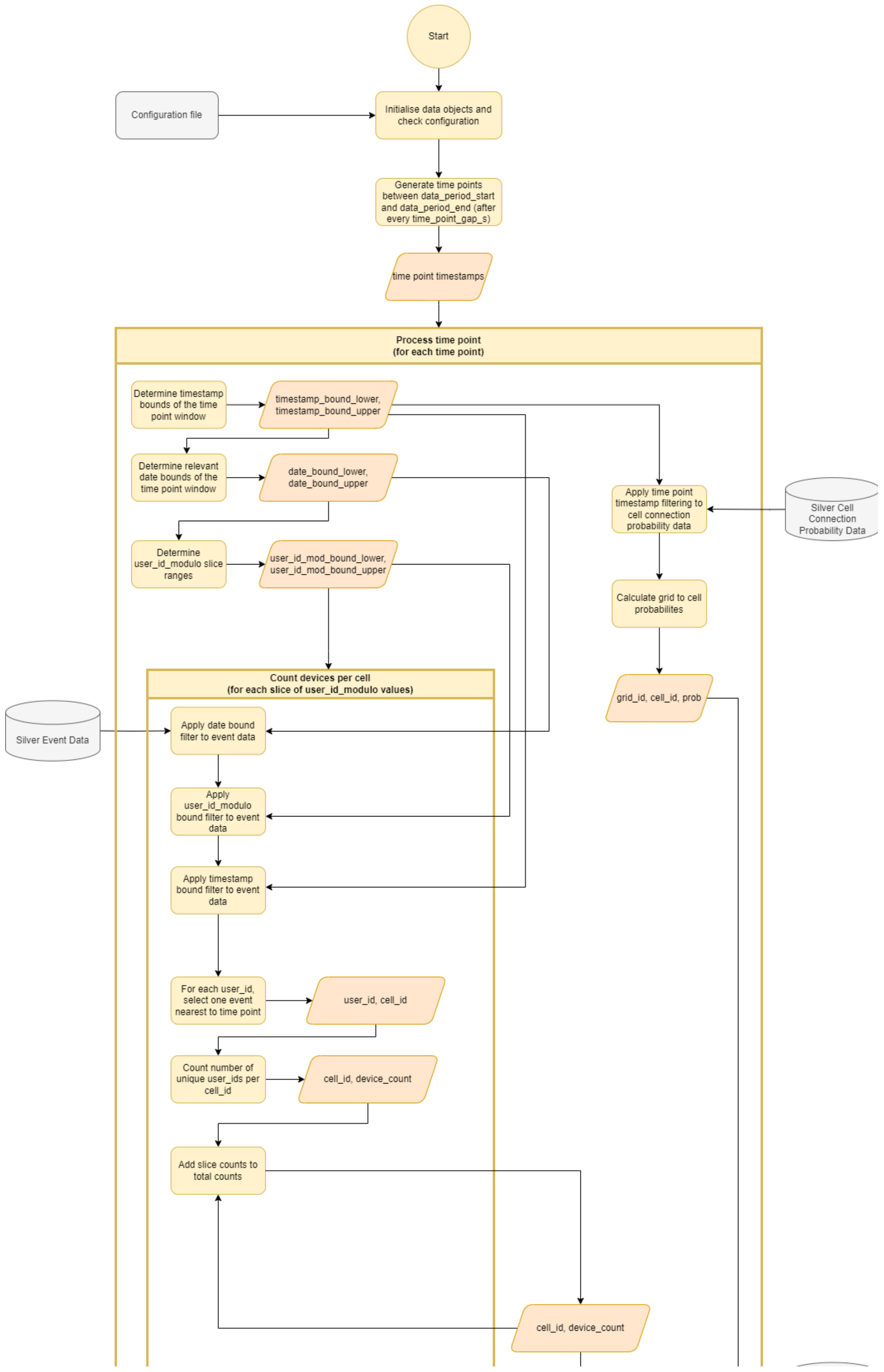
\ IF AGGREGATING BY GRID, THEN THE RESULTS ARE DONE.

Write results partitioned by day, month, year calculated from the time point timestamp.

\ WRITE RESULTS

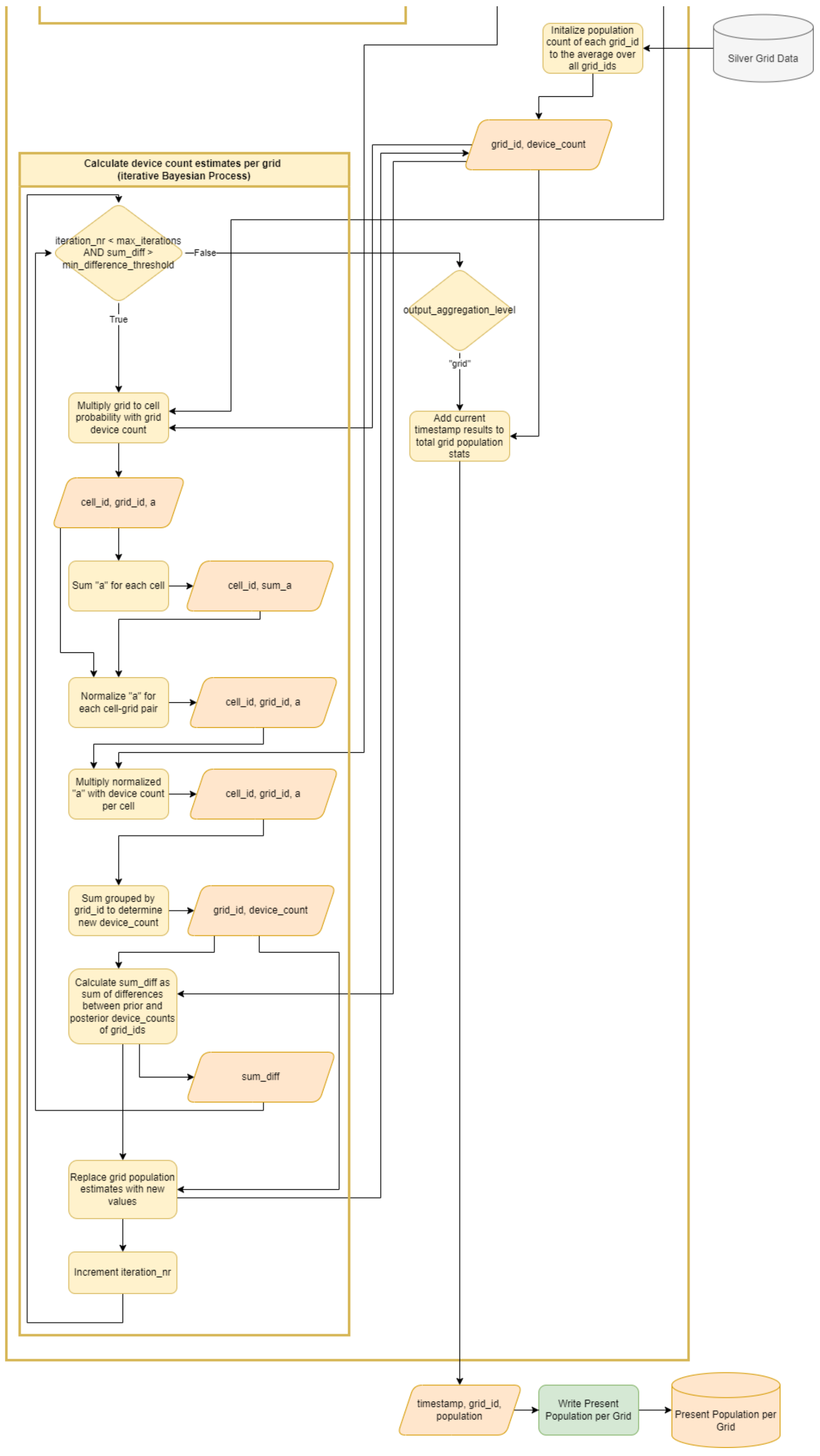
Write the output data object I.42 Present Population partitioned by day, month, year calculated from the time point timestamp.

\ DATA FLOW DIAGRAM (PART 1)



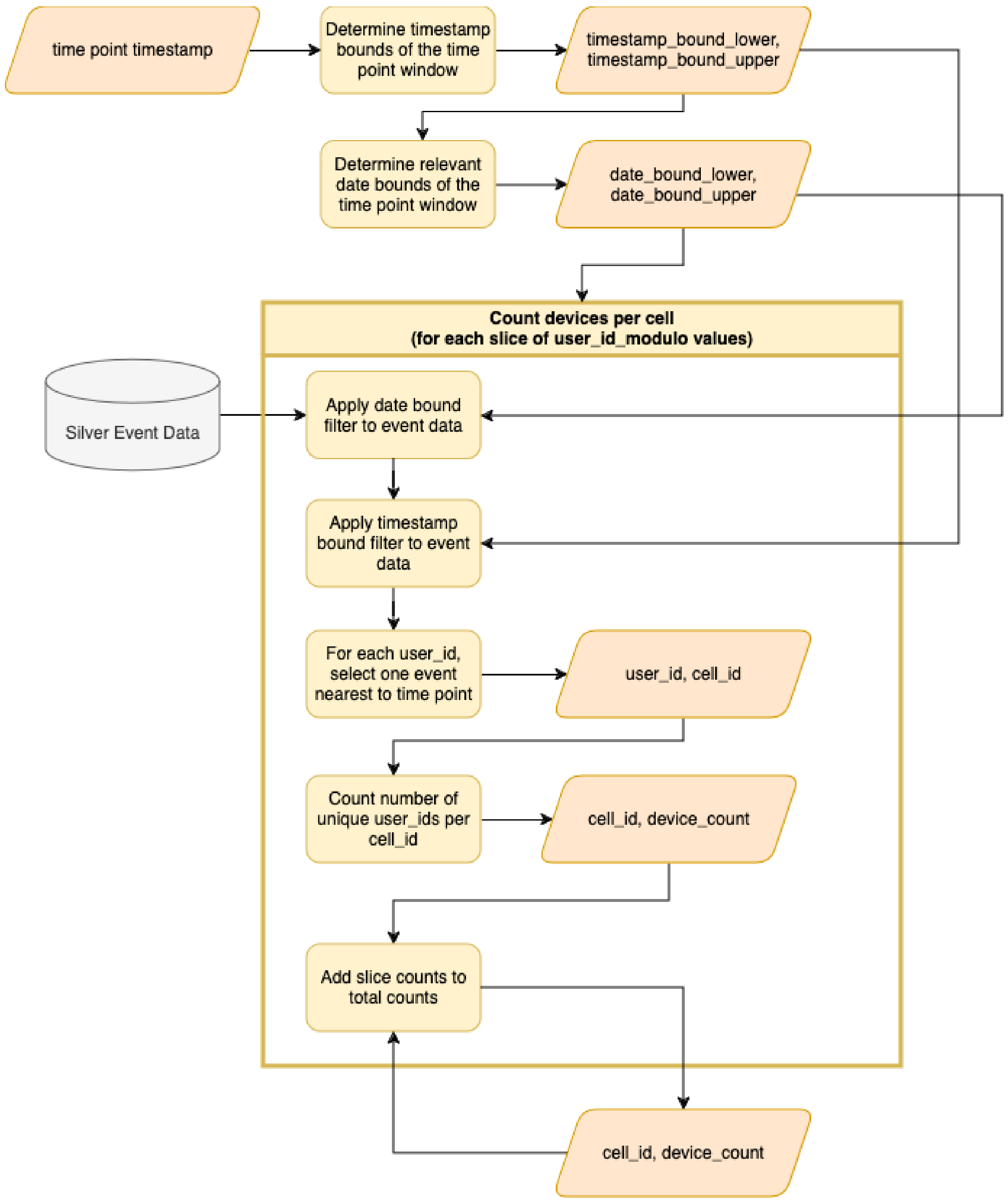
Start
Configuration file
Initialise data objects and check configuration
Generate time points between data_period_start and data_period_end (after every time_point_gap_s)
time point timestamps
Process time point (for each time point)
Determine timestamp bounds of the time point window
timestamp_bound_lower, timestamp_bound_upper
Determine relevant date bounds of the time point window
date_bound_lower, date_bound_upper
Determine user_id_modulo slice ranges
user_id_mod_bound_lower, user_id_mod_bound_upper
Apply time point timestamp filtering to cell connection probability data
Silver Cell Connection Probability Data
Calculate grid to cell probabilites
grid_id, cell_id, prob
Count devices per cell (for each slice of user_id_modulo values)
Silver Event Data
Apply date bound filter to event data
Apply user_id_modulo bound filter to event data
Apply timestamp bound filter to event data
For each user_id, select one event nearest to time point
user_id, cell_id
Count number of unique user_ids per cell_id
cell_id, device_count
Add slice counts to total counts
cell_id, device_count

\ DATA FLOW DIAGRAM (PART 2)

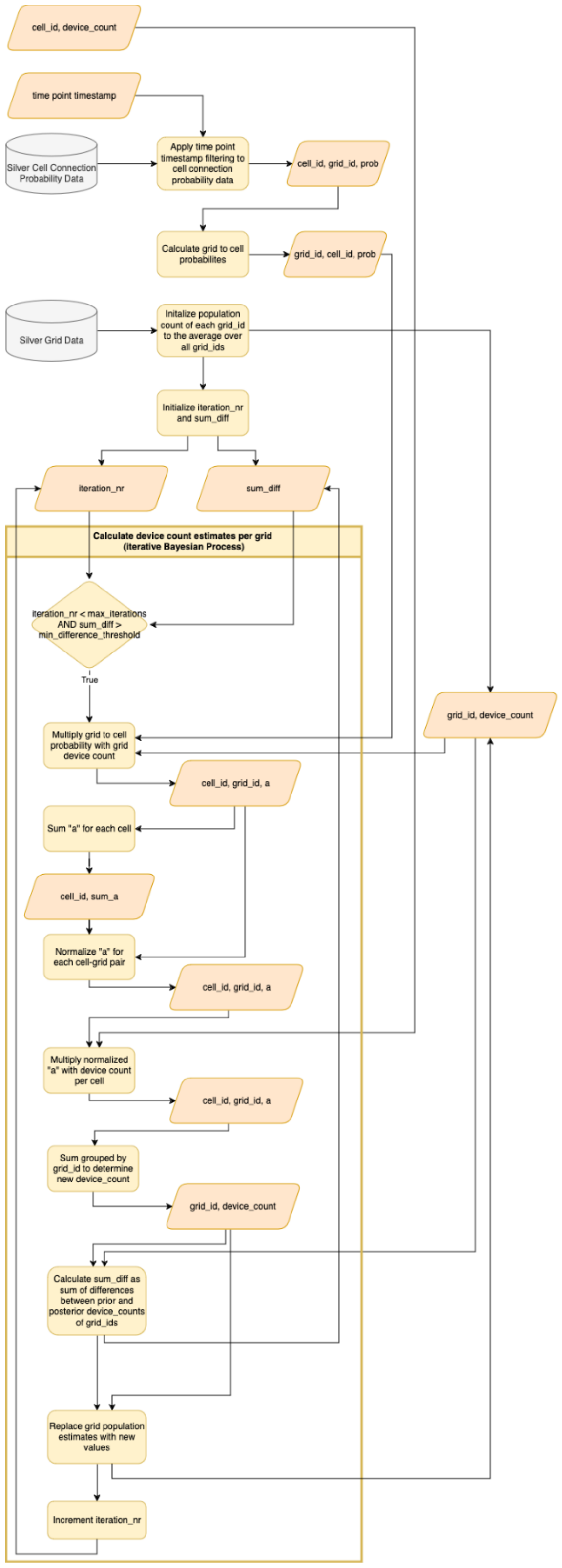


Initalize population count of each grid_id to the average over all grid_ids
Silver Grid Data
grid_id, device_count
Calculate device count estimates per grid (iterative Bayesian Process)
iteration_nr < max_iterations AND sum_diff > min_difference_threshold
False
True
output_aggregation_level
"grid"
Multiply grid to cell probability with grid device count
Add current timestamp results to total grid population stats
cell_id, grid_id, a
Sum "a" for each cell
cell_id, sum_a
Normalize "a" for each cell-grid pair
cell_id, grid_id, a
Multiply normalized "a" with device count per cell
cell_id, grid_id, a
Sum grouped by grid_id to determine new device_count
grid_id, device_count
Calculate sum_diff as sum of differences between prior and posterior device_counts of grid_ids
sum_diff
Replace grid population estimates with new values
Increment iteration_nr
timestamp, grid_id, population
Write Present Population per Grid
Present Population per Grid

\ DATA FLOW DIAGRAM (COUNT DEVICES PER CELL)

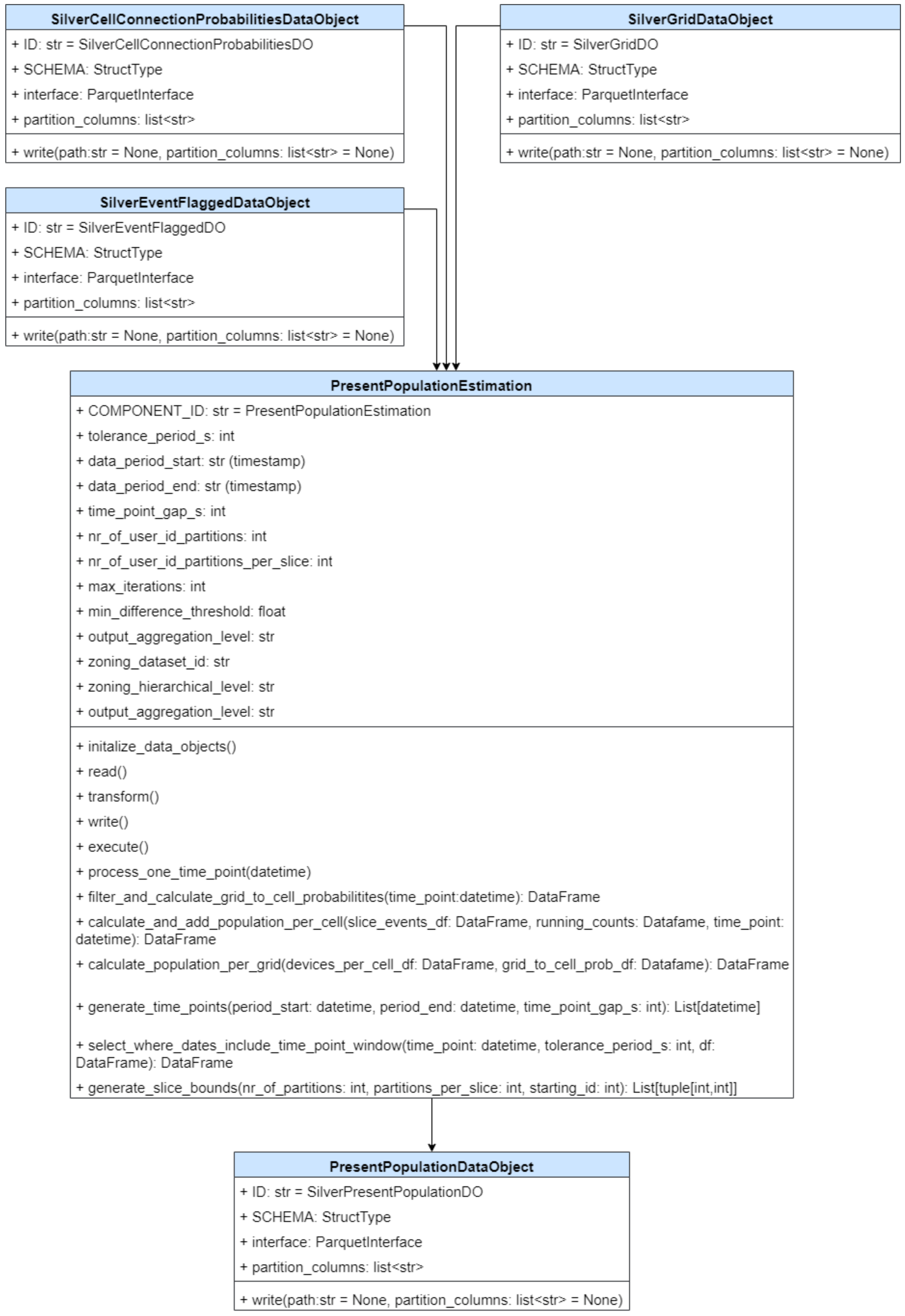

time point timestamp
Determine timestamp bounds of the time point window
timestamp_bound_lower, timestamp_bound_upper
Determine relevant date bounds of the time point window
date_bound_lower, date_bound_upper
Count devices per cell (for each slice of user_id_modulo values)
Silver Event Data
Apply date bound filter to event data
Apply timestamp bound filter to event data
For each user_id, select one event nearest to time point
user_id, cell_id
Count number of unique user_ids per cell_id
cell_id, device_count
Add slice counts to total counts
cell_id, device_count

\ DATA FLOW DIAGRAM (CALCULATE DEVICES PER GRID)



cell_id, device_count
time point timestamp
Silver Cell Connection Probability Data
Apply time point timestamp filtering to cell connection probability data
cell_id, grid_id, prob
Calculate grid to cell probabilites
grid_id, cell_id, prob
Silver Grid Data
Initalize population count of each grid_id to the average over all grid_ids
Initialize iteration_nr and sum_diff
iteration_nr
sum_diff
Calculate device count estimates per grid (iterative Bayesian Process)
iteration_nr < max_iterations AND sum_diff > min_difference_threshold
True
grid_id, device_count
Multiply grid to cell probability with grid device count
cell_id, grid_id, a
Sum "a" for each cell
cell_id, sum_a
Normalize "a" for each cell-grid pair
cell_id, grid_id, a
Multiply normalized "a" with device count per cell
cell_id, grid_id, a
Sum grouped by grid_id to determine new device_count
grid_id, device_count
Calculate sum_diff as sum of differences between prior and posterior device_counts of grid_ids
Replace grid population estimates with new values
Increment iteration_nr

\ CLASS DIAGRAM


SilverCellConnectionProbabilitiesDataObject
+ ID: str = SilverCellConnectionProbabilitiesDO
+ SCHEMA: StructType
+ interface: ParquetInterface
+ partition_columns: list<str>
+ write(path:str = None, partition_columns: list<str> = None)
SilverGridDataObject
+ ID: str = SilverGridDO
+ SCHEMA: StructType
+ interface: ParquetInterface
+ partition_columns: list<str>
+ write(path:str = None, partition_columns: list<str> = None)
SilverEventFlaggedDataObject
+ ID: str = SilverEventFlaggedDO
+ SCHEMA: StructType
+ interface: ParquetInterface
+ partition_columns: list<str>
+ write(path:str = None, partition_columns: list<str> = None)
PresentPopulationEstimation
+ COMPONENT_ID: str = PresentPopulationEstimation
+ tolerance_period_s: int
+ data_period_start: str (timestamp)
+ data_period_end: str (timestamp)
+ time_point_gap_s: int
+ nr_of_user_id_partitions: int
+ nr_of_user_id_partitions_per_slice: int
+ max_iterations: int
+ min_difference_threshold: float
+ output_aggregation_level: str
+ zoning_dataset_id: str
+ zoning_hierarchical_level: str
+ output_aggregation_level: str
+ initalize_data_objects()
+ read()
+ transform()
+ write()
+ execute()
+ process_one_time_point(datetime)
+ filter_and_calculate_grid_to_cell_probabilitites(time_point:datetime): DataFrame
+ calculate_and_add_population_per_cell(slice_events_df: DataFrame, running_counts: Datafame, time_point: datetime): DataFrame
+ calculate_population_per_grid(devices_per_cell_df: DataFrame, grid_to_cell_prob_df: Datafame): DataFrame
+ generate_time_points(period_start: datetime, period_end: datetime, time_point_gap_s: int): List[datetime]
+ select_where_dates_include_time_point_window(time_point: datetime, tolerance_period_s: int, df: DataFrame): DataFrame
+ generate_slice_bounds(nr_of_partitions: int, partitions_per_slice: int, starting_id: int): List[tuple[int,int]]
PresentPopulationDataObject
+ ID: str = SilverPresentPopulationDO
+ SCHEMA: StructType
+ interface: ParquetInterface
+ partition_columns: list<str>
+ write(path:str = None, partition_columns: list<str> = None)

\ CODE STRUCTURE

The code structure follows the format set by the core package, and the general repository structure.

The location of the module script in the repository is as follows:

```
/multimno_internal/
 └──── multimno
     └──── components
         └──── execution
             └──── present_population
                 └──── present_population_estimation.py
```

present_population_estimation.py contains one class named PresentPopulationEstimation which is a subclass of Component.

- The PresentPopulationEstimation class overwrites __init__, transform and execute in the Component class.
- __init__ method initialises the data objects and reads the necessary values from the config file. transform performs all necessary transformations and calculation of activity statistics for daily data.
- transform contains calls to other smaller functions that perform the actual data manipulation.
- execute is responsible for calling read, write and transform for each unique date in the dataset. The processing is done one time point at a time.

5.2.21 MIDTERMPERMANENCESCORE

5.2.21.1 MODULE DESCRIPTION

- **Module Name:** MidtermPermanenceScore
- **Objectives:** Process Daily Permanence Score to obtain mid-term permanence score metrics, including frequency and regularity of stays, for different sub-monthly and sub-daily periods.
- **Functionality:** needed functionalities are outlined in the software requirement specifications:
  - 3.2.20 MidTermPermanenceEstimation
- **Data Inputs and Outputs:**
  - Input:
    - I.21 Daily Permanence Score
    - I.40 Holiday Dates Calendar
    - I.13 Cell Footprints
  - Output:
    - I.38 Mid-Term Permanence Metrics

5.2.21.2DEVELOPMENT DESIGN

- **Key Algorithms/Processes:**
  - Initialise data objects.
  - Parse and validate configuration parameters:

        - Read months for which the mid-term metrics will be computed.
        - Read the number of days before and after each month that will be used to compute the regularity metrics.
        - Read the hour that marks the start of a day.
        - Read the definition of each time interval (i.e., subdaily period), and reject non-allowed time intervals
            - It is not allowed, when interval_end is not 00:00, that interval_end < interval_start < day_start
            - (Except for night_time) It is not allowed that interval_start < day_start < interval_end
        - Read start and end days of the week defining the weekend.
        - Read each combination (day_type, time_interval) for which the mid-term metrics are to be computed in each month.
    - For each month to be studied:
        - Read Daily Permanence Score data necessary for the processing of this month.
        - Select only rows where DPS > 0 (i.e., DPS = 1).
        - Check that the duration of the time slots of each date of Daily Permanence Score data is compatible with the time intervals' start and end times (in particular, their minutes) by taking one row from each date. If they are not compatible, raise an error.
        - For each day type and time interval combination to be studied:
            - Filter out the time slots that do not belong to this time interval.
            - Assign the correct date that each time slot belongs to, according to the definition of a day following the hour that marks the start of each day: a time slot belongs to the date that contains its start time.
            - Filter out the time slots that do not belong to a date of the current day type:
                - In particular, work days are defined as those dates that are not part of the weekend and are not holidays.
            - Find, for each grid tile and device, the latest date in the regularity look-back dates with any time slot with DPS = 1, if it exists.
            - Find, for each grid tile and device, the earliest date in the regularity look-forward dates with any time slot with DPS = 1, if it exists.
            - For each device, calculate the number of time slots in this month, day type and time interval in which any grid tile had DPS = 1. The sum of these DPS values (equal to the count of these time slots) is equal to the "Device Observation" Mid-term Permanence Score. Similarly, the number of dates in which any grid tile in any time slot had DPS = 1 is equal to the "Device Observation" frequency. Store these values.
            - Compute the mid-term permanence score of a device and grid tile as the sum of the DPS values of its time slots in this month, day type and time interval.
            - For each device and grid tile (as well as unknown location) find the dates in this month, day type and time interval in which the DPS value of any time slot was equal to 1.
                - Compute the mid-term frequency of this device and location as the number of these dates.
                - Compute the day difference or gap between the consecutive dates of this list, considering the following: i) if there was a latest date in the regularity look-back dates, put it at the beginning of the ordered list, and if not, put the start date of the look-back period instead; ii) if there was an earliest date in the regularity look-forward dates, put

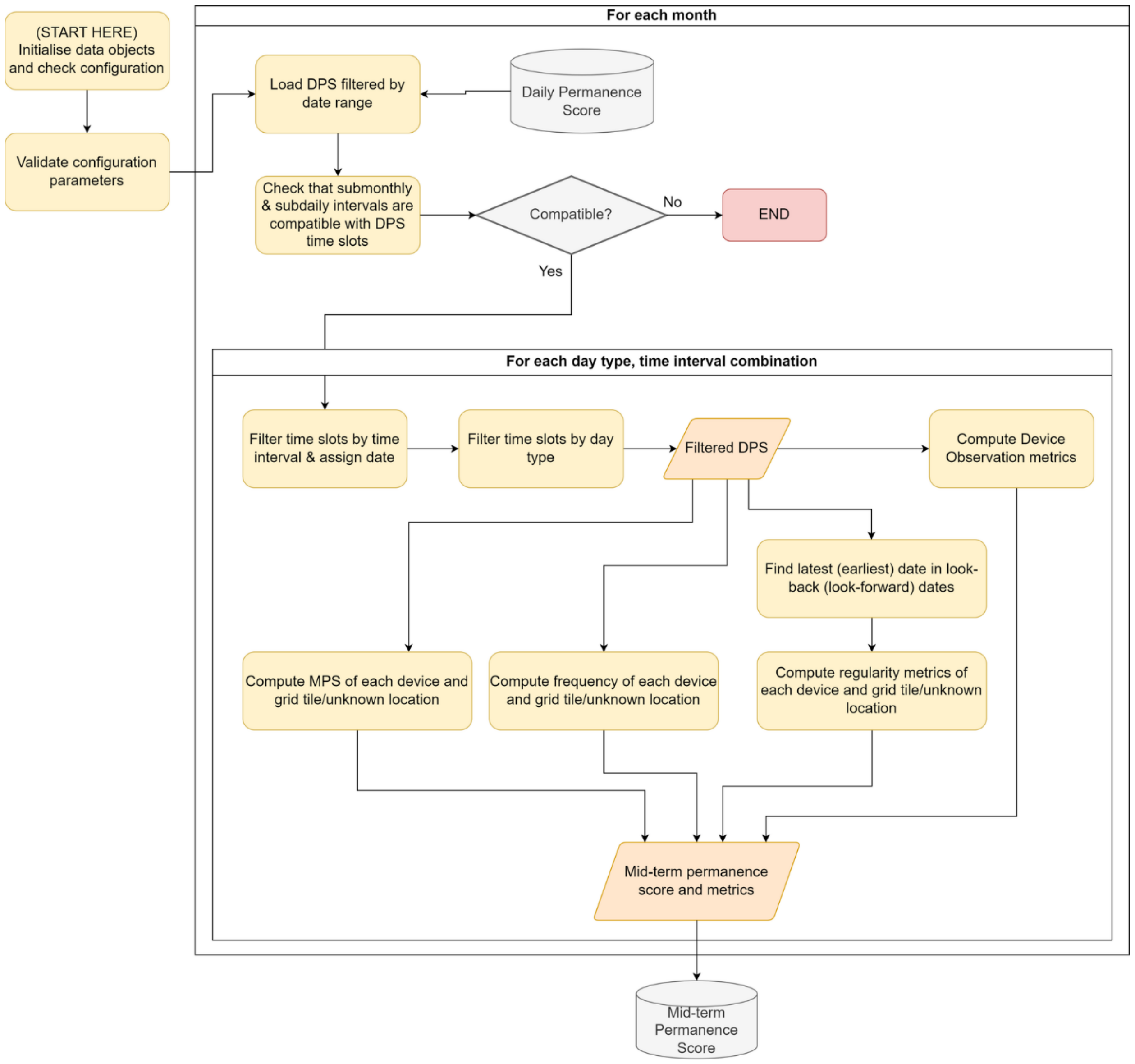
it at the end of the ordered list, and if not, put the end date of the look-forward period instead.

- Compute the regularity mean as the mean of these day distances.
- Compute the regularity standard deviation as the sample standard deviation of these day distances:

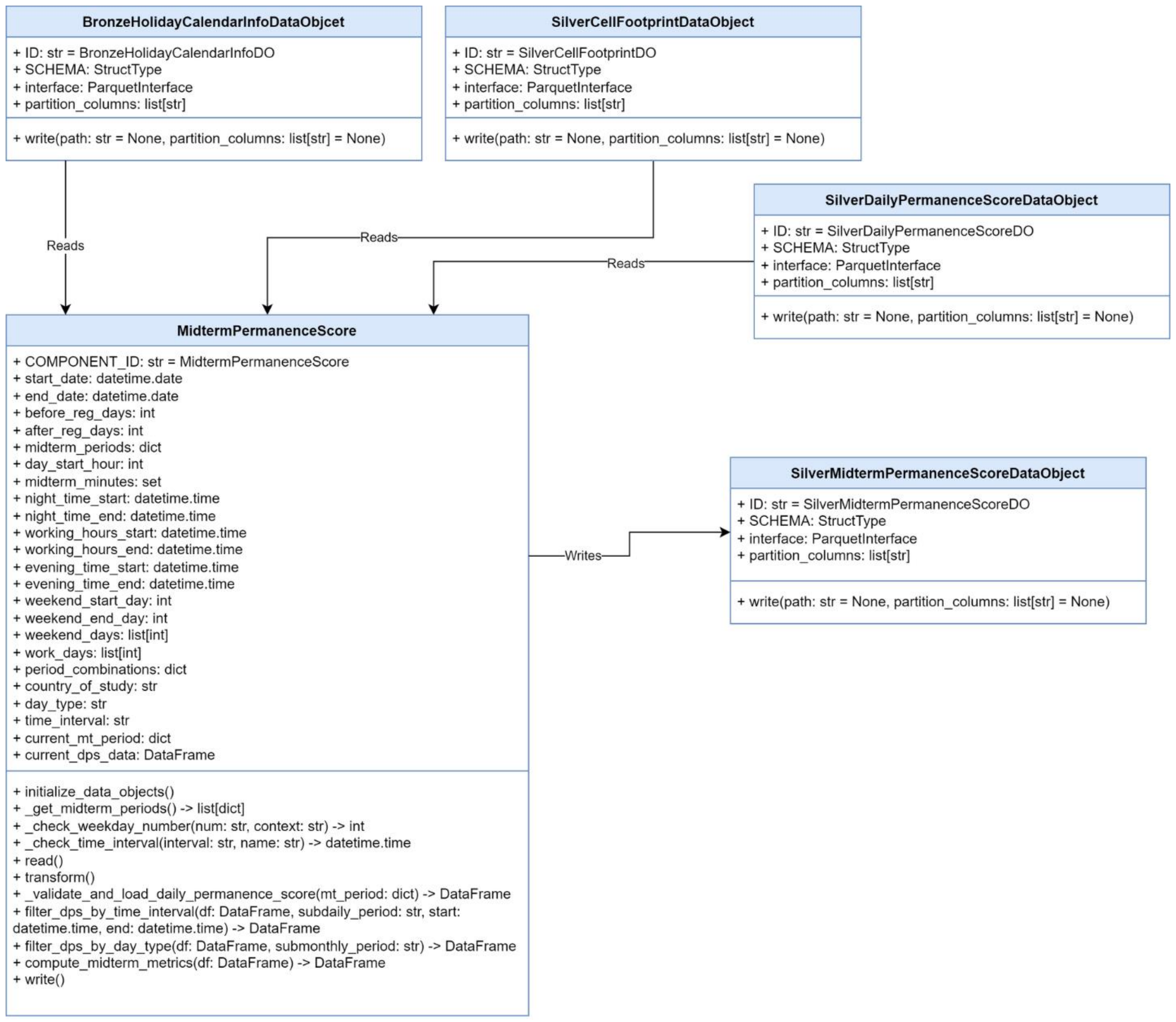
$$s = \sqrt{\frac{1}{N-1}\sum_{i=1}^{n}(x_i - \bar{x})}$$

- Save the mid-term permanence score and metrics computed for this month and all combinations of day types and time intervals considered.

- **Data flow diagram:**


(START HERE) Initialise data objects and check configuration
Validate configuration parameters
For each month
Load DPS filtered by date range
Daily Permanence Score
Check that submonthly & subdaily intervals are compatible with DPS time slots
Compatible?
No
END
Yes
For each day type, time interval combination
Filter time slots by time interval & assign date
Filter time slots by day type
Filtered DPS
Compute Device Observation metrics
Find latest (earliest) date in look-back (look-forward) dates
Compute MPS of each device and grid tile/unknown location
Compute frequency of each device and grid tile/unknown location
Compute regularity metrics of each device and grid tile/unknown location
Mid-term permanence score and metrics
Mid-term Permanence Score

- **Class diagram:**


BronzeHolidayCalendarInfoDataObjcet
+ ID: str = BronzeHolidayCalendarInfoDO
+ SCHEMA: StructType
+ interface: ParquetInterface
+ partition_columns: list[str]
+ write(path: str = None, partition_columns: list[str] = None)
SilverCellFootprintDataObject
+ ID: str = SilverCellFootprintDO
+ SCHEMA: StructType
+ interface: ParquetInterface
+ partition_columns: list[str]
+ write(path: str = None, partition_columns: list[str] = None)
SilverDailyPermanenceScoreDataObject
+ ID: str = SilverDailyPermanenceScoreDO
+ SCHEMA: StructType
+ interface: ParquetInterface
+ partition_columns: list[str]
+ write(path: str = None, partition_columns: list[str] = None)
Reads
Reads
Reads
MidtermPermanenceScore
+ COMPONENT_ID: str = MidtermPermanenceScore
+ start_date: datetime.date
+ end_date: datetime.date
+ before_reg_days: int
+ after_reg_days: int
+ midterm_periods: dict
+ day_start_hour: int
+ midterm_minutes: set
+ night_time_start: datetime.time
+ night_time_end: datetime.time
+ working_hours_start: datetime.time
+ working_hours_end: datetime.time
+ evening_time_start: datetime.time
+ evening_time_end: datetime.time
+ weekend_start_day: int
+ weekend_end_day: int
+ weekend_days: list[int]
+ work_days: list[int]
+ period_combinations: dict
+ country_of_study: str
+ day_type: str
+ time_interval: str
+ current_mt_period: dict
+ current_dps_data: DataFrame
+ initialize_data_objects()
+ _get_midterm_periods() -> list[dict]
+ _check_weekday_number(num: str, context: str) -> int
+ _check_time_interval(interval: str, name: str) -> datetime.time
+ read()
+ transform()
+ _validate_and_load_daily_permanence_score(mt_period: dict) -> DataFrame
+ filter_dps_by_time_interval(df: DataFrame, subdaily_period: str, start: datetime.time, end: datetime.time) -> DataFrame
+ filter_dps_by_day_type(df: DataFrame, submonthly_period: str) -> DataFrame
+ compute_midterm_metrics(df: DataFrame) -> DataFrame
+ write()
Writes
SilverMidtermPermanenceScoreDataObject
+ ID: str = SilverMidtermPermanenceScoreDO
+ SCHEMA: StructType
+ interface: ParquetInterface
+ partition_columns: list[str]
+ write(path: str = None, partition_columns: list[str] = None)

- **Code Structure:** The code structure follows the format set by the core package, and the general repository structure. The location of the module script in the repository is as follows:

```
/multimno_internal/
└── src
    └── components
        └── execution
            └── midterm_permanence_score
                └── midterm_permanence_score.py
```

  - midterm_permanence_score.py contains one class named MidtermPermanenceScorewhich is a subclass of Component. It also contains the function frequency_and_regularity, a PySpark UDF that computes the mid-term frequency and regularity metrics for each device and grid tile or unknown location.
  - The MidtermPermanenceScoreclass overrides some of the methods of Component
    - The __init__ method first call its parent's __init__ method, which sets up the Spark session, initialises data objects and reads the configuration file.
    - The transform method handles all the logic behind the component.
  - The MidtermPermanenceScore also has the following methods:
    - _get_midterm_periods returns a list of dictionaries, where each dictionary contains the start and end date of the month of study of each mid-term period, together with the start and end date of the additional dates used for computing the regularity metrics.
    - _check_weekday_number parses and validates a numerical day of the week.
    - _check_time_interval parses and validates the start or end of a time interval/sub-daily period.
    - _validate_and_load_daily_permanence_score reads the Daily Permanence Data Object data that will be used for a particular mid-term period and validates that the time slot duration of every date to be used is compatible with the time intervals defined in the configuration file.
    - filter_dps_by_time_interval filters out the time slots that do not belong to a particular time interval, and adds the "date" column, assigning each time slot to its corresponding date according to the day start hour parameter.
    - filter_dps_by_day_type filters out the time slots that do not belong to a particular day type, based on the "date" column previously generated by the filter_dps_by_time_interval method.
    - compute_midterm_metrics computes the mid-term permanence score and metrics.

5.2.22 LONGTERMPERMANENCESCORE

5.2.22.1 MODULE DESCRIPTION

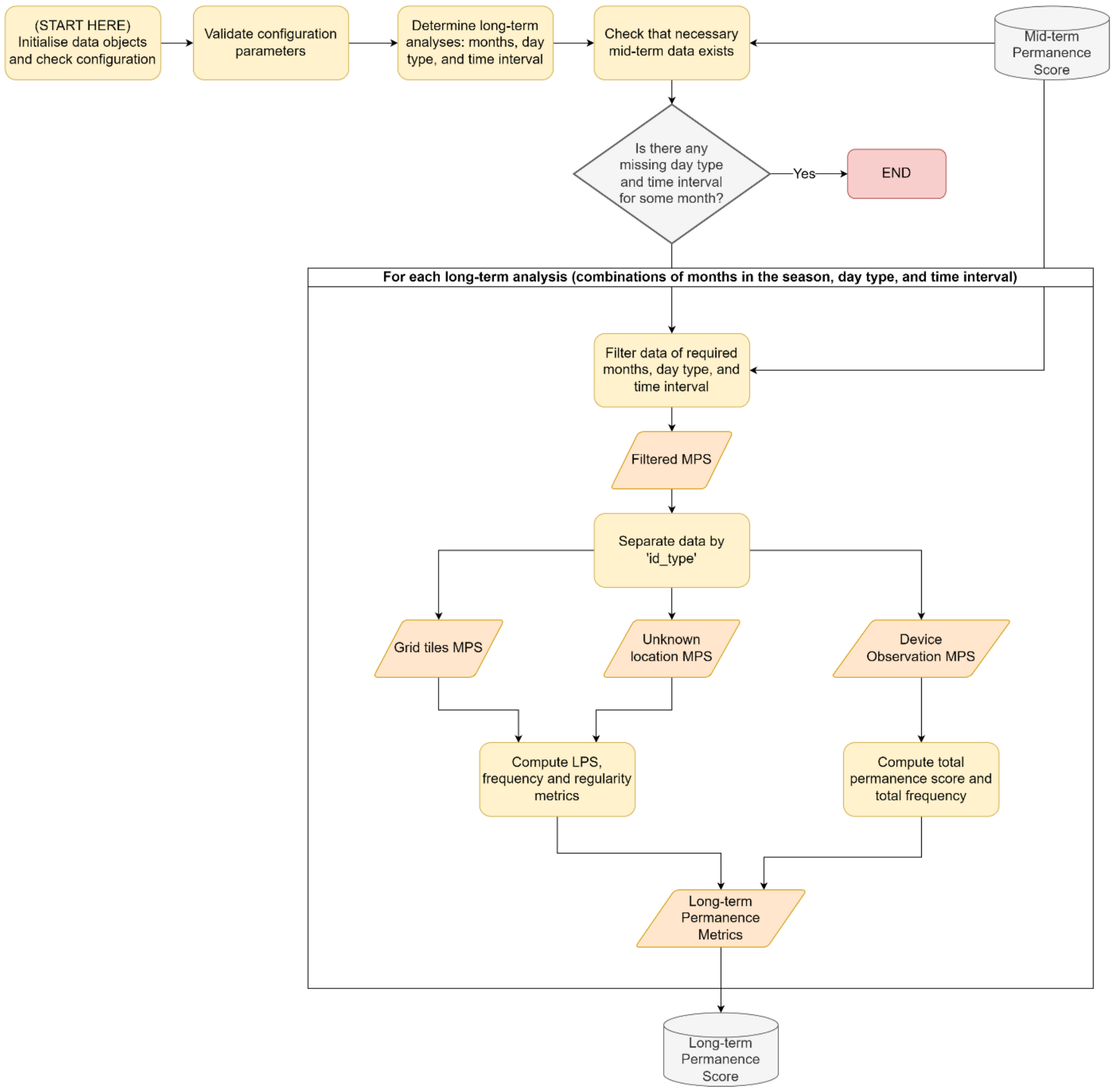
- **Module Name:** LongtermPermanenceScore
- **Objectives:** Process Mid-term Permanence Score to obtain long-term permanence score metrics, including total frequency, mean and standard deviation of mid-term frequency, and mean and standard deviation of the mid-term regularity mean metric, for different sub-yearly, sub-monthly, and sub-daily period combinations.
- **Functionality:** needed functionalities are outlined in the software requirement specifications:
  - 3.2.21 LongTermPermanenceEstimation

- **Data Inputs and Outputs:**
    - Input:
        - I.38 Mid-Term Permanence Metrics
    - Output:
        - I.39 Long-Term Permanence Metrics

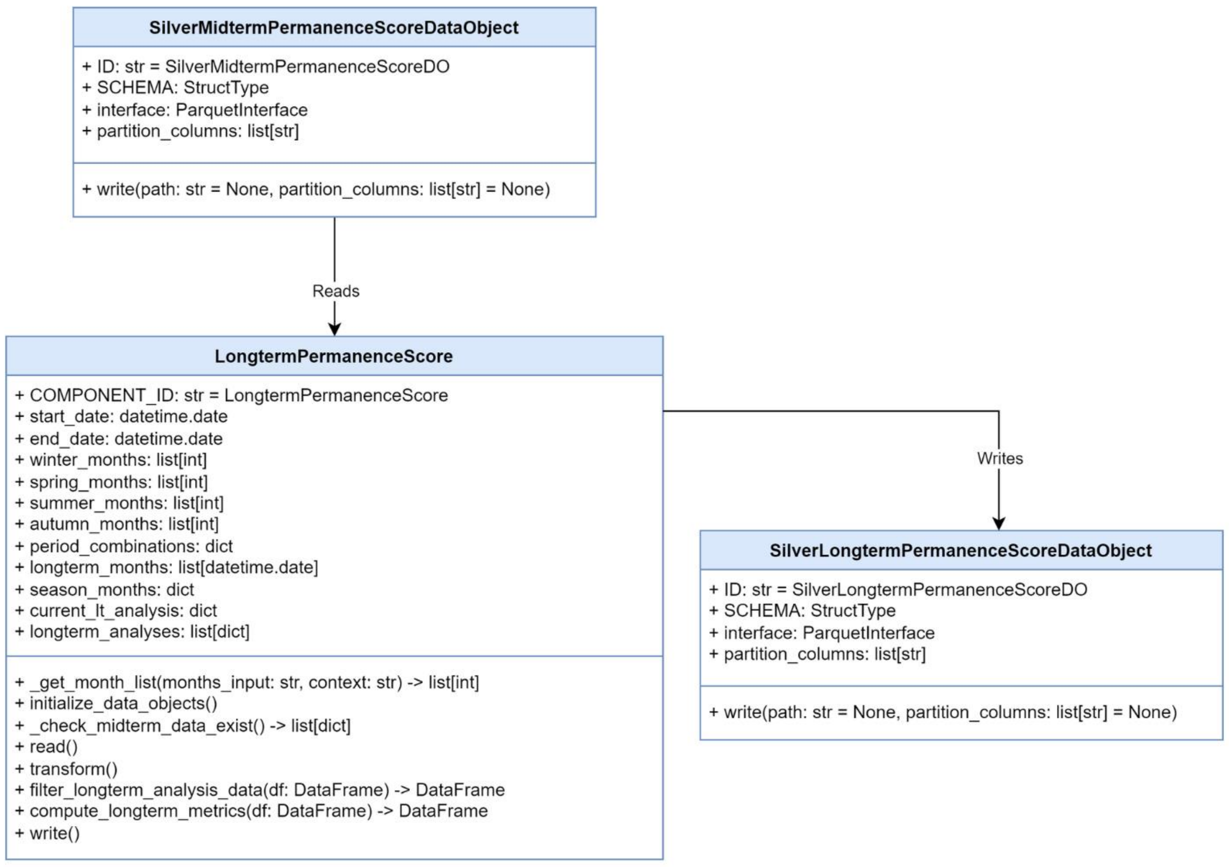
5.2.22.2 DEVELOPMENT DESIGN

- **Key Algorithms/Processes:**
    - Initialise data objects.
    - Parse and validate configuration parameters:
        - Read initial and final month that define the complete long-term analysis.
        - Read the months that are assigned to each of the four seasons: winter, spring, summer, and autumn, as integers from 1 to 12. They must not be repeated in the same season or appear in more than one season.
        - Read and validate all desired combinations of season, day type, and time interval (i.e., sub-yearly, sub-monthly, and sub-daily periods) for which the long-term permanence metrics will be computed separately.
        - Check that, if some season has been requested, it has been assigned via configuration at least one month. If not, raise an error.
        - For each season, day type, and time interval, determine the concrete set of months between the initial and final month (both inclusive) that belong to this combination.
    - For each season, day type, and time interval combination, check that for its assigned months there is mid-term permanence score data available. If not, warn the user and stop the component.
    - For each season, day type, and time interval combination:
        - Compute the long-term permanence score and total frequency of each device and grid tile / unknown location / device observation as the sum of the mid-term permanence score and mid-term frequency respectively.
        - Compute the mean and standard deviation of the mid-term frequency, as well as the mean and standard deviation of the mid-term regularity mean metric for each device and grid tile / unknown location.

- **Data flow diagram:**


(START HERE) Initialise data objects and check configuration
Validate configuration parameters
Determine long-term analyses: months, day type, and time interval
Check that necessary mid-term data exists
Mid-term Permanence Score
Is there any missing day type and time interval for some month?
Yes
END
For each long-term analysis (combinations of months in the season, day type, and time interval)
Filter data of required months, day type, and time interval
Filtered MPS
Separate data by 'id_type'
Grid tiles MPS
Unknown location MPS
Device Observation MPS
Compute LPS, frequency and regularity metrics
Compute total permanence score and total frequency
Long-term Permanence Metrics
Long-term Permanence Score

- **Class diagram:**



SilverMidtermPermanenceScoreDataObject
+ ID: str = SilverMidtermPermanenceScoreDO
+ SCHEMA: StructType
+ interface: ParquetInterface
+ partition_columns: list[str]
+ write(path: str = None, partition_columns: list[str] = None)
Reads
LongtermPermanenceScore
+ COMPONENT_ID: str = LongtermPermanenceScore
+ start_date: datetime.date
+ end_date: datetime.date
+ winter_months: list[int]
+ spring_months: list[int]
+ summer_months: list[int]
+ autumn_months: list[int]
+ period_combinations: dict
+ longterm_months: list[datetime.date]
+ season_months: dict
+ current_lt_analysis: dict
+ longterm_analyses: list[dict]
+ _get_month_list(months_input: str, context: str) -> list[int]
+ initialize_data_objects()
+ _check_midterm_data_exist() -> list[dict]
+ read()
+ transform()
+ filter_longterm_analysis_data(df: DataFrame) -> DataFrame
+ compute_longterm_metrics(df: DataFrame) -> DataFrame
+ write()
Writes
SilverLongtermPermanenceScoreDataObject
+ ID: str = SilverLongtermPermanenceScoreDO
+ SCHEMA: StructType
+ interface: ParquetInterface
+ partition_columns: list[str]
+ write(path: str = None, partition_columns: list[str] = None)

- **Code Structure:** The code structure follows the format set by the core package, and the general repository structure. The location of the module script in the repository is as follows:

```
/multimno_internal/
└── src
    └── components
        └── execution
            └── longterm_permanence_score
                └── longterm_permanence_score.py
```

  - longterm_permanence_score.py contains one class named LongtermPermanenceScorewhich is a subclass of Component.
  - The LongtermPermanenceScoreclass overrides some of the methods of Component
    - The __init__ method first call its parent's __init__ method, which sets up the Spark session, initialises data objects and reads the configuration file.
    - The transform method handles all the logic behind the component.
  - The LongtermPermanenceScore also has the following methods:
    - _get_month_list parses and validates a list of integers representing the months that will comprise a season and returns them as a list of integers between 1 and 12.
    - _check_midterm_data_exist checks that, for each combination of season, day type and time interval, the mid-term permanence score of the months that belong to that combination has been computed for those months, day type, and time interval. If there is some data missing, the component stops and warns the user of the missing data. If the check passes, the function returns a list of dictionaries, each containing the season, day type, time interval, and list of months that form an individual long-term analysis.
    - filter_longterm_analysis_data filters the mid-term permanence score data that is going to be used for the current long-term analysis being performed, by selecting only the necessary months, day types, and time intervals.
    - compute_longterm_metrics calculates the long-term permanence score and metrics for the current long-term analysis being performed.

5.2.23 USUALENVIRONMENTLABELING

5.2.23.1 MODULE DESCRIPTION

- **Module Name:** UsualEnvironmentLabeling
- **Objectives:** The objective of this module is to get measures on a large time scale (e.g. 6 months, 1 year) at the device level. For each device, this module aims to get as output a proxy for its Usual Environment and a tentative identification of meaningful locations - Home Location and Work/Study place. Usual Environment and Meaningful Locations (home, work) in the country of study are represented by INSPIRE grid id values. Usual Environment and Meaningful Locations abroad are represented by MCC codes of corresponding countries.
- **Functionality:** needed functionalities are outlined in the software requirement specifications:
  - 3.2.22 UsualEnvironmentLabeling
- **Data Inputs and Outputs:**
  - Input:
    - I.39 Long-Term Permanence Metrics

- Output:
    - I.37 UE Labels
    - I.43 Labeling Quality Metrics

5.2.23.2 DEVELOPMENT DESIGN

- **Key Algorithms/Processes:**

Initialisation:

1. Read configuration parameters for component processing, date range for which to read dataset (start month and end month), and thresholds to consider.
2. Clear output location if configured.
3. Load input data object for Long-term Permanence Metrics.
4. Initialize the output data objects for UE Labels and Labeling Quality Metrics.

Processing:

1. Get specified start date and end date:
    - Find the start_date of the specified period by selecting the first day of the *start_month*
    - Find the end_date of the specified period by selecting the last day of the *end_month*
2. Filter Long-term Permanence Metrics dataset to required time range by filtering 'start_date' = start_date and 'end_date' = end_date. Set this filtered Long-term Permanence Metrics dataset as the new Long-term Permanence Metrics dataset to be used from here onwards.
3. Check that all of the combinations of values for the columns 'day_type' and 'time_interval' which are required for Usual Environment and other meaningful location labeling are present (at least once) in the Long-term Permanence Metrics dataset
4. If some of these combinations of values for the columns 'day_type' and 'time_interval' are not present in the input data object, exit method with an error message.
5. Detect 'rarely observed devices' and 'discountinously observed devices':
    - Filter Long-term Permanence Metrics dataset by 'id_type' = 'device_observation', 'day_type' = 'all_days' and 'time_interval' = 'all_intervals' to obtain Device Observation Metrics dataset.
    - Now, for 'rarely observed devices':
        - Filter rows of Device Observation Metrics dataset for which 'lps' < *total_ps_threshold.*
        - Find the list of unique values of 'user_id' column from the resulting filtered Device Observation Metrics dataset.
        - Count the number of discarded devices and save it for later quality metrics generation
    - Now, for 'discountinously observed devices':
        - Filter rows of Device Observation Metrics dataset for which 'total_frequency' < *freq_days_threshold.*
        - Find the list of unique values of 'user_id' column from the resulting filtered Device Observation Metrics dataset.
        - Count the number of discarded devices and save it for later quality metrics generation.
6. Discard from the Long-term Permanence Metrics all those rows with a 'user_id' value that is included either in the 'rarely observed devices' list or in the 'discountinously observed devices'. Set this filtered Long-term Permanence Metrics dataset as the new Long-term Permanence Metrics dataset to be used from here onwards.
7. Use Generic Labeling function, explained in the corresponding section*, to produce the Usual Environment Tiles Dataset. Following is the summary of the process:
    1. Remove tiles after the gap between consecutive 'lps' values is more than *ue_gap_ps_threshold* parameter (gap cut preprocessing).

    2. For remaining tiles, apply UE labeling rules iteratively with using only unlabeled tiles for each new rule iteration
8. Format, repartition and write Usual Environment tiles dataset.
9. If configured, proceed with Meaningful Locations labeling (home and work currently). Each labeling process includes following steps:
    1. Read Usual Environment tiles. Only these tiles will be used for Meaningful Location detection.
    2. Use Generic Labeling function to produce the Home (Work) tiles dataset:
        1. Remove tiles after the gap between consecutive 'lps' values is more than *home(work)_gap_ps_threshold* parameter (gap cut preprocessing).
        2. For remaining tiles, apply corresponding labeling rules iteratively. If any tiles are labeled, stop execution. All following rules are not applied
    3. Format, repartition and write Labeled tiles dataset.
10. Generate Labeling Quality Metrics dataset:
    1. Load and filter the current labeled tiles dataset
    2. Prepare a reference set of all tiles
        - Filter the Long Term Permanence dataset to include only those tiles that fall under an “all-day”/“all-time-interval” period combination (excluding device observations).
        - This defines the universe of possible tiles for each user.
    3. Compute the total tile count per user
    4. Count how many tiles were labeled per user and label rule in current labeled tiles dataset
    5. Create a special grouping for location-based comparisons:
        - Reassign a simplified label rule (“loc_na” vs. “ue_na”) based on whether the tile label is “ue” (usual environment) or not.
        - Count the number of distinct grid IDs within each user’s group.
        - Join with the total tile count for each user to calculate the difference between all tiles and those assigned to that location or environment group (the resulting “count” column represents, for example, the unlabeled portion or complementary set).
    6. Unify the two sets of metrics
    7. Add column to mark if a device has UE labels abroad and additional metric code - ‘ue_abroad’
    8. Aggregate metrics across label rules:
        - Groups by the label rule (or the special location-based rules) and computes a sum, minimum, maximum, and average of the tile counts within each rule grouping.
        - These metrics offer insight into how many tiles, at minimum or maximum, were labeled or excluded across different rules per device.
    9. Apply schema casting and write metrics dataset

\ *GENERIC LABELING PROCESS DESCRIPTION:

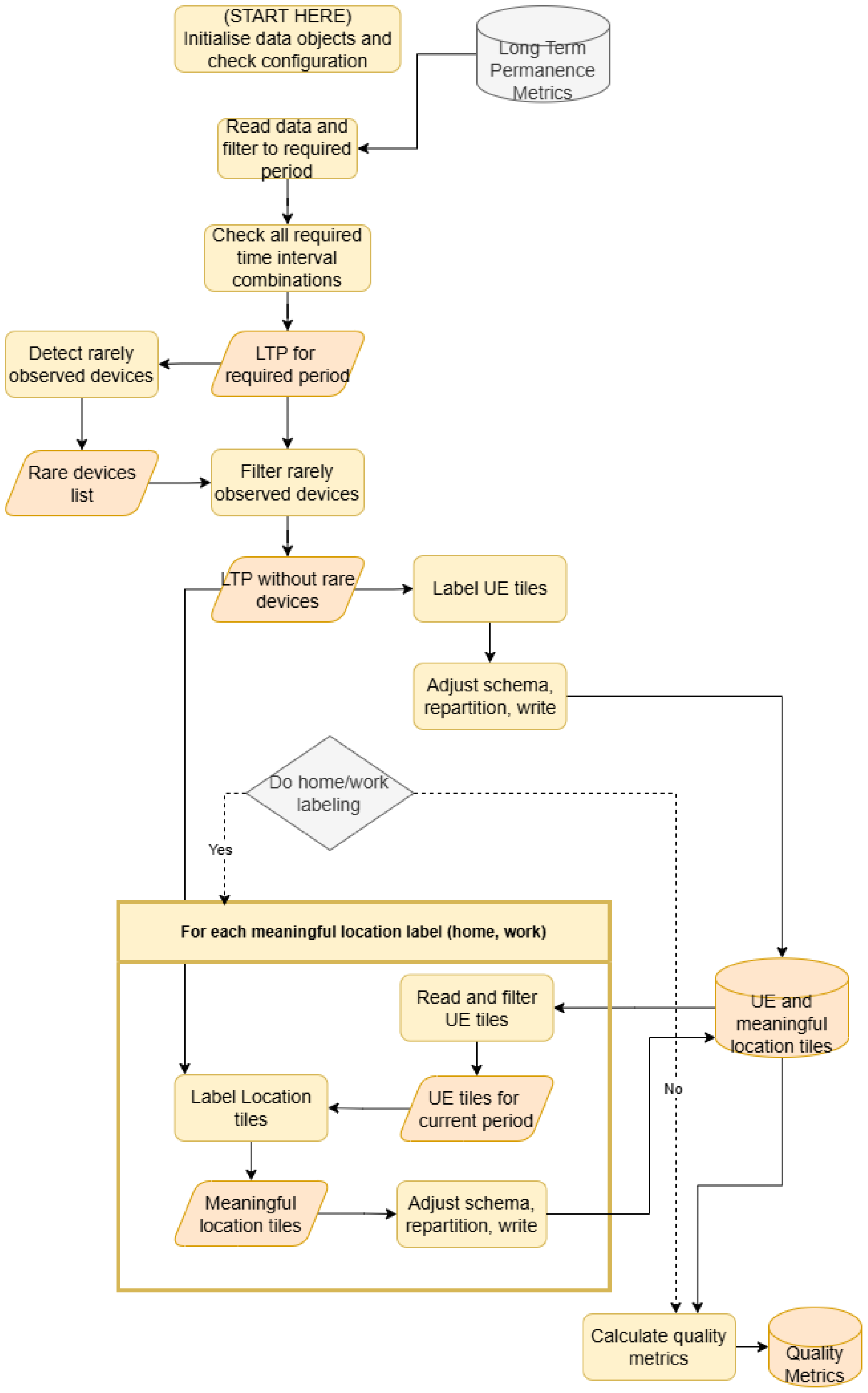
1. Read the relevant configuration values
   The function begins by extracting information from the provided labeling configuration object. This includes:
    - A label code (e.g., "home", "work", or "ue")
    - The permanence gap threshold value to use for cutting tiles
    - Whether the gap threshold is absolute or relative
    - The day type and time interval combination used for filtering
    - Set of labeling rules with the following information
        - A unique code identifying the rule
        - A threshold value (e.g., a certain percentage)
        - A check type which determines which column should be compared to threshold - permanence or frequency

- A condition that specifies when to stop applying further rules - either as soon as at least one tile was labeled or until all rules have been applied
- The day type and time interval for that rule.

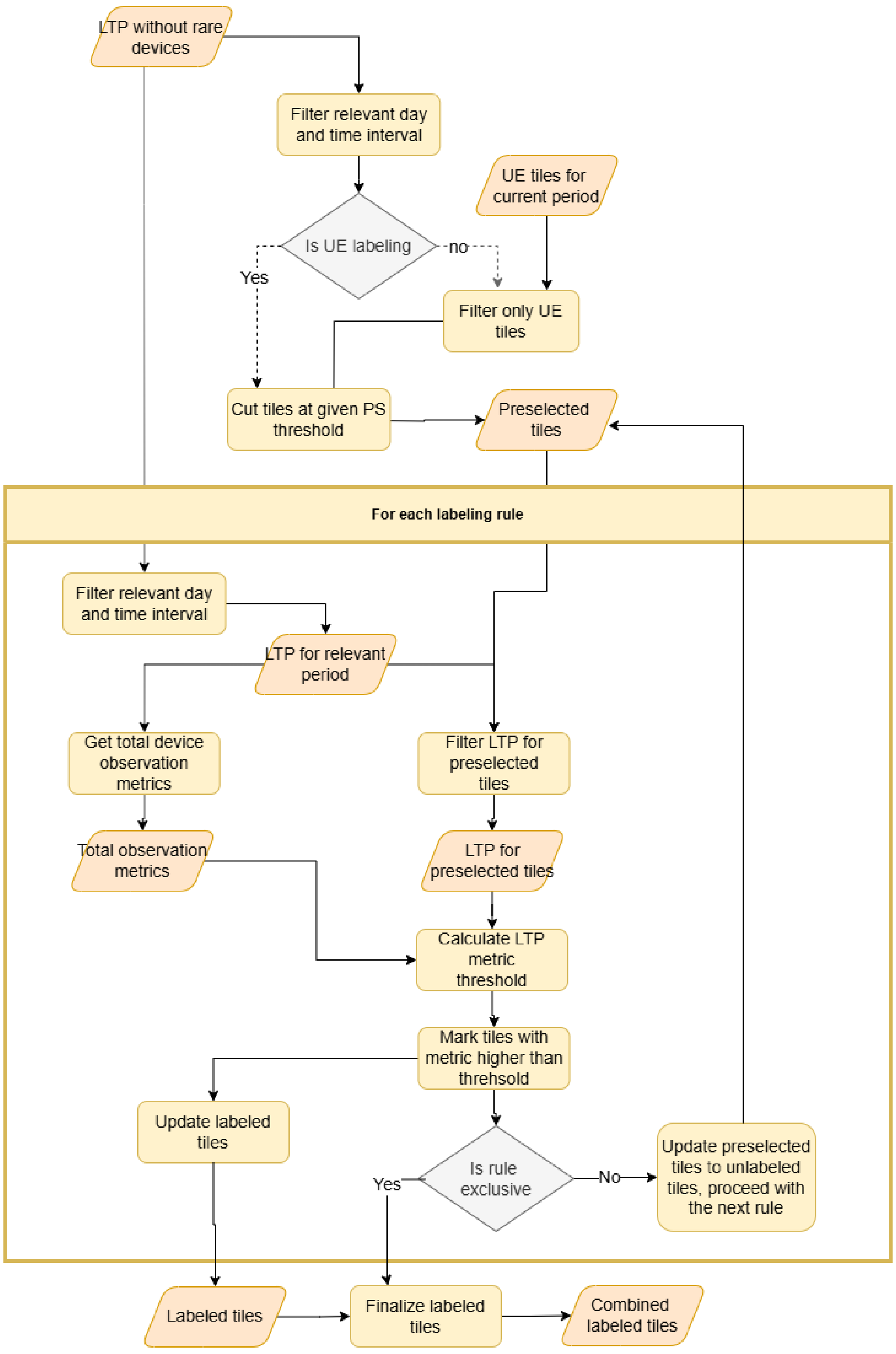
2. Filter the main dataset according to the initial period combination
   Using the day type, and time interval from the configuration, the function filters the initial Long Term Permanence dataset so that only the rows matching these criteria remain.
3. Optionally filter only Usual Environment tiles.
4. Generate the "preselected" tiles.
   The function then calls a subfunction (cut_tiles_at_gap) that:
   - Sorts each user's tiles by their permanence scores (LPS).
   - Finds any sharp drop in the scores that meets or exceeds the chosen threshold.
   - Retains only the tiles before that large drop.
5. Iterate over the labeling rules.
   For each rule:
   - If it is not the first rule, the function filters out any tiles that were already labeled in a previous step.
   - The main Long Term Permanence dataset is filtered again according to the new rule's period combination.
   - Rows corresponding to device observations (instead of grid tiles) are separated out so that the total device-level score can be determined later.
   - A join is performed so that only the relevant tiles (from the preselected set) are left
   - Another subfunction (calculate_device_abs_threshold) calculates an "absolute" threshold by taking a given percentage of each device's total value of a relevant for current rule metric (permanence, frequency or regularity).
   - A new column indicates whether each tile meets (or exceeds) this threshold, effectively marking it as labeled.
   - If the rule is meant to label only devices that had none of their tiles labeled so far and at least one tile gets labeled, the process halts.
   - If the rule is meant to attempt to label all unlabeled tiles, execution continues to the next rule for tiles which are left unlabeled by the current rule
6. Combine and finalize the labeled results.
   After processing all rules:
   - The function unifies the labeled tiles from each rule into one dataset.
   - A final label (e.g., "home" or "work") is attached according to the label code obtained from the configuration.

\ DATA FLOW DIAGRAMS:

- **KEY ALGORITHMS/PROCESSES (GENERAL VIEW):**

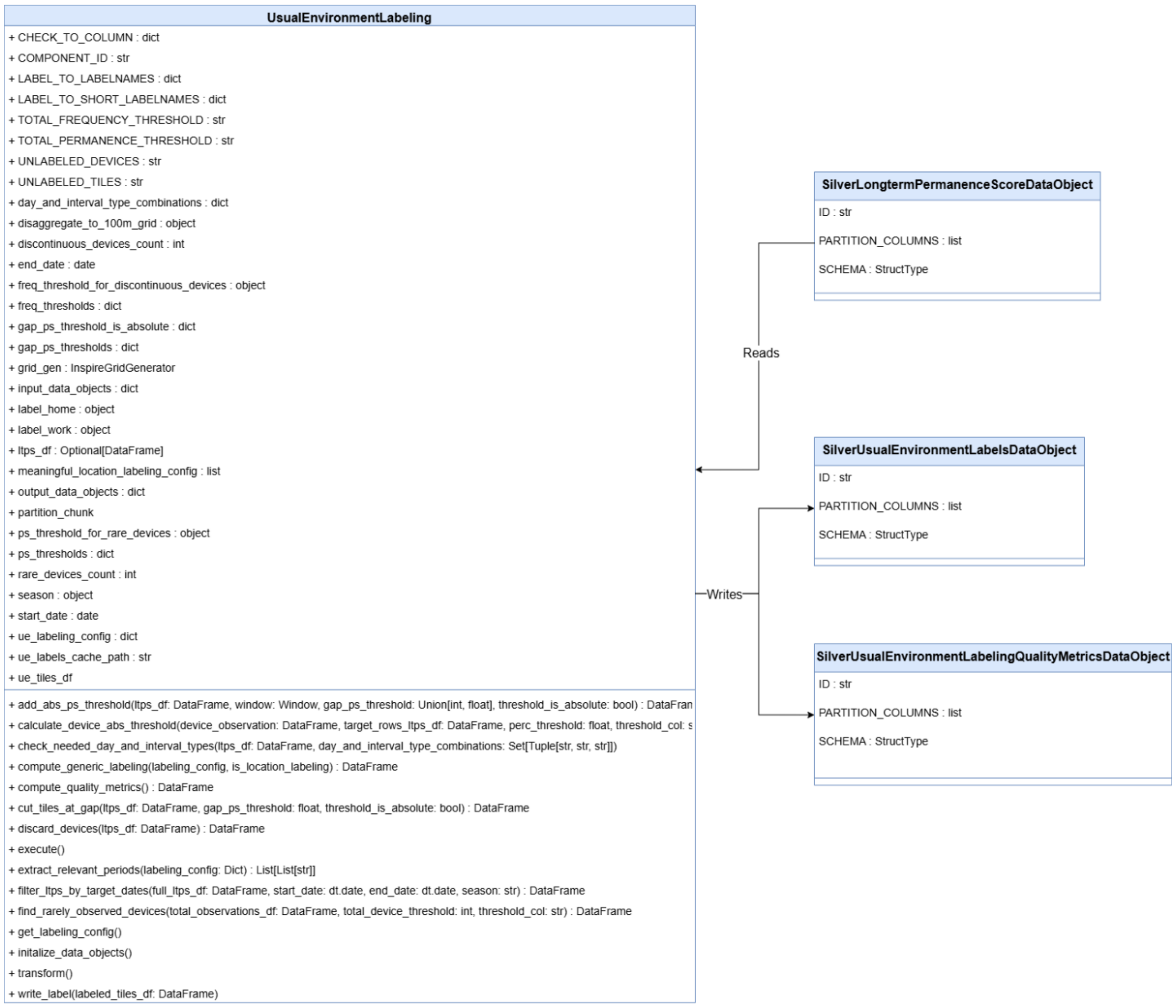

(START HERE) Initialise data objects and check configuration
Long Term Permanence Metrics
Read data and filter to required period
Check all required time interval combinations
LTP for required period
Detect rarely observed devices
Rare devices list
Filter rarely observed devices
LTP without rare devices
Label UE tiles
Adjust schema, repartition, write
Do home/work labeling
Yes
No
For each meaningful location label (home, work)
Read and filter UE tiles
UE and meaningful location tiles
UE tiles for current period
Label Location tiles
Meaningful location tiles
Adjust schema, repartition, write
Calculate quality metrics
Quality Metrics

- **FUNCTION DETAILS – GENERIC LABELING:**



LTP without rare devices
Filter relevant day and time interval
UE tiles for current period
Is UE labeling
no
Yes
Filter only UE tiles
Cut tiles at given PS threshold
Preselected tiles
For each labeling rule
Filter relevant day and time interval
LTP for relevant period
Get total device observation metrics
Filter LTP for preselected tiles
Total observation metrics
LTP for preselected tiles
Calculate LTP metric threshold
Mark tiles with metric higher than threhsold
Update labeled tiles
Is rule exclusive
Yes
No
Update preselected tiles to unlabeled tiles, proceed with the next rule
Labeled tiles
Finalize labeled tiles
Combined labeled tiles

\ CLASS DIAGRAM:


UsualEnvironmentLabeling
+ CHECK_TO_COLUMN : dict
+ COMPONENT_ID : str
+ LABEL_TO_LABELNAMES : dict
+ LABEL_TO_SHORT_LABELNAMES : dict
+ TOTAL_FREQUENCY_THRESHOLD : str
+ TOTAL_PERMANENCE_THRESHOLD : str
+ UNLABELED_DEVICES : str
+ UNLABELED_TILES : str
+ day_and_interval_type_combinations : dict
+ disaggregate_to_100m_grid : object
+ discontinuous_devices_count : int
+ end_date : date
+ freq_threshold_for_discontinuous_devices : object
+ freq_thresholds : dict
+ gap_ps_threshold_is_absolute : dict
+ gap_ps_thresholds : dict
+ grid_gen : InspireGridGenerator
+ input_data_objects : dict
+ label_home : object
+ label_work : object
+ ltps_df : Optional[DataFrame]
+ meaningful_location_labeling_config : list
+ output_data_objects : dict
+ partition_chunk
+ ps_threshold_for_rare_devices : object
+ ps_thresholds : dict
+ rare_devices_count : int
+ season : object
+ start_date : date
+ ue_labeling_config : dict
+ ue_labels_cache_path : str
+ ue_tiles_df
+ add_abs_ps_threshold(ltps_df: DataFrame, window: Window, gap_ps_threshold: Union[int, float], threshold_is_absolute: bool) : DataFran
+ calculate_device_abs_threshold(device_observation: DataFrame, target_rows_ltps_df: DataFrame, perc_threshold: float, threshold_col: s
+ check_needed_day_and_interval_types(ltps_df: DataFrame, day_and_interval_type_combinations: Set[Tuple[str, str, str]])
+ compute_generic_labeling(labeling_config, is_location_labeling) : DataFrame
+ compute_quality_metrics() : DataFrame
+ cut_tiles_at_gap(ltps_df: DataFrame, gap_ps_threshold: float, threshold_is_absolute: bool) : DataFrame
+ discard_devices(ltps_df: DataFrame) : DataFrame
+ execute()
+ extract_relevant_periods(labeling_config: Dict) : List[List[str]]
+ filter_ltps_by_target_dates(full_ltps_df: DataFrame, start_date: dt.date, end_date: dt.date, season: str) : DataFrame
+ find_rarely_observed_devices(total_observations_df: DataFrame, total_device_threshold: int, threshold_col: str) : DataFrame
+ get_labeling_config()
+ initalize_data_objects()
+ transform()
+ write_label(labeled_tiles_df: DataFrame)
Reads
Writes
SilverLongtermPermanenceScoreDataObject
ID : str
PARTITION_COLUMNS : list
SCHEMA : StructType
SilverUsualEnvironmentLabelsDataObject
ID : str
PARTITION_COLUMNS : list
SCHEMA : StructType
SilverUsualEnvironmentLabelingQualityMetricsDataObject
ID : str
PARTITION_COLUMNS : list
SCHEMA : StructType

\ CODE STRUCTURE:

The code structure follows the format set by the core package, and the general repository structure. The location of the module script in the repository is as follows:

```
/multimno_internal/
└── src
    └── components
        └── execution
            └── user_environment_labeling
                └── user_environment_labeling.py
```

- user_environment_labeling.py contains one class named UserEnvironmentLabeling which is a subclass of Component. The UserEnvironmentLabeling class overrides some of the methods of Component.
- The __init__ method first call its parent's __init__ method, which sets up the Spark session, initialises data objects and reads the configuration file.
- transform method performs all necessary filtering and transformations pertaining to the user environment labeling calculation.

5.2.24 USUALENVIRONMENTAGGREGATION

5.2.24.1 MODULE DESCRIPTION

- **Module Name:** UEAggregation
- **Objectives:** Aggregate individual devices usual environment tiles over reference INSPIRE grid.
- **Functionality:** The component takes Usual Environment Labels dataset for the given period and performs aggregation of individual devices over grid tiles. The component computes device weight in each tile in its usual environment either based on assumption of uniform distribution so that all tiles have the same weight or takes into account prior probabilities from land use information. Tile weights of all devices are then summed up per each tile.
    - Functionality specification: 3.2.23 UsualEnvironmentAggregation
- **Data Inputs and Outputs:**
    - Inputs:
        - I.37 UE Labels
        - I.31 Enriched Grid
    - Outputs:
        - I.44 Aggregated Usual Environments

5.2.24.2 DEVELOPMENT DESIGN

- **Key Algorithms/Processes:**

Initialisation:

1. Read configuration parameters for component processing, date range for which to read labeling dataset, either to use land use information for device weights.
2. Clear the destination directory if configured.
3. Load input data objects for UE labels, and, optionally, enriched grid
4. Initialize the output data object for aggregated usual environment.

Processing:

1. Filter Usual Environment Labels dataset to required time range
2. Assign tile weights (tw) to each tile in device usual environment
    1. If landuse information is not used, all tile weights are assigned as 1.
    2. If landuse information is used, tile weights are assigned using landuse prior probabilities values.
3. Repeat next steps for all tiles for UE counts and for each label type (home, work):
    1. Calculate device weights weigth_td for each tile as:

    weight_td (grid_i) = tw (grid_i) / Σj(tw (grid_j))

    Where:

    grid_i: is a target grid tile, i.e., a tile that is included in the current device's usual environment, and for which we are calculating pue.

    weight_td (grid_i): is the weight of the device in the target grid tile (grid_1).

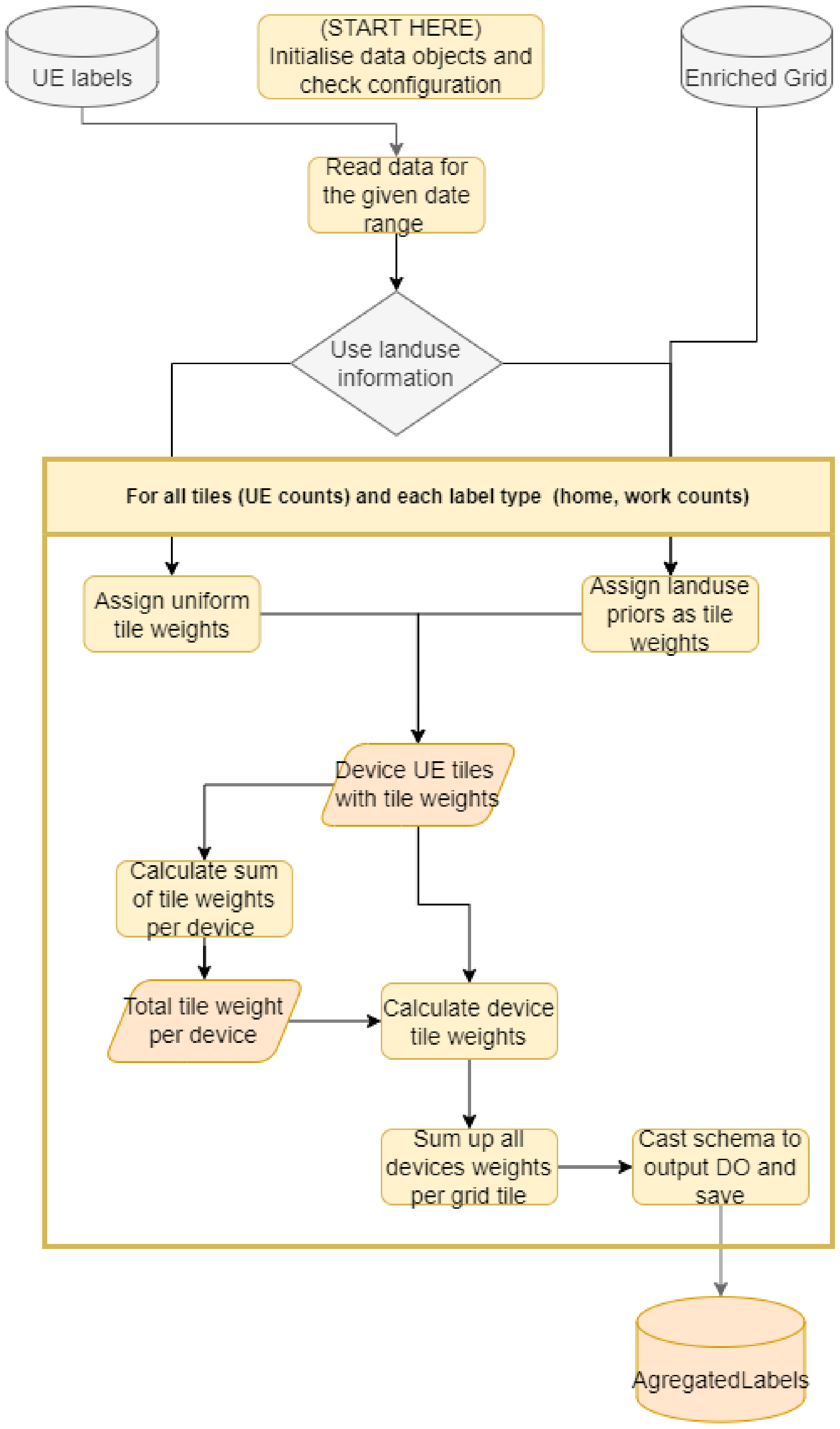
    tw (grid_i): is the tile weight for target grid tile (grid_1), either 1 or coming from the enriched grid data.

    Σj(tw (grid_j)): is the sum of the tile weights of all the grid tiles in the device's usual environment.

 b. Sum up all device weights per tile using grid_id

 c. Write aggregated results as a parquet partitioned by start and end date

- **Data flow diagram:**


UE labels
(START HERE) Initialise data objects and check configuration
Enriched Grid
Read data for the given date range
Use landuse information
For all tiles (UE counts) and each label type (home, work counts)
Assign uniform tile weights
Assign landuse priors as tile weights
Device UE tiles with tile weights
Calculate sum of tile weights per device
Total tile weight per device
Calculate device tile weights
Sum up all devices weights per grid tile
Cast schema to output DO and save
AgregatedLabels

- **Code Structure:**

The code structure follows the format set by the core package, and the general repository structure. The location of the module script in the repository is as follows:

```
            multimno
                └── components
                    └── aggregation
                        └── ue_aggregation
                            └── ue_aggregation.py
```

ue_aggregation.py contains one class named UEAggregation which is a subclass of Component. The UEAggregation class overrides transform method of base Component class.

5.2.25 CELLPROXIMITYESTIMATION

5.2.25.1 MODULE DESCRIPTION

- **Module Name:** CellProximityEstimation
- **Objectives:** The component uses existing cell footprint information (grid coverage) to estimate which cells have overlapping coverage area geometries. Additionally, the component calculates distances between the coverage area geometries of nearby cells.
- **Functionality:** Takes as input a configuration file and a collection of cell footprints (grid ids covered by cell) per date. The component calculates coverage area geometries of each cell based on the concave hull of the cell footprint's grid centroids. The component calculates distances to nearby cells' coverage area geometries, up to a maximum of config parameter distance away. Each cell pair with a distance of zero is considered overlapping. For each cell, the list of overlapping cell ids is collected.
- **Data Inputs and Outputs:**
  - Inputs:
    - I.13 Cell Footprints
  - Outputs:
    - I.14 Cell Intersection Groups
    - I.45 Cell Distances

5.2.25.2 DEVELOPMENT DESIGN

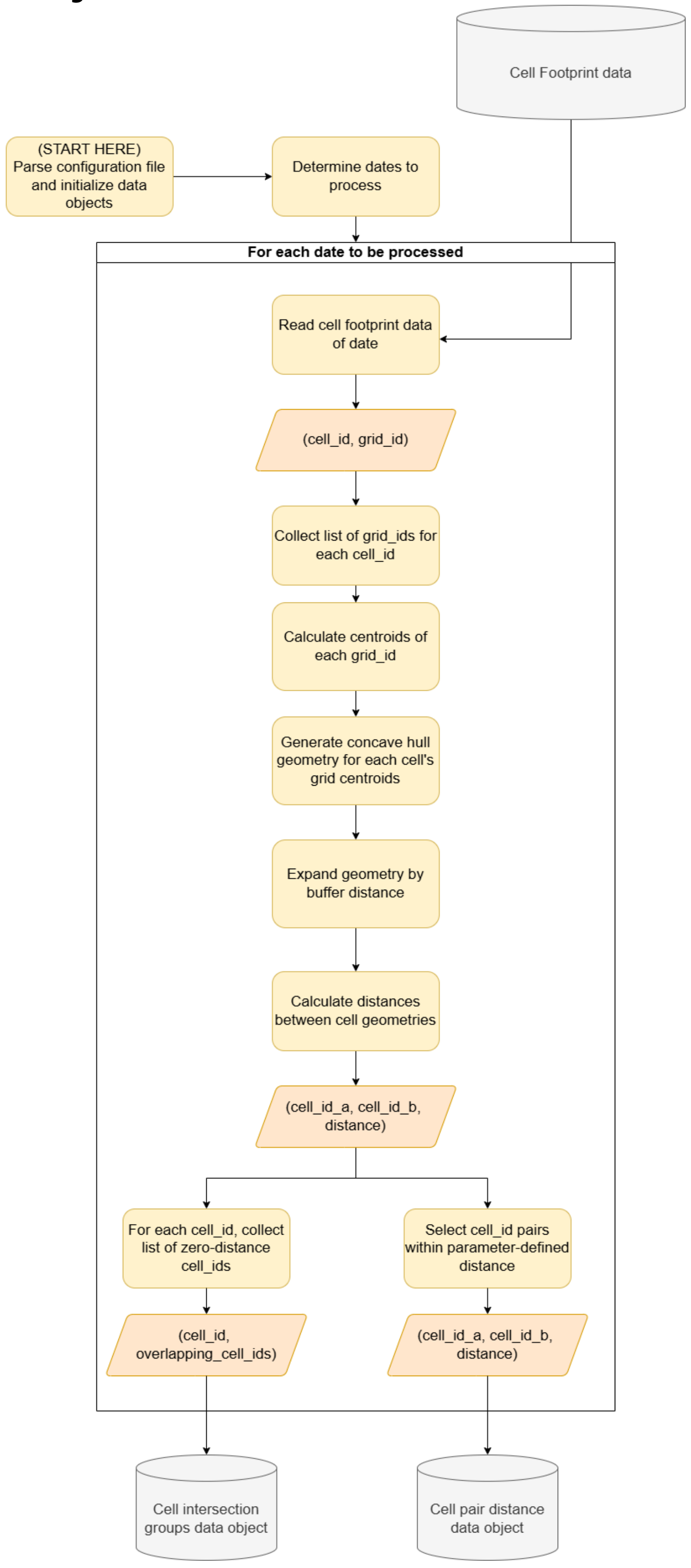
- **Key Algorithms/Processes:**

1. Initialisation. Read all necessary config parameters, check the availability of input data, read in data objects

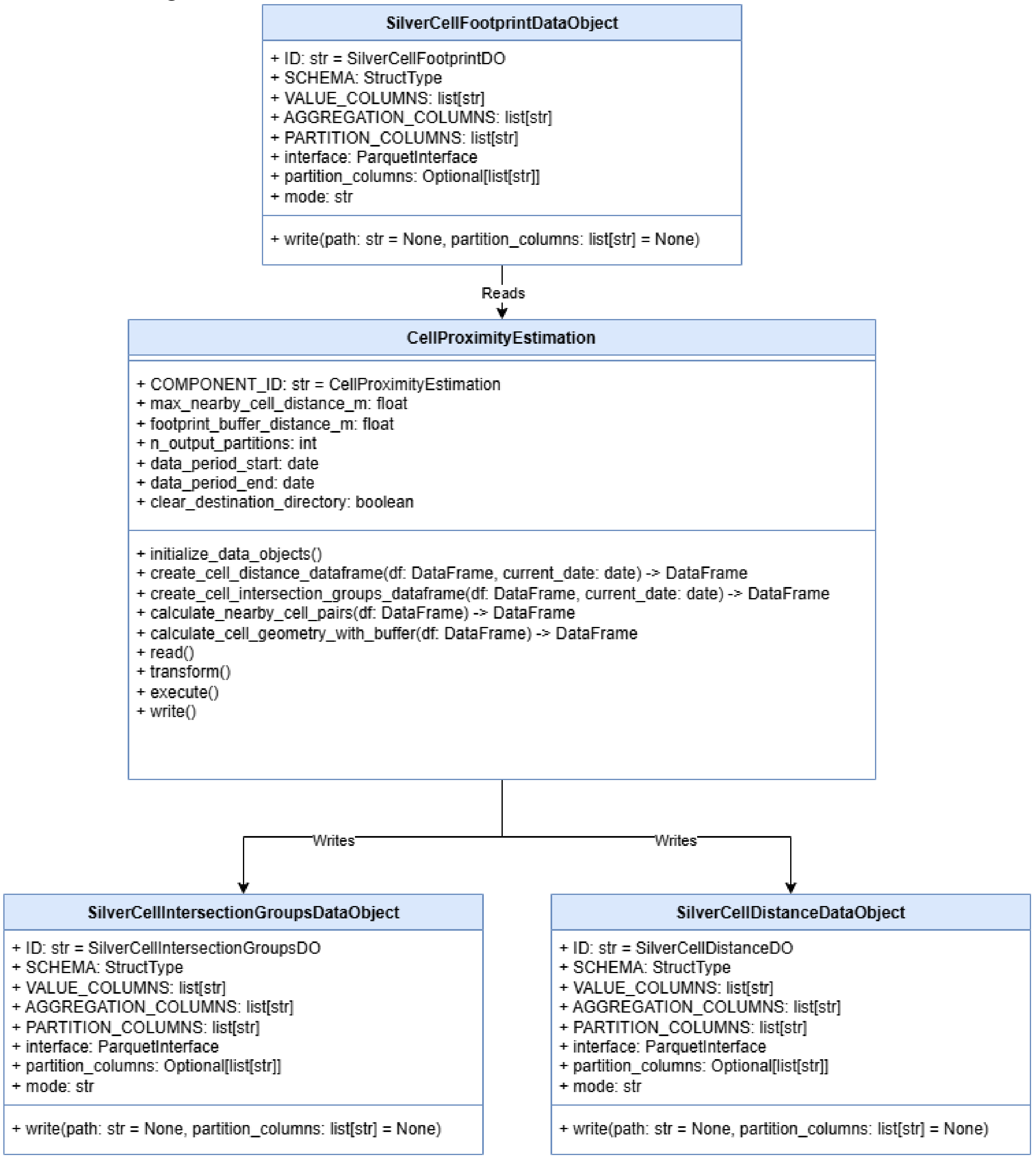
2. Processing. Process dates in chronological order, one at a time, as defined by the data period parameters.

   1. Filter input cell footprints to select (*cell_id, grid_id*) pairs only from the active date.
   2. For each cell, calculate its cell geometry:
      1. Map each grid id to its centroid point,
      2. Calculate the concave hull of centroid points,
      3. Apply buffer zone as per config parameter footprint_buffer_distance_m to increase geometry area.
   3. Calculate distances between cell pairs for all pairs within a maximum distance max_nearby_cell_distance_m between the cell geometries.
   4. Mark each pair as overlapping if the distance is zero.
   5. Collect cell intersection groups output data: for each cell id, collect the list of other cell ids which are overlapping.
   6. Write out cell intersection groups data and cell distance data.

- **Data flow diagram:**


Cell Footprint data
(START HERE) Parse configuration file and initialize data objects
Determine dates to process
For each date to be processed
Read cell footprint data of date
(cell_id, grid_id)
Collect list of grid_ids for each cell_id
Calculate centroids of each grid_id
Generate concave hull geometry for each cell's grid centroids
Expand geometry by buffer distance
Calculate distances between cell geometries
(cell_id_a, cell_id_b, distance)
For each cell_id, collect list of zero-distance cell_ids
Select cell_id pairs within parameter-defined distance
(cell_id, overlapping_cell_ids)
(cell_id_a, cell_id_b, distance)
Cell intersection groups data object
Cell pair distance data object

- **Class diagram:**


SilverCellFootprintDataObject
+ ID: str = SilverCellFootprintDO
+ SCHEMA: StructType
+ VALUE_COLUMNS: list[str]
+ AGGREGATION_COLUMNS: list[str]
+ PARTITION_COLUMNS: list[str]
+ interface: ParquetInterface
+ partition_columns: Optional[list[str]]
+ mode: str
+ write(path: str = None, partition_columns: list[str] = None)
Reads
CellProximityEstimation
+ COMPONENT_ID: str = CellProximityEstimation
+ max_nearby_cell_distance_m: float
+ footprint_buffer_distance_m: float
+ n_output_partitions: int
+ data_period_start: date
+ data_period_end: date
+ clear_destination_directory: boolean
+ initialize_data_objects()
+ create_cell_distance_dataframe(df: DataFrame, current_date: date) -> DataFrame
+ create_cell_intersection_groups_dataframe(df: DataFrame, current_date: date) -> DataFrame
+ calculate_nearby_cell_pairs(df: DataFrame) -> DataFrame
+ calculate_cell_geometry_with_buffer(df: DataFrame) -> DataFrame
+ read()
+ transform()
+ execute()
+ write()
Writes
Writes
SilverCellIntersectionGroupsDataObject
+ ID: str = SilverCellIntersectionGroupsDO
+ SCHEMA: StructType
+ VALUE_COLUMNS: list[str]
+ AGGREGATION_COLUMNS: list[str]
+ PARTITION_COLUMNS: list[str]
+ interface: ParquetInterface
+ partition_columns: Optional[list[str]]
+ mode: str
+ write(path: str = None, partition_columns: list[str] = None)
SilverCellDistanceDataObject
+ ID: str = SilverCellDistanceDO
+ SCHEMA: StructType
+ VALUE_COLUMNS: list[str]
+ AGGREGATION_COLUMNS: list[str]
+ PARTITION_COLUMNS: list[str]
+ interface: ParquetInterface
+ partition_columns: Optional[list[str]]
+ mode: str
+ write(path: str = None, partition_columns: list[str] = None)

- **Code structure:**

The code structure follows the format set by the core package, and the general repository structure. The location of the module script in the repository is as follows:

```
multimno
    └──── components
        └──── execution
            └──── cell_proximity_estimation
                └──── cell_proximity_estimation.py
```

- cell_footprint_estimation.py contains one class named CellFootprintEstimationwhich is a subclass of Component.
- The CellProximityEstimation class overrides the transform and execute methods of the base Component class. The executemethod iterates over dates and invokes read once; invokes transform and write for each date. transform reads, filters and processes the input data, prepares output data.

5.2.26 INTERNALMIGRATION

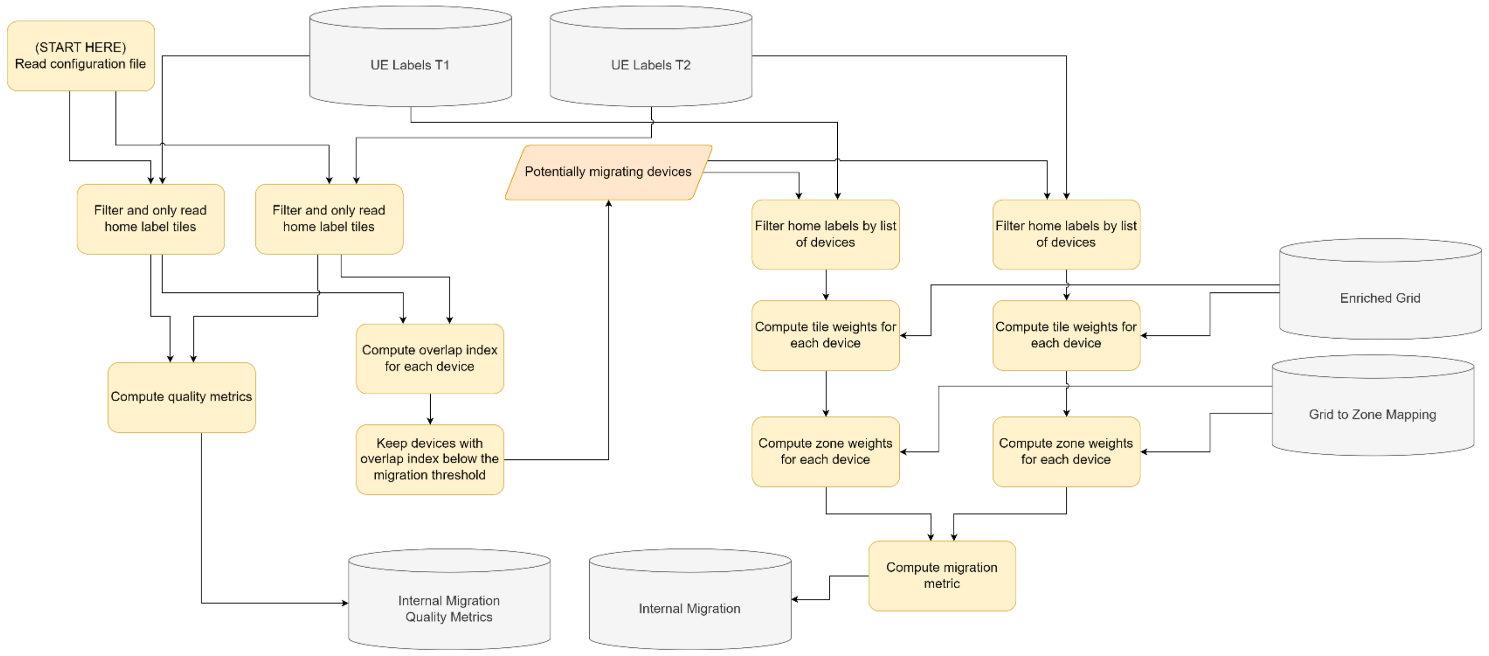
5.2.26.1 MODULE DESCRIPTION

- **Module Name:** InternalMigration
- **Objectives:** The objective of this module is to estimate the number of people that have migrated inside the country of an MNO, i.e. changed their home location, between two long-term periods.
- **Functionality:**
  - 3.2.25 InternalMigration
- **Data Inputs and Outputs:**
  - Inputs:
    - I.36 Zones - Grid Map
    - I.37 UE Labels
    - I.31 Enriched Grid (optional)
  - Outputs:
    - I.46 Internal Migration
    - I.47 Internal Migration Quality Metrics

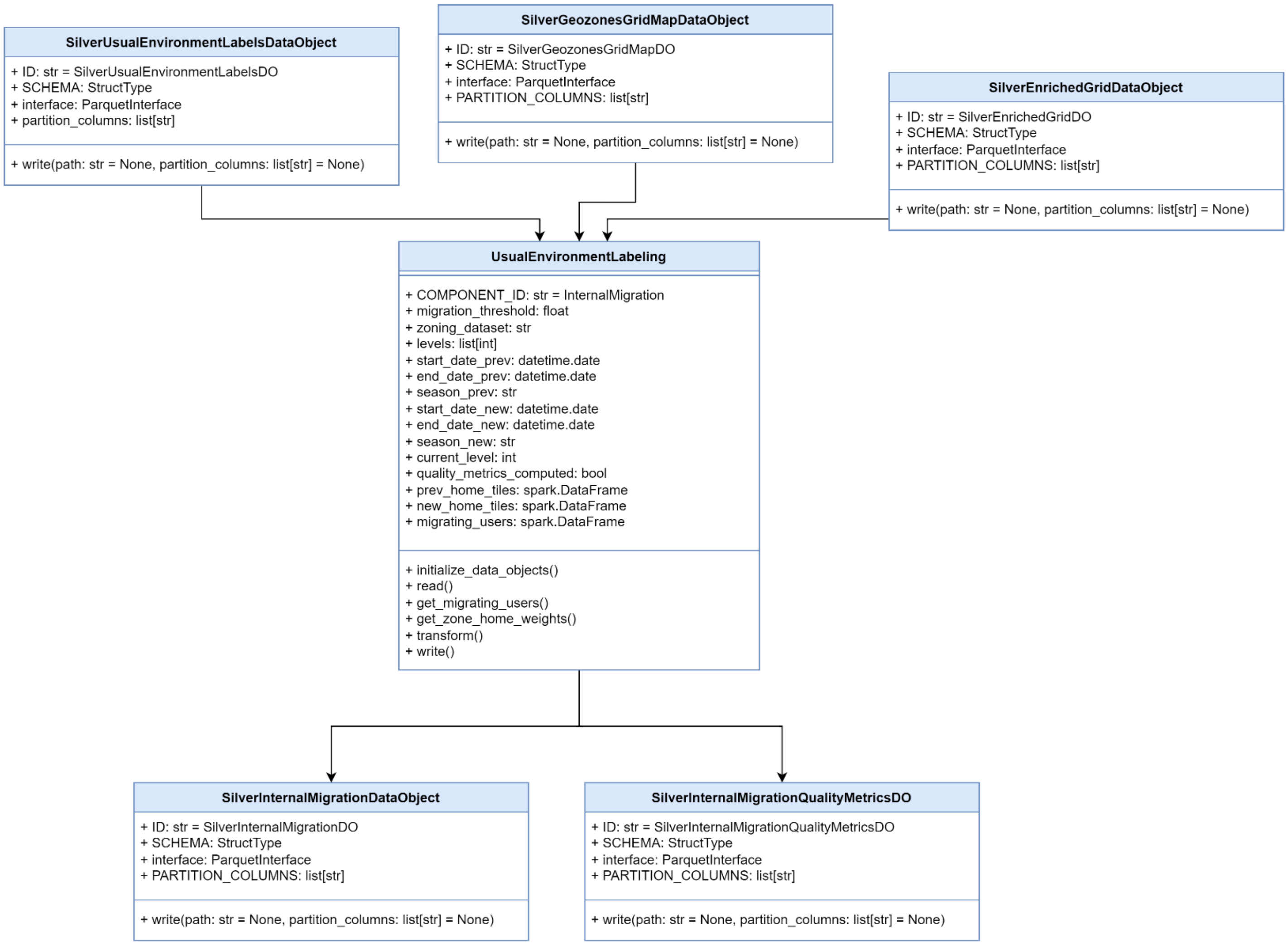
5.2.26.2 DEVELOPMENT DESIGN

- **Key Algorithms/Processes:**
  1. Read the configuration file to get the two long-term datasets that are going to be compared together.
  2. Create the corresponding data objects – if not using uniform weights, read the enriched grid with custom weights.
  3. Compute the devices that have potentially performed internal migration:
     1. Compute an overlap index for each device to determine if it may have migrated or not. This index is equal to two times the number of shared home tiles in both long-term periods, divided by the sum of the number of home tiles in the first time period and the number of home tiles in the second period.
     2. Select those devices that have an overlap index below the threshold specified via configuration: they are the devices whose home tiles have changed enough to be considered as potential internal migrants.
     3. Also compute as a quality metric the following three values: number of unique devices with at least one home tile in the first long-term period, number of unique devices with at least one home tile in the second long-term period, and number of unique users with at least one home tile in both the first and second long-term periods.
  4. Filtering by the devices that have potentially performed internal migration, map their home tiles to the zones of the specified zoning system.
  5. For each of those devices, compute the weight that each zone has as a "home zone" for a given device, which is proportional to the sum of the weights of the home tiles that are mapped to that zone. The weight of the home tiles may be uniform or the values given through the enriched grid data object.
  6. Compute the migration metric:
     1. For each device, the migration metric from zone A to zone B is equal to the product of its home weight for zone A times its home weight for zone B. Compute this metric for all distinct pairs of zones for which the device has a non-zero home weight.
     2. Group by each distinct pair of zones and sum up the migration metric at device level to obtain the final migration metric between two zones.

- **Data flow diagram:**


(START HERE) Read configuration file
UE Labels T1
UE Labels T2
Filter and only read home label tiles
Filter and only read home label tiles
Potentially migrating devices
Filter home labels by list of devices
Filter home labels by list of devices
Enriched Grid
Compute tile weights for each device
Compute tile weights for each device
Compute overlap index for each device
Compute quality metrics
Keep devices with overlap index below the migration threshold
Grid to Zone Mapping
Compute zone weights for each device
Compute zone weights for each device
Compute migration metric
Internal Migration Quality Metrics
Internal Migration

- **Class diagram:**



SilverUsualEnvironmentLabelsDataObject
+ ID: str = SilverUsualEnvironmentLabelsDO
+ SCHEMA: StructType
+ interface: ParquetInterface
+ partition_columns: list[str]
+ write(path: str = None, partition_columns: list[str] = None)
SilverGeozonesGridMapDataObject
+ ID: str = SilverGeozonesGridMapDO
+ SCHEMA: StructType
+ interface: ParquetInterface
+ PARTITION_COLUMNS: list[str]
+ write(path: str = None, partition_columns: list[str] = None)
SilverEnrichedGridDataObject
+ ID: str = SilverEnrichedGridDO
+ SCHEMA: StructType
+ interface: ParquetInterface
+ PARTITION_COLUMNS: list[str]
+ write(path: str = None, partition_columns: list[str] = None)
UsualEnvironmentLabeling
+ COMPONENT_ID: str = InternalMigration
+ migration_threshold: float
+ zoning_dataset: str
+ levels: list[int]
+ start_date_prev: datetime.date
+ end_date_prev: datetime.date
+ season_prev: str
+ start_date_new: datetime.date
+ end_date_new: datetime.date
+ season_new: str
+ current_level: int
+ quality_metrics_computed: bool
+ prev_home_tiles: spark.DataFrame
+ new_home_tiles: spark.DataFrame
+ migrating_users: spark.DataFrame
+ initialize_data_objects()
+ read()
+ get_migrating_users()
+ get_zone_home_weights()
+ transform()
+ write()
SilverInternalMigrationDataObject
+ ID: str = SilverInternalMigrationDO
+ SCHEMA: StructType
+ interface: ParquetInterface
+ PARTITION_COLUMNS: list[str]
+ write(path: str = None, partition_columns: list[str] = None)
SilverInternalMigrationQualityMetricsDO
+ ID: str = SilverInternalMigrationQualityMetricsDO
+ SCHEMA: StructType
+ interface: ParquetInterface
+ PARTITION_COLUMNS: list[str]
+ write(path: str = None, partition_columns: list[str] = None)

- **Code Structure:**

The code structure follows the format set by the core package, and the general repository structure. The location of the module script in the repository is as follows:

```
/multimno/
 └─── components
    └─── execution
       └─── internal_migration
          └─── internal_migration.py
```

- internal_migration.py contains one class named InternalMigration which is a subclass of Component. It overrides the following methods:
    - The __init__ method first call its parent's __init__ method, which sets up the Spark session, initialises data objects and reads the configuration file.
    - The transform method handles all the logic behind the component.
    - The execute method handles the reading, execution and writing of each data object to be worked with.
    - The initialise_data_objects creates the input and output data objects that will be used according to what data object types are to be processed as it will be specified in a configuration file.
- The InternalMigration component also has the following methods:
    - get_migrating_users takes the home tiles of both long-term periods, computes the overlap index for each device or user that appears in both periods, and returns a list of those devices whose overlap index is below a certain migration threshold – the "potentially migrating devices". The method also returns the number of unique devices with at least one home tile in the first period, in the second period, and in both.
    - get_zone_home_weights takes as input home tiles of both long-term periods (only those of potentially migrating users are passed) that have already been mapped to some zone, computes the weight of each home tile for a given device (either uniform weights or not), and adds them up in order to return a "home weight" for each device and zone, for both the first and second periods.

5.2.27 TOURISMSTAYSESTIMATION

5.2.27.1 MODULE DESCRIPTION

- **Module Name:** TourismStaysEstimation
- **Objectives:** The component calculates the geographical zoning distribution of inbound and domestic time segments (stays). The component marks overnight stays.
- **Functionality:** The component parses the configuration file. The component calculates the geographical zoning distribution of inbound and domestic time segments (stays) using cell to grid to zone mapping and aggregation of grid weights. The component marks overnight stays using functional midnight.
- **Data Inputs and Outputs:**
  - Inputs:
    - I.20 Daily Continuous Time Segments
    - I.15 Cell Connection and Posterior Probabilities
    - I.36 Zones - Grid Map
    - I.37 UE Labels (optional)
  - Outputs:
    - I.48 Daily Tourism Stays

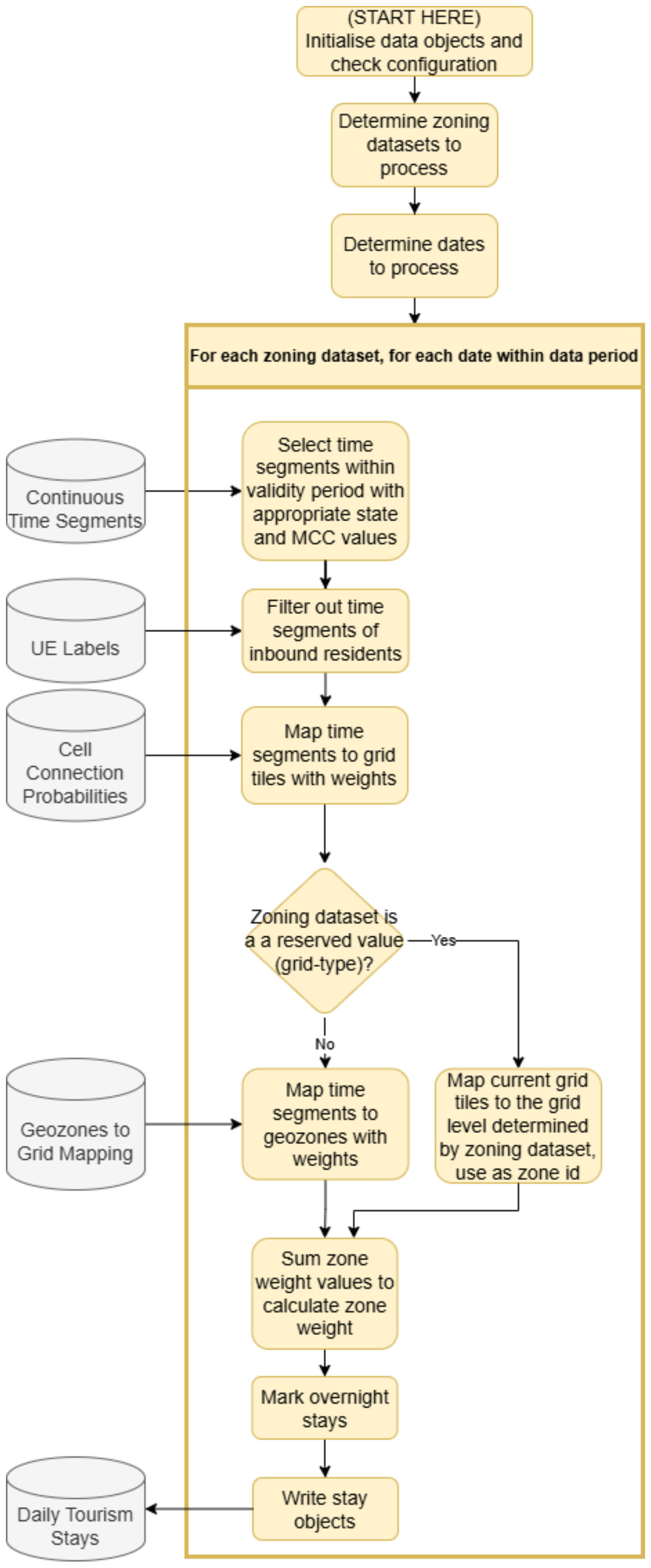
5.2.27.2 DEVELOPMENT DESIGN

- **Key Algorithms/Processes:**
  1. Initialisation. Read all necessary config parameters, check the availability of input data. Optionally delete existing trips and output aggregations.
  2. For each parameter-specified zoning system:
     1. If the zoning dataset is not a reserved dataset (INSPIRE_1km), retrieve Geozones to Grid Mapping input data for the current zoning dataset.
     2. For each date in the parameter-specified range of dates to process:
        1. Select input time segments. Read Continuous Time Segments which are from the current date, which have the proper segment state value (STAY), which have the MCC value different from the parameter-specified local MCC value, and which are longer than the parameter-specified threshold.
        2. Filter out time segments of inbound residents. Inbound residents are inbound users who have existing usual environment entries that overlap the current date. As they do not reflect active tourism, we omit their time segments from the data.
        3. Calculate the weighted distribution of the stay among grid tiles. Join the time segments with cell connection probabilities data. This maps each cell of the time segment to one or more grid ids, each with posterior probability values. The cells in the cells list have equal weighting between them and we want the time segment's grid weights to sum to 1, so the posterior probabilities are normalized by dividing them with the stay's cell count. This gives us a time segment's weighted distribution across grid tiles.
        4. Map grid tiles to zones:
           - If the zoning dataset is not a reserved dataset, join the stays with Geozones to Grid Mapping data to map zone ids to grid ids.
           - If the zoning dataset is a reserved dataset, map each existing grid id (expected to be 100m resolution) to the corresponding grid id on

the current zoning level. For further calculations, treat the new grid id as the zone id.

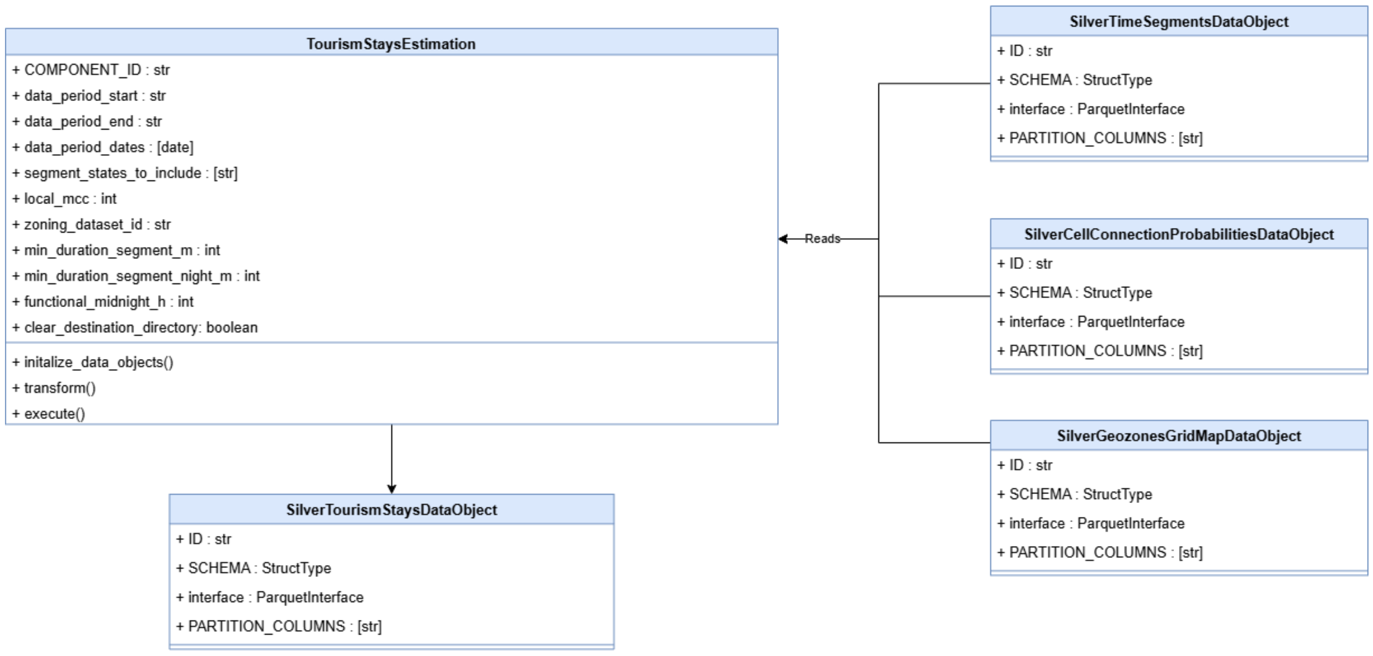
5. Aggregate by zone id for each stay to get the weighted spatial distribution of the stay among zones.
6. Mark overnight stays. A stay is overnight if it contains the parameter-specified functional midnight hour and its duration is longer than the parameter-specified threshold.
7. Write the Daily Tourism Stay data object for the current date.

- **Data flow diagram:**



(START HERE) Initialise data objects and check configuration
Determine zoning datasets to process
Determine dates to process
For each zoning dataset, for each date within data period
Continuous Time Segments
Select time segments within validity period with appropriate state and MCC values
UE Labels
Filter out time segments of inbound residents
Cell Connection Probabilities
Map time segments to grid tiles with weights
Zoning dataset is a a reserved value (grid-type)?
Yes
No
Geozones to Grid Mapping
Map time segments to geozones with weights
Map current grid tiles to the grid level determined by zoning dataset, use as zone id
Sum zone weight values to calculate zone weight
Mark overnight stays
Write stay objects
Daily Tourism Stays

- **Class diagram:**



TourismStaysEstimation
+ COMPONENT_ID : str
+ data_period_start : str
+ data_period_end : str
+ data_period_dates : [date]
+ segment_states_to_include : [str]
+ local_mcc : int
+ zoning_dataset_id : str
+ min_duration_segment_m : int
+ min_duration_segment_night_m : int
+ functional_midnight_h : int
+ clear_destination_directory: boolean
+ initalize_data_objects()
+ transform()
+ execute()
Reads
SilverTimeSegmentsDataObject
+ ID : str
+ SCHEMA : StructType
+ interface : ParquetInterface
+ PARTITION_COLUMNS : [str]
SilverCellConnectionProbabilitiesDataObject
+ ID : str
+ SCHEMA : StructType
+ interface : ParquetInterface
+ PARTITION_COLUMNS : [str]
SilverGeozonesGridMapDataObject
+ ID : str
+ SCHEMA : StructType
+ interface : ParquetInterface
+ PARTITION_COLUMNS : [str]
SilverTourismStaysDataObject
+ ID : str
+ SCHEMA : StructType
+ interface : ParquetInterface
+ PARTITION_COLUMNS : [str]

- **Code structure:**

The code structure follows the format set by the core package, and the general repository structure. The location of the module script in the repository is as follows:

```
multimno
   └──── components
      └──── execution
         └──── tourism_stays_estimation
            └──── tourism_stays_estimation.py
```

- tourism_stays_estimation.py contains one class named TourismStaysEstimation which is a subclass of Component.
- The TourismStaysEstimation class overrides the transform and execute methods of the base Component class.

5.2.28 TOURISMSTATISTICSCALCULATION

5.2.28.1 MODULE DESCRIPTION

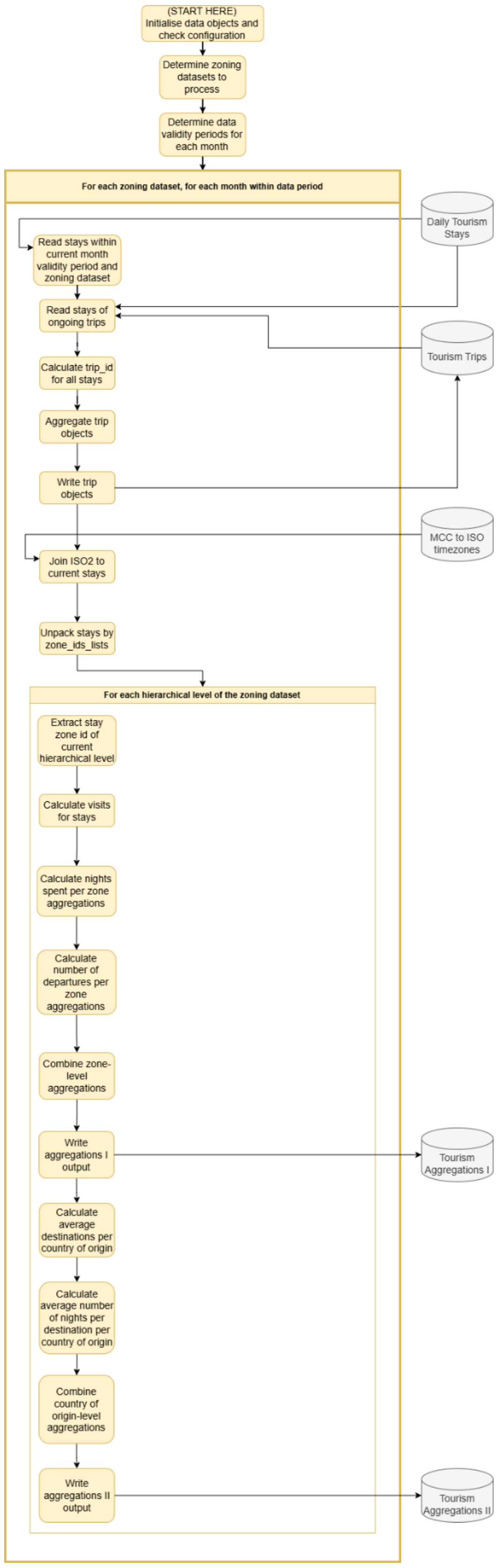
- **Module Name:** TourismStatisticsCalculation
- **Objectives:** The component calculates aggregated tourism statistics of the local country. The aggregates are nights spent and number of departures per geographical zone on each hierarchical level, and average number of destinations and nights spent per country of origin.
- **Functionality:** The component parses the configuration file. The component determines the valid dates for input data for each month in the range specified by the data period start and end parameters. For each month within the data period, the component calculates trips and statistical aggregations (nights spent per zone, departures per zone, average number of destinations per trip, average nights spent per destination per trip).
- **Data Inputs and Outputs:**
    - Inputs:
        - I.48 Daily Tourism Stays
        - I.49 Monthly Tourism Trips
        - I.50 MCC ISO Timezone mapping
    - Outputs:
        - I.49 Monthly Tourism Trips
        - I.51 Inbound Tourism Aggregations I: Nights spent and departures per zone
        - I.52 Inbound Tourism Aggregations II: Average number of destinations and nights spent per country of origin

5.2.28.2 DEVELOPMENT DESIGN

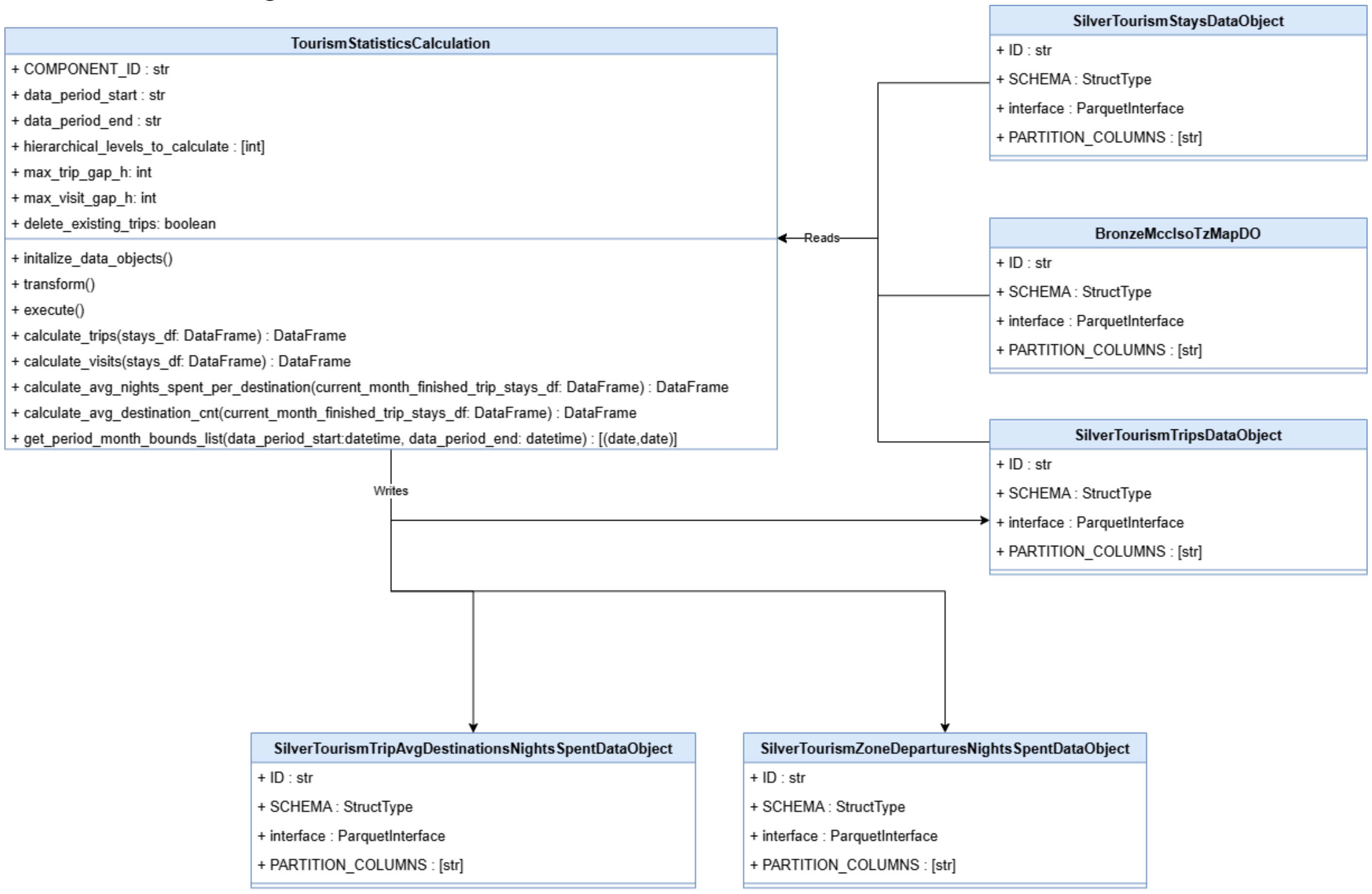
- **Key Algorithms/Processes:**
    1. Initialisation. Read all necessary config parameters, check the availability of input data. Optionally delete existing trips and output aggregations.
    2. Determine zoning datasets to process. Each parameter-specified zoning dataset is expected to have a corresponding list of hierarchical levels upon which the tourism statistics will be calculated.
    3. Determine data validity periods for each month. For each month between the parameter-specified data period start and end, determine which dates of data are included. One month's input data includes stays from the previous month's unfinished trips, stays from the current month, and stays within the parameter-specified look-forward window in the next month.
    4. For each zoning dataset, for each month in the data period:
        1. Calculate trips for each month:
            1. For each user, read input stays which are within the current month's data validity period and match the current zoning dataset.
            2. Order the stays chronologically.
            3. For each stay determine if it is part of the same trip as the previous stay or not:
                1. If a stay is already marked as part of an ongoing trip from the previous month, it keeps the existing trip id.
                2. If the stay has no existing trip id, and either there is no previous stay or the time gap with the previous stay is above the parameter-specified value, the stay is considered part of a new trip and is given a new trip id. The new trip id is an MD5 hash of concatenated user id and trip start timestamp.

        3. Otherwise, the stay is considered part of the previous stay's trip and is given the same trip id as the previous stay.
2. Determine if each trip is finished. A trip is unfinished if it includes any stays from the look-forward window (within the next month).
3. Create Tourism Trips output data object.
4. Write Tourism Trips output data for the current month.
5. Map MCC codes of stays to ISO2. Join the stays data to MCC-ISO2 mapping data to get country short form name strings instead of MCC codes. Rows with no matches get the ISO2 set to XX.
6. For each parameter-specified hierarchical level of the current zoning dataset, performaggregation calculations:
    1. Extract the stays' zone id on the current hierarchical level. The id is extracted from the hierarchical zone ids string of each stay.
    2. Calculate visits. A visit is a collection of consecutive stays of one trip within the same zone with a maximum parameter-specified time gap between two consecutive stays. Since a stay can be composed of parts located in multiple zones, visit aggregation is performed on the part-stays of each zone separately, independent of the overall chronological order of stays.
    3. Determine if visits are finished. A visit is finished if the last stay of the visit is within the current month.
    4. Perform nights spent aggregation per zone per country. For each zone on the current hierarchical level, select visits that are finished and that are overnight visits. For each such visit, add its zone's weighted value to the summed value of the corresponding (*zone, country_of_origin*).
    5. Perform departures aggregation per zone per country with overnight/non-overnight breakdown. A departure is the last location of a finished trip. For each such trip, add 1 to the summed value of the corresponding (*zone, country_of_origin, is_overnight*). If the trip contains any overnight visits, it increments the *is_overnight=True* values. If the trip contains any non-overnight visits, it increments the *is_overnight=False* values.
    6. Combine nights spent and departures into one data object.
    7. Perform average destination count per country aggregation. For each trip that finished in the current month, count the number of distinct zone ids visited. For each country of origin, count the average of that value across all trips.
    8. Perform average nights spent per destination per country aggregation. For each trip that finished in the current month, count the number of overnight stays. For each country of origin, count the average of that value across all trips.
    9. Combine average destinations and average nights spent per destination into one data object.
    10. Write aggregation outputs of the current hierarchical level.

- **Data flow diagram:**


(START HERE) Initialise data objects and check configuration
Determine zoning datasets to process
Determine data validity periods for each month
For each zoning dataset, for each month within data period
Daily Tourism Stays
Read stays within current month validity period and zoning dataset
Read stays of ongoing trips
Tourism Trips
Calculate trip_id for all stays
Aggregate trip objects
Write trip objects
MCC to ISO timezones
Join ISO2 to current stays
Unpack stays by zone_ids_lists
For each hierarchical level of the zoning dataset
Extract stay zone id of current hierarchical level
Calculate visits for stays
Calculate nights spent per zone aggregations
Calculate number of departures per zone aggregations
Combine zone-level aggregations
Write aggregations I output
Tourism Aggregations I
Calculate average destinations per country of origin
Calculate average number of nights per destination per country of origin
Combine country of origin-level aggregations
Write aggregations II output
Tourism Aggregations II

- **Class diagram:**


TourismStatisticsCalculation
+ COMPONENT_ID : str
+ data_period_start : str
+ data_period_end : str
+ hierarchical_levels_to_calculate : [int]
+ max_trip_gap_h: int
+ max_visit_gap_h: int
+ delete_existing_trips: boolean
+ initalize_data_objects()
+ transform()
+ execute()
+ calculate_trips(stays_df: DataFrame) : DataFrame
+ calculate_visits(stays_df: DataFrame) : DataFrame
+ calculate_avg_nights_spent_per_destination(current_month_finished_trip_stays_df: DataFrame) : DataFrame
+ calculate_avg_destination_cnt(current_month_finished_trip_stays_df: DataFrame) : DataFrame
+ get_period_month_bounds_list(data_period_start:datetime, data_period_end: datetime) : [(date,date)]
Reads
Writes
SilverTourismStaysDataObject
+ ID : str
+ SCHEMA : StructType
+ interface : ParquetInterface
+ PARTITION_COLUMNS : [str]
BronzeMccIsoTzMapDO
+ ID : str
+ SCHEMA : StructType
+ interface : ParquetInterface
+ PARTITION_COLUMNS : [str]
SilverTourismTripsDataObject
+ ID : str
+ SCHEMA : StructType
+ interface : ParquetInterface
+ PARTITION_COLUMNS : [str]
SilverTourismTripAvgDestinationsNightsSpentDataObject
+ ID : str
+ SCHEMA : StructType
+ interface : ParquetInterface
+ PARTITION_COLUMNS : [str]
SilverTourismZoneDeparturesNightsSpentDataObject
+ ID : str
+ SCHEMA : StructType
+ interface : ParquetInterface
+ PARTITION_COLUMNS : [str]

- **Code structure:**

The code structure follows the format set by the core package, and the general repository structure. The location of the module script in the repository is as follows:

```
multimno
   └──── components
      └──── execution
         └──── tourism_statistics_calculation
            └──── tourism_statistics_calculation.py
```

- tourism_statistics_calculation.py contains one class named TourismStatisticsCalculation which is a subclass of Component.
- The TourismStatisticsCalculation class overrides the transform and execute methods of the base Component class.

5.2.29 TOURISMOUTBOUNDSTATISTICSCALCULATION

5.2.29.1 MODULE DESCRIPTION

- **Module Name:** TourismOutboundStatisticsCalculation
- **Objectives:** The component calculates aggregated tourism statistics of outbound data (local users visiting foreign countries). The aggregates are nights spent and number of departures per geographical zone on each hierarchical level, and average number of destinations and nights spent per country of origin.
- **Functionality:** The component parses the configuration file. The component determines the valid dates for input data for each month in the range specified by the data period start and end parameters. For each month within the data period, the component calculates trips and statistical aggregations (nights spent per zone, departures per zone, average number of destinations per trip, average nights spent per destination per trip).
- **Data Inputs and Outputs:**
  - Inputs:
    - I.20 Daily Continuous Time Segments
    - I.49 Monthly Tourism Trips
    - I.50 MCC ISO Timezone mapping
    - I.37 UE Labels (optional)
  - Outputs:
    - I.49 Monthly Tourism Trips
    - I.53 Outbound Tourism Aggregations: Nights spent per destination country

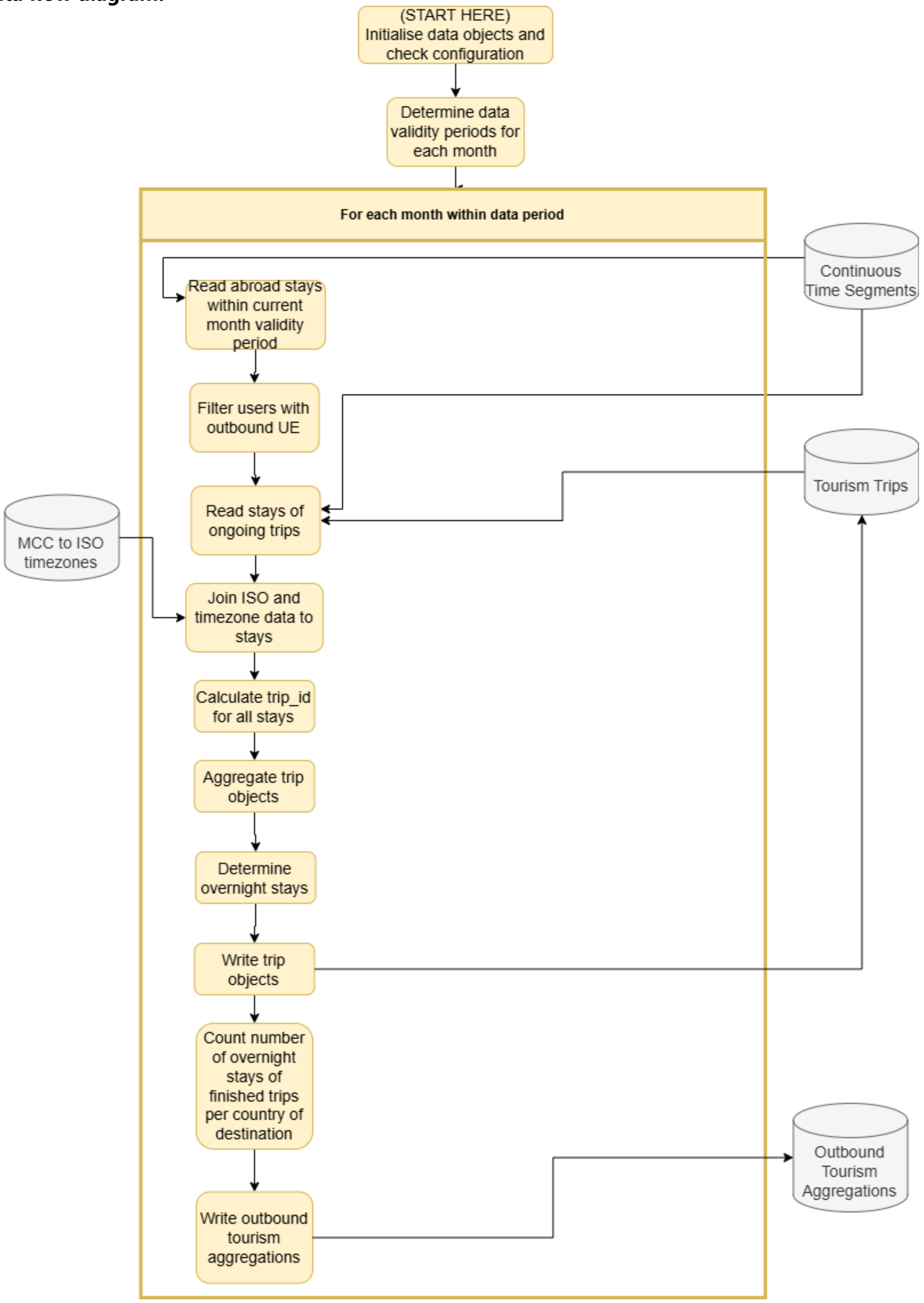
5.2.29.2 DEVELOPMENT DESIGN

- **Key Algorithms/Processes:**
  1. Initialisation. Read all necessary config parameters, check the availability of input data. Optionally delete existing trips and output aggregations.
  2. Determine data validity periods for each month. For each month between the parameter-specified data period start and end, determine which dates of data are included.
  3. For each month in the data period:
     1. Determine the look-forward window. The look-forward window is a parameter-specified time period after the last date of the data period which is used for deciding when trips end.
     2. Retrieve input data for the current month. This includes time segments from the previous month's unfinished trips, time segments from the current month and time segments within the parameter-specified look-forward window in the next month which have the segment state ABROAD. We consider these time segments as outbound stays.
     3. Filter out time segments of outbound residents in corresponding foreign countries. Outbound residents are domestic users who have existing usual environment entries that overlap the current date. As they do not reflect active tourism, we omit their time segments from the data.
     4. Join stays to MCC-ISO mapping data to get the country of destination and its local timezone for each stay.
     5. Mark overnight stays. A stay is overnight if the stay contains the parameter-specified functional midnight hour in the stay's local timezone and its duration is longer than the parameter-specified threshold.
     6. Calculate trips for each month.

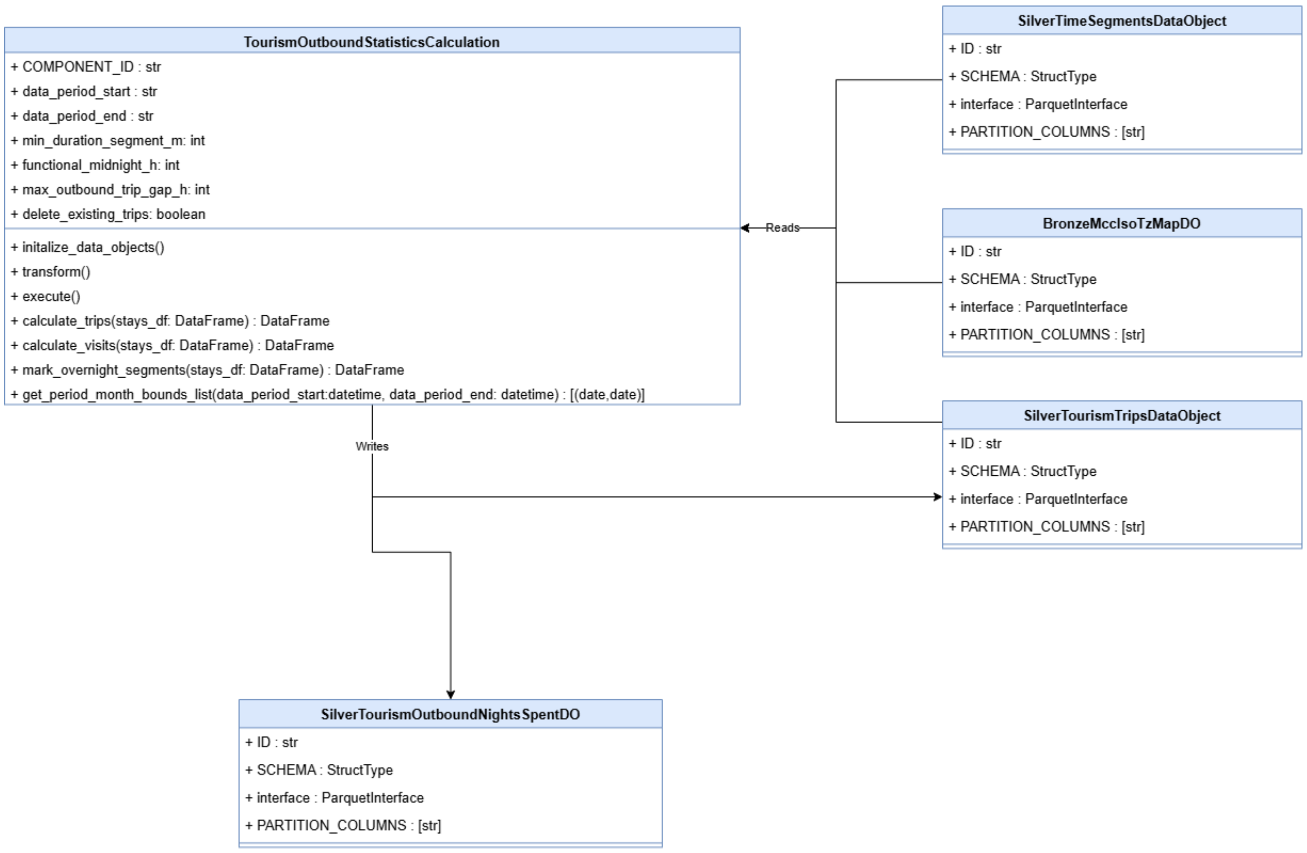
1. For each user, order the stays chronologically.
2. Then for each stay determine if it is part of the same trip as the previous stay or not:
    - If a stay is part of an ongoing trip from the previous month, it keeps the existing trip id.
    - If the stay has no existing trip id, and either there is no previous stay or the time gap with the previous stay is above the parameter-specified value, the stay is considered part of a new trip and is given a new trip id. The trip id is an MD5 hash of concatenated user id and trip start timestamp.
    - Otherwise, the stay is considered part of the previous stay's trip and is given the same trip id as the previous stay.

7. Determine if each trip is finished. A trip is unfinished if it includes any stays from the look-forward window.
8. Create Tourism Trips output data object.
9. Write Tourism Trips output data for the current month.
10. Calculate nights spent per country of destination. Count the number of overnight stays which are part of trips finished in the current month, aggregated by country of destination.
11. Write Outbound Tourism Aggregations data for the current month.

- **Data flow diagram:**


(START HERE) Initialise data objects and check configuration
Determine data validity periods for each month
For each month within data period
Continuous Time Segments
Read abroad stays within current month validity period
Filter users with outbound UE
Tourism Trips
MCC to ISO timezones
Read stays of ongoing trips
Join ISO and timezone data to stays
Calculate trip_id for all stays
Aggregate trip objects
Determine overnight stays
Write trip objects
Count number of overnight stays of finished trips per country of destination
Outbound Tourism Aggregations
Write outbound tourism aggregations

- **Class diagram:**



TourismOutboundStatisticsCalculation
+ COMPONENT_ID : str
+ data_period_start : str
+ data_period_end : str
+ min_duration_segment_m: int
+ functional_midnight_h: int
+ max_outbound_trip_gap_h: int
+ delete_existing_trips: boolean
+ initalize_data_objects()
+ transform()
+ execute()
+ calculate_trips(stays_df: DataFrame) : DataFrame
+ calculate_visits(stays_df: DataFrame) : DataFrame
+ mark_overnight_segments(stays_df: DataFrame) : DataFrame
+ get_period_month_bounds_list(data_period_start:datetime, data_period_end: datetime) : [(date,date)]
Reads
Writes
SilverTimeSegmentsDataObject
+ ID : str
+ SCHEMA : StructType
+ interface : ParquetInterface
+ PARTITION_COLUMNS : [str]
BronzeMccIsoTzMapDO
+ ID : str
+ SCHEMA : StructType
+ interface : ParquetInterface
+ PARTITION_COLUMNS : [str]
SilverTourismTripsDataObject
+ ID : str
+ SCHEMA : StructType
+ interface : ParquetInterface
+ PARTITION_COLUMNS : [str]
SilverTourismOutboundNightsSpentDO
+ ID : str
+ SCHEMA : StructType
+ interface : ParquetInterface
+ PARTITION_COLUMNS : [str]

- **Code structure:**

The code structure follows the format set by the core package, and the general repository structure. The location of the module script in the repository is as follows:

```
multimno
  └──── components
      └──── execution
          └──── tourism_outbound_statistics_calculation
              └──── tourism_outbound_statistics_calculation.py
```

- tourism_outbound_statistics_calculation.py contains one class named TourismOutboundStatisticsCalculation which is a subclass of Component.
- The TourismOutboundStatisticsCalculation class overrides the transform and execute methods of the base Component class.

5.2.30 OUTPUTINDICATORS

5.2.30.1 MODULE DESCRIPTION

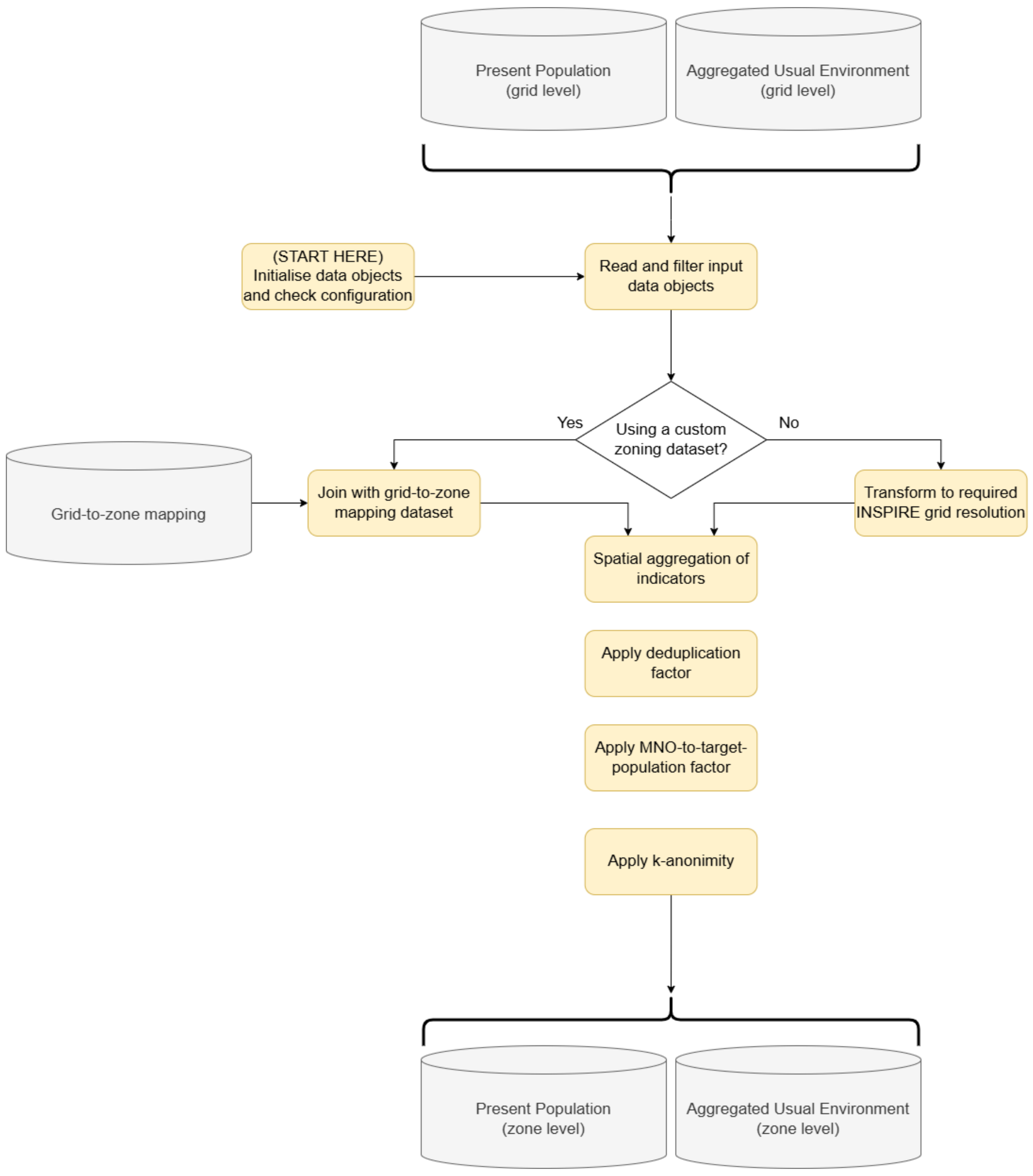
- **Module Name:** OutputIndicators
- **Objectives:** The objective of this module is to process the output of different use cases by spatially aggregating indicators when needed, by estimating the indicators at population level instead of device level and applying the k-anonymity process so the output can be exported outside of the MNO premises.
- **Functionality:**
  - 3.2.29 OutputIndicators
- **Data Inputs and Outputs:**
  - Inputs:
    - For Present Population:
      - I.42 Present Population
      - I.36 Zones - Grid Map (if required)
    - For Usual Environment:
      - I.44 Aggregated Usual Environments
      - I.36 Zones - Grid Map (if required)
    - For Internal Migration:
      - I.46 Internal Migration
    - For Inbound Tourism:
      - I.51 Inbound Tourism Aggregations I: Nights spent and departures per zone
      - I.52 Inbound Tourism Aggregations II: Average number of destinations and nights spent per country of origin
      - I.54 Inbound Estimation Factors (optional)
    - For Outbound Tourism:
      - I.53 Outbound Tourism Aggregations: Nights spent per destination country
  - Outputs:
    - For Present Population:
      - I.41 Present Population - Zones
    - For Usual Environment:
      - I.55 Aggregated Usual Environments - Zones
    - For Internal Migration:
      - I.46 Internal Migration
    - For Inbound Tourism:
      - I.51 Inbound Tourism Aggregations I: Nights spent and departures per zone
      - I.52 Inbound Tourism Aggregations II: Average number of destinations and nights spent per country of origin
    - For Outbound Tourism:
      - I.53 Outbound Tourism Aggregations: Nights spent per destination country

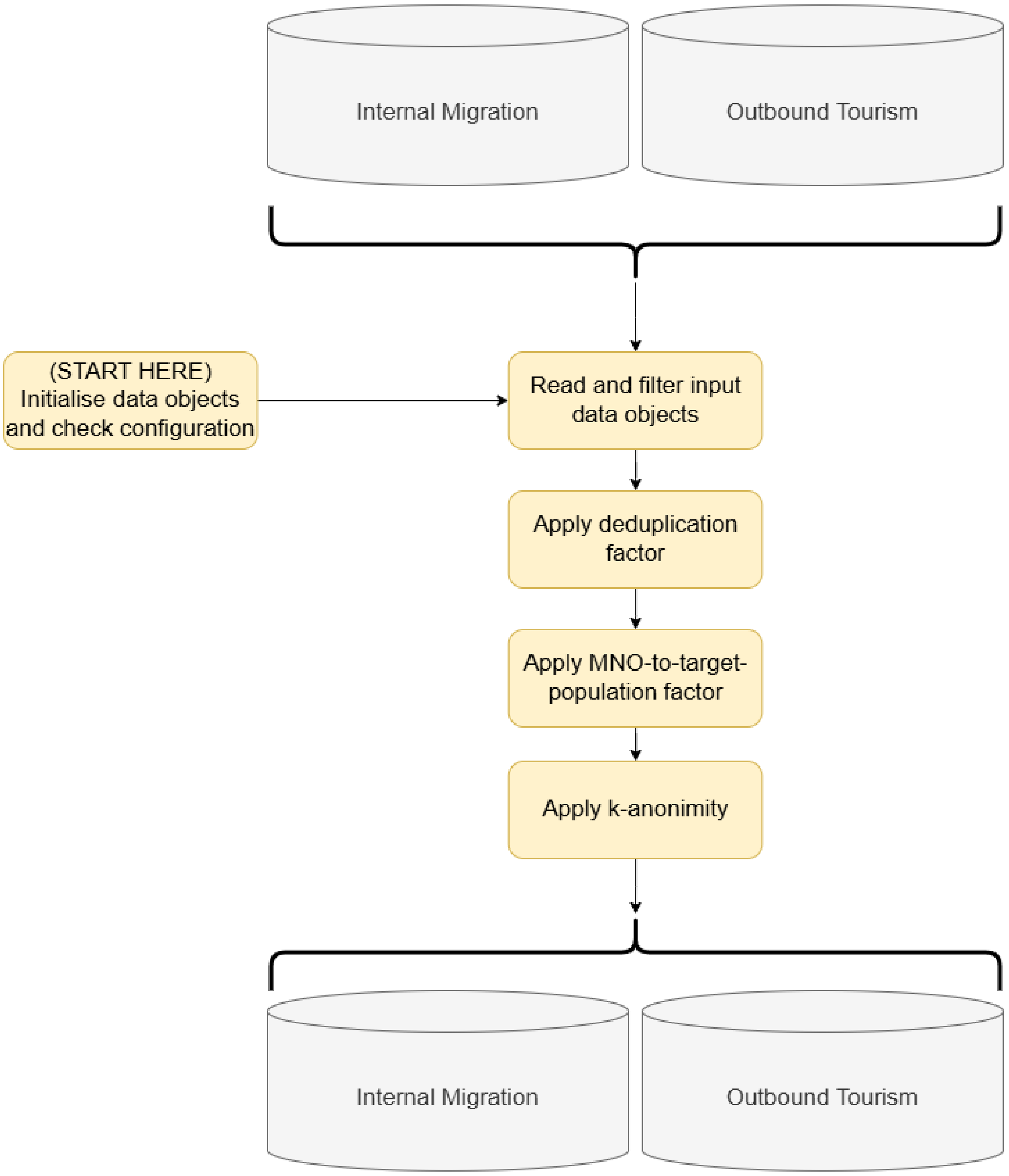
5.2.30.2 DEVELOPMENT DESIGN

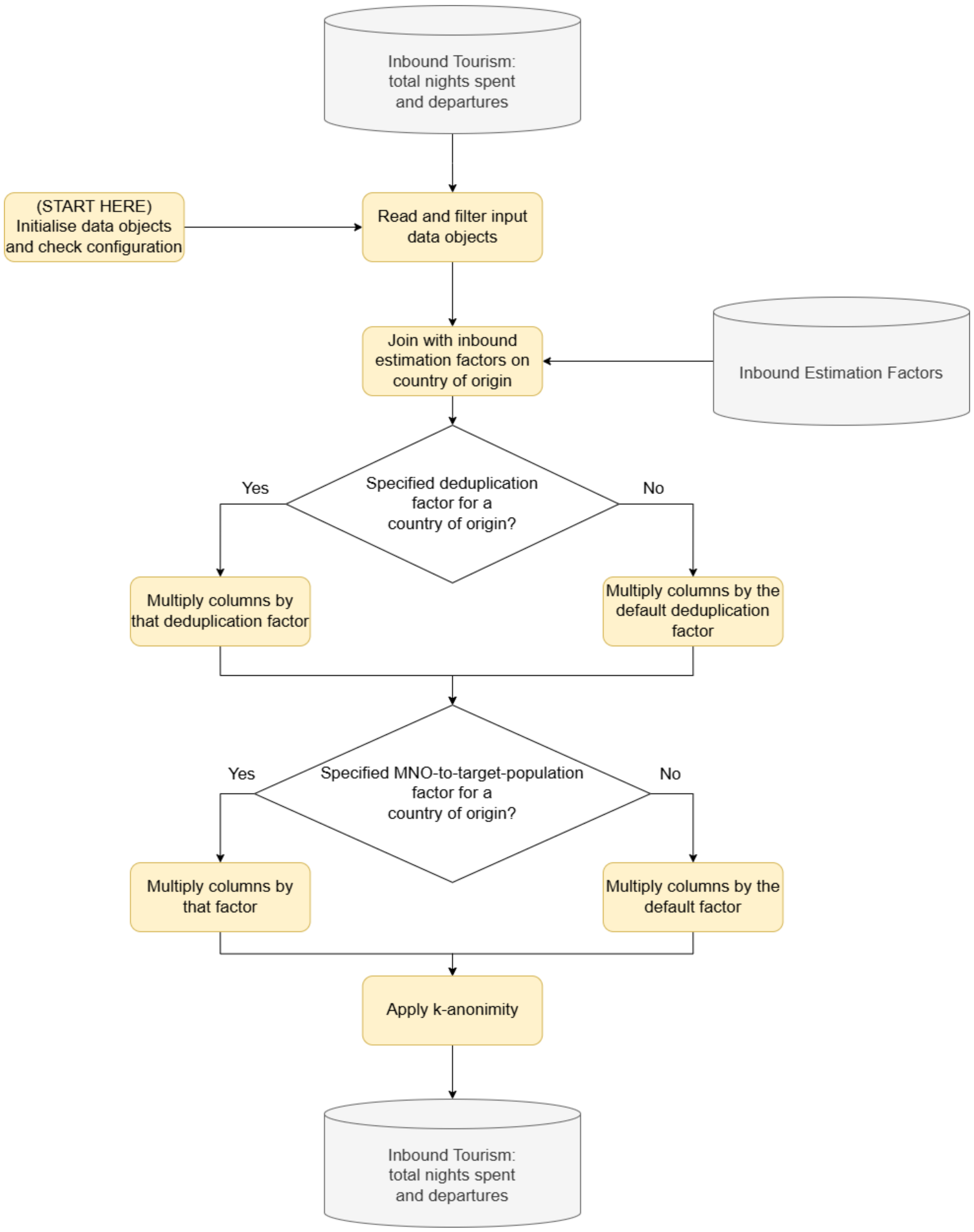
- **Key Algorithms/Processes:**
    1. Read the configuration file to determine what use case data will be processed by the execution, define data objects, and configuration parameters.
    2. Filter the input data by the partition identifiers specified via configuration.
    3. **Spatial aggregation** (only for present population and usual environment/home location)**:**
        1. If the zoning system to be used is the INSPIRE 100 m grid itself, no aggregation needs to be performed. Create the INSPIRE grid IDs from the grid internal representation and add "metadata" columns" of the zoning ID and hierarchical level.
        2. If the zoning system to be used is the INSPIRE 1 km grid, aggregate the indicators from the internal INSPIRE 100 m grid to the 1 km grid, create the correct INSPIRE grid IDs, and add "metadata columns" of the zoning ID and hierarchical level.
        3. If the zoning system is not one of the two above, for each of the hierarchical levels specified in configuration, map the grid tiles to their corresponding zones based on the grid-to-zone mapping data object, aggregate the indicators, and add the "metadata column" with the zoning ID and hierarchical level. If there is more than one hierarchical level, the output data object created at initialisation is deleted and replaced with as many output data objects as levels specified.
    4. **Deduplication**:
        1. With the exception of inbound tourism data, the "estimation" columns of the datasets are multiplied by the constant, local deduplication factor.
        2. For inbound tourism data, the indicators are given for different countries of origin. If the inbound estimation factors dataset exists, first try to find a deduplication factor for each of these countries. If the factor does not exist for a specific country, or the dataset does not exist, a default inbound deduplication factor specified via configuration is used instead. Multiply the "estimation" columns by the appropriate factor.
    5. **MNO to target population**:
        1. With the exception of inbound tourism data, the "estimation" columns of the datasets are multiplied by the constant, local MNO-to-target-population factor.
        2. For inbound tourism data, the indicators are given for different countries of origin. If the inbound estimation factors dataset exists, first try to find a MNO-to-target-population factor for each of these countries. If the factor does not exist for a specific country, or the dataset does not exist, a default inbound MNO-to-target-population factor specified via configuration is used instead. Multiply the "estimation" columns by the appropriate factor.
    6. **k-anonymity:**
        1. If the k-anonymity type is "obfuscate", replace all values of the "kanonymity columns" that are strictly lower than the configuration-specified value *k* by the value -1.".
        2. If the k-anonymity type is "delete", delete all rows where at least one of the values of the "kanonymity columns" is strictly lower than the configuration2-specified value *k*.
    7. Save the result as the corresponding output data object.
    8. For each of the saved output data objects, verify that the fields, field names, and field types match the expected data schema, and that no null values appear under a field that does not allow them. Raise a warning when any of the previous happens.

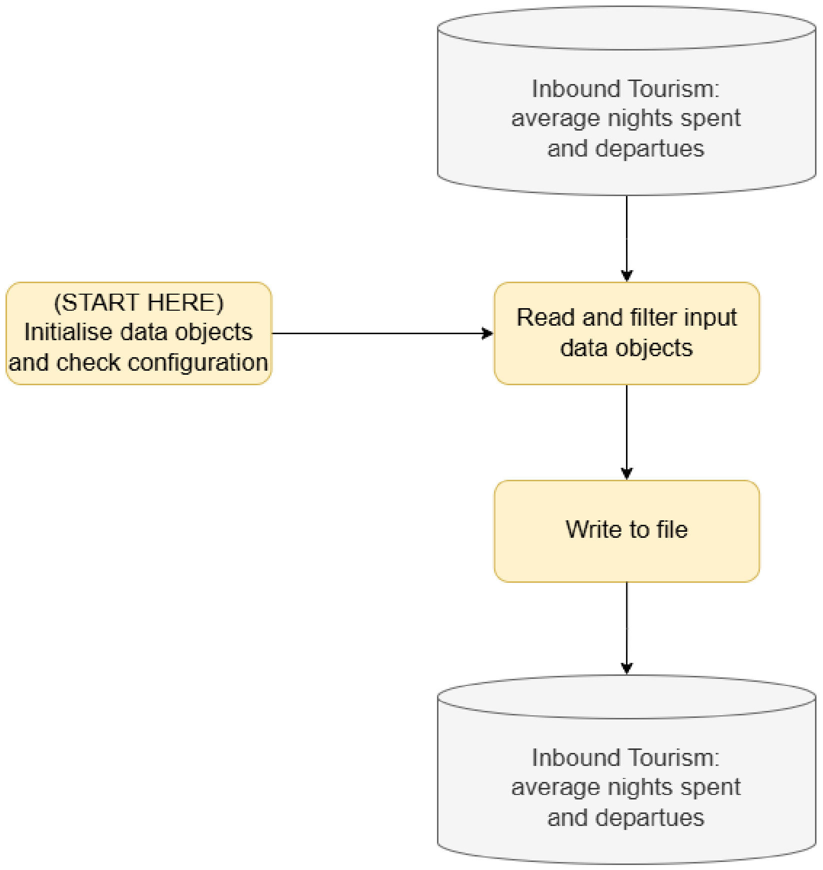
- **Data flow diagram:**

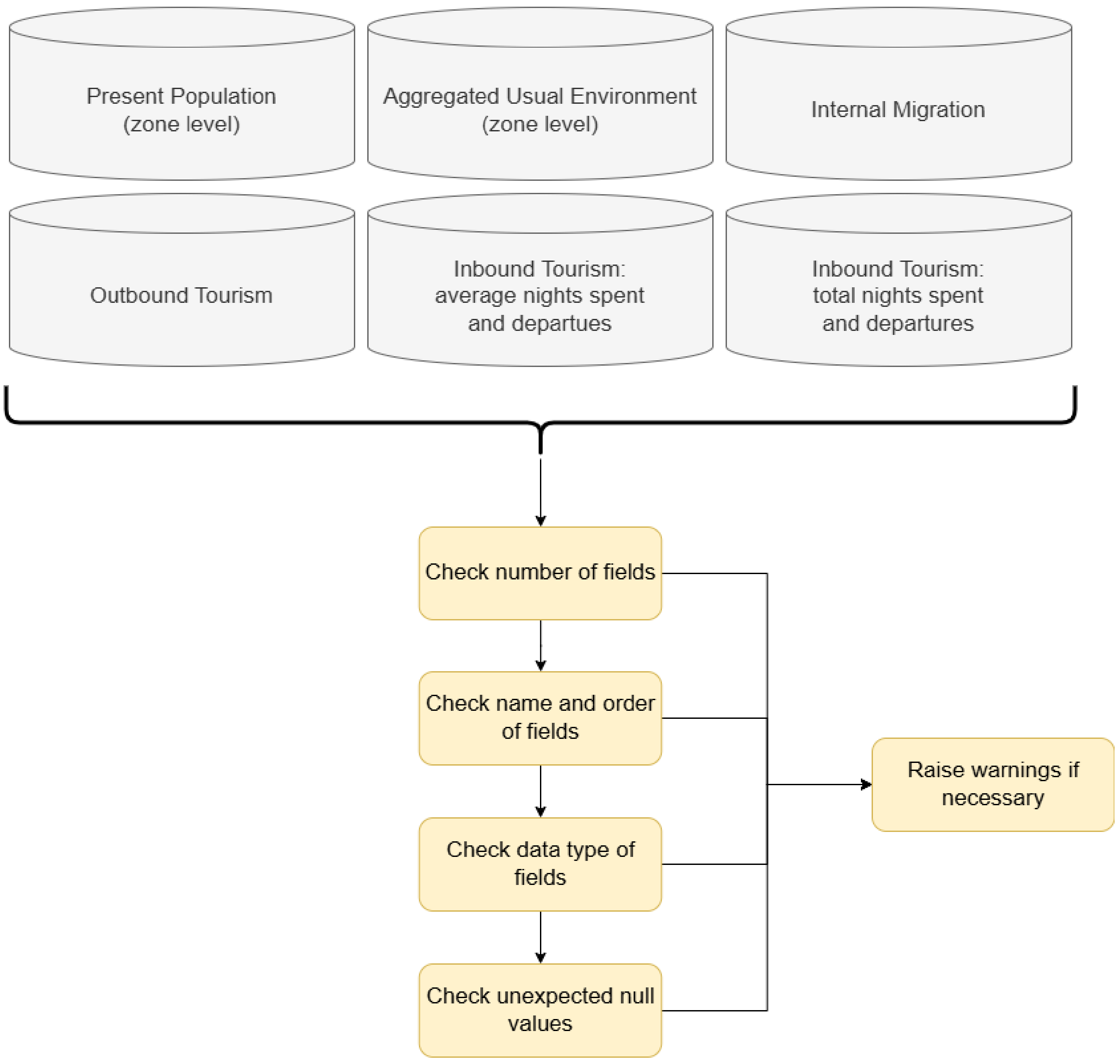
Below one can find the data flow diagrams for the data according to the use case being processed. Use case data that follow the same flow have been grouped together. One final diagram, containing all of the outputs, is shown in the last image of this section.


Present Population (grid level)
Aggregated Usual Environment (grid level)
(START HERE) Initialise data objects and check configuration
Read and filter input data objects
Using a custom zoning dataset?
Yes
No
Grid-to-zone mapping
Join with grid-to-zone mapping dataset
Transform to required INSPIRE grid resolution
Spatial aggregation of indicators
Apply deduplication factor
Apply MNO-to-target-population factor
Apply k-anonimity
Present Population (zone level)
Aggregated Usual Environment (zone level)

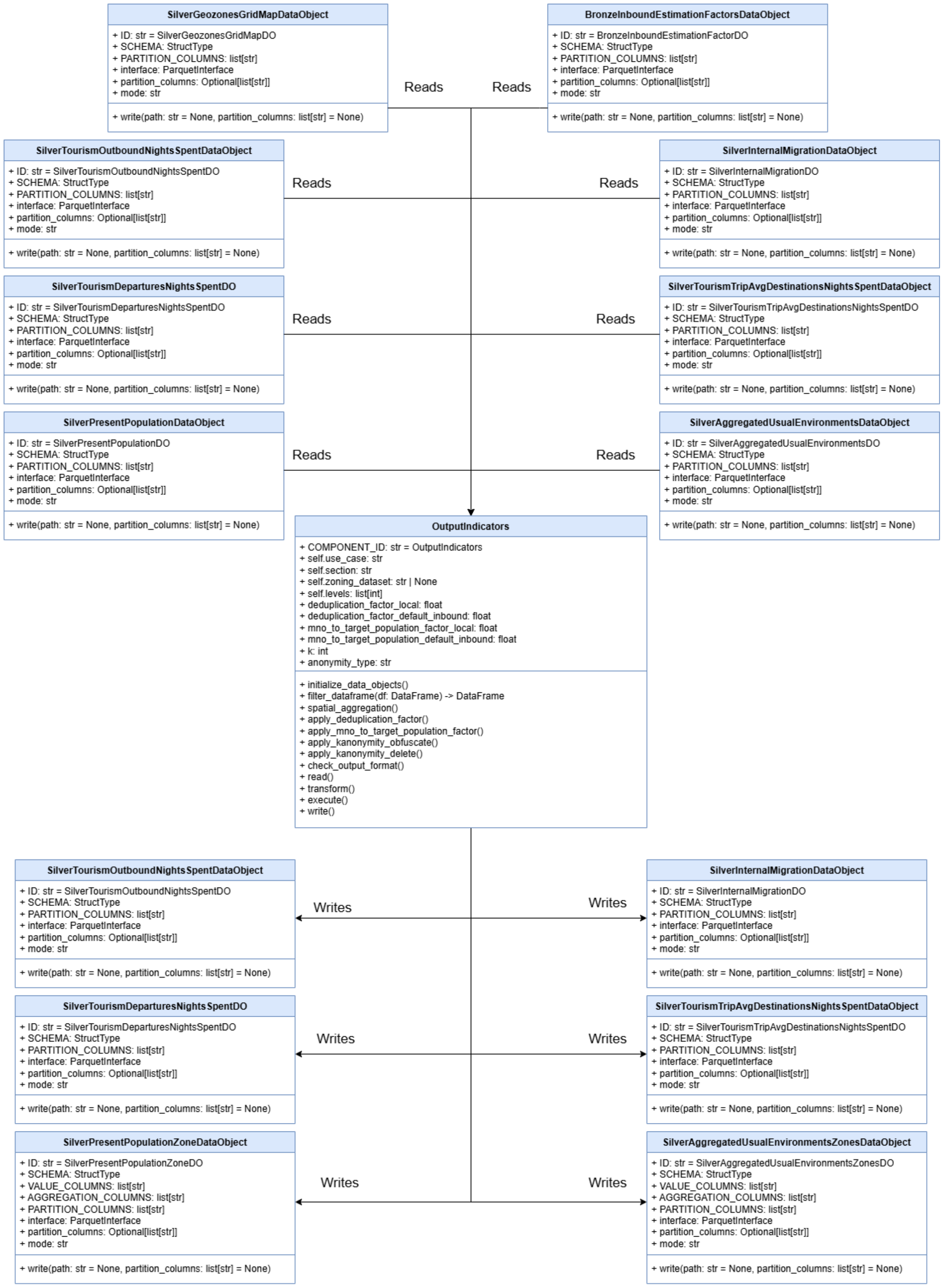

Internal Migration
Outbound Tourism
(START HERE) Initialise data objects and check configuration
Read and filter input data objects
Apply deduplication factor
Apply MNO-to-target-population factor
Apply k-anonimity
Internal Migration
Outbound Tourism


Inbound Tourism: total nights spent and departures
(START HERE) Initialise data objects and check configuration
Read and filter input data objects
Join with inbound estimation factors on country of origin
Inbound Estimation Factors
Specified deduplication factor for a country of origin?
Yes
No
Multiply columns by that deduplication factor
Multiply columns by the default deduplication factor
Specified MNO-to-target-population factor for a country of origin?
Yes
No
Multiply columns by that factor
Multiply columns by the default factor
Apply k-anonimity
Inbound Tourism: total nights spent and departures


Inbound Tourism: average nights spent and departues
(START HERE) Initialise data objects and check configuration
Read and filter input data objects
Write to file
Inbound Tourism: average nights spent and departues


Present Population (zone level)
Aggregated Usual Environment (zone level)
Internal Migration
Outbound Tourism
Inbound Tourism: average nights spent and departures
Inbound Tourism: total nights spent and departures
Check number of fields
Check name and order of fields
Check data type of fields
Check unexpected null values
Raise warnings if necessary

- **Class diagram:**


SilverGeozonesGridMapDataObject
+ ID: str = SilverGeozonesGridMapDO
+ SCHEMA: StructType
+ PARTITION_COLUMNS: list[str]
+ interface: ParquetInterface
+ partition_columns: Optional[list[str]]
+ mode: str
+ write(path: str = None, partition_columns: list[str] = None)
BronzeInboundEstimationFactorsDataObject
+ ID: str = BronzeInboundEstimationFactorDO
+ SCHEMA: StructType
+ PARTITION_COLUMNS: list[str]
+ interface: ParquetInterface
+ partition_columns: Optional[list[str]]
+ mode: str
+ write(path: str = None, partition_columns: list[str] = None)
Reads
Reads
SilverTourismOutboundNightsSpentDataObject
+ ID: str = SilverTourismOutboundNightsSpentDO
+ SCHEMA: StructType
+ PARTITION_COLUMNS: list[str]
+ interface: ParquetInterface
+ partition_columns: Optional[list[str]]
+ mode: str
+ write(path: str = None, partition_columns: list[str] = None)
Reads
Reads
SilverInternalMigrationDataObject
+ ID: str = SilverInternalMigrationDO
+ SCHEMA: StructType
+ PARTITION_COLUMNS: list[str]
+ interface: ParquetInterface
+ partition_columns: Optional[list[str]]
+ mode: str
+ write(path: str = None, partition_columns: list[str] = None)
SilverTourismDeparturesNightsSpentDO
+ ID: str = SilverTourismDeparturesNightsSpentDO
+ SCHEMA: StructType
+ PARTITION_COLUMNS: list[str]
+ interface: ParquetInterface
+ partition_columns: Optional[list[str]]
+ mode: str
+ write(path: str = None, partition_columns: list[str] = None)
Reads
Reads
SilverTourismTripAvgDestinationsNightsSpentDataObject
+ ID: str = SilverTourismTripAvgDestinationsNightsSpentDO
+ SCHEMA: StructType
+ PARTITION_COLUMNS: list[str]
+ interface: ParquetInterface
+ partition_columns: Optional[list[str]]
+ mode: str
+ write(path: str = None, partition_columns: list[str] = None)
SilverPresentPopulationDataObject
+ ID: str = SilverPresentPopulationDO
+ SCHEMA: StructType
+ PARTITION_COLUMNS: list[str]
+ interface: ParquetInterface
+ partition_columns: Optional[list[str]]
+ mode: str
+ write(path: str = None, partition_columns: list[str] = None)
Reads
Reads
SilverAggregatedUsualEnvironmentsDataObject
+ ID: str = SilverAggregatedUsualEnvironmentsDO
+ SCHEMA: StructType
+ PARTITION_COLUMNS: list[str]
+ interface: ParquetInterface
+ partition_columns: Optional[list[str]]
+ mode: str
+ write(path: str = None, partition_columns: list[str] = None)
OutputIndicators
+ COMPONENT_ID: str = OutputIndicators
+ self.use_case: str
+ self.section: str
+ self.zoning_dataset: str | None
+ self.levels: list[int]
+ deduplication_factor_local: float
+ deduplication_factor_default_inbound: float
+ mno_to_target_population_factor_local: float
+ mno_to_target_population_default_inbound: float
+ k: int
+ anonymity_type: str
+ initialize_data_objects()
+ filter_dataframe(df: DataFrame) -> DataFrame
+ spatial_aggregation()
+ apply_deduplication_factor()
+ apply_mno_to_target_population_factor()
+ apply_kanonymity_obfuscate()
+ apply_kanonymity_delete()
+ check_output_format()
+ read()
+ transform()
+ execute()
+ write()
SilverTourismOutboundNightsSpentDataObject
+ ID: str = SilverTourismOutboundNightsSpentDO
+ SCHEMA: StructType
+ PARTITION_COLUMNS: list[str]
+ interface: ParquetInterface
+ partition_columns: Optional[list[str]]
+ mode: str
+ write(path: str = None, partition_columns: list[str] = None)
Writes
Writes
SilverInternalMigrationDataObject
+ ID: str = SilverInternalMigrationDO
+ SCHEMA: StructType
+ PARTITION_COLUMNS: list[str]
+ interface: ParquetInterface
+ partition_columns: Optional[list[str]]
+ mode: str
+ write(path: str = None, partition_columns: list[str] = None)
SilverTourismDeparturesNightsSpentDO
+ ID: str = SilverTourismDeparturesNightsSpentDO
+ SCHEMA: StructType
+ PARTITION_COLUMNS: list[str]
+ interface: ParquetInterface
+ partition_columns: Optional[list[str]]
+ mode: str
+ write(path: str = None, partition_columns: list[str] = None)
Writes
Writes
SilverTourismTripAvgDestinationsNightsSpentDataObject
+ ID: str = SilverTourismTripAvgDestinationsNightsSpentDO
+ SCHEMA: StructType
+ PARTITION_COLUMNS: list[str]
+ interface: ParquetInterface
+ partition_columns: Optional[list[str]]
+ mode: str
+ write(path: str = None, partition_columns: list[str] = None)
SilverPresentPopulationZoneDataObject
+ ID: str = SilverPresentPopulationZoneDO
+ SCHEMA: StructType
+ VALUE_COLUMNS: list[str]
+ AGGREGATION_COLUMNS: list[str]
+ PARTITION_COLUMNS: list[str]
+ interface: ParquetInterface
+ partition_columns: Optional[list[str]]
+ mode: str
+ write(path: str = None, partition_columns: list[str] = None)
Writes
Writes
SilverAggregatedUsualEnvironmentsZonesDataObject
+ ID: str = SilverAggregatedUsualEnvironmentsZonesDO
+ SCHEMA: StructType
+ VALUE_COLUMNS: list[str]
+ AGGREGATION_COLUMNS: list[str]
+ PARTITION_COLUMNS: list[str]
+ interface: ParquetInterface
+ partition_columns: Optional[list[str]]
+ mode: str
+ write(path: str = None, partition_columns: list[str] = None)

- **Code structure:**

  The code structure follows the format set by the core package, and the general repository structure. The location of the module script in the repository is as follows:

```
/multimno/
└──── components
   └──── execution
      └──── output_indicators
         └──── output_indicators.py
```

- output_indicators.py contains one class named OutputIndicators which is a subclass of Component. It overrides the following methods:
  - The __init__ method first call its parent's __init__ method, which sets up the Spark session, initialises data objects and reads the configuration file.
  - The transform method handles all the logic behind the component.
  - The execute method handles the reading, execution and writing of each data object to be worked with.
  - The initialise_data_objects creates the input and output data objects that will be used according to what data object types are to be processed as it will be specified in a configuration file.
- The OutputIndicators component also has the following methods:
  - init_internal_migration initialises parameters for filtering the input internal migration data.
  - init_present_population initialises parameters for filtering the input present population data.
  - init_usual_environment initialises parameters for filtering the input usual environment/home location data.
  - init_inbound_tourism initialises parameters for filtering the input inbound tourism data.
  - init_outbound_tourism initialises parameters for filtering the input outbound tourism data.
  - filter_dataframe filters the input data according to the configuration-specified parameters.
  - spatial_aggregation performs the spatial aggregation of indicators for the present population and usual environment/home location data.
  - apply_deduplication_factor handles the multiplication of the appropriate columns by the corresponding deduplication factor.
  - apply_mno_to_target_population_factor handles the multiplication of the appropriate columns by the corresponding MNO-to-target-population factor.
  - apply_anonimity_obfuscate applies the k-anonymity process with obfuscation
  - apply_anonymity_delete applies the k-anonymity process with deletion
  - check_output_format checks that each of the written output data objects have the correct data schema and that they do no contain null values where they are not expected.

5.2.31 MULTIMNOAGGREGATION

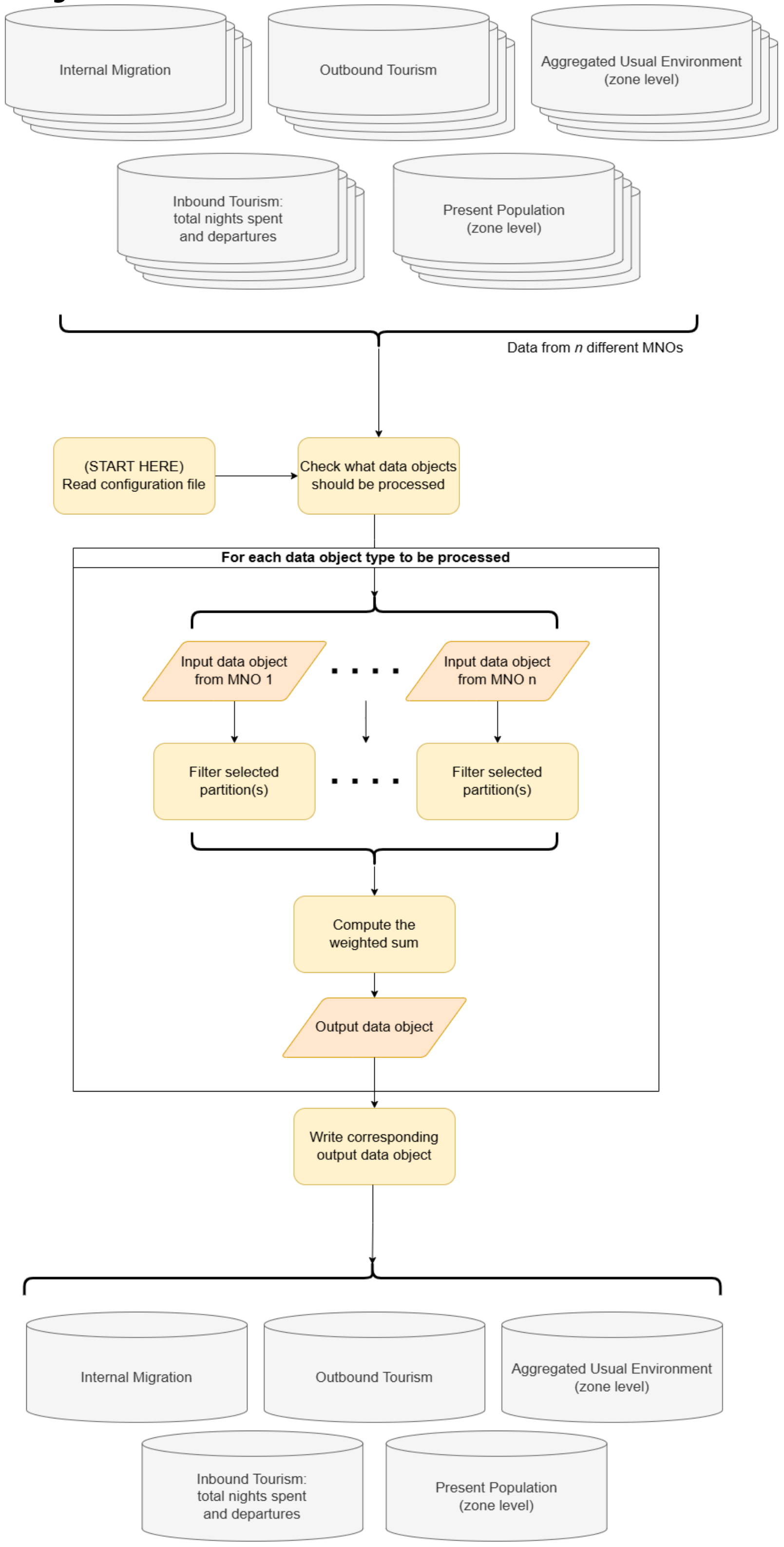
5.2.31.1 MODULE DESCRIPTION

- **Module Name:** MultiMNOAggregation
- **Objectives:** The objective of this module is to aggregate together the indicators produced by different MNOs into one.
- **Functionality:**
    - 3.2.30 MultiMNO Aggregation
- **Data Inputs and Outputs:**
    - Inputs:
        - I.41 Present Population - Zones
        - I.55 Aggregated Usual Environments - Zones
        - I.46 Internal Migration
        - I.51 Inbound Tourism Aggregations I: Nights spent and departures per zone
        - I.53 Outbound Tourism Aggregations: Nights spent per destination country
    - Outputs:
        - I.41 Present Population - Zones
        - I.55 Aggregated Usual Environments - Zones
        - I.46 Internal Migration
        - I.51 Inbound Tourism Aggregations I: Nights spent and departures per zone
        - I.53 Outbound Tourism Aggregations: Nights spent per destination country

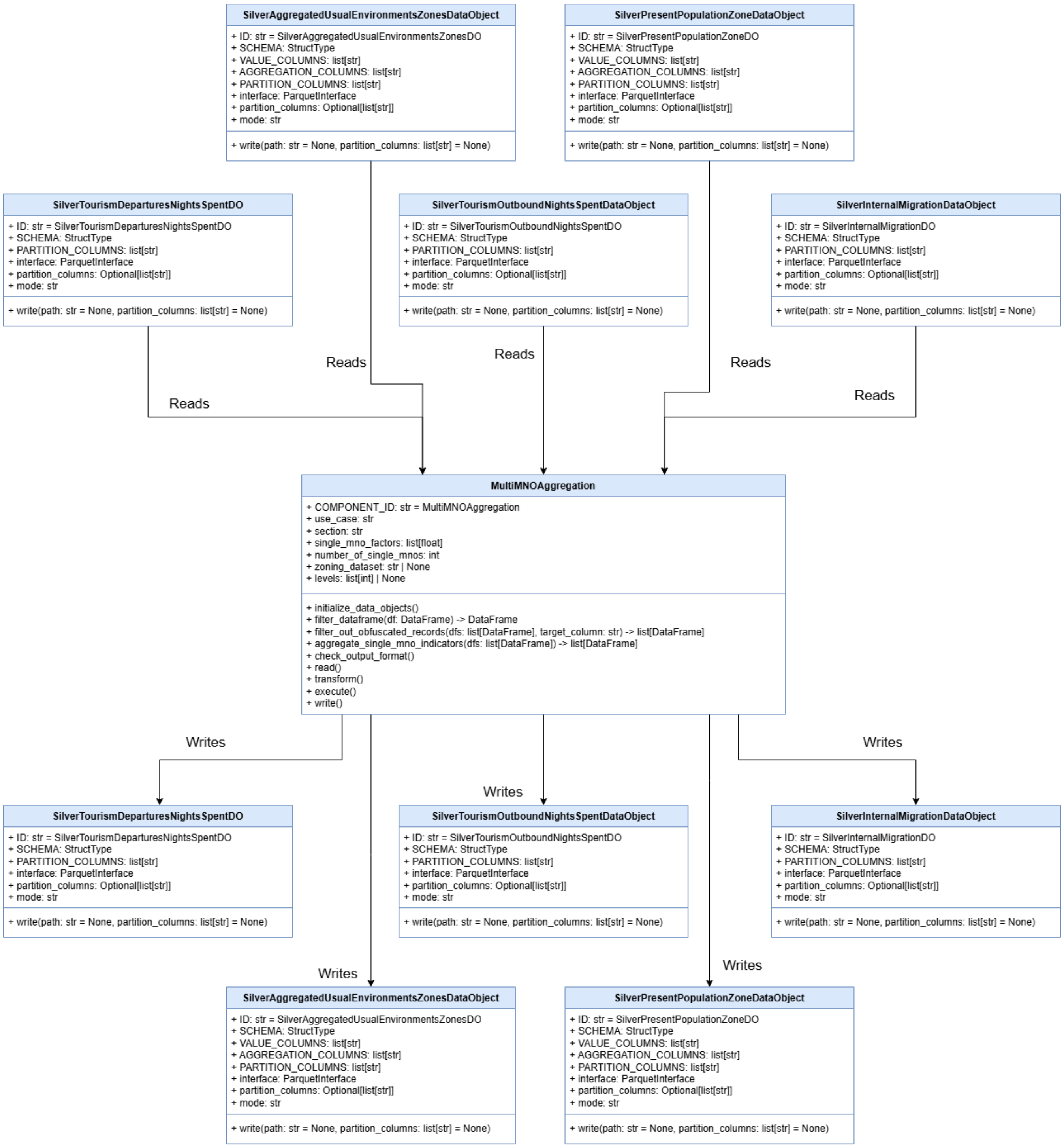
5.2.31.2 DEVELOPMENT DESIGN

- **Key Algorithms/Processes:**
    1. Read from the configuration file what input data objects are to be processed.
    2. Create the corresponding data objects.
    3. For each of the input data objects to be processed:
        1. Check whether the user specified in the configuration file that the indicators of at least 2 MNOs are to be combined. If not, raise this issue and stop the execution.
        2. Read only the partition or partitions specified in the configuration file, on all the datasets of each MNO.
        3. Perform the weighted sum of the indicator of each MNO to produce a single, aggregated indicator. If any value was obfuscated during k-anonimity, it is ignored.
        4. Save the result as the corresponding output data object.

- **Data flow diagram:**


Internal Migration
Outbound Tourism
Aggregated Usual Environment (zone level)
Inbound Tourism: total nights spent and departures
Present Population (zone level)
Data from *n* different MNOs
(START HERE) Read configuration file
Check what data objects should be processed
For each data object type to be processed
Input data object from MNO 1
Input data object from MNO n
Filter selected partition(s)
Filter selected partition(s)
Compute the weighted sum
Output data object
Write corresponding output data object
Internal Migration
Outbound Tourism
Aggregated Usual Environment (zone level)
Inbound Tourism: total nights spent and departures
Present Population (zone level)

- **Class diagram:**


SilverAggregatedUsualEnvironmentsZonesDataObject
+ ID: str = SilverAggregatedUsualEnvironmentsZonesDO
+ SCHEMA: StructType
+ VALUE_COLUMNS: list[str]
+ AGGREGATION_COLUMNS: list[str]
+ PARTITION_COLUMNS: list[str]
+ interface: ParquetInterface
+ partition_columns: Optional[list[str]]
+ mode: str
+ write(path: str = None, partition_columns: list[str] = None)
SilverPresentPopulationZoneDataObject
+ ID: str = SilverPresentPopulationZoneDO
+ SCHEMA: StructType
+ VALUE_COLUMNS: list[str]
+ AGGREGATION_COLUMNS: list[str]
+ PARTITION_COLUMNS: list[str]
+ interface: ParquetInterface
+ partition_columns: Optional[list[str]]
+ mode: str
+ write(path: str = None, partition_columns: list[str] = None)
SilverTourismDeparturesNightsSpentDO
+ ID: str = SilverTourismDeparturesNightsSpentDO
+ SCHEMA: StructType
+ PARTITION_COLUMNS: list[str]
+ interface: ParquetInterface
+ partition_columns: Optional[list[str]]
+ mode: str
+ write(path: str = None, partition_columns: list[str] = None)
SilverTourismOutboundNightsSpentDataObject
+ ID: str = SilverTourismOutboundNightsSpentDO
+ SCHEMA: StructType
+ PARTITION_COLUMNS: list[str]
+ interface: ParquetInterface
+ partition_columns: Optional[list[str]]
+ mode: str
+ write(path: str = None, partition_columns: list[str] = None)
SilverInternalMigrationDataObject
+ ID: str = SilverInternalMigrationDO
+ SCHEMA: StructType
+ PARTITION_COLUMNS: list[str]
+ interface: ParquetInterface
+ partition_columns: Optional[list[str]]
+ mode: str
+ write(path: str = None, partition_columns: list[str] = None)
Reads
Reads
Reads
Reads
Reads
MultiMNOAggregation
+ COMPONENT_ID: str = MultiMNOAggregation
+ use_case: str
+ section: str
+ single_mno_factors: list[float]
+ number_of_single_mnos: int
+ zoning_dataset: str | None
+ levels: list[int] | None
+ initialize_data_objects()
+ filter_dataframe(df: DataFrame) -> DataFrame
+ filter_out_obfuscated_records(dfs: list[DataFrame], target_column: str) -> list[DataFrame]
+ aggregate_single_mno_indicators(dfs: list[DataFrame]) -> list[DataFrame]
+ check_output_format()
+ read()
+ transform()
+ execute()
+ write()
Writes
Writes
Writes
SilverTourismDeparturesNightsSpentDO
+ ID: str = SilverTourismDeparturesNightsSpentDO
+ SCHEMA: StructType
+ PARTITION_COLUMNS: list[str]
+ interface: ParquetInterface
+ partition_columns: Optional[list[str]]
+ mode: str
+ write(path: str = None, partition_columns: list[str] = None)
SilverTourismOutboundNightsSpentDataObject
+ ID: str = SilverTourismOutboundNightsSpentDO
+ SCHEMA: StructType
+ PARTITION_COLUMNS: list[str]
+ interface: ParquetInterface
+ partition_columns: Optional[list[str]]
+ mode: str
+ write(path: str = None, partition_columns: list[str] = None)
SilverInternalMigrationDataObject
+ ID: str = SilverInternalMigrationDO
+ SCHEMA: StructType
+ PARTITION_COLUMNS: list[str]
+ interface: ParquetInterface
+ partition_columns: Optional[list[str]]
+ mode: str
+ write(path: str = None, partition_columns: list[str] = None)
Writes
Writes
SilverAggregatedUsualEnvironmentsZonesDataObject
+ ID: str = SilverAggregatedUsualEnvironmentsZonesDO
+ SCHEMA: StructType
+ VALUE_COLUMNS: list[str]
+ AGGREGATION_COLUMNS: list[str]
+ PARTITION_COLUMNS: list[str]
+ interface: ParquetInterface
+ partition_columns: Optional[list[str]]
+ mode: str
+ write(path: str = None, partition_columns: list[str] = None)
SilverPresentPopulationZoneDataObject
+ ID: str = SilverPresentPopulationZoneDO
+ SCHEMA: StructType
+ VALUE_COLUMNS: list[str]
+ AGGREGATION_COLUMNS: list[str]
+ PARTITION_COLUMNS: list[str]
+ interface: ParquetInterface
+ partition_columns: Optional[list[str]]
+ mode: str
+ write(path: str = None, partition_columns: list[str] = None)

- **Code structure:**

The code structure follows the format set by the core package, and the general repository structure. The location of the module script in the repository is as follows:

```
/multimno/
 └─── components
     └─── execution
         └─── multimno_aggregation
             └─── multimno_aggregation.py
```

- multimno_aggregation.py contains one class named MultiMNOAggretion which is a subclass of Component. It overrides the following methods:
  - The __init__ method first call its parent's __init__ method, which sets up the Spark session, initialises data objects and reads the configuration file.
  - The transform method handles all the logic behind the component.
  - The execute method handles the reading, execution and writing of each data object to be worked with.
  - The initialise_data_objects creates the input and output data objects that will be used according to what data object types are to be processed as it will be specified in a configuration file.
- The MultiMNOAggregation component also has the following methods:
  - filter_dataframe correctly selects the partition or partitions of the data object to be processed as specified in the configuration file.
  - filter_out_obfuscated_records takes as input a list of DataFrames and returns the same list of DataFrames with their obfuscated records, i.e. those records or rows with value -1, removed.
  - aggregate_single_mno_indicators carries out the weighted sum of the single MNO indicators and returns the final aggregated DataFrame.
  - check_output_format checks that each of the written output data objects have the correct data schema and that they do no contain null values where they are not expected.

5.2.32 DAILYPERMANENCESCOREQUALITYMETRICS

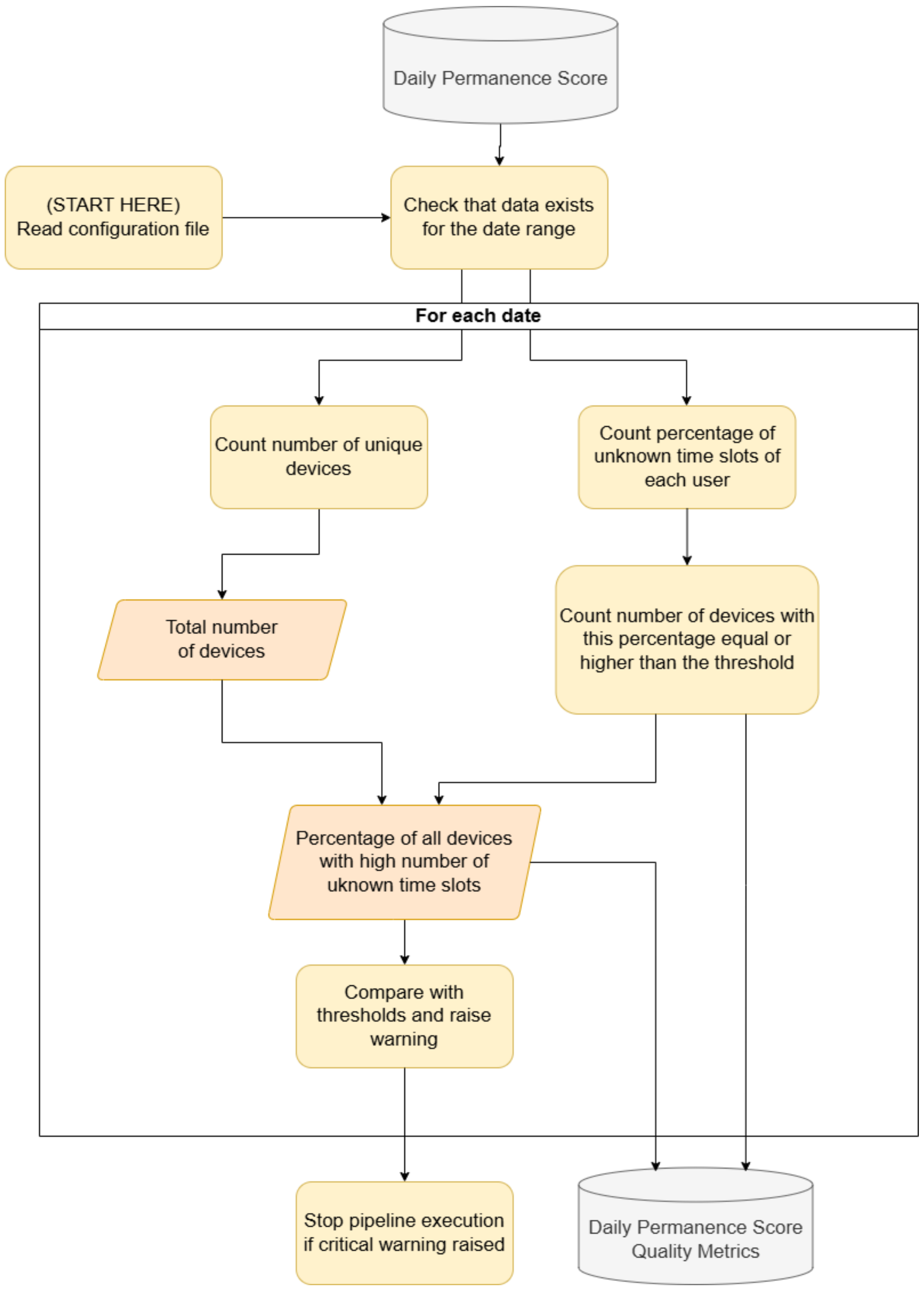
5.2.32.1 MODULE DESCRIPTION

- **Module Name:** DailyPermanenceScoreQualityMetrics
- **Objectives:** The objective of this module is to compute quality metrics on the output of the daily permanence score component and raise critical or non-critical warnings accordingly.
- **Functionality:**
    - 3.2.31 DailyPermanenceScoreQualityMetrics
- **Data Inputs and Outputs:**
    - Inputs:
        - I.21 Daily Permanence Score
    - Outputs:
        - I.56 Daily Permanence Score Quality Metrics

5.2.32.2 DEVELOPMENT DESIGN

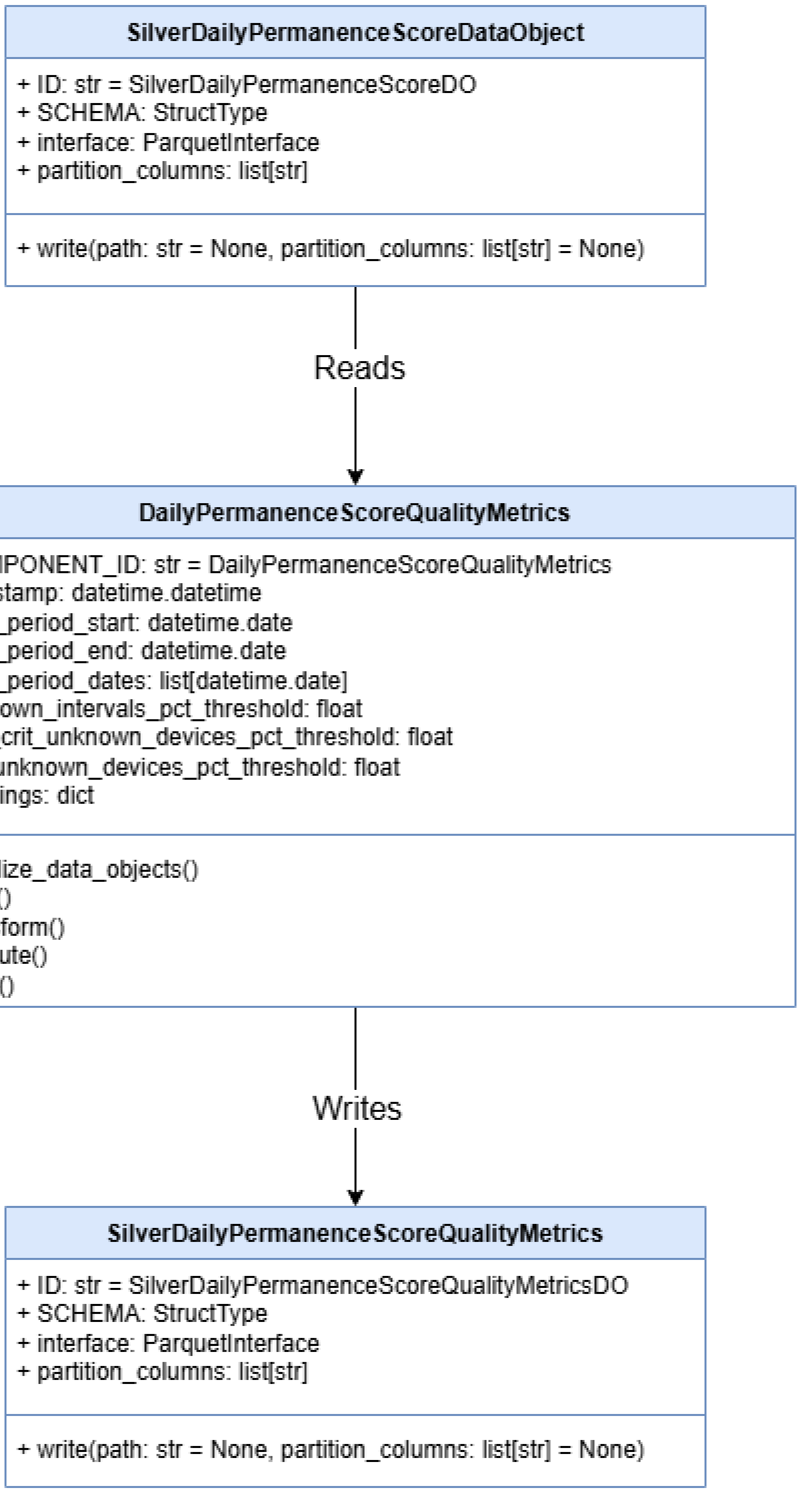
- **Key Algorithms/Processes:**
    1. Read the configuration file to get the date range for which to compute the quality metrics, as well as the threshold for a high number of "unknown" time slots and the non-critical and critical threshold for number of users with this high number of time slots.
    2. Create the corresponding data objects
    3. For each date of the date range:
        1. Count the number of unique devices in the daily permanence score dataset.
        2. Count the percentage of "unknown" time slots that each user has.
        3. Count the number of unique devices whose percentage of "unknown" time slots is equal or higher than the threshold.
        4. Obtain the percentage of devices with high number of "unknown" time slots from the previous counts of devices.
            1. If this percentage is equal or higher than the critical threshold, raise a critical warning
            2. If this percentage is strictly higher than the non-critical threshold and strictly lower than the critical threshold, raise a non-critical warning
            3. Otherwise, do not raise a warning
        5. Save the number and percentage of devices with a high number of "unknown" time slots for this date.

- **Data flow diagram:**



Daily Permanence Score
(START HERE) Read configuration file
Check that data exists for the date range
For each date
Count number of unique devices
Count percentage of unknown time slots of each user
Total number of devices
Count number of devices with this percentage equal or higher than the threshold
Percentage of all devices with high number of uknown time slots
Compare with thresholds and raise warning
Stop pipeline execution if critical warning raised
Daily Permanence Score Quality Metrics

- **Class diagram:**


SilverDailyPermanenceScoreDataObject
+ ID: str = SilverDailyPermanenceScoreDO
+ SCHEMA: StructType
+ interface: ParquetInterface
+ partition_columns: list[str]
+ write(path: str = None, partition_columns: list[str] = None)
Reads
DailyPermanenceScoreQualityMetrics
+ COMPONENT_ID: str = DailyPermanenceScoreQualityMetrics
+ timestamp: datetime.datetime
+ data_period_start: datetime.date
+ data_period_end: datetime.date
+ data_period_dates: list[datetime.date]
+ unknown_intervals_pct_threshold: float
+ non_crit_unknown_devices_pct_threshold: float
+ crit_unknown_devices_pct_threshold: float
+ warnings: dict
+ initialize_data_objects()
+ read()
+ transform()
+ execute()
+ write()
Writes
SilverDailyPermanenceScoreQualityMetrics
+ ID: str = SilverDailyPermanenceScoreQualityMetricsDO
+ SCHEMA: StructType
+ interface: ParquetInterface
+ partition_columns: list[str]
+ write(path: str = None, partition_columns: list[str] = None)

- **Code structure:**

The code structure follows the format set by the core package, and the general repository structure. The location of the module script in the repository is as follows:

```
/multimno/
└──── components
    └──── execution
        └──── daily_permanence_score_quality_metrics
            └──── daily_permanence_score_quality_metrics.py
```

daily_permanence_score_quality_metrics.py contains one class named DailyPermanenceScoreQualityMetrics which is a subclass of Component. It overrides the following methods:

- The __init__ method first call its parent's __init__ method, which sets up the Spark session, initialises data objects and reads the configuration file.
- The transform method handles all the logic behind the component.
- The execute method handles the reading, execution and writing of each data object to be worked with.
- The initialise_data_objects creates the input and output data objects that will be used according to what data object types are to be processed as it will be specified in a configuration file.

5.2.33 CELLFOOTPRINTQUALITYMETRICS

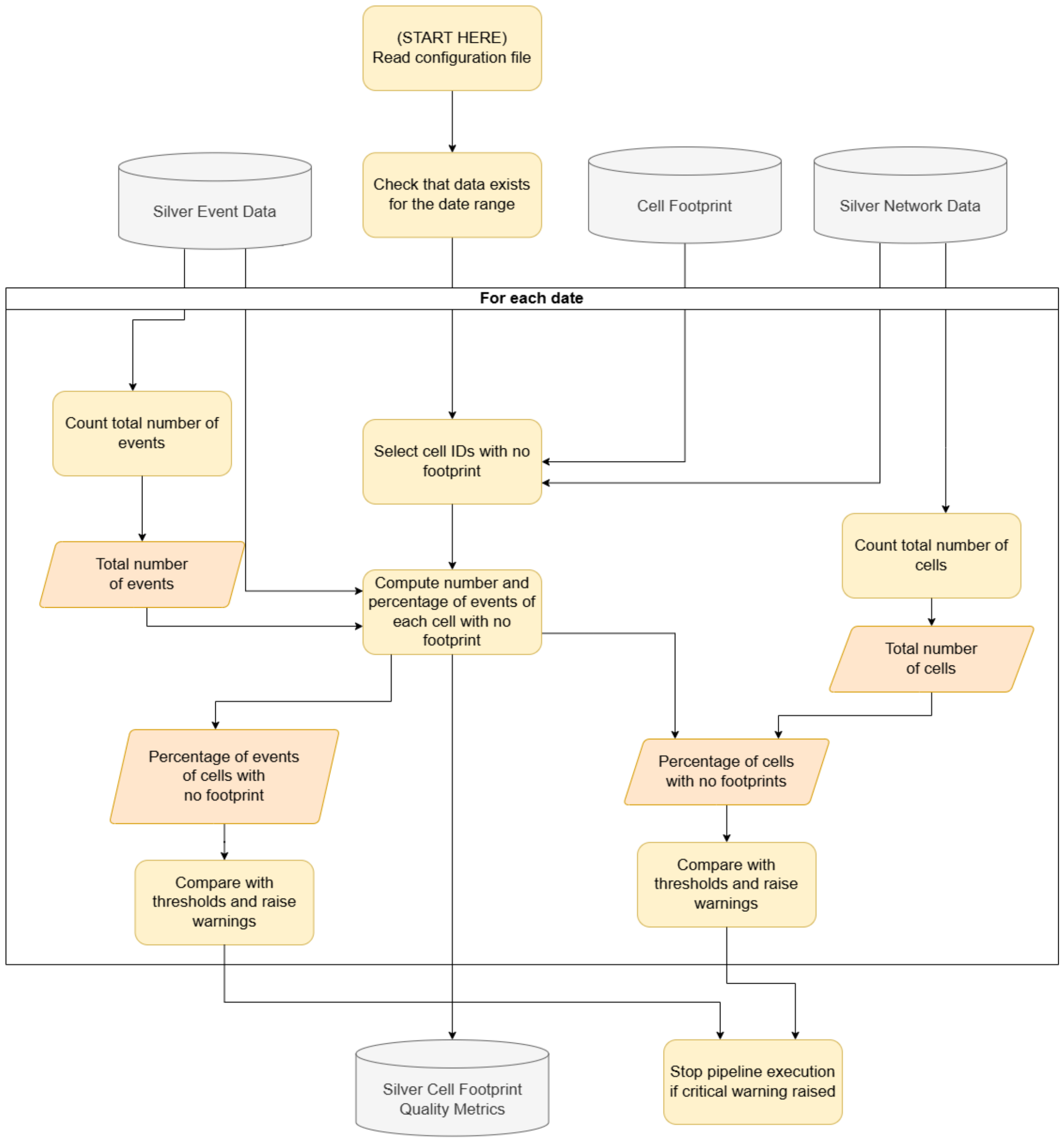
5.2.33.1 MODULE DESCRIPTION

- **Module Name:** CellFootprintQualityMetrics
- **Objectives:** The objective of this module is to compute quality metrics on the output of the cell footprint component and raise critical or non-critical warnings accordingly.
- **Functionality:**
    - 3.2.32 CellFootprintQualityMetrics
- **Data Inputs and Outputs:**
    - Inputs:
        - I.8 Cell locations with Physical Properties - Cleaned
        - I.2 MNO Event Data - Syntactically Cleaned
        - I.13 Cell Footprints
    - Outputs:
        - I.57 Cell Footprint Quality Metrics

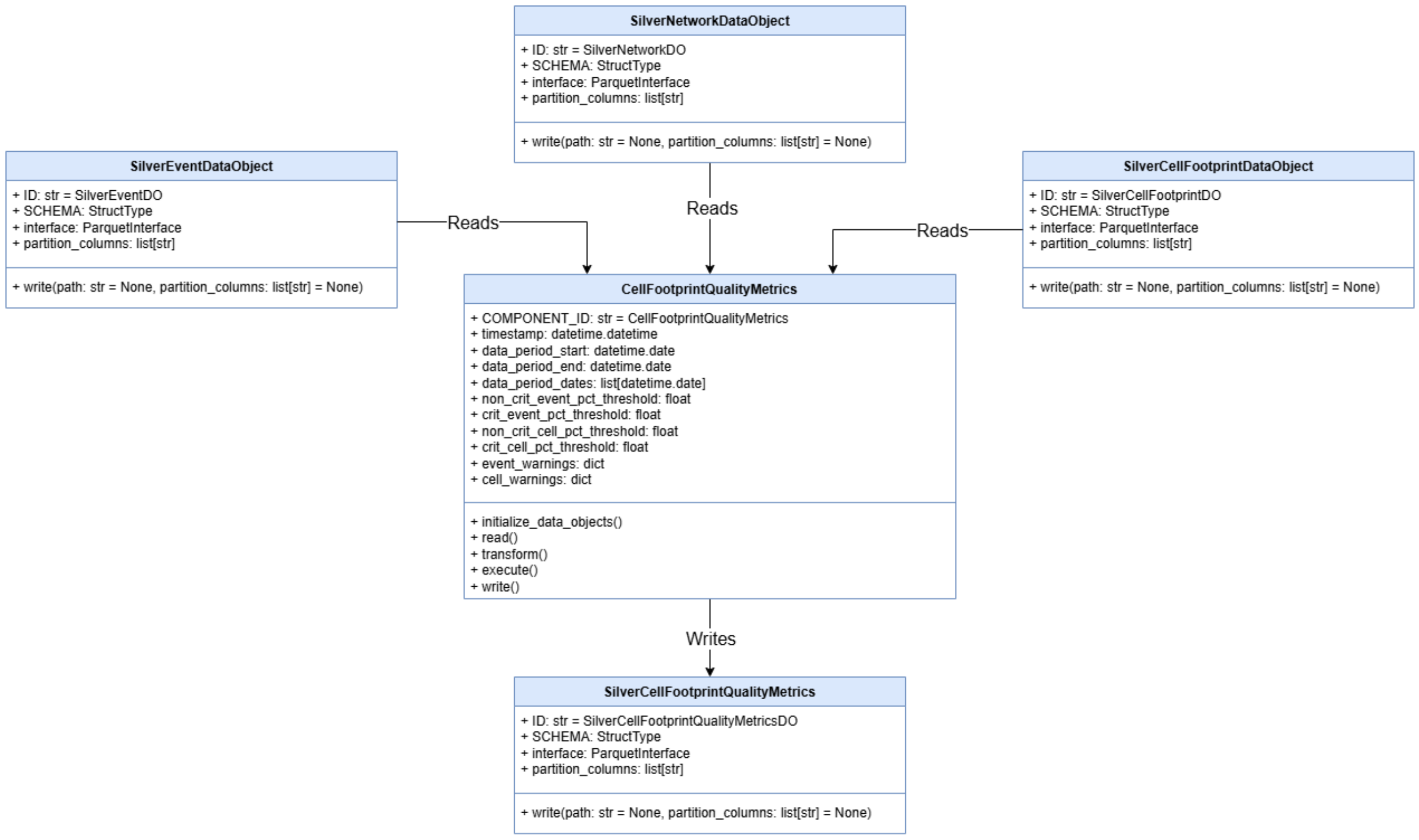
5.2.33.2 DEVELOPMENT DESIGN

- **Key Algorithms/Processes:**
    1. Read the configuration file to get the date range for which to compute the quality metrics, as well as the non-critical and critical threshold for number of cells with no footprint and number of events assigned to those cells.
    2. Create the corresponding data objects
    3. For each date of the date range:
        1. Count the number of cells in the syntactically clean cell dataset.
        2. Count the number of events in the syntactically clean event dataset.
        3. Compare the unique cell IDs that appear in the syntactically cleaned cell data with the IDs that appear in the cell footprint data to determine the cells that appear in the first dataset but not in the second. These are the cells with no footprint assigned.
        4. Count the number of events assigned to each of the cells with no footprint assigned, as well as the percentage they represent with respect to the total number of events.
            1. If this percentage is equal or higher than the critical threshold, raise a critical warning
            2. If this percentage is strictly higher than the non-critical threshold and strictly lower than the critical threshold, raise a non-critical warning
            3. Otherwise, do not raise a warning
        5. Count the total number of events assigned to cells with no footprint, as well as the percentage they represent with respect to the total number of cells.
            1. If this percentage is equal or higher than the critical threshold, raise a critical warning
            2. If this percentage is strictly higher than the non-critical threshold and strictly lower than the critical threshold, raise a non-critical warning
            3. Otherwise, do not raise a warning
        6. Save the ID of each cell with no footprint, together with the number and percentage of events assigned to each of them.

- **Data flow diagram:**


(START HERE) Read configuration file
Check that data exists for the date range
Silver Event Data
Cell Footprint
Silver Network Data
For each date
Count total number of events
Select cell IDs with no footprint
Total number of events
Count total number of cells
Compute number and percentage of events of each cell with no footprint
Total number of cells
Percentage of events of cells with no footprint
Percentage of cells with no footprints
Compare with thresholds and raise warnings
Compare with thresholds and raise warnings
Silver Cell Footprint Quality Metrics
Stop pipeline execution if critical warning raised

- **Class diagram:**


SilverNetworkDataObject
+ ID: str = SilverNetworkDO
+ SCHEMA: StructType
+ interface: ParquetInterface
+ partition_columns: list[str]
+ write(path: str = None, partition_columns: list[str] = None)
SilverEventDataObject
+ ID: str = SilverEventDO
+ SCHEMA: StructType
+ interface: ParquetInterface
+ partition_columns: list[str]
+ write(path: str = None, partition_columns: list[str] = None)
SilverCellFootprintDataObject
+ ID: str = SilverCellFootprintDO
+ SCHEMA: StructType
+ interface: ParquetInterface
+ partition_columns: list[str]
+ write(path: str = None, partition_columns: list[str] = None)
Reads
Reads
Reads
CellFootprintQualityMetrics
+ COMPONENT_ID: str = CellFootprintQualityMetrics
+ timestamp: datetime.datetime
+ data_period_start: datetime.date
+ data_period_end: datetime.date
+ data_period_dates: list[datetime.date]
+ non_crit_event_pct_threshold: float
+ crit_event_pct_threshold: float
+ non_crit_cell_pct_threshold: float
+ crit_cell_pct_threshold: float
+ event_warnings: dict
+ cell_warnings: dict
+ initialize_data_objects()
+ read()
+ transform()
+ execute()
+ write()
Writes
SilverCellFootprintQualityMetrics
+ ID: str = SilverCellFootprintQualityMetricsDO
+ SCHEMA: StructType
+ interface: ParquetInterface
+ partition_columns: list[str]
+ write(path: str = None, partition_columns: list[str] = None)

- **Code structure:**

The code structure follows the format set by the core package, and the general repository structure. The location of the module script in the repository is as follows:

```
/multimno/
└──── components
    └──── execution
        └──── cell_footprint_quality_metrics
            └──── cell_footprint_quality_metrics.py
```

cell_footprint_quality_metrics.py contains one class named CellFootprintQualityMetrics which is a subclass of Component. It overrides the following methods:

- The __init__ method first call its parent's __init__ method, which sets up the Spark session, initialises data objects and reads the configuration file.
- The transform method handles all the logic behind the component.
- The execute method handles the reading, execution and writing of each data object to be worked with.
- The initialise_data_objects creates the input and output data objects that will be used according to what data object types are to be processed as it will be specified in a configuration file.

ANNEX I – DATA OBJECTS

I.1 MNO EVENT DATA – RAW

NAME	BRONZEEVENTDATAOBJECT
Description	'*MNO Event Data*' contains geolocation data from MNO subscribers. Data shall be created using at least one of the following data sources: (i) **CDRs** and/or (ii) **signalling data**. Additional information from MNO Apps can be added in order to improve the quality of the dataset, but this information is not mandatory. CDRs information shall contain all the information coming from voice, messages, internet connections, etc. CDRs shall also include roaming-in and roaming-out data. Each record of the dataset corresponds to a **MNO data event**, containing at least information about the identifier of the user, the timestamp of the event and the identifier of the cell to which the user is connected. When location information is estimated at point level (e.g. through signal triangulation or GPS data) information can be also be provided. This dataset shall only contain information about **personal mobile devices**. IoT, M2M and other related devices not associated to people shall not be included in the dataset.
Owner/Holder	MNO
Object/Unit/Record	Mobile network event associated to a specific subscriber
Contents	**Mandatory fields**: • **user_id:** ○ Type: Binary ○ Requirements: 32 bytes (256 bits) field. ○ Description: Unique pseudonymized identifier of the device, generated by hashing the user's IMSI using the SHA-256 function. • **timestamp:** ○ Type: String ○ Requirements: String with date and time following ISO:8601 format: YYYY-MM-DDThh:mm.ss ○ Description: Point in time where the event took place. • **mcc:** ○ Type: Integer ○ Requirement: 3 digits code ○ Description: Mobile Country Code derived from the user's IMSI • **mnc:** ○ Type: String ○ Requirement: 2- or 3-digits code ○ Description: Mobile Network Code, a code of a home operator. It might help to assess the selectivity bias that is in place due to preferential roaming agreements between MNOs. This must be string, as it can start with 0 digit. Possible options can also be 01 or 001, so it cannot be integer. • **plmn:** ○ Type: Integer ○ Requirement: 5- or 6-digits code. Mandatory only for outbound data ○ Description: Network identifier of the foreign roaming partner MNO consists of PLMN=MCC+MNC. • **cell_id:** ○ Type: String ○ Requirements: 14- or 15-character length string. All characters must be numbers. Optional if 'latitude' and 'longitude' are not null. ○ Description: Identifier of the cell following CGI and eCGI standards.

NAME	BRONZEEVENTDATAOBJECT
	• **latitude:** ○ Type: Float ○ Requirements: Latitude value in WGS84 system. Value must be within WGS84 bounds. Optional if 'cell_id' is not null. ○ Description: Latitude value of the location of the event. • **longitude**: ○ Type: Float ○ Requirements: Longitude value in WGS84 system. Value must be within WGS84 bounds. Optional if 'cell_id' is not null. ○ Description: Longitude value of the location of the event. **Optional fields**: • **loc_error**: ○ Type: Float ○ Requirements: Positive value. If 'latitude' and 'longitude' are null, this field shall be set to null. ○ Description: Location error in meters.

\ EXAMPLE

user_id	timestamp	mcc	mnc	plmn	cell_id	latitude	longitude	loc_error
000000000000..01	2023-01-01T00:00:00	214	01	null	214030412038931	–3.62958	40.51873	100.0
000000000000..10	2023-01-01T00:01:15	214	01	null	214030412038931	–3.62952	40.51871	100.0
000000000000..11	2023-01-01T12:05:03	214	01	null	214035484123541	null	null	null

I.2 MNO EVENT DATA – SYNTACTICALLY CLEANED

NAME	SILVEREVENTDATAOBJECT
Description	This data is basically the same as MNO Event Data - Raw. The only difference is that the events with syntactic errors have been removed.
Object/Unit/Record	Mobile network event associated to a specific subscriber
Contents	**Mandatory fields**: • **year:** o Type: Integer 16 o Requirements: Integer of 16 bits. o Description: Year the event took place. • **month:** o Type: Integer 8 o Requirements: Integer of 8 bits. o Description: Month the event took place. • **day:** o Type: Integer 8 o Requirements: Integer of 8 bits. o Description: Day the event took place. • **user_id:** o Type: Binary o Requirements: 32 bytes (256 bits) field. o Description: Unique pseudonymized identifier of the device. • **user_id_modulo:** o Type: Integer o Requirements: Integer of 8 bits. o Description: Modulo division result, as applied to the integer part of the user_id column. • **timestamp:** o Type: Time o Requirements: Parquet time type in hour, minutes and seconds. o Description: Point in time where the event took place. • **mcc:** o Type: Integer o Requirement: 3 digits code o Description: Mobile Country Code derived from the user's IMSI. • **mnc:** o Type: String o Requirement: 2- or 3-digits code o Description: Mobile Network Code, a code of a home operator. It might help to assess the selectivity bias that is in place due to preferential roaming agreements between MNOs. This must be string, as it can start with 0 digit. Possible options can also be 01 or 001, so it cannot be integer. • **plmn:** o Type: Integer o Requirement: 5- or 6-digits code. Mandatory only for outbound data o Description: Network identifier of the foreign roaming partner MNO consists of PLMN=MCC+MNC. • **cell_id:** o Type: String o Requirements: 14- or 15-character length string. All characters must be numbers. Optional if "latitude" and "longitude" are not null. o Description: Identifier of the cell following CGI and eCGI standards.

NAME	SILVEREVENTDATAOBJECT
	• **latitude:** ○ Type: Float ○ Requirements: Latitude value in WGS84 system. Value must be within WGS84 bounds. Optional if "cell_id" is not null. ○ Description: Latitude value of the location of the event. • **longitude**: ○ Type: Float ○ Requirements: Longitude value in WGS84 system. Value must be within WGS84 bounds. Optional if "cell_id" is not null. ○ Description: Longitude value of the location of the event. **Optional fields**: • **loc_error**: ○ Type: Integer ○ Requirements: Positive value ○ Description: Location error in meters.

\ EXAMPLE

year	**month**	**day**	**user_id**	**timestamp**	**mcc**	**mnc**	**plmn**	**cell_id**	**lon**	**lat**	**loc_error**
2023	01	01	000000000000..01	00:00:00	214	01	null	214030412038931	40.51873	–3.62958	100
2023	01	01	000000000000..01	00:01:15	214	01	null	214030412038931	40.51871	–3.62952	100
2023	01	01	000000000000..10	12:05:03	214	01	null	214035484123541	null	null	null

I.3 MNO EVENT DATA SYNTACTIC QUALITY METRICS – BY COLUMN

NAME	SILVEREVENTDATASYNTACTICQUALITYMETRICSBYCOLUMN
Description	Quality metrics produced by EventCleaning. It includes counts of records removed or labelled by variable and by type of error.
Object/Unit/Record	Quality metrics
Contents	**Mandatory fields:** • **result_timestamp**: ○ Type: TimestampType ○ Requirements: Timestamp ○ Description: Timestamp of the start of the process when the metrics were produced. One process can generate multiple metrics. • **date**: ○ Type: DateType ○ Requirements: The date that the data was about. ○ Description: The date for which the quality metrics were produced. • **variable:** ○ Type: StringType ○ Requirements: Must be a name of a column ○ Description: The name of the field to which the metric refers to. it could be null if the error refers to more then a variable. • **type of error** ○ Type: ShortType ○ Requirements: Integer of 16 bits. ○ Description: Shows which error occurred. Possible errors are in table below. • **type of transformation** ○ Type: ShortType ○ Requirements: Integer of 16 bits ○ Description: Shows which type of transformation occurred. Possible transformations are in table below. • **value**: ○ Type: IntegerType ○ Requirements: Integer of 32 bits. ○ Description: Count of records with the characteristics in the previous field

\ EXAMPLE

TYPE_OF_ERROR	ERROR_TYPE_DESCRIPTION
1	Missing value
2	Not right syntactic format
3	Out of admissible values
4	Inconsistency between variables
5	No location (no cell_id and no latitude&longitude), for that type or error there is None for variable column
6	Out of bounding box
7	No domain columns
9	No error
10	Different location duplicate
11	Same location duplicate

TYPE_OF_TRANSFORMATION	ERROR_TYPE_DESCRIPTION
1	Converted timestamps
2	Other conversion
9	No transformation

RESULT_TIMESTAMP	DATE	VARIABLE	TYPE_OF_ERROR	TYPE OF TRANSFORMATION	VALUE
2023-01-01 12:00:00	2022-12-01	cell_id	1	-	1000
2023-01-01 12:00:00	2022-12-01	cell_id	2	-	20
2023-01-01 12:00:00	2022-12-01	cell_id	9	-	10000
2023-01-01 12:00:00	2022-12-01	timestamp	-	1	1

I.4 MNO EVENT DATA SYNTACTIC QUALITY METRICS – FREQUENCY DISTRIBUTION

NAME	SILVEREVENTDATASYNTACTICQUALITYMETRICSFREQUENCYDISTRIBUTION
Description	Quality metrics produced by EventCleaning. This data object includes a table to show distribution of records by **user_id** and **cell_id** before and after the application of MNO Event Data Syntactic Quality Metrics method.
Object/Unit/Record	Quality metrics
Contents	**Mandatory fields**: • **cell_id:** ○ Type: StringType ○ Requirements: 14- or 15-character length string. All characters must be numbers. ○ Description: Identifier of the cell following CGI and eCGI standards. • **user_id:** ○ Type: BinaryType ○ Requirements: 32 bytes (256 bits) field. ○ Description: Unique pseudonymized identifier of the device, generated by hashing the user's IMSI using the SHA-256 function. • **initial_frequency:** ○ Type: IntegerType ○ Requirements: Integer of 32 bits. ○ Description: Number of records with given cell_id and user_id before filtering. • **final_frequency:** ○ Type: IntegerType ○ Requirements: Integer of 32 bits. ○ Description: Number of records with given cell_id and user_id after filtering. • **date:** ○ Type: DateType ○ Requirements: Date of the data in UTC. ○ Description: Date of the data in UTC.

\ EXAMPLE

cell_id	user_id	date	initial_frequency	final_frequency
214030412038931	000000000000..01	2023-07-20	200	10
214030412038931	000000000000..01	2023-07-21	600	600

I.5 MNO EVENT DATA QUALITY WARNINGS – LOG TABLE

NAME	SILVEREVENTDATASYNTACTICQUALITYWARNINGSLOGTABLE
Description	Data Object is meant to store warnings in unified format.
Object/Unit/Record	Quality warnings
Contents	**Mandatory fields**: • **date:** ○ Type: Date ○ Description: date a warning happened. • **measure_definition:** ○ Type: String ○ Description: A name of warning group, e.g. 'Error rate …' • **lookback_period:** ○ Type: String ○ Description: The text representation of a lookback period, e.g. 'week' meaning 7 days • **daily_value:** ○ Type: Float ○ Description: The value that does not meet warning condition. • **condition_value:** ○ Type: Float ○ Description: Value to compare with daily_value to check if condition is met. • **condition**: ○ Type: String ○ Description: Condition description. • **warning_text**: ○ Type: String ○ Description: Warning description

\ EXAMPLE

date	measure_definition	lookback_period	daily_value	condition_value	condition	warning_text
2024-01-29	Error rate for date	week	23.41	22.48	Error rate is over the upper control limit calculated on the basis of average and standard deviation of the distribution of the error rate in previous	The error rate after syntactic checks application is unexpectedly high with respect to previous period, taking into account its usual variability

I.6 MNO EVENT DATA – DEDUPLICATED

NAME	SILVEREVENTDATAOBJECT
Description	This data is schematically identical to I.1 MNO Event Data – Raw. The difference is that duplicated rows have been removed.
Object/Unit/Record	Mobile network event associated to a specific subscriber
Contents	**Mandatory fields**: • **year:** ○ Type: Integer 16 ○ Requirements: Integer of 16 bits. ○ Description: Year the event took place. • **month:** ○ Type: Integer 8 ○ Requirements: Integer of 8 bits. ○ Description: Month the event took place. • **day:** ○ Type: Integer 8 ○ Requirements: Integer of 8 bits. ○ Description: Day the event took place. • **user_id:** ○ Type: Binary ○ Requirements: 32 bytes (256 bits) field. ○ Description: Unique pseudonymized identifier of the device. • **user_id_modulo:** ○ Type: Integer ○ Requirements: Integer of 8 bits. ○ Description: Modulo division result, as applied to the integer part of the user_id column. • **timestamp:** ○ Type: Time ○ Requirements: Parquet time type in hour, minutes and seconds. ○ Description: Point in time where the event took place. • **mcc:** ○ Type: Integer ○ Requirement: 3 digits code ○ Description: Mobile Country Code derived from the user's IMSI. • **cell_id:** ○ Type: String ○ Requirements: 14- or 15-character length string. All characters must be numbers. Optional if 'latitude' and 'longitude' are not null. ○ Description: Identifier of the cell following CGI and eCGI standards. • **latitude:** ○ Type: Float ○ Requirements: Latitude value in WGS84 system. Value has to be within WGS84 bounds. Optional if 'cell_id' is not null. ○ Description: Latitude value of the location of the event. • **longitude**: ○ Type: Float ○ Requirements: Longitude value in WGS84 system. Value has to be within WGS84 bounds. Optional if 'cell_id' is not null. ○ Description: Longitude value of the location of the event. **Optional fields**: • **loc_error**: ○ Type: Integer

NAME	SILVEREVENTDATAOBJECT
	○ Requirements: Positive value ○ Description: Location error in meters.

\ EXAMPLE

year	month	day	user_id	timestamp	mcc	cell_id	lon	lat	loc_error
2023	01	01	000000000000..01	00:00:00	214	214030412038931	40.51873	-3.62958	100
2023	01	01	000000000000..01	00:01:15	214	214030412038931	40.51871	-3.62952	100

I.7 CELL LOCATIONS WITH PHYSICAL PROPERTIES - RAW

NAME	BRONZENETWORKDATAOBJECT
Description	Contains information about the location and physical properties of network cells for a specific day. Data updated along with MNO event data representing the network parameters for all active cells for a specific date.
Owner/Holder	MNO
Object/Unit/Record	Characteristic of a specific cell
Contents	**Mandatory fields**: • **cell_id**: ○ Type: String ○ Requirements: 14-digit or 15-digit numeric code following CGI and eCGI standards ○ Description: Code uniquely identifying one cell. • **latitude:** ○ Type: Float ○ Requirements: Latitude value in WGS84 system. Value must be within WGS84 bounds. ○ Description: Latitude of cell location (location of the antenna). • **longitude:** ○ Type: Float ○ Requirements: Longitude in WGS84 system. Value must be within WGS84 bounds. ○ Description: Longitude of cell location (location of the antenna). • **directionality:** ○ Type: Integer ○ Requirements: value is either 0 or 1 ○ Description: 0 for omnidirectional antennas and 1 for directional antenas. • **azimuth_angle:** ○ Type: Float, nullable ○ Requirements: value between 0 and 360 if 'directionality' equal to 1, null otherwise. ○ Description: angle in degrees of the main propagation direction with respect to the North clockwise; for directional cells only. **Optional fields**: • **altitude:** ○ Type: Float ○ Requirements: ○ Description: Altitude (meters) of the antenna base from the sea level. • **antenna_height:** ○ Type: Float ○ Requirements: Positive value ○ Description: Height of the antenna in meters from ground • **elevation_angle:** ○ Type: Float ○ Requirements: value between -90 and 90 ○ Description: Antenna placement angle; also known as tilt • **horizontal_beam_width:** ○ Type: Float ○ Requirements: value between 0 and 360 ○ Description: The angular extent of the cell beam in the horizontal plane • **vertical_beam_width:** ○ Type: Float ○ Requirements: value between 0 and 360

NAME	BRONZENETWORKDATAOBJECT
	◦ Description: The angular extent of the cell beam in the vertical plane • **power:** ◦ Type: Float ◦ Requirements: Positive value ◦ Description: W • **range:** ◦ Type: Float ◦ Requirements: Positive value ◦ Description: maximum coverage range of the cell, in metres • **frequency:** ◦ Type: Integer ◦ Requirements: Positive value ◦ Description: MHz • **technology:** ◦ Type: String ◦ Requirements: ◦ Description: Technology of the cell. • **valid_date_start:** ◦ Type: String ◦ Requirements: String with date and time following ISO:8601 format: YYYY-MM-DDThh:mm.ss. Has to be earlier than **valid_period_end**. ◦ Description: Start of time window in which the antenna is operational in this location. Period start timestamp is *included* within the time window. • **valid_date_end:** ◦ Type: String, nullable ◦ Requirements: String with date and time following ISO:8601 format: YYYY-MM-DDThh:mm.ss. Has to be later than **valid_period_start**. It shall be set to null if it still operational. ◦ Description: End of time window in which the antenna is operational in this location. Period end timestamp is *excluded* from the time window. • **cell_type:** ◦ Type: String ◦ Requirements: ◦ Description: picocell, femtocell, etc. • **year:** ◦ Type: Integer 16. ◦ Description: Year the register corresponds to. • **month:** ◦ Type: Integer 8. ◦ Description: Month the register corresponds to. • **day:** ◦ Type: Integer 8. ◦ Description: Day the register corresponds to.

\ EXAMPLE

cell_id	latitude	longitude	altitude	antenna_height	directionality	azimuth_angle	elevation_angle	horizontal_beam_width	vertical_beam_width	power	frequency	technology	valid_date_start	valid_date_end	cell_type	year	month	day
214030412038931	-3.62958	40.51873	20.0	42	1	90	4	65	9	3	3500	LTE	2023-07-20T10:00:00	2023-12-31T23:30:00	TBD	2023	10	10
214035484123541	-3.8245	40.8952	30.5	12	0	null	5	42	9	7	1800	LTE	2023-07-20T12:34:56	null	TBD	2023	10	10

I.8 CELL LOCATIONS WITH PHYSICAL PROPERTIES – CLEANED

NAME	SILVERNETWORKDATAOBJECT
Description	Contains syntactically cleaned information about the location and physical properties of network cells for a specific day.
Object/Unit/Record	Characteristic of a specific cell
Contents	**Mandatory fields**: • **cell_id**: o Type: String o Description: Code uniquely identifying one cell. • **latitude:** o Type: Float o Description: Latitude of cell location (location of the antenna). • **longitude:** o Type: Float o Description: Longitude of cell location (location of the antenna). • **altitude:** o Type: Float, nullable o Description: Altitude (meters) of the antenna base from the sea level. • **antenna_height:** o Type: Float, nullable o Description: Height of the antenna in meters from ground • **directionality:** o Type: Integer, nullable o Description: 0 for omnidirectional antennas and 1 for directional antenas. • **azimuth_angle:** o Type: Float, nullable o Description: angle in degrees of the main propagation direction with respect to the North clockwise; for directional cells only. • **elevation_angle:** o Type: Float, nullable o Description: Antenna placement angle; also known as tilt • **horizontal_beam_width:** o Type: Float, nullable o Description: The angular extent of the cell beam in the horizontal plane • **vertical_beam_width:** o Type: Float, nullable o Description: The angular extent of the cell beam in the vertical plane • **power:** o Type: Float, nullable o Description: W • **range:** o Type: Float, nullable o Description: maximum coverage range of the cell, in metres • **frequency:** o Type: Integer, nullable o Description: MHz • **technology:** o Type: String, nullable o Description: Technology of the cell. • **valid_date_start:** o Type: String, nullable o Description: Start of time window in which the antenna is operational in this location. Period start timestamp is *included* within the time window.

NAME	SILVERNETWORKDATAOBJECT
	• **valid_date_end:** ○ Type: String, nullable ○ Description: End of time window in which the antenna is operational in this location. Period end timestamp is *excluded* from the time window. • **cell_type:** ○ Type: String, nullable ○ Description: normal, picocell, femtocell, etc. • **year:** ○ Type: Integer 16. ○ Description: Year corresponding to the register. • **month:** ○ Type: Integer 8. ○ Description: Month correspoding to the register. • **day:** ○ Type: Integer 8. ○ Description: Day corresponding to the register.

\ EXAMPLE

cell_id	latitude	longitude	altitude	antenna_height	directionality	azimuth_angle	elevation_angle	horizontal_beam_width	vertical_beam_width	power	frequency	technology	valid_date_start	valid_date_end	cell_type	year	month	day
214030412038931	-3.62958	40.51873	20.0	42	1	90	4	65	9	3	3500	LTE	2023-07-20T10:00:00	2023-12-31T23:30:00	normal	2023	07	01
214035484123541	-3.8245	40.8952	30.5	12	0	null	5	42	9	7	1800	LTE	2023-07-20	null	microcell	2023	07	01

I.9 MNO NETWORK TOPOLOGY DATA QUALITY METRICS

NAME	SILVERNETWORKDATAQUALITYMETRICSBYCOLUMN
Description	Quality metrics produced by NetworkCleaning.
Object/Unit/Record	Quality metrics
Contents	**Mandatory fields**: • **result_timestamp**: o Type: Timestamp o Requirements: - o Description: Timestamp of the start of the process when the metrics were produced. One process can generate multiple metrics. • **date**: o Type: Date o Requirements: - o Description: Date of the dataset to which the quality metrics refer (not from topology data but from parameters) • **field_name**: o Type: String o Requirements: Either null or same as the name of a column present in input data o Description: Name of the field to which the metric refers to. Value is null if the metric refers to multiple fields. • **type_code**: o Type: Integer o Requirements: One value from the type codes (see table below). o Description: Numeric code indicating the type of the metric. See table below. • **value**: o Type: Integer o Requirements: - o Description: Numeric value of the metric. • **year:** o Type: Integer 16 o Description: Year the event took place. Partition column • **month:** o Type: Integer 8 o Description: Month the event took place. Partition column. • **day:** o Type: Integer 8 o Description: Day the event took place. Partition column.

\ CODE TYPES

CODE	SHORT DESCRIPTION	DESCRIPTION
0	no errors	
1	value is null	
2	value is not within the set of accepted values	
3	unsupported input data type	
4	unable to parse correctly	
100	total rows at the start of method	
101	total rows at the end of method	

\ EXAMPLE

result_timestamp	date	field_name	type_code	value	year	month	day
2023-06-12 12:00:00	01-01-2023	cell_id	0	1900	2023	1	1
2023-06-12 12:00:00	01-01-2023	cell_id	1	95	2023	1	1
2023-06-12 12:00:00	01-01-2023	cell_id	2	5	2023	1	1
2023-06-12 12:00:00	01-01-2023	-	100	2000	2023	1	1
2023-06-12 12:00:00	01-01-2023	-	101	1900	2023	1	1

I.10 MNO NETWORK TOPOLOGY DATA QUALITY WARNINGS – LOG TABLE

NAME	SILVERNETWORKDATASYNTACTICQUALITYWARNINGSLOGTABLE
Description	Quality warnings log table produced by NetworkQualityWarnings.
Object/Unit/Record	Quality Warning logs
Contents	**Mandatory fields**: • **title**: o Type: String o Requirements: 'MNO Network Topology Data Quality Warnings'. o Description: Title of the log table warnings. • **timestamp**: o Type: Timestamp o Requirements: - o Description: Timestamp of the start of the process when the quality warnings were produced. • **date**: o Type: Date o Requirements: - o Description: Date of the dataset to which the quality metrics analysed refer to (contained in their own 'date' field). • **measure_definition**: o Type: String o Requirements: - o Description: Name of the metric or measure that was studied in order to raise a warning. • **daily_value**: o Type: Float o Requirements: Non-negative value. o Description: Value that the metric that raised this warning had in this date. • **condition**: o Type: String o Requirements: - o Description: Logical condition that the daily_value had to verify in order to raise a warning. • **parameter_time**: o Type: String o Requirements: 'week', 'month', or 'quarter'. o Description: Lookback period length used to compute the average and sample standard deviation of the metric being studied. • **condition_value**: o Type: Float o Requirements: Non-negative value o Description: Threshold value that the daily_value was compared with in order to fulfill the condition of this warning. • **warning_text**: o Type: String o Requirements: - o Description: Verbose description of what this warning means and implies.

\ CODE TYPES

CODE	SHORT DESCRIPTION	DESCRIPTION
0	no errors	
1	value is null	
2	value is not within the set of accepted values	
3	unsupported input data type	
4	unable to parse correctly	
100	total rows at the start of method	
101	total rows at the end of method	

\ EXAMPLE

title	timestamp	date	measure_definition	daily_value	condition	parameter_time	condition_value	warning_text
MNO Network Topology Data Quality Warnings	2024-02-01 10:00:00	2024-01-29	Error rate	3.73	Error rate is over the upper control limit calculated on the basis of average and standard deviation of the distribution of the error rate in the previous period. Upper control limit = 3.70.	week	3.70	The error rate after syntactic checks application is unexpectedly high with respect to previous period, taking into account its usual variability

I.11 REFERENCE GRID

DESCRIPTION	INSPIRE GRID GEOMETRY WITH ADDITIONAL INFORMATION
Object/Unit/Record	Grid centroid geometry with additional information
Contents	**Mandatory fields**: • **grid_id**: o Type: String o Requirements: string following INSPIRE specification format o Description: Code uniquely identifying one grid tile. • **geometry:** o Type: Binary o Requirements: ETRS89 Lambert Azimuthal Equal Area coordinate reference system (EPSG:3035) o Description: grid centroids point geometry **Optional fields**: • **elevation:** o Type: Float o Requirements: o Description: Elevation of a grid centroids • **land_use_main** o Type: string o Main land use category • **prior_probabilty_value** o Type: float o Prior probability value.

\ EXAMPLE

grid_id	elevation	land_use_main	prior_probabilty_value	geometry
100mN4056000E5275300	12.1	RURAL	0.00	POINT()
100mN4056000E5275400	11.9	URBAN	0.70	POINT()

I.12 CELLS SIGNAL STRENGTHS

DESCRIPTION	THE SIGNAL STRENGTH VALUES PER CELL PER GRID TILE
Object/Unit/Record	Cell / grid tile combination
Contents	Mandatory fields: • **cell_id** ○ Type: String ○ Description: Unique ID of cell • **grid_id** ○ Type: String ○ Description: Unique ID of grid tile • **valid_date_start** ○ Type: Timestamp ○ Description: Start date of validity period (inclusive) • **valid_date_end** ○ Type: Timestamp ○ Description: End date of validity period (exclusive) • **signal_strength** ○ Type: Float ○ Description: Signal strength in dBm • **year:** ○ Type: Integer 16. ○ Description: Year the intersection group determined. • **month:** ○ Type: Integer 8. ○ Description: Month the intersection group determined. • **day:** ○ Type: Integer 8. ○ Description: Day the intersection group determined. Optional fields: • **distance_to_cell** ○ Type: Integer ○ Description: Distance of grid tile to cell location may be necessary for some calculation during the Location Assignation Module (e.g., taking into account the Timing Advance parameter of the MNO event data).

\ EXAMPLE

cell_id	grid_id	valid_date_start	valid_date_end	signal_strength	distance_to_cell	year	month	day
214030412038931	123231342131341	2023-01-01	2023-01-01	-120	4623	2023	01	01
214030412038931	123231342131342	2023-01-01	2023-01-01	-78	4627	2023	01	01
214030412038932	123231342131341	2023-02-01	2023-02-01	-59	4629	2023	02	01

I.13 CELL FOOTPRINTS

DESCRIPTION	THE SIGNAL DOMINANCE (CELL FOOTPRINT) VALUES PER GRID TILE
Object/Unit/Record	Cell / grid tile combination
Contents	**Mandatory fields:** • **cell_id** o Type: String o Description: Unique ID of cell • **grid_id** o Type: String o Description: Unique ID of grid tile • **signal_dominance** o Type: Float o Description: Signal dominance value (0 to 1) • **year:** o Type: Integer 16. o Description: Year the intersection group determined. • **month:** o Type: Integer 8. o Description: Month the intersection group determined. • **day:** o Type: Integer 8. o Description: Day the intersection group determined.

\ EXAMPLE

cell_id	grid_id	signal_dominance	year	month	day
123456789101112	123231342131341	0.5405	2023	01	01
123456789101112	123231342131342	0.4193	2023	01	01

I.14 CELL INTERSECTION GROUPS

NAME	SILVERCELLINTERSECTIONGROUPSDATAOBJECT
Description	Contains for each cell, for each date, the list of cells which overlap with that cell's coverage area (cell footprint).
Object/Unit/Record	cell_id, date, overlapping_cell_ids
Contents	**Mandatory fields**: • **cell_id:** ○ Type: String. ○ Description: Cell ID. • **overlapping_cell_ids:** ○ Type: Array of strings. ○ Description: Array of overlapping cells' ids. • **year:** ○ Type: Integer 16. ○ Description: Year of the date the intersection is valid on. • **month:** ○ Type: Integer 8. ○ Description: Month of the date the intersection is valid on. • **day:** ○ Type: Integer 8. ○ Description: Day of the date the intersection is valid on.

\ EXAMPLE

cell_id	overlapping_cell_ids	year	month	day
123456789101112	[1234545455910114, 12345456789101675]	2024	01	01
123454567891016	[1234567891011124, 12345456789101675]	2024	01	01
123454567891016	[1234545678910167, 123454567891016, 123456789101112]	2024	01	01

I.15 CELL CONNECTION AND POSTERIOR PROBABILITIES

NAME	SILVERCELLCONNECTIONPROBABILITIESDATAOBJECT
Description	Cell connection and posterior probability values per grid tile and cell_id.
Object/Unit/Record	Cell / grid tile combination
Contents	**Mandatory fields:** • **cell_id** o Type: String o Description: Unique ID of cell • **grid_id** o Type: String o Description: Unique ID of grid tile • **cell_connection_probability** o Type: Float o Description: Connection probability value within range [0, 1] • **posterior_probability** o Type: float o Posterior probability value within range [0, 1] • **year:** o Type: Integer 16. o Description: Year the intersection group determined. • **month:** o Type: Integer 8. o Description: Month the intersection group determined. • **day:** o Type: Integer 8. o Description: Day the intersection group determined.

\ EXAMPLE

cell_id	grid_id	cell_connection_probability	posterior_probability	year	month	day
123456789101112	123231342131341	0.5405	0.2192	2023	01	01
123456789101112	123231342131342	0.4193	0.5411	2023	01	01

I.16 MNO EVENT DATA – SEMANTICALLY CLEANED

NAME	SILVEREVENTFLAGGEDDATAOBJECT
Description	Mobile network event data associated to a specific subscriber, after semantic checks has been completed with semantic error flags.
Object/Unit/Record	Mobile network event associated to a specific subscriber with semantic error flags
Contents	**Mandatory fields**: • **user_id:** ○ Type: Binary ○ Description: Unique pseudonymized identifier of the device. • **timestamp:** ○ Type: Time ○ Description: Point in time where the event took place. • **mcc:** ○ Type: Integer ○ Description: Mobile Country Code derived from the user's IMSI. • **mnc:** ○ Type: String ○ Description: Mobile Network Code, a code of a home operator. It might help to assess the selectivity bias that is in place due to preferential roaming agreements between MNOs. This must be string, as it can start with 0 digit. Possible options can also be 01 or 001, so it cannot be integer. • **plmn:** ○ Type: Integer ○ Requirement: 5- or 6-digits code. Mandatory only for outbound data ○ Description: Network identifier of the foreign roaming partner MNO consists of PLMN=MCC+MNC. • **cell_id:** ○ Type: String ○ Description: Identifier of the cell following CGI and eCGI standards. Optional if "latitude" and "longitude" are not null. • **latitude:** ○ Type: Float ○ Description: Latitude value of the location of the event. Optional if "cell_id" is not null. • **longitude**: ○ Type: Float ○ Description: Longitude value of the location of the event. Optional if "cell_id" is not null. • **error_flag**: ○ Type: Integer, referring to global error type code ○ Description: Error flag referring to a error type code of the specific identified error • **loc_error**: ○ Type: Integer ○ Description: Location error in meters. • **year:** ○ Type: Integer 16 ○ Description: Year the event took place. • **month:** ○ Type: Integer 8 ○ Description: Month the event took place. • **day:** ○ Type: Integer 8

NAME	SILVEREVENTFLAGGEDDATAOBJECT
	○ Description: Day the event took place. • **user_id_modulo** ○ Type: Integer ○ Description: Partition key

I.17 MNO DEVICE SEMANTIC QUALITY METRICS

NAME	SILVEREVENTSEMANTICQUALITYMETRICS
Description	Quality metrics obtained in SemanticCleaning.
Object/Unit/Record	Quality metric
Contents	**Mandatory fields**: • **result_timestamp**: ○ Type: Timestamp ○ Requirements: - ○ Description: Timestamp of the start of the process when the metrics were produced. One process can generate multiple metrics. • **variable**: ○ Type: String ○ Requirements: Same as the name of a column present in input data ○ Description: Name of the field to which the metric refers to. Value is null if the metric refers to multiple fields. • **type_of_error**: ○ Type: Integer ○ Requirements: One value from the type codes (see table below). ○ Description: Numeric code indicating the type of the metric. See table below. • **value**: ○ Type: Integer ○ Requirements: - ○ Description: Numeric value of the metric. • **year:** ○ Type: Integer 16 ○ Requirements: Integer of 16 bits. ○ Description: Year of the datasets used. • **month:** ○ Type: Integer 8 ○ Requirements: Integer of 8 bits. ○ Description: Month of the datasets used. • **day:** ○ Type: Integer 8 ○ Requirements: Integer of 8 bits. ○ Description: Day of the datasets used.

\ CODE TYPES

CODE	SHORT DESCRIPTION	DESCRIPTION
0	No error	
1	Cell ID non-existent	Event made a reference to a non-existent cell ID
2	Invalid cell ID	Event made a reference to an existent cell ID, but the cell was not operative when the event was registered
3	Incorrect event location	
4	Suspicious event location	
5	Different location duplicate	Event has the same timestamp for the same user on either a previous or following row, but not identical values in the columns cell_id, longitude, latitude.

\ EXAMPLE

result_timestamp	variable	type_of_error	value	year	month	day
2024-03-01T09:03:08.432637Z	cell_id	3	50	2024	02	19
2024-03-01T09:03:08.432637Z	cell_id	2	103	2024	02	19

I.18 MNO EVENT DATA AT DEVICE LEVEL SEMANTIC QUALITY WARNINGS – LOG TABLE

NAME	SILVEREVENTSEMANTICQUALITYWARNINGSLOGTABLE
Description	Quality warnings log table produced by SemanticQualityWarnings.
Object/Unit/Record	Quality Warning logs
Contents	**Mandatory fields**: • **date**: ○ Type: Date ○ Requirements: - ○ Description: Date of the datasets that produced the quality metrics. • **Error 1**: ○ Type: Float ○ Requirements: - ○ Description: Percentage of the error type 1 over the total of events in this date. • **Error 2**: ○ Type: Float ○ Requirements: - ○ Description: Percentage of the error type 2 over the total of events in this date. • **Error 3**: ○ Type: Float ○ Requirements: - ○ Description: Percentage of the error type 3 over the total of events in this date. • **Error 4**: ○ Type: Float ○ Requirements: - ○ Description: Percentage of the error type 4 over the total of events in this date. • **Error 5**: ○ Type: Float ○ Requirements: - ○ Description: Percentage of the error type 5 over the total of events in this date. • **Error 1 upper control limit**: ○ Type: Float ○ Requirements: Can be null if there any date of the lookback period was missing. ○ Description: Threshold value that the percentage of this error type must surpass in order to raise a warning. • **Error 2 upper control limit**: ○ Type: Float ○ Requirements: Can be null if there any date of the lookback period was missing. ○ Description: Threshold value that the percentage of this error type must surpass in order to raise a warning. • **Error 3 upper control limit**: ○ Type: Float ○ Requirements: Can be null if there any date of the lookback period was missing. ○ Description: Threshold value that the percentage of this error type must surpass in order to raise a warning. • **Error 4 upper control limit**: ○ Type: Float ○ Requirements: Can be null if there any date of the lookback period was missing. ○ Description: Threshold value that the percentage of this error type must surpass in order to raise a warning. • **Error 5 upper control limit**: ○ Type: Float

NAME	SILVEREVENTSEMANTICQUALITYWARNINGSLOGTABLE
	◦ Requirements: Can be null if there any date of the lookback period was missing. ◦ Description: Threshold value that the percentage of this error type must surpass in order to raise a warning. • **Error 1 display warning**: ◦ Type: Boolean ◦ Requirements: - ◦ Description: Whether a warning regarding error type 1 was raised. • **Error 2 display warning**: ◦ Type: Boolean ◦ Requirements: - ◦ Description: Whether a warning regarding error type 2 was raised. • **Error 3 display warning**: ◦ Type: Boolean ◦ Requirements: - ◦ Description: Whether a warning regarding error type 3 was raised. • **Error 4 display warning**: ◦ Type: Boolean ◦ Requirements: - ◦ Description: Whether a warning regarding error type 4 was raised. • **Error 5 display warning**: ◦ Type: Boolean ◦ Requirements: - ◦ Description: Whether a warning regarding error type 5 was raised. • **year:** ◦ Type: Integer 16 ◦ Requirements: Integer of 16 bits. ◦ Description: Year of the datasets used. • **month:** ◦ Type: Integer 8 ◦ Requirements: Integer of 8 bits. ◦ Description: Month of the datasets used. • **day:** ◦ Type: Integer 8 ◦ Requirements: Integer of 8 bits. ◦ Description: Day of the datasets used. • **execution_id** ◦ Type: Timestamp ◦ Requirements: - ◦ Description: execution ID of the calculation of a given row of warnings by using the moment in time they were computed as identifier.

\ EXAMPLE

date	Error 1	Error 2	Error 3	Error 4	Error 1 upper control limit	Error 2 upper control limit	Error 3 upper control limit	Error 4 upper control limit	Error 1 display warning	Error 2 display warning	Error 3 display warning	Error 4 display warning	year	month	day	execution_id
2023-07-15	0.000023%	0.013808%	0.023779%	0.006592%					FALSE	FALSE	FALSE	FALSE	2023	7	15	2024-03-01T09:03:08.432637Z
2023-07-16	0.000033%	0.012508%	0.027985%	0.006316%					FALSE	FALSE	FALSE	FALSE	2023	7	16	2024-03-01T10:03:08.432637Z
2023-07-17	0.000015%	0.011912%	0.009095%	0.005089%	0.000038%	0.015686%	0.031660%	0.007711%	FALSE	FALSE	FALSE	FALSE	2023	7	17	2024-03-01T11:03:08.432637Z
2023-07-18	0.000016%	0.013569%	0.008527%	0.006879%	0.000037%	0.015761%	0.032400%	0.007504%	FALSE	FALSE	FALSE	FALSE	2023	7	18	2024-03-01T12:03:08.432637Z
2023-07-19	0.000003%	0.012459%	0.005626%	0.006862%	0.000034%	0.015630%	0.033952%	0.007731%	FALSE	FALSE	FALSE	FALSE	2023	7	19	2024-03-01T13:03:08.432637Z
2023-07-20	24.860163%	0.015080%	4.693755%	0.004985%	0.000036%	0.015171%	0.032098%	0.007613%	TRUE	FALSE	TRUE	FALSE	2023	7	20	2024-03-01T14:03:08.432637Z
2023-07-21	0.000023%	3.115898%	0.011088%	3.522027%	20.949944%	0.015196%	3.957762%	0.007699%	FALSE	TRUE	FALSE	TRUE	2023	7	21	2024-03-01T15:03:08.432637Z

I.19 DEVICE ACTIVITY STATISTICS

DESCRIPTION	METRICS PRODUCED BY THE METHOD *DEVICE ACTIVITY STATISTICS*
Object / Unit / Record	Metrics / statistics
Contents	Description of the metrics computed for the specific device along with their values and the choice of period parameter (if needed). • **user_id:** o Type: Binary o Requirements: 32 bytes (256 bits) field. o Description: Unique pseudonymized identifier of the device. • **year:** o Type: Integer 16 o Requirements: Integer of 16 bits. o Description: Year the metrics refer to in the local timezone. • **month:** o Type: Integer 8 o Requirements: Integer of 8 bits. o Description: Month the metrics refer to in the local timezone. • **day:** o Type: Integer 8 o Requirements: Integer of 8 bits. o Description: Day the metrics refer to in the local timezone. • **event_cnt:** o Type: Integer 32 o Requirements: Integer of 32 bits. o Description: Number of events per day. • **unique_cell_cnt:** o Type: Integer 16 o Requirements: Integer of 16 bits. o Description: Number of unique cells per day. • **unique_location_cnt:** o Type: Integer 16 o Requirements: Integer of 16 bits. o Description: Number of different locations per day (based on the location point of the cell). • **sum_distance_m:** o Type: Integer 32 o Requirements: Integer of 32 bits. o Description: Sum of the distances between the events (based on the location point of the cell). • **unique_hour_cnt:** o Type: Integer 8 o Requirements: Integer of 8 bits. Up to 24. o Description: Number of unique hours in the date with events. • **mean_time_gap:** o Type: Integer 32 o Requirements: Integer of 32 bits. o Description: Average time gap between events (in seconds). • **stdev_time_gap:** o Type: Float o Requirements: Float o Description: Standard deviation of the time gap between events (in seconds).

DESCRIPTION	METRICS PRODUCED BY THE METHOD *DEVICE ACTIVITY STATISTICS*
	Notes • All the indicators are calculated per device per day. When longer period assessment of the device activity is needed (e.g., for specific use case), then this must be done by combining the metrics for different dates that are inside the necessary period. For simplicity and optimisation reasons, this longer-period aggregates are not stored in this data object. This is also necessary due to the requirement of periodical deletion of historical device-level data that can be successfully done using the 'date' here but could not be done very well with longer periods.

\ EXAMPLE

device_id	year	month	day	event_cnt	unique_cell_cnt	unique_location_cnt	sum_distance_m	unique_hour_cnt	mean_time_gap	stdev_time_gap
A	2023	1	1	12	10	10	45778	10	5090	2951.61
A	2023	1	2	8	2	2	7592	7	5118	3169.484
B	2023	1	1	12	10	10	45036	8	4358	3614.575
C	2023	1	1	11	1	1	0	10	5939	4039.195
C	2023	1	2	20	1	1	0	14	4173	3017.242
C	2023	1	3	12	1	1	0	10	7313	3111.024
C	2023	1	4	7	1	1	0	5	4062	1536.541
D	2023	1	1	112	80	80	1035035	9	276	163.491
E	2023	1	1	142	37	37	13083	2	28	17.225
F	2023	1	1	41	1	1	0	1	33	13.647
G	2023	1	1	24	13	13	51061	24	3600	0
H	2023	1	1	1	1	1	0	1	0	0

I.20 DAILY CONTINUOUS TIME SEGMENTS

NAME	SILVERTIMESEGMENTSDATAOBJECT
Description	Daily time segments of a specific user covering the 24 hours of a specific date under study. The individual MND events are grouped into time segments. Four categories are supported: **stay** (set of events that are close in time and space during a minimum dwell time), **move** (set of events that are close in time but further away in space), **unknown** (longer gaps between events), **undetermined** (punctual events that are not possible to classify either as stay or move) and **abroad** (set of events in foreign country and gaps between such events).
Object/Unit/Record	Time segment
Contents	• **user_id**: ○ Type: Binary. ○ Description: Unique pseudonymized identifier of the device. • **time_segment_id**: ○ Type: String. ○ Description: Unique identifier of the time segment associated to a specific user. • **start_timestamp:** ○ Type: timestamp ('YYYY-MM-DD hh:mm:ss') in UTC standard. ○ Description: the date and time of the first event of the time segment. • **end_timestamp:** ○ Type: timestamp ('YYYY-MM-DD hh:mm:ss') in UTC standard. ○ Description: the date and time of the last event of the time segment. • **mcc:** ○ Type: Integer. ○ Description: Mobile Country Code derived from the user's IMSI. • **mnc:** ○ Type: String ○ Requirement: 2 or 3 digit code. ○ Description: Mobile Network Code of a home operator. This must be string as it can start with a 0 digit. • **plmn:** ○ Type: Integer ○ Requirement: 5 or 6 digit code. Mandatory only for outbound data. ○ Description: Network identifier of the foreign roaming partner MNO. Consists of PLMN=MCC+MNC. • **cells:** ○ Type: Array of strings. ○ Description: set of cells identifiers associated to the time segment. • **state**: ○ Type: String. ○ Description: type of time segment (stay, move, abroad, undetermined or unknown). • **is_last**: ○ Type: Boolean. ○ Description: If the time segment is the last time segment of a user in a day. • **year:** ○ Type: Integer 16. ○ Description: Year the event took place. • **month:** ○ Type: Integer 8. ○ Description: Month the event took place. • **day:** ○ Type: Integer 8. ○ Description: Day the event took place.

NAME	SILVERTIMESEGMENTSDATAOBJECT
	• **user_id_modulo** ○ Type: Integer. ○ Description: Partition key.

\ EXAMPLE

time_seg	device_i	start_timestamp	end_time_stamp	cells	state	is_last	mcc	mnc	plmn	year	month	day	user_id_
1	1	2023-01-01 00:00:00	2023-01-01 06:45:01	[214030412038931, 214030412038932, 214030412038935, 214030412038938]	stay	false	222	01	22201	2023	1	1	1
2	1	2023-01-01 06:45:01	2023-01-01 07:16:21	[214030412038940, 214035484123541, 214035484123544]	move	false	222	01	22201	2023	1	1	1
3	1	2023-01-01 07:16:21	2023-01-01 22:16:15	null	unknown	false	222	01	22201	2023	1	1	1
4	1	2023-01-01 22:16:15	2023-01-01 23:59:59	[214030412038931, 214030412038932]	stay	true	222	01	22201	2023	1	1	1
…	…	…	…	…	…	…							

I.21 DAILY PERMANENCE SCORE

NAME	DAILYPERMANENCESCOREDATAOBJECT
Description	Contains each user's grid tiles or outbound countries with non-zero permanence score for the set of time slots of each date, calculated from events data.
Object/Unit/Record	Set of grid tiles or outbound countries with non-zero permanence in a given time slot.
Contents	**Mandatory fields**: • **user_id:** ○ Type: Binary ○ Description: Unique pseudonymized identifier of the device. • **time_slot_initial_time:** ○ Type: Timestamp ○ Description: Initial time of time slot. • **time_slot_end_time:** ○ Type: Timestamp ○ Description: Final time of the time slot. • **dps:** ○ Type: Array of Integer 64 ○ Description: Matrix of tiles where Daily Permanence Score value is 1. • **year:** ○ Type: Integer 16 ○ Description: Year the event took place. • **month:** ○ Type: Integer 8 ○ Description: Month the event took place. • **day:** ○ Type: Integer 8 ○ Description: Day the event took place. • **user_id_modulo:** ○ Type: Integer 16 ○ Description: Partition key • **id_type:** ○ Type: String ○ Description: Partition key that takes 3 values: grid whenever the "dps" field contains an actual grid tiles ids of the INSPIRE 100x100m grid, unknown when the "dps" field contains the value unknown or abroad when "dps" field contains mobile country code of a foreign country

\ EXAMPLE

user_id	time_slot_initial_time	time_slot_initial_time	dps	year	month	day	user_id_modulo	id_type
000000000000..01	2024-01-15 10:00	2024-01-15 11:00	[40560005275300,40561005275300]	2024	01	15	511	grid
000000000000..01	2024-01-15 10:00	2024-01-15 11:00	[40560005275300,40561005275300]	2024	01	15	511	grid

user_id	time_slot_initial_time	time_slot_initial_time	dps	year	month	day	user_id_modulo	id_type
000000000000..01	2024-01-15 11:00	2024-01-15 12:00	[-1]	2024	01	15	511	unknown
000000000000..01	2024-01-16 00:00	2024-01-16 01:00	[222]	2024	01	15	511	abroad

I.22 MNO EVENT DATA QUALITY WARNINGS – FOR PLOTS

NAME	SILVEREVENTDATASYNTACTICQUALITYWARNINGSFORPLOTS
Description	The data object is meant to store the data needed for plot creation, the plots' data are differentiated in three categories • daily 'Total initial frequency' along with its average and the control limits computed based on lookback period • daily 'Total final frequency' along with its average and the control limits computed based on lookback period • 'Error rate by date' along with its average and only upper control limit computed based on lookback period In the future releases it is planned to add a report creation option.
Object/Unit/Record	Quality warnings
Contents	**Mandatory fields**: • **date:** o Type: Date o Description: date of a value and its statistics were taken/computed. • **type_of_qw:** o Type: String o Description: Indicator of what type of data is stored, could be raw_data_size, clean_data_size, error_rate. • **lookback_period:** o Type: String ▪ Description: The text representation of a lookback period, e.g. 'week' meaning 7 days • **daily_value:** o Type: Float o Description: The value of either initial frequency, final frequency, or error rate calculated on this date. • **average:** o Type: Float o Description: mean computed based on a lookback period • **LCL**: o Type: Float o Description: Low Control limit, mean - X*std computed based on a lookback period (applicable only for data size values). • **UCL**: o Type: Float o Description: Upper Control limit, mean + X*std computed based on a lookback period

\ EXAMPLE

date	type_of_qw	lookback_period	daily_value	average	LCL	UCL
2024-01-29	Error rate	week	23.41	20.2	None	22.48

I.23 MNO NETWORK SYNTACTIC QUALITY WARNINGS LINE PLOT DATA

NAME	SILVERNETWORKSYNTACTICQUALITYWARNINGSLINEPLOTDATA
Description	The data object is meant to store the data needed for line plots that show the daily evolution of the number of rows before and after the syntactic checks, as well as the overall error rate. • Number of rows before syntactic cleaning: data for a line plot containing said number of rows for the lookback period and the study date, together with the average, upper control limit, and lower control limit over the lookback period. • Number of rows after syntactic cleaning: data for a line plot containing said number of rows for the lookback period and the study date, together with the average, upper control limit, and lower control limit over the lookback period. Error rate: data for a line plot containing the error rate of the dataset (i.e., percentage of non-erroneous rows) for the lookback period and the study date, together with the average and upper control limit over the lookback period.
Object/Unit/Record	Quality Warnings
Contents	**Mandatory fields**: • **date:** ○ Type: Date ○ Description: date that the 'daily_value' in this row refers to. • **daily_value:** ○ Type: Float ○ Description: Value that the variable of this row takes in the date 'date'. • **average:** ○ Type: float ▪ Description: Average of the variable of this row over the lookback period. • **LCL:** ○ Type: Float, nullable ○ Description: The lower control limit of the variable of this row over the lookback period. This value is null and not recorded for the error rate. • **UCL:** ○ Type: Float ○ Description: The upper control limit of the variable of this row over the lookback period. This value is null and not recorded for the error rate. • **variable**: ○ Type: String ○ Description: Variable that the data in this row refers to. Can be one of rows_before_syntactic_check, rows_after_syntactic_check, and error_rate. Partition column. • **year**: ○ Type: Integer 16 ○ Description: year of the study date of the execution of the quality warnings component. Partition column. • **month**: ○ Type: Integer 8 ○ Description: month of the study date of the execution of the quality warnings component. Partition column. • **day**: ○ Type: Integer 8 ○ Description: day of the study date of the execution of the quality warnings component. Partition column. • **timestamp:** ○ Type: Timestamp

NAME	SILVERNETWORKSYNTACTICQUALITYWARNINGSLINEPLOTDATA
	○ Description: timestamp of the execution of the quality warnings component that produced this data object, serving as a execution ID. Partition column.

\ EXAMPLE

date	daily_value	average	LCL	UCL	variable	year	month	day	timestamp
2023-01-01	62.071918	61.818996	62.011372	null	error_rate	2023	1	8	2024-03-14 17:57:41.958112
2023-01-02	61.904762	61.818996	62.011372	null	error_rate	2023	1	8	2024-03-14 17:57:41.958112
2023-01-03	61.616955	61.818996	62.011372	null	error_rate	2023	1	8	2024-03-14 17:57:41.958112
2023-01-04	61.681549	61.818996	62.011372	null	error_rate	2023	1	8	2024-03-14 17:57:41.958112
2023-01-05	61.911556	61.818996	62.011372	null	error_rate	2023	1	8	2024-03-14 17:57:41.958112
2023-01-06	61.575344	61.818996	62.011372	null	error_rate	2023	1	8	2024-03-14 17:57:41.958112
2023-01-07	61.970898	61.818996	62.011372	null	error_rate	2023	1	8	2024-03-14 17:57:41.958112
2023-01-08	61.460957	61.818996	62.011372	null	error_rate	2023	1	8	2024-03-14 17:57:41.958112
2023-01-01	443.000000	511.571442	560.655884	462.486938	rows_after_syntactic_check	2023	1	8	2024-03-14 17:57:41.958112
2023-01-02	464.000000	511.571442	560.655884	462.486938	rows_after_syntactic_check	2023	1	8	2024-03-14 17:57:41.958112
2023-01-03	489.000000	511.571442	560.655884	462.486938	rows_after_syntactic_check	2023	1	8	2024-03-14 17:57:41.958112
2023-01-04	515.000000	511.571442	560.655884	462.486938	rows_after_syntactic_check	2023	1	8	2024-03-14 17:57:41.958112
2023-01-05	534.000000	511.571442	560.655884	462.486938	rows_after_syntactic_check	2023	1	8	2024-03-14 17:57:41.958112
2023-01-06	561.000000	511.571442	560.655884	462.486938	rows_after_syntactic_check	2023	1	8	2024-03-14 17:57:41.958112
2023-01-07	575.000000	511.571442	560.655884	462.486938	rows_after_syntactic_check	2023	1	8	2024-03-14 17:57:41.958112
2023-01-08	612.000000	511.571442	560.655884	462.486938	rows_after_syntactic_check	2023	1	8	2024-03-14 17:57:41.958112
2023-01-01	1168.000000	1339.714233	1466.644287	1212.784180	rows_before_syntactic_check	2023	1	8	2024-03-14 17:57:41.958112
2023-01-02	1218.000000	1339.714233	1466.644287	1212.784180	rows_before_syntactic_check	2023	1	8	2024-03-14 17:57:41.958112
2023-01-03	1274.000000	1339.714233	1466.644287	1212.784180	rows_before_syntactic_check	2023	1	8	2024-03-14 17:57:41.958112
2023-01-04	1344.000000	1339.714233	1466.644287	1212.784180	rows_before_syntactic_check	2023	1	8	2024-03-14 17:57:41.958112
2023-01-05	1402.000000	1339.714233	1466.644287	1212.784180	rows_before_syntactic_check	2023	1	8	2024-03-14 17:57:41.958112
2023-01-06	1460.000000	1339.714233	1466.644287	1212.784180	rows_before_syntactic_check	2023	1	8	2024-03-14 17:57:41.958112
2023-01-07	1512.000000	1339.714233	1466.644287	1212.784180	rows_before_syntactic_check	2023	1	8	2024-03-14 17:57:41.958112

date	daily_value	average	LCL	UCL	variable	year	month	day	timestamp
2023-01-08	1588.000000	1339.714233	1466.644287	1212.784180	rows_before_syntactic_check	2023	1	8	2024-03-14 17:57:41.958112

I.24 MNO NETWORK SYNTACTIC QUALITY WARNINGS PIE PLOT DATA

NAME	SILVERNETWORKSYNTACTICQUALITYWARNINGSPIEPLOTDATA
Description	The data object is meant to store the data needed for pie plots that show the counts of each type of error for each of the fields of the Network Topology data.
Object/Unit/Record	Quality Warnings
Contents	**Mandatory fields**: • **type_of_error:** o Type: String o Description: name of the type of error this row refers to. • **value:** o Type: Integer o Description: Count of this type of error for the variable this row refers to. • **variable**: o Type: String o Description: Variable that the data in this row refers to. Can be one of the fields of I.8 Cell Locations with Physical Properties – Cleaned. Partition column. • **year**: o Type: Integer 16 o Description: year of the study date of the execution of the quality warnings component. Partition column. • **month**: o Type: Integer 8 o Description: month of the study date of the execution of the quality warnings component. Partition column. • **day**: o Type: Integer 8 o Description: day of the study date of the execution of the quality warnings component. Partition column. • **timestamp:** o Type: Timestamp o Description: timestamp of the execution of the quality warnings component that produced this data object, serving as a execution ID. Partition column.

\ EXAMPLE

type_of_error	value	variable	year	month	day	timestamp
NULL_VALUE	145	altitude	2023	1	8	2024-03-14 17:57:41.958112
NULL_VALUE	145	antenna_height	2023	1	8	2024-03-14 17:57:41.958112
OUT_OF_RANGE	78	antenna_height	2023	1	8	2024-03-14 17:57:41.958112
OUT_OF_RANGE	35	azimuth_angle	2023	1	8	2024-03-14 17:57:41.958112
OUT_OF_RANGE	69	cell_id	2023	1	8	2024-03-14 17:57:41.958112
NULL_VALUE	72	cell_id	2023	1	8	2024-03-14 17:57:41.958112
NULL_VALUE	145	cell_type	2023	1	8	2024-03-14 17:57:41.958112
OUT_OF_RANGE	358	cell_type	2023	1	8	2024-03-14 17:57:41.958112
OUT_OF_RANGE	59	directionality	2023	1	8	2024-03-14 17:57:41.958112
NULL_VALUE	145	directionality	2023	1	8	2024-03-14 17:57:41.958112

type_of_error	value	variable	year	month	day	timestamp
OUT_OF_RANGE	63	elevation_angle	2023	1	8	2024-03-14 17:57:41.958112
NULL_VALUE	145	elevation_angle	2023	1	8	2024-03-14 17:57:41.958112
OUT_OF_RANGE	63	frequency	2023	1	8	2024-03-14 17:57:41.958112
NULL_VALUE	145	frequency	2023	1	8	2024-03-14 17:57:41.958112
NULL_VALUE	145	horizontal_beam_width	2023	1	8	2024-03-14 17:57:41.958112
OUT_OF_RANGE	62	horizontal_beam_width	2023	1	8	2024-03-14 17:57:41.958112
OUT_OF_RANGE	41	latitude	2023	1	8	2024-03-14 17:57:41.958112
NULL_VALUE	78	latitude	2023	1	8	2024-03-14 17:57:41.958112
OUT_OF_RANGE	676	longitude	2023	1	8	2024-03-14 17:57:41.958112
NULL_VALUE	68	longitude	2023	1	8	2024-03-14 17:57:41.958112
OUT_OF_RANGE	63	power	2023	1	8	2024-03-14 17:57:41.958112
NULL_VALUE	145	power	2023	1	8	2024-03-14 17:57:41.958112
NULL_VALUE	145	technology	2023	1	8	2024-03-14 17:57:41.958112
CANNOT_PARSE	19	valid_date_end	2023	1	8	2024-03-14 17:57:41.958112
NULL_VALUE	689	valid_date_end	2023	1	8	2024-03-14 17:57:41.958112
NULL_VALUE	162	valid_date_start	2023	1	8	2024-03-14 17:57:41.958112
CANNOT_PARSE	25	valid_date_start	2023	1	8	2024-03-14 17:57:41.958112
NULL_VALUE	145	vertical_beam_width	2023	1	8	2024-03-14 17:57:41.958112
OUT_OF_RANGE	77	vertical_beam_width	2023	1	8	2024-03-14 17:57:41.958112

I.25 EVENT DATA AT DEVICE LEVEL SEMANTIC QUALITY WARNINGS BAR PLOT DATA

NAME	SILVER EVENT SEMANTIC QUALITY WARNINGS BAR PLOT DATA
Description	The object is meant to store the data needed for bar plots that show the daily evolution of the number of occurrences and percentage of each type of error flag in the semantic checks of the MNO Event Data at Device Level.
Object/Unit/Record	Quality Warnings
Contents	**Mandatory fields**: • **date:** ○ Type: Date ○ Description: date that the "daily_value" in this row refers to. • **type_of_error:** ○ Type: String ○ Description: name of the type of error this row refers to. • **value:** ○ Type: Float ○ Description: Count or percentage of this type of error for the variable this row refers to. • **variable**: ○ Type: String ○ Description: Variable that the data in this row refers to. Can be either Percentage or Number of occurrences. Partition column. • **year**: ○ Type: Integer 16 ○ Description: year of the study date of the execution of the quality warnings component. Partition column. • **month**: ○ Type: Integer 8 ○ Description: month of the study date of the execution of the quality warnings component. Partition column. • **day**: ○ Type: Integer 8 ○ Description: day of the study date of the execution of the quality warnings component. Partition column. • **timestamp:** ○ Type: Timestamp ○ Description: timestamp of the execution of the quality warnings component that produced this data object, serving as a execution ID. Partition column.

\ EXAMPLE

date	type_of_error	value	variable	year	month	day	timestamp
2023-01-03	Error 3	2.0	Number of occurrences	2023	1	3	2024-03-15 10:25:58.734726
2023-01-03	Error 4	10.0	Number of occurrences	2023	1	3	2024-03-15 10:25:58.734726
2023-01-03	No Error	11.0	Number of occurrences	2023	1	3	2024-03-15 10:25:58.734726
2023-01-03	Error 2	1.0	Number of occurrences	2023	1	3	2024-03-15 10:25:58.734726

date	type_of_error	value	variable	year	month	day	timestamp
2023-01-03	Error 1	1.0	Number of occurrences	2023	1	3	2024-03-15 10:25:58.734726
2023-01-03	Error 3	8.0	Percentage	2023	1	3	2024-03-15 10:25:58.734726
2023-01-03	Error 4	40.0	Percentage	2023	1	3	2024-03-15 10:25:58.734726
2023-01-03	No Error	44.0	Percentage	2023	1	3	2024-03-15 10:25:58.734726
2023-01-03	Error 2	4.0	Percentage	2023	1	3	2024-03-15 10:25:58.734726
2023-01-03	Error 1	4.0	Percentage	2023	1	3	2024-03-15 10:25:58.734726

I.26 MNO NETWORK TOPOLOGY TOP FREQUENT ERROS

NAME	SILVERNETWORKDATATOPFREQUENTERRORS
Description	Most frequent errors found in the MNO network topology data syntactic cleaning, together with their absolute frequency and their contribution to the total number of errors found. Data is sorted from most to least frequent error.
Object/Unit/Record	Value of the error found, together with its absolute frequency and accumulated error percentage.
Contents	**Mandatory fields**: • **result_timestamp**: ○ Type: Timestamp ○ Description: Timestamp of the start of the process when the metrics were produced. One process can generate multiple metrics. • **field_name**: ○ Type: String ○ Requirements: Either null or same as the name of a column present in input data ○ Description: Name of the field to which the metric refers to. Value is null if the metric refers to multiple fields. • **type_code**: ○ Type: Integer ○ Requirements: One value from the type codes (see table below). ○ Description: Numeric code indicating the type of the metric. See table below. • **error_value:** ○ Type: String ○ Description: erroneous value found in the field in question during syntactic cleaning. The values can be either null, if the invalid value was null or if it refers to an error concerning more than one field, or a string parsing of the erroneous value found. • **error_count:** ○ Type: Integer ○ Description: number of times that this error_value was found in the raw data. • **accumulated_percentage:** ○ Type: Float ○ Description: Accumulated percentage with respect to the total number of invalid values, accumulated from the most frequent error up to this one, included. • **year:** ○ Type: Integer 16 ○ Description: Year the event took place. • **month:** ○ Type: Integer 8 ○ Description: Month the event took place. • **day:** ○ Type: Integer 8 ○ Description: Day the event took place.

\ CODE TYPES

CODE	SHORT DESCRIPTION	DESCRIPTION
0	no errors	
1	value is null	
2	value is not within the set of accepted values	
3	unsupported input data type	
4	unable to parse correctly	
100	total rows at the start of method	
101	total rows at the end of method	

\ EXAMPLE

result_timestamp	field_name	type_code	error_value	error_count	accumulated_percentage	year	month	day
2024-01-07 10:00:00	cell_id	2	000000	400	40.0	2023	1	1
2024-01-07 10:00:00	cell_id	1	null	300	70.0	2023	1	1
2024-01-07 10:00:00	cell_id	2	123456789	200	90.0	2023	1	1
2024-01-07 10:00:00	cell_id	2	xxx123	50	95.0	2023	1	1
2024-01-07 10:00:00	cell_id	2	AVSADD	50	100.0	2023	1	1

I.27 MNO NETWORK TOPOLOGY ROW ERROR METRICS

NAME	SILVERNETWORKROWERRORMETRICS
Description	Metrics regarding the number of rows that are deleted during the syntactic cleaning process and the number of rows that had any erroneous field, be it in a mandatory one (so it is deleted) or in an optional one (it is replaced by the null value).
Object/Unit/Record	Number of rows.
Contents	**Mandatory fields**: • **result_timestamp**: ○ Type: Timestamp ○ Description: Timestamp of the start of the process when the metrics were produced. One process can generate multiple metrics. • **variable**: ○ Type: String ○ Requirements: "rows_with_some_error" or "rows_deleted". ○ Description: What the count of rows of this record refers to: either to rows that had any erroneous value, or rows that were deleted because of an unavoidable erroneous value in a mandatory field. • **value**: ○ Type: Integer ○ Description: Number of rows. • **year:** ○ Type: Integer 16 ○ Description: Year the event took place. • **month:** ○ Type: Integer 8 ○ Description: Month the event took place. • **day:** ○ Type: Integer 8 ○ Description: Day the event took place.

\ EXAMPLE

result_timestamp	variable	value	year	month	day
2024-01-07 10:00:00	rows_with_some_error	400	2023	1	1
2024-01-07 10:00:00	rows_deleted	300	2023	1	1
2024-01-07 10:00:00	rows_with_some_error	200	2023	1	2
2024-01-07 10:00:00	rows_deleted	50	2023	1	2

I.28 INSPIRE GRID

NAME	SILVERGRIDDATAOBJECT
Description	INSPIRE grid geometry
Object/Unit/Record	grid centroid geometry with additional information
Contents	**Mandatory fields**: • **grid_id**: ○ Type: String ○ Requirements: string following INSPIRE specification format ○ Description: Code uniquely identifying one grid tile. • **geometry:** ○ Type: Binary ○ Requirements: ETRS89 Lambert Azimuthal Equal Area coordinate reference system (EPSG:3035) ○ Description: grid centroids point geometry • **quadkey:** ○ Type: String ○ Requirements: String of integers of fixed length ○ Description: Quadkey of a fixed length to which grid centroid belongs to. Used for explicit spatial partitioning

\ EXAMPLE

grid_id	geometry	quadkey
100mN4056000E5275300	POINT()	1201303
100mN4056000E5275400	POINT()	1201304

I.29 COUNTRIES

NAME	BRONZECOUNTRIESDATAOBJECT
Description	Dataset with countries polygons
Object/Unit/Record	A country polygon with additional information
Contents	**Mandatory fields**: • **iso2**: ○ Type: String ○ Requirements: 2 capital characters string ○ Description: ISO2 code of a country • **name**: ○ Type: Integer ○ Requirements: ○ Description: Name of a country • **geometry:** ○ Type: Binary ○ Requirements: ▪ ETRS89 Lambert Azimuthal Equal Area coordinate reference system (EPSG:3035) ▪ Has to be topologically valid (polygons without self-intersections, polygons of the same level don't overlap) ▪ Hierarchical administrative units have to have one-to-one child to parent relationships ○ Description: polygon geometry which represents country

\ EXAMPLE

iso2	name	geometry
ES	Spain	POLYGON (24.36...
ES	Spain	POLYGON (24.37...
ES	Spain	POLYGON (24.37...

I.30 SYNTHETIC DIARIES

NAME	BRONZESYNTHETICDIARIESDATAOBJECT
Description	Contains user_id based diaries that describe the movement or stays over a period of time for a given set of users.
Object/Unit/Record	Description of a movement diary for a specific subscriber and given time interval.
Contents	**Mandatory fields**: • **year:** ○ Type: Integer 16 ○ Requirements: Integer of 16 bits. ○ Description: Year of the time for which to generate events for. Partition key. • **month:** ○ Type: Integer 8 ○ Requirements: Integer of 8 bits. ○ Description: Month of the time for which to generate events for. Partition key. • **day:** ○ Type: Integer 8 ○ Requirements: Integer of 8 bits. ○ Description: Day of the time for which to generate events for. Partition key. • **user_id:** ○ Type: Binary ○ Requirements: 32 bytes (256 bits) field. ○ Description: Unique pseudonymized identifier of the device, generated by hashing the user's IMSI using the SHA-256 function. • **activity_type:** ○ Type: String ○ Requirements: either "stay" or "move" ○ Description: Labels the row of either a movement or stay diary description. • **stay_type:** ○ Type: String ○ Requirement: one of "home, "work", "other" ○ Description: The type of stay, signifying that the user is either in their home location, work location or some other location. • **longitude**: ○ Type: Float ○ Requirements: Longitude value in WGS84 system. Value has to be within WGS84 bounds. Optional if "cell_id" is not null. ○ Description: Longitude value of the location of the event. • **latitude:** ○ Type: Float ○ Requirements: Latitude value in WGS84 system. Value has to be within WGS84 bounds. Optional if "cell_id" is not null. ○ Description: Latitude value of the location of the event. • **initial_timestamp** ○ Type: String ○ Requirements: String with date and time following ISO:8601 format: YYYY-MM-DDThh:mm.ss ○ Description: Start of time for which to generate events with the current stay and activity types for the given user. • **final_timestamp** ○ Type: String ○ Requirements: String with date and time following ISO:8601 format: YYYY-MM-DDThh:mm.ss

NAME	BRONZESYNTHETICDIARIESDATAOBJECT
	○ Description: End of time for which to generate events with the current stay and activity types for the given user.

\ EXAMPLE

user_id	activity_type	stay_type	initial_timestamp	final_timestamp	longitude	latitude	year	month	day
1	stay	'home'	2024-01-01 00:00:00	2024-01-01 10:00:00	40.41740	-3.69303	2024	1	1
1	move	null	2024-01-01 10:00:00	2024-01-01 10:26:20	null	null	2024	1	1
1	stay	'work'	2024-01-01 10:26:20	2023-01-01 16:26:20	40.44566	-3.62655	2024	1	1
1	move	null	2023-01-01 16:26:20	2023-01-01 16:34:17	null	null	2024	1	1
1	stay	'other'	2023-01-01 16:34:17	2023-01-01 18:34:17	40.44325	-3.70723	2024	1	1
1	move	null	2023-01-01 18:34:17	2023-01-01 19:00:17	null	null	2024	1	1
1	stay	'home'	2023-01-01 19:00:17	2023-01-01 23:59:59	40.41740	-3.69303	2024	1	1

I.31 ENRICHED GRID

NAME	ENRICHED GRID
Description	INSPIRE grid geometry with additional information
Object/Unit/Record	Grid centroid geometry with additional information
Contents	**Mandatory fields**: • **grid_id**: ○ Type: String ○ Requirements: string following INSPIRE specification format ○ Description: Code uniquely identifying one grid tile. • **geometry:** ○ Type: Binary ○ Requirements: ETRS89 Lambert Azimuthal Equal Area coordinate reference system (EPSG:3035) ○ Description: grid centroids point geometry • **elevation:** ○ Type: Float ○ Requirements: ○ Description: Elevation of a grid centroids • **prior_probability** ○ Type: float ○ Requirements: ○ Description: Prior probability value. Sum of weighted landuse ratios normalized to 1 over the whole grid • **environment_ple_coefficient** ○ Type: Float ○ Requirements: ○ Description: Sum of weighted landuse ratios • **quadkey:** ○ Type: String ○ Requirements: String of integers of fixed length ○ Description: Quadkey of a fixed length to which grid centroid belongs to. Used for explicit spatial partitioning

\ EXAMPLE

grid_id	geometry	elevation	prior_probability	environment_ple_coefficient	quadkey
100mN4056000E5275300	POINT()	12.1	0.00001	0.01	1201303
100mN4056000E5275400	POINT()	11.9	0.00034	0.05	1201304

I.32 LANDUSE

NAME	BRONZELANDUSEDATAOBJECT
Description	Dataset with landuse information.
Object/Unit/Record	Landuse polygons categorized into predefined set of classes
Contents	**Mandatory fields**: • **category**: ○ Type: String ○ Requirements: class name from the predefined list ○ Description: Name of a class which represents high-level landuse type. • **geometry:** ○ Type: Binary ○ Requirements: ETRS89 Lambert Azimuthal Equal Area coordinate reference system (EPSG:3035) ○ Description: polygon geometry representing landuse class • **year:** ○ Type: Integer 16 ○ Requirements: Integer of 16 bits. ○ Description: Year of dataset extraction. • **month:** ○ Type: Integer 8 ○ Requirements: Integer of 8 bits. ○ Description: Month of dataset extraction. • **day:** ○ Type: Integer 8 ○ Requirements: Integer of 8 bits. ○ Description: Day of dataset extraction. **Optional fields**: • **quadkey:** ○ Type: String ○ Requirements: String of integers of fixed length ○ Description: Quadkey of a fixed length to which a geometry centroid belongs to. Used for explicit spatial partitioning

\ CATEGORY NAMES

CATEGORY	SHORT DESCRIPTION
residential_builtup	Built-up areas mostly occupied by residential buildings
other_builtup	Built-up areas occupied by non-residential buildings
open_area	Open areas with minimal human activities (agriculture, parks, golf fields etc)
forest	Forests
water	Water bodies and wetlands

\ EXAMPLE

category	geometry	year	month	day	quadkey
residential_builtup	POLYGON (24.36...	2024	04	01	033111001
forest	POLYGON (24.37...	2024	04	01	033111001

I.33 TRANSPORTATION

NAME	BRONZETRANSPORTATIONDATAOBJECT
Description	Dataset with roads and railroads.
Object/Unit/Record	Transportation segments categorized into predefined set of classes
Contents	**Mandatory fields**: • **category**: ○ Type: String ○ Requirements: class name from the predefined list ○ Description: Name of a class which represents hierarchy of a road. • **geometry:** ○ Type: Binary ○ Requirements: ETRS89 Lambert Azimuthal Equal Area coordinate reference system (EPSG:3035) ○ Description: linestring geometry representing roads or railroads • **year:** ○ Type: Integer 16 ○ Requirements: Integer of 16 bits. ○ Description: Year of dataset extraction. • **month:** ○ Type: Integer 8 ○ Requirements: Integer of 8 bits. ○ Description: Month of dataset extraction. • **day:** ○ Type: Integer 8 ○ Requirements: Integer of 8 bits. ○ Description: Day of dataset extraction. **Optional fields**: • **quadkey:** ○ Type: String ○ Requirements: String of integers of fixed length ○ Description: Quadkey of a fixed length to which a geometry centroid belongs to. Used for explicit spatial partitioning

\ CATEGORY NAMES

CATEGORY	SHORT DESCRIPTION
primary	Major highways
secondary	Main streets in cities, towns and minor highways
tertiary	Minor streets in cities, towns, villages
pedestrian	Cycling paths, footpaths and other ways not accessible to motorized vehicles
rail	Railroads

\ EXAMPLE

category	geometry	year	month	day	quadkey
primary	LINESTRING (24.36...	2024	04	01	033111001
secondary	LINESTRING (24.37...	2024	04	01	033111001

I.34 ADMINISTRATIVE UNITS

NAME	BRONZEADMINUNITSDATAOBJECT
Description	Dataset with administrative units
Object/Unit/Record	An administrative unit polygon with additional information
Contents	**Mandatory fields**: • **id**: ○ Type: String ○ Requirements: has to be unique for the whole dataset ○ Description: unique identifier of an administrative unit • **name**: ○ Type: String ○ Requirements: English transliteration ○ Description: Name of administrative unit • **level**: ○ Type: Integer ○ Requirements: Starting from 0 representing the whole country. Can be null if administrative unit dataset not hierarchical ○ Description: Level of the administrative unit. Example: 0 - whole country, 1 - municipalities, 2 - districts, and so on • **parent_id** ○ Type: String ○ Requirements: can be null if administrative units dataset is not hierarchical ○ Description: id of the parent administrative unit • **counry_iso2_code** ○ Type: String ○ Requirements: 2 capital characters string ○ Description: ISO2 code of a country • **geometry:** ○ Type: Binary ○ Requirements: ▪ ETRS89 Lambert Azimuthal Equal Area coordinate reference system (EPSG:3035) ▪ Must be topologically valid (polygons without self-intersections, polygons of the same level don't overlap) ▪ Hierarchical administrative units have to have one-to-one child to parent relationships ○ Description: polygon geometry which represents administrative unit • **dataset_id:** ○ Type: String ○ Requirements: Must be unique for each administrative units dataset ○ Description: Unique dataset identifier • **year:** ○ Type: Integer 16 ○ Requirements: Integer of 16 bits. ○ Description: Year of the datasets used. • **month:** ○ Type: Integer 8 ○ Requirements: Integer of 8 bits. ○ Description: Month of the datasets used. • **day:** ○ Type: Integer 8 ○ Requirements: Integer of 8 bits. ○ Description: Day of the datasets used.

\ EXAMPLE

id	name	level	parent_id	counry_iso2_code	geometry	dataset_id	year	month	day
01	Estonia	0	null	EE	POLYGON (24.36...	ETAK	2024	04	01
0103	Tartu Maakond	1	01	EE	POLYGON (24.37...	ETAK	2024	04	01
010302	Tartu Vald	2	0103	EE	POLYGON (24.37...	ETAK	2024	04	01

I.35 GEOGRAPHIC ZONES

NAME	BRONZEGEOGRAPHICZONESDATAOBJECT
Description	Dataset with geographical zones. Can be any geographic divisions.
Object/Unit/Record	A geographic zone polygon with additional information
Contents	**Mandatory fields**: • **zone_id**: ○ Type: String ○ Requirements: must be unique for the whole dataset ○ Description: unique identifier of a zone • **name**: ○ Type: String ○ Requirements: English transliteration ○ Description: Name of administrative unit • **level**: ○ Type: Integer ○ Requirements: Starting from 0 representing the whole country. Can be null if zoning dataset is not hierarchical ○ Description: Level of the administrative unit. Example: 0 - whole country, 1 - municipalities, 2 - districts, and so on • **parent_id** ○ Type: String ○ Requirements: can be null if administrative units dataset is not hierarchical ○ Description: id of the parent administrative unit • **iso2** ○ Type: String ○ Requirements: 2 capital characters string ○ Description: ISO2 code of a country • **geometry:** ○ Type: Binary ○ Requirements: ▪ ETRS89 Lambert Azimuthal Equal Area coordinate reference system (EPSG:3035) ▪ Has to be topologically valid (polygons without self-intersections, polygons of the same level don't overlap) ▪ Hierarchical administrative units have to have one-to-one child to parent relationships ○ Description: polygon geometry which represents zonning unit • **dataset_id:** ○ Type: String ○ Requirements: Has to be unique for each geographic zones dataset ○ Description: Unique dataset identifier • **year:** ○ Type: Integer 16 ○ Requirements: Integer of 16 bits. ○ Description: Year of the datasets used. • **month:** ○ Type: Integer 8 ○ Requirements: Integer of 8 bits. ○ Description: Month of the datasets used. • **day:** ○ Type: Integer 8 ○ Requirements: Integer of 8 bits. ○ Description: Day of the datasets used.

\ EXAMPLE

id	name	level	parent_id	iso2	geometry	dataset_id	year	month	day
ES53	Illes Balears	2	ES5	ES	POLYGON (24.36...	nuts	2024	04	01
ES5	Este	1	ES	ES	POLYGON (24.37...	nuts	2024	04	01
ES532	Mallorca	3	ES53	ES	POLYGON (24.37...	nuts	2024	04	01

I.36 ZONES – GRID MAP

NAME	SILVERGEOZONESGRIDMAPDATAOBJECT
Description	Dataset with geographical zones ids to grid ids mapping
Object/Unit/Record	zoning unit id to grid id map
Contents	**Mandatory fields**: • **grid_id**: ○ Type: String ○ Requirements: String following INSPIRE specification ○ Description: Code uniquely identifying one grid tile • **zone_id**: ○ Type: String ○ Requirements: Unique identifier. If dataset hierarchical has to be the lowest level ○ Description: Unique identifier of a zoning unit. • **hierarchical_id**: ○ Type: String ○ Requirements: Combination of identifiers in hierarchy. Each zone level id separated by |. ○ Description: Unique identifiers of a zoning units in hierarchy. If zoning dataset hierarchical, id will be combined from ids of all zones in a hierarchy, each level id separated by |. If zoning dataset is not hierarchical, id will be same as zone_id • **dataset_id:** ○ Type: String ○ Requirements: Has to be unique for each zoning dataset ○ Description: Unique dataset identifier • **year:** ○ Type: Integer 16 ○ Requirements: Integer of 16 bits. ○ Description: Year of the mapped dataset • **month:** ○ Type: Integer 8 ○ Requirements: Integer of 8 bits. ○ Description: Month of the mapped dataset. • **day:** ○ Type: Integer 8 ○ Requirements: Integer of 8 bits. ○ Description: Day of the mapped dataset.

\ EXAMPLE

grid_id	zone_id	hierarchical_id	dataset_id	year	month	day
100mN4056000E5275300	ES532	ES5|ES53|ES532	nuts	2024	4	1
100mN4056000E5275400	ES532	ES5|ES53|ES532	nuts	2024	4	1
100mN4056000E5275500	ES532	ES5|ES53|ES532	nuts	2024	4	1

I.37 UE LABELS

NAME	UE LABELS
Description	Grid tiles that have been determined to be part of the usual environment of a given device / user with meaningful location labeling
Object/Unit/Record	Usual Environment grid tile.
Contents	**Mandatory fields:** • **user_id:** o Type: Binary o Description: Unique pseudonymized identifier of the device. • **grid_id:** o Type: String o Description: ID of grid tile • **label:** o Type: String o Description: Label that has been inferred for this usual environment. Options are: home, second_home, work, and no_label. • **label_rule:** o Type: String o Description: Code of a rule based on which UE label was assigned. **Has to be predefined list of rules with unique codes.** • **start_date** o Type: date o Description: Start date (inclusive) of the label period. Partition key. • **end_date** o Type: date o Description: End date (inclusive) of the label period. Partition key. • **season** o Type: String o Requirements: A value from predefined set: all, summer, autumn, winter, spring o Description: Name of the type of season over which the long-term permanence metrics are computed. Partition key. • **id_type:** o Type: String o Description: Can take 2 values: grid whenever the grid_id field contains an actual grid tiles ids of the INSPIRE grid or abroad when grid_id field contains mobile country code of a foreign country • **user_id_modulo:** o Type: Integer 16 o Description: Partition key

\ LABEL RULE CODES

CODE	RULE DESCRIPTION
ue_1	If the device was observed all days: all intervals period in top tiles at least ue_ps_threshold (default is 70% of total_assigned_ps) such tiles are labeled as UE tiles.
ue_2	For tiles which have not got UE label in previous step perform the same check for all other combinations of day types and periods. If the condition is met for any of the combinations, label tiles as UE tiles.
ue_3	For tiles which have not got UE label in previous step perform frequency check for all days: all intervals period
h_2	If no home label being assigned, repeat this condition check for all days: night-time period. Tiles that fulfilled this condition are labeled as Home tiles.

CODE	RULE DESCRIPTION
h_3	If no home label being assigned, check if the device was in the tiles at least home_ndays_threshold (default value is 80% of total_observed_days). Tiles that fulfilled this condition are labeled as Home tiles.
w_1	If the device was observed in working_days: daytime period in top tiles at least work_ps_threshold (default is 70% of total_assigned_ps). Such tiles are labeled as Work tiles.
w_2	If no work label is being assigned, check if the device in working_days: daytime period was in the tiles at least work_ndays_threshold (default value is 70% of total_observed_days). Tiles that fulfilled this condition are labeled as Work tiles.

\ EXAMPLE

user_id	grid_id	label	label_rule	start_date	end_date	season	id_type	user_id_
000000000000..01	100mN4056000E5275300	ue	ue_1	2024-02-01	2024-07-31	all	grid	1
000000000000..01	100mN4056000E5275301	home	h_1	2024-02-01	2024-07-31	all	grid	1
000000000000..01	100mN4056050E5275300	work	w_2	2024-02-01	2024-07-31	all	grid	1

I.38 MID-TERM PERMANENCE METRICS

NAME	MID-TERM PERMANENCE METRICS
Description	Mid-term permanence score for grid tiles over a predefined subset of day types (sub-monthly time intervals) (weekdays, weekends, holidays) and a predefined subset of sub-daily time intervals (nighttime, daytime, working hours, …)
Object/Unit/Record	Mid-term permanence metrics per user_id, grid_id, sub_monthly and sub_daily period.
Contents	**Mandatory fields:** • **user_id:** o Type: Binary o Description: Unique pseudonymized identifier of the device. • **grid_id:** o Type: String o Description: Unique ID of grid tile. Takes a valid grid ID value whenever "id_type" is equal to grid; and values unknown or device_observation when the indicators refer to the unknown location or the global device observation, respectively. • **mps**: o Type: Integer o Description: midterm permanence score, the result of adding up the daily permanence scores of this grid_id and user_id over the specified day_type and time_interval. • **frequency**: o Type: Integer o Description: absolute count of the number of days of this day_type for which the daily permanence score was not null in the specified time_interval. • **regularity_mean**: o Type: Float o Description: mean of the number of days between two consecutive non-null daily permanence scores in the specified day_type and time_interval. • **regularity_std:** o Type: Float o Description: standard deviation of the number of days between two consecutive non-null daily permanence scores in the specified day_type and time_interval. • **day_type**: o Type: String o Requirements: A value from predefined set: all, workdays, weekends, holidays, Mondays, Tuesdays, Wednesdays, Thursdays, Fridays, Saturdays, Sundays. o Description: Name of the type of days over which the midterm permanence metrics are computed. Partition key. • **time_interval:** o Type: String o Requirements: A value from predefined set: all, working_hours, night_time, evening_time. o Description: Name of the sub-daily interval over which the midterm permanence metrics are computed. Partition key. • **year:** o Type: Integer 16 o Description: year of the month for which this midterm permanence score was computed. Partition key. • **month:** o Type: Integer 8 o Description: month for which this midterm permanence score was computed. Partition key.

NAME	MID-TERM PERMANENCE METRICS
	• **user_id_modulo:** ○ Type: Integer ○ Requirements: Integer of 8 bits. ○ Description: Modulo division result, as applied to the integer part of the user_id column. Partition key. • **id_type:** ○ Type: String ○ Description: Partition key that takes one of three values: grid whenever the "grid_id" field contains an actual grid ID of the INSPIRE 100x100m grid; unknown when the "grid_id" field contains the value unknown; or device_observation when the "grid_id" field contains the value device_observation.

\ EXAMPLE

user_id	grid_id	day_type	time_interval	mps	frequency	regularity_mean	regularity_std	year	month	user_id_modulo	id_type
000000000000..01	100mN4056000E5275300	all	all	896	26	1.071428571428571	1	2024	2	23	grid
000000000000..01	100mN4056000E5275300	weekend	all	256	7	5.45	3.123213	2024	2	23	grid
000000000000..01	100mN4056000E5275300	all	night_time	880	24	1.142857142857143	1	2024	2	23	grid
000000000000..01	100mN4056000E5275300	weekend	night_time	233	7	6.5	4.17347	2024	2	23	grid

I.39 LONG-TERM PERMANENCE METRICS

NAME	LONG-TERM PERMANENCE METRICS
Description	Long-term permanence score for grid tiles over a predefined subset of seasons (sub-yearly time intervals: spring, summer…), day types (sub-monthly time intervals: weekdays, weekends, holidays) and a predefined subset of sub-daily time intervals (nighttime, daytime, working hours, …)
Object/Unit/Record	Long-term permanence metrics per user_id, grid_id, sub_yearly, sub_monthly and sub_daily period.
Contents	**Mandatory fields:** • **user_id:** ○ Type: Binary ○ Description: Unique pseudonymized identifier of the device. • **grid_id:** ○ Type: String ○ Description: Unique ID of grid tile • **lps**: ○ Type: Integer ○ Description: long term permanence score, the result of adding up the monthly permanence scores of this grid_id and user_id over the specified season, day_type and time_interval. • **total_frequency**: ○ Type: Integer ○ Description: absolute count of the number of days of this day_type during specified season for which the monthly permanence score was not null in the specified time_interval. • **frequency_mean** ○ Type: Float ○ Description: mean of monthly frequency of this day_type during specified season for the specified time_interval. • **frequency_std** ○ Type: Float ○ Description: standard deviation of monthly frequency of day_type during specified season for the specified time_interval. • **regularity_mean**: ○ Type: Float ○ Description: mean of the monthly regularity_mean in the specified season for day_type and time_interval. • **regularity_std:** ○ Type: Float ○ Description: standard deviation of the monthly regularity_mean in the specified season for day_type and time_interval. • **season** ○ Type: String ○ Requirements: A value from predefined set: all, summer, autumn, winter, spring ○ Description: Name of the type of season over which the long-term permanence metrics are computed. Partition key. • **day_type**: ○ Type: String ○ Requirements: A value from predefined set: all, workdays, weekends, holidays, Mondays, Tuesdays, Wednesdays, Thursdays, Fridays, Saturdays, Sundays. ○ Description: Name of the type of days over which the long-term permanence metrics are computed. Partition key. • **time_interval:** ○ Type: String

NAME	LONG-TERM PERMANENCE METRICS
	○ Requirements: A value from predefined set: all, working_hours, night_time, evening_time. ○ Description: Name of the sub-daily interval over which the long-term permanence metrics are computed. Partition key. • **start_date** ○ Type: date ○ Description: Start date (inclusive) of the period for which long-term permanence metrics were computed. Partition key. • **end_date** ○ Type: date ○ Description: End date (inclusive) of the period for which long-term permanence metrics were computed. Partition key. • **user_id_modulo:** ○ Type: Integer ○ Requirements: Integer of 8 bits. ○ Description: Modulo division result, as applied to the integer part of the user_id column. Partition key. • **id_type:** ○ Type: String ○ Description: Partition key that takes one of three values: grid whenever the "grid_id" field contains an actual grid ID of the INSPIRE 100x100m grid; unknown when the "grid_id" field contains the value unknown; or device_observation when the "grid_id" field contains the value device_observation.

\ EXAMPLE

user_id	grid_id	season	day_type	time_interval	lps	total_frequency	frequency_mean	frequency_std	regularity_mean	regularity_std	start_date	end_date	user_id_modulo	id_type
000000000000..01	100mN4056000E5275300	all	all	all	896	26	20	8	1.071428571428571	1	2024-02-01	2024-07-31	10	grid
000000000000..01	100mN4056000E5275300	summer	weekends	all	256	7	7	1	??	??	2024-02-01	2024-07-31	10	grid
000000000000..01	100mN4056000E5275300	winter	all	night_time	880	24	18	2	1.142857142857143	1	2024-02-01	2024-07-31	10	grid
000000000000..01	100mN4056000E5275300	summer	weekends	night_time	233	7	6	1	??	??	2024-02-01	2024-07-31	10	grid

I.40 HOLIDAY DATES CALENDAR

NAME	HOLIDAY DATES CALENDAR
Description	Contains a row of type Date for each day that is a holiday for a country and its name.
Object/Unit/Record	Date (a date that is considered a holiday).
Contents	**Mandatory fields**: • **iso_a2:** ○ Type: String ○ Description: ISO A2 country code. • **date:** ○ Type: Date ○ Description: Date that is a holiday. • **name:** ○ Type: String ○ Description: Holiday name.

\ EXAMPLE

iso_a2	date	name
IT	2024-05-16	Holiday name
ES	2024-12-24	Holiday name

I.41 PRESENT POPULATION - ZONES

NAME	PRESENTPOPULATIONZONEDATAOBJECT
Description	Estimation of the population present at a given time at the level of some zoning system.
Object/Unit/Record	Number of people present in a given zone at a given time
Contents	**Mandatory fields**: • **zone_id:** ○ Type: String ○ Description: Unique ID of the zone • **population:** ○ Type: Float ○ Description: Number of estimated present population for this grid tile at this time of day. • **timestamp:** ○ Type: Time ○ Description: Time for which the present population is estimated. • **dataset_id:** ○ Type: String ○ Requirements: Has to be unique for each zoning dataset ○ Description: Unique dataset identifier • **level** ○ Type: int ○ Requirements: ○ Description: Level of hierarchy for hierarchical datasets • **year:** ○ Type: Integer 16 ○ Description: Year of the present population estimation. • **month:** ○ Type: Integer 8 ○ Description: Month of the present population estimation. • **day:** ○ Type: Integer 8 ○ Description: Day of the present population estimation.

\ EXAMPLE

zone	population	timestamp	dataset_id	year	month	day
CityX_DistrictA	1232131.3	12:05:03	nuts	2024	01	01
CityX_DistrictB	65645.0	12:05:03	nuts	2024	01	01
CityX_DistrictC	628357.4	12:05:03	nuts	2024	01	01

I.42 PRESENT POPULATION

NAME	PRESENTPOPULATIONDATAOBJECT
Description	Estimation of the population present at a given time at the grid tile level.
Object/Unit/Record	Number of people present in a given tile at a given time
Contents	**Mandatory fields**: • **grid_id:** ○ Type: String ○ Description: Unique ID of grid tile • **population:** ○ Type: Float ○ Description: Number of estimated present population for this grid tile at this time of day. • **timestamp:** ○ Type: Time ○ Description: Time for which the present population is estimated. • **year:** ○ Type: Integer 16 ○ Description: Year of the present population estimation. • **month:** ○ Type: Integer 8 ○ Description: Month of the present population estimation. • **day:** ○ Type: Integer 8 ○ Description: Day of the present population estimation.

\ EXAMPLE

grid_id	population	timestamp	year	month	day
100mN4056000E5275300	156.3	12:05:03	2024	01	01
100mN4056000E5275301	2.3	12:05:03	2024	01	01
100mN4056000E5275302	123.4	12:05:03	2024	01	01

I.43 LABELING QUALITY METRICS

NAME	SILVERUSUALENVIRONMENTLABELINGQUALITYMETRICSDATAOBJECT
Description	Quality metrics for UE and meaningful locations labeling process
Object/Unit/Record	A metric, number of devices/tiles and time period
Contents	**Mandatory fields**: • **metric** ○ Type: String ○ Requirements: A string value from predefine list of metrics. ○ Description: Metric name. • **count** ○ Type: Integer ○ Description: Counts of devices/tiles labeled. • **min** ○ Type: Integer ○ Description: Minimum tiles per device labeled. • **max** ○ Type: Integer ○ Description: Maximum tiles per device labeled. • **avg** ○ Type: Float ○ Description: Average tiles per device labeled. • **start_date** ○ Type: date ○ Description: Start date (inclusive) of the label period. Partition key. • **end_date** ○ Type: date ○ Description: End date (inclusive) of the label period. Partition key.

\ POSSIBLE METRICS

CODE	DESCRIPTION
ue_1	Number of tiles with assigned labels based on ue_1 rule - top permanence in all days all intervals
ue_2	Number of tiles with assigned labels based on ue_2 rule - top permanence on subsets of days and intervals
ue_3	Number of tiles with assigned labels based on ue_3 rule - top frequency in all days all intervals
h_1	Number of tiles with assigned labels based on h_1 rule - top permanence in all days all intervals
h_2	Number of tiles with assigned labels based on h_2 rule - top permanence in all days nighttime interval
h_3	Number of tiles with assigned labels based on h_3 rule - top frequency in all days all intervals
w_1	Number of tiles with assigned labels based on w_1 rule - top permanence in work days working hours interval
w_2	Number of tiles with assigned labels based on w_2 rule - top frequency in work days working hours interval
ue_na	Number of tiles without UE label assigned
loc_na	Number of tiles without any location label assigned
device_filter_1_rule	Number of devices which were filtered out as rarely observed based on device_fitler_1 rule
device_filter_2_rule	Number of devices which were filtered out as rarely observed based on device_fitler_2 rule
ue_abroad	Number of devices which have usual environment abroad

\ EXAMPLE

metric	count	min	max	avg	start_date	end_date
device_filter_1_rule	5000	5000	5000	5000	2023-06-01	2023-11-31
ue_1_rule	1000	2	200	50.3	2023-06-01	2023-11-31

I.44 AGGREGATED USUAL ENVIRONMENTS

NAME	AGGREGATEDUSUALENVIRONMENTS
Description	Number of weighed devices that have usual environments in grid tiles.
Object/Unit/Record	Weighed device counts that have usual environment per grid tile.
Contents	**Mandatory fields**: • **grid_id** ○ Type: String ○ Description: Unique ID of grid tile. • **weighted_device_count** ○ Type: Float ○ Description: Count of weighed devices with usual environment assigned to this grid tile. • **label** ○ Type: String ○ Description: type of aggregate - ue, home, work. Partition key. • **start_date** ○ Type: date ○ Description: Start date (inclusive) of the period for which the usual environment was computed. Partition key. • **end_date** ○ Type: date ○ Description: End date (inclusive) of the period for which the usual environment was computed. Partition key. • **season** ○ Type: String ○ Description: season of the period for which the usual environment was computed. Partition key.

\ EXAMPLE

grid_id	weighted_device_count	label	start_date	end_date	season
100mN4052000E5271300	50.95	ue	2024-01-01	2024-06-30	winter
100mN4056500E5270500	120.33	ue	2024-01-01	2024-06-30	winter
100mN4053100E5275200	60.09	home	2024-01-01	2024-06-30	winter
100mN4056400E5274400	20.65	work	2024-01-01	2024-06-30	winter
…	…	…	…	…	…

I.45 CELL DISTANCES

NAME	SILVERCELLDISTANCEDATAOBJECT
Description	Distance between two cells' coverage areas (cell footprints) on a specified date.
Object/Unit/Record	For each cell pair, for a certain date, the distance between the cells.
Contents	**Mandatory fields**: • **cell_id_a:** ○ Type: String. ○ Description: cell ID of one cell. • **cell_id_b:** ○ Type: String. ○ Description: cell ID of another cell. • **distance:** ○ Type: Float. ○ Description: Distance between the cells' coverage areas. • **year:** ○ Type: Integer 16. ○ Description: Year of the date the distance is valid on. • **month:** ○ Type: Integer 8. ○ Description: Month of the date the distance is valid on. • **day:** ○ Type: Integer 8. ○ Description: Day of the date the distance is valid on.

\ EXAMPLE

cell_id_a	cell_id_b	distance	year	month	day
123456789101112	12345454559101144	2355	2024	01	01
123456789101112	12345456789101675	500	2024	01	01
123456789101112	12345456789101355	1345	2024	01	01

I.46 INTERNAL MIGRATION

NAME	INTERNALMIGRATION
Description	Estimation of the internal migration that has taken place between any two different zones when comparing two long-term periods.
Object/Unit/Record	Number of migrating devices between two given zones.
Contents	**Mandatory fields:** • **previous_zone:** o Type: String o Requirements: Unique identifier. o Description: Unique identifier of a zoning unit, corresponding to the zone that devices migrated from. • **new_zone:** o Type: String o Requirements: Unique identifier. o Description: Unique identifier of a zoning unit, corresponding to the zone that devices migrated to. • **migration** o Type: Float o Requirements: Positive value. o Description: number of weighted devices that migrated from the previous zone to the new zone of this record between the two long-term periods considered. • **dataset_id:** o Type: String o Requirements: Has to be unique for each zoning dataset o Description: Unique dataset identifier. Partition key. • **level** o Type: int o Requirements: o Description: Level of hierarchy for hierarchical datasets. Partition key. • **start_date_previous** o Type: date o Description: Start date (inclusive) of the first long-term period, used to check where home location migrants used to reside in. Partition key. • **end_date_previous** o Type: date o Description: End date (inclusive) of the first long-term period, used to check where home location migrants used to reside in. Partition key. • **season_previous** o Type: String o Requirements: A value from predefined set: all, summer, autumn, winter, spring o Description: Name of the type of season of the first long-term period, used to check where home location migrants used to reside in. Partition key. • **start_date_new** o Type: date o Description: Start date (inclusive) of the second long-term period, used to check where home location migrants moved to. Partition key. • **end_date_new** o Type: date o Description: End date (inclusive) of the second long-term period, used to check where home location migrants moved to. Partition key. • **season_new** o Type: String o Requirements: A value from predefined set: all, summer, autumn, winter, spring

NAME	INTERNALMIGRATION
	○ Description: Name of the type of season of the second long-term period, used to check where home location migrants moved to. Partition key.

\ EXAMPLE

previous	new_zone	migration	dataset_id	level	start_date_previous	end_date_previous	season_previous	start_date_new	end_date_new	season_new
1	2	2.4	nuts	2	2024-02-01	2024-07-31	all	2024-08-01	2025-01-31	all
1	3	25.6	nuts	2	2024-02-01	2024-07-31	all	2024-08-01	2025-01-31	all
2	1	40.2	nuts	2	2024-02-01	2024-07-31	all	2024-08-01	2025-01-31	all
2	3	10.9	nuts	2	2024-02-01	2024-07-31	all	2024-08-01	2025-01-31	all

I.47 INTERNAL MIGRATION QUALITY METRICS

NAME	INTERNALMIGRATIONQUALITYMETRICS
Description	Quality metrics of the internal migration process regarding the number of users with at least one home location in each long-time period and users with home location in both of them.
Object/Unit/Record	Number of devices with at least one home tile.
Contents	**Mandatory fields:** • **previous_home_users:** ○ Type: Integer ○ Requirements: Non-negative. ○ Description: Number of unique users with at least one home tile in the first long-term period analysed. • **new_home_users:** ○ Type: Integer ○ Requirements: Non-negative. ○ Description: Number of unique users with at least one home tile in the second long-term period analysed. • **common_home_users:** ○ Type: Integer ○ Requirements: Non-negative. ○ Description: Number of unique users with at least one home tile in both the first and second long-term periods analysed. • **result_timestamp**: ○ Type: Timestamp ○ Requirements: - ○ Description: Timestamp of the start of the process when the metrics were produced. • **dataset_id:** ○ Type: String ○ Requirements: Has to be unique for each zoning dataset ○ Description: Unique dataset identifier. • **level:** ○ Type: int ○ Requirements: ○ Description: Level of hierarchy for hierarchical datasets. • **start_date_previous:** ○ Type: date ○ Description: Start date (inclusive) of the first long-term period, used to check where home location migrants used to reside in. • **end_date_previous:** ○ Type: date ○ Description: End date (inclusive) of the first long-term period, used to check where home location migrants used to reside in. • **season_previous:** ○ Type: String ○ Requirements: A value from predefined set: all, summer, autumn, winter, spring ○ Description: Name of the type of season of the first long-term period, used to check where home location migrants used to reside in. • **start_date_new:** ○ Type: date ○ Description: Start date (inclusive) of the second long-term period, used to check where home location migrants moved to. • **end_date_new:** ○ Type: date

NAME	INTERNALMIGRATIONQUALITYMETRICS
	○ Description: End date (inclusive) of the second long-term period, used to check where home location migrants moved to. • **season_new:** ○ Type: String ○ Requirements: A value from predefined set: all, summer, autumn, winter, spring ○ Description: Name of the type of season of the second long-term period, used to check where home location migrants moved to.

\ EXAMPLE

previous home us	new_home users	common_h	dataset_id	level	start_date_previous	end_date_previous	season_previous	start_date_new	end_date_new	season_new
100	130	60	nuts	2	2024-02-01	2024-07-31	all	2024-08-01	2025-01-31	all

I.48 DAILY TOURISM STAYS

NAME	SILVERTOURISMSTAYSDATAOBJECT
Description	Daily tourism stays in a zone
Object/Unit/Record	Stay

Contents

- **user_id**:
  - Type: Binary.
  - Description: Unique pseudonymized identifier of the device.
- **time_segment_id**:
  - Type: String.
  - Description: Unique identifier of the time segment among time segments of one user.
- **start_timestamp:**
  - Type: timestamp ('YYYY-MM-DD hh:mm:ss') in UTC standard.
  - Description: the date and time of the first event of the time segment.
- **end_timestamp:**
  - Type: timestamp ('YYYY-MM-DD hh:mm:ss') in UTC standard.
  - Description: the date and time of the end of the time segment.
- **mcc:**
  - Type: Integer 16.
  - Description: Mobile Country Code derived from the user's IMSI.
- **mnc:**
  - Type: String.
  - Requirement: 2 or 3 digit code.
  - Description: Mobile Network Code of a home operator. This must be string as it can start with a 0 digit.
- **plmn:**
  - Type: String.
  - Requirement: 5 or 6 digit code. Mandatory only for outbound data.
  - Description: Network identifier of the foreign roaming partner MNO. Consists of PLMN=MCC+MNC.
- **zone_ids_list:**
  - Type: List of Strings.
  - Description: Geographic zone ids from the event records composing the time segment. In the same order as the event records.
- **zone_weights_list:**
  - Type: float.
  - Description: List of weights/probabilities that the device is the zone. Order corresponds to *zone_ids_list.*
- **is_overnight**:
  - Type: Boolean.
  - Description: If the stay overlaps with functional midnight and is longer than the minimum duration threshold.
- **year:**
  - Type: Integer 16.
  - Description: Year the event took place.
- **month:**
  - Type: Integer 8.
  - Description: Month the event took place.
- **day:**
  - Type: Integer 8.
  - Description: Day the event took place.
- **user_id_modulo:**
  - Type: Integer.

NAME	SILVERTOURISMSTAYSDATAOBJECT
	◦ Description: Partition key. • **dataset_id:** ◦ Type: String. ◦ Description: Name of the zoning dataset.

EXAMPLE

user_id	time_segment_id	start_timestamp	end_timestamp	mcc	mnc	zone_ids_list	zone_weights_list	is_overnight	dataset_id
1	x75abd	2023-01-01 00:00:00	2023-01-01 06:45:01	321	01	ES3040, ES3041	0.7, 0.3	true	nuts
1	x75abd	2023-01-01 06:45:01	2023-01-01 07:16:21	321	01	ES3040, ES3041	0.7, 0.3	false	nuts

I.49 MONTHLY TOURISM TRIPS

NAME	SILVERTOURISMTRIPSDO
Description	Tourism trips of users. Aggregated per month from stays. Represents trip state during one month: a multi-month trip shall exist in a finished state in its last month, and in an unfinished state in all its previous months.
Object/Unit/Record	Trip (aggregation of consecutive stay-type time segments)
Contents	**Mandatory fields:** • **user_id**: o Type: Binary. o Description: Unique pseudonymized identifier of the device. • **trip_id**: o Type: String. o Description: Identifier for one trip. Unique among trips of one user. • **trip_start_timestamp:** o Type: Timestamp. o Description: Start time of first time segment included in the trip. • **time_segment_ids_list:** o Type: Array of String. o Description: List of time segment ids corresponding to the user's time segments included in this trip. • **is_trip_finished:** o Type: Boolean. o Description: Flag marking the trip as either finished or ongoing/unfinished. • **year:** o Type: Integer 16. o Description: Year the event took place. • **month:** o Type: Integer 8. o Description: Month the event took place. • **user_id_modulo:** o Type: Integer. o Description: Partition key. • **dataset_id:** o Type: String. o Description: Partition key. Name/id of zoning dataset.

\ EXAMPLE

user_id	**trip_id**	**trip_start_timestamp**	**time_segment_ids_list**	**is_trip_finished**	**year**	**month**	**user_id_**	**dataset_id**
1000001	tt423	2023-01-04 15:51:00	[e323, r43q, re2]	False	2023	1	1	nuts
1000001	tx652	2023-01-04 15:51:00	[g45f, 352s, u53]	True	2023	2	1	nuts

I.50 MCC ISO TIMEZONE MAPPING

NAME	BRONZEMCCISOTZMAPDO
Description	Maps MCC codes to country ISO2 and local timezones.
Object/Unit/Record	MCC to ISO2 pair with timezone value
Contents	**Mandatory fields:** • **mcc**: ○ Type: Integer. ○ Description: Mobile Country Code. Numeric code identifying the country. • **name**: ○ Type: String. ○ Description: Name of the country. • **iso2:** ○ Type: String. ○ Description: ISO2 (two-letter) code for the country. • **iso3:** ○ Type: String. ○ Description: ISO3 (three-letter) code for the country. • **eurostat_code:** ○ Type: String. ○ Description: • **latitude:** ○ Type: Float. ○ Description: Latitude for the country (capital). • **longitude:** ○ Type: Float. ○ Description: Longitude for the country (capital). • **timezone:** ○ Type: String. ○ Description: Timezone name string.

\ EXAMPLE

mcc	name	iso2	iso3	eurostat_code	latitude	longitude	timezone
248	Estonia	EE	EST	EE	59.436962	24.753574	Europe/Tallinn

I.51 INBOUND TOURISM AGGREGATIONS I: NIGHTS SPENT AND DEPARTURES PER ZONE

NAME	SILVERTOURISMDEPARTURESNIGHTSSPENTDO
Description	Statistical aggregations of inbound tourism that use zone-level categorization.
Object/Unit/Record	Departures and nights spent by inbound and domestic tourists, per geographical zone, country of origin, and overnight stays.
Contents	**Mandatory fields:** • **time_period**: ○ Type: String. ○ Description: Breakdown category. YYYY-MM string of the month the statistics apply to. • **zone_id**: ○ Type: String. ○ Description: Breakdown category. Unique identifier of the geographical zone the statistics apply to. • **country_of_origin**: ○ Type: String. ○ Description: Breakdown category. Country of residence based on MCC country, represented as ISO 3166-1 alpha-2 (ISO_A2) code (https://www.iban.com/country-codes). • **is_overnight**: ○ Type: Boolean. ○ Description: Breakdown category. Separates overnight and same-day visits. • **nights_spent**: ○ Type: Float. ○ Description: Statistical indicator. Indicates total number of nights spent in the corresponding zone. • **num_of_departures**: ○ Type: Float. ○ Description: Statistical indicator. Indicates number of departures (last stay of finished trip) from the corresponding zone. • **year:** ○ Type: Integer 16. ○ Description: Partitioning column. Year of the time period. • **month:** ○ Type: Integer 8. ○ Description: Partitioning column. Month of the time period. • **level:** ○ Type: Integer 8. ○ Description: Partitioning column/Breakdown category. Hierarchical zoning level the *zone_id* corresponds to. • **dataset_id:** ○ Type: String. ○ Description: Partition key. Name/id of zoning dataset.

\ EXAMPLE

time_period	zone_id	country_	is_overnight	nights_spent	num_of_departures	year	month	level	dataset_id
2024-06	Lazio region	FR	false	0	12478	2024	6	2	nuts
2024-06	Lazio region	DE	false	0	1987	2024	6	2	nuts
2024-06	Lazio region	FR	true	15747	12478	2024	6	2	nuts
2024-06	Lazio region	DE	true	2571	1987	2024	6	2	nuts
2024-06	Italy	FR	false	0	201474	2024	6	1	nuts
2024-06	Italy	DE	false	0	28744	2024	6	1	nuts
2024-06	Italy	FR	true	248714	201474	2024	6	1	nuts
2024-06	Italy	DE	true	39874	28744	2024	6	1	nuts

I.52 INBOUND TOURISM AGGREGATIONS II: AVERAGE NUMBER OF DESTINATIONS AND NIGHTS SPENT PER COUNTRY OF ORIGIN

NAME	SILVERTOURISMTRIPAVGDESTINATIONSNIGHTSSPENTDO
Description	Statistical aggregations of inbound tourism that use country of origin-level categorization.
Object/Unit/Record	Average number of destinations and average number of nights spent, per month, per country of origin.
Contents	**Mandatory fields:** • **time_period**: ○ Type: String. ○ Description: Breakdown category. YYYY-MM string of the month the statistics apply to. • **country_of_origin**: ○ Type: String. ○ Description: Breakdown category. Country of residence based on MCC country, represented as ISO 3166-1 alpha-2 (ISO_A2) code (https://www.iban.com/country-codes). • **avg_destinations**: ○ Type: Float. ○ Description: Statistical indicator. Average number of destinations (unique zones per trip) across all trips. • **avg_nights_spent_per_destination**: ○ Type: Float. ○ Description: Statistical indicator. Average number of nights spent per destination across all trips. • **year:** ○ Type: Integer 16. ○ Description: Partitioning column. Year of the time period. • **month:** ○ Type: Integer 8. ○ Description: Partitioning column. Month of the time period. • **level:** ○ Type: Integer 8. ○ Description: Breakdown category. Hierarchical zoning level the statistics corresponds to. • **dataset_id:** ○ Type: String. ○ Description: Partition key. Name/id of zoning dataset.

\ EXAMPLE

time_period	country_	avg_destinations	avg_nights_spent	year	month	level	dataset_id
2024-06	FR	1.7	2.9	2024	6	1	nuts
2024-06	DE	2.8	3.7	2024	6	1	nuts
2024-07	FR	1.79	2.2	2024	6	1	nuts
2024-07	DE	2.6	3.3	2024	6	1	nuts

I.53 OUTBOUND TOURISM AGGREGATIONS: NIGHTS SPENT PER DESTINATION COUNTRY

NAME	SILVERTOURISMOUTBOUNDNIGHTSSPENTDO
Description	Statistical aggregations of outbound tourism that use country of destination-level categorization.
Object/Unit/Record	Average number of number of nights spent, per month, per country of destination.
Contents	**Mandatory fields:** • **time_period**: o Type: String. o Description: Breakdown category. YYYY-MM string of the month the statistics apply to. • **country_of_destination**: o Type: String. o Description: Breakdown category. Country of destination represented as ISO 3166-1 alpha-2 (ISO_A2) code (https://www.iban.com/country-codes). • **nights_spent**: o Type: Float. o Description: Statistical indicator. Number of nights spent across all trips. • **year:** o Type: Integer 16. o Description: Partitioning column. Year of the time period. • **month:** o Type: Integer 8. o Description: Partitioning column. Month of the time period.

\ EXAMPLE

time_period	country_of_destination	nights_spent	year	month
2024-06	FR	30303	2024	6
2024-06	DE	20202	2024	6

I.54 INBOUND ESTIMATION FACTORS

NAME	INBOUNDESTIMATIONFACTORS
Description	Deduplication factor and MNO-to-target-population factor for the inbound visitors from other countries
Object/Unit/Record	Deduplication factor and MNO-to-target-population factor for the inbound visitors from a given country
Contents	**Mandatory fields:** • **iso2**: ○ Type: String ○ Description: Country of residence of foreign visitors based on MCC country, represented as ISO 3166-1 alpha-2 (ISO_A2) code (https://www.iban.com/country-codes). • **deduplication_factor:** ○ Type: Float ○ Requirements: nullable field ○ Description: Factor that will multiply appropriate metrics in order to account for the fact that one user may possess more than one device. • **mno_to_target_population_factor:** ○ Type: Float ○ Requirements: nullable field ○ Description: Factor that will multiply appropriate metrics in order to account for the fact that the number of devices does not represent the total target population that the metric refers to.

\ EXAMPLE

iso2	deduplication_factor	mno_to_target_population_factor
ES	0.98	NULL
EE	0.95	3.4
IT	NULL	4.5

I.55 AGGREGATED USUAL ENVIRONMENTS - ZONES

NAME	AGGREGATEDUSUALENVIRONMENTS
Description	Number of weighed devices that have usual environments in given geographic zone
Object/Unit/Record	Weighed device counts that have usual environment per geographic zone
Contents	**Mandatory fields**: • **zone_id**: o Type: String o Requirements: Unique identifier. o Description: Unique identifier of a zoning unit. • **weighted_device_count** o Type: Float o Description: Count of weighed devices with usual environment assigned to this grid tile. • **dataset_id:** o Type: String o Requirements: Has to be unique for each zoning dataset o Description: Unique dataset identifier • **level:** o Type: int o Requirements: o Description: Level of hierarchy for hierarchical datasets • **label:** o Type: String o Description: type of aggregate - ue, home, work. Partition key. • **start_date:** o Type: date o Description: Start date (inclusive) of the period for which the usual environment was computed. Partition key. • **end_date:** o Type: date o Description: End date (inclusive) of the period for which the usual environment was computed. Partition key. • **season:** o Type: String o Description: season of the period for which the usual environment was computed. Partition key.

\ EXAMPLE

zone_id	weighted_device_count	dataset_id	level	label	start_date	end_date	season
ES532	50.95	nuts	3	ue	2024-01-01	2024-06-30	winter
ES532	60.09	nuts	3	home	2024-01-01	2024-06-30	winter
ES532	20.65	nuts	3	work	2024-01-01	2024-06-30	winter
…	…			…	…	…	…

I.56 DAILY PERMANENCE SCORE QUALITY METRICS

NAME	DAILYPERMANENCESCOREQUALITYMETRICS
Description	Number of devices with a high number of unknown time slots
Object/Unit/Record	Number and percentage of devices with a high number of unknown time slots for a given day
Contents	**Mandatory fields:** • **result_timestamp**: ○ Type: Timestamp ○ Description: Timestamp of the start of the process when the metrics were produced. • **number_unknown_devices:** ○ Type: Integer 64 ○ Description: Number of devices that have a high percentage of time slots classified as "unknown" for this date • **percentage_unknown_devices:** ○ Type: Float ○ Description: Percentage of "**number_unknown_devices**" over the total number of devices present in the Daily Permanence Score data for this date. • **month:** ○ Type: Integer 8. ○ Description: Month the intersection group determined. • **day:** ○ Type: Integer 8. ○ Description: Day the intersection group determined. • **year:** ○ Type: Integer 16. ○ Description: Year the intersection group determined.

\ EXAMPLE

result_timestamp	number_unknown_devices	percentage_unknown_devices	month	day	year
2025-01-03 12:34:56	100	0.24	01	01	2025
2025-01-04 11:22:33	200	0.45	01	02	2025

I.57 CELL FOOTPRINT QUALITY METRICS

NAME	CELLFOOTPRINTQUALITYMETRICS
Description	Cell IDs that have no footprint and their events
Object/Unit/Record	Cell ID with no grid footprint and their events
Contents	**Mandatory fields:** • **result_timestamp**: ○ Type: Timestamp ○ Description: Timestamp of the start of the process when the metrics were produced. • **cell_id** ○ Type: String ○ Description: Unique ID of cell • **number_of_events** ○ Type: Integer 64 ○ Description: Number of events on this date that reference the current cell ID with no footprint • **percentage_total_events** ○ Type: Float ○ Description: Percentage of the number of events that reference the current cell ID over the total number of events in this date • **year:** ○ Type: Integer 16. ○ Description: Year the intersection group determined. • **month:** ○ Type: Integer 8. ○ Description: Month the intersection group determined. • **day:** ○ Type: Integer 8. ○ Description: Day the intersection group determined.

\ EXAMPLE

result_timestamp	cell_id	number_of_events	percentage_total_events	year	month	day
2025-01-02 12:34:56	123231342131341	100	0.0123	2025	01	01
2025-01-02 12:34:56	123231342131342	200	0.0246	2025	01	01

ANNEX II – NOTES FOR FUTURE REVISION

The final version of the software documentation (deliverable **D4.4)** will include:

- Current work-in-progress on software improvements, specifically: (i) optimisation of storage and performance based hierarchical encoding and (ii) additional quality metrics/warnings for main components.
- Potential software improvements based on testing phase results with real MNO data and other backlog priorities.
- Annex II - pipeline schemas for each UC implemented, representing the orchestation of diferent software modules and the temporal scale of the calculation (i.e. daily, mid-term, long-term, etc.).