RCA

Reference CCS Architecture

An initiative of the ERTMS users group and the EULYNX consortium

Concept: Operational Plan

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Version history

Gamma.1	31.01.2020	P. Moosmann / Y. Wyder	Integrated review feedback from RCA Core Group

1. Introduction

1.1. Purpose of the document

This document provides an overview about the concept of the Operational Plan, which is a foundation for the RCA interface SCI_1, as shown in the figure below:

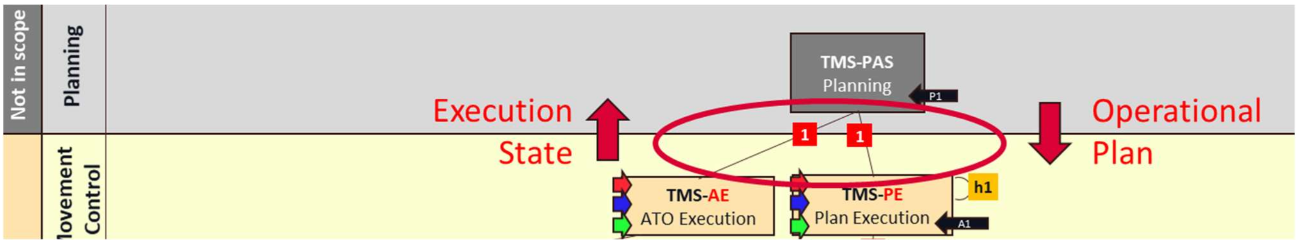


Figure 1 Scope of Operational Plan

The SCI_1 interface is at the border of the RCA systems scope and defines the interface between the planning system and RCA components. This interface will be specified for and by RCA since no directly re-usable interface specification has been discovered in our research. These factors make this interface and thereby the Operational Plan a focal point of the architecture.

SCI_1 is a bidirectional interface. TMS-PAS sends Operational Plans to RCA components (TMS-PE and TMS-AE) and the RCA components provide Execution State updates to TMS-PAS. This document focusses on the Operational Plan. The concept of Execution State is still in an early stage of discussion. Nevertheless, the Execution State is mentioned where it's necessary for the understanding of the SCI_1 interface.

More detailed information can be found in the model-based specification documents [3], [4] (see chapter "Additional material" below).

1.2. Definition of the "Operational Plan" and the relevance to RCA

The Operational Plan is a plan for a single train provided by the planning system TMS-PAS. The Operational Plan contains detailed execution instructions for "producing" the railway traffic by RCA components.

SCI_1 connects the outer non-standardised world to the standardised world of RCA. On the outer world, IMs are using different planning systems today. It is the aim of the Operational Plan to bridge these different worlds and to provide interoperability for the involved systems. Interoperability will be given, if:

- the planning systems are able to produce Operational Plans or it is possible to translate a proprietary planning outputs to the Operational Plans (which is done by SBB with RCS);
- The Operational Plan is interpretable/executable by the RCA components;
- Operational Plan contains all information to be translated for existing interlockings to facilitate and support stepwise migration.

1.3. Definition of the "Execution State"

With the Execution State, RCA provides information about the current situation of the railway traffic to the planning systems. Our vision is, that this includes location of vehicles and their reserved paths but also the actual state of the infrastructure (points, level crossing, …) and detected malfunction or usage restrictions of infrastructure.

1.4. Scope and maturity of the concept, ongoing work, related topics

This is the very first publication on this topic from RCA and its main purpose is to establish the topic and get discussions with stakeholders in the sector started.

The content of this document is coming from smartrail 4.0. Parts of the concept of the Operational Plan have been currently implemented in smartrail 4.0 for the interface between the Rail Control System (RCS) and the existing interlocking (Iltis). This document is largely based on this implementation work.

The Operational Plan is still work in progress. See section 6 for missing parts.

1.5. Additional material

The following RCA document provides more detailed information:

[1] RCA System Architecture, RCA.Doc.35
[2] RCA Glossary, RCA.Doc.4
[3] Component Specification TMS-PE, RCA.Doc.19
[4] Component Specification TMS-AE, RCA.Doc.20
[5] Interface Specification SCI_1, RCA.Doc.25

2. Principles of the Operational Plan

Infrastructure management organisations typically run separate processes for the railway traffic planning and the railway traffic operations. The planning processes' intention is to create and optimise a schedule, that allows it to produce traffic according to the railway companies' demands, the required maintenance, construction work and considers the current traffic situation. Normally, the planning will be done over different forecast horizons, with detailed and precise information for the near future and decreasing accuracy further away. The process of traffic operations executes the planned traffic schedule by controlling and monitoring trackside assets such as points or signals and providing instructions to the vehicles to enable automatic train operations.

The interface SCI_1 is the link between the planning and the traffic operation process. An Operational Plan carries all information needed to produce a planned schedule for a train. The Operational Plan is the output of the planning process and the input for the traffic operations process. The other linking element is the Execution State. The Execution State is the feedback loop back from the traffic operation to the planning process. It reports the execution progress of the Operational Plan. The Execution State contains information about the train's location, its allocated and reserved tracks, but it also contains information about the actual state of the infrastructure.

As the traffic situation may change because of conditions in the physical world (e.g., train delay due to weather, landslide, point malfunction), the schedule needs to be adapted. By receiving Execution State updates, the planning system knows about the traffic situation. Based on that situation, the planning system (or responsible staff) might decide to reoptimise the schedule (e.g., change the ordering of trains) and to calculate a new version of the Operational Plan. The rescheduling could be largely done by the planning system itself. But staff need to be able to understand the systems behavior, intervene if necessary and provide planning guidelines. To support frequent updates, the Operational Plans must be versioned. New versions may be generated for Operational Plans that are not yet in execution as well as Operational Plans that are already in execution. Changes to partly executed Operational Plans are restricted to the part, that is not yet in execution.

An Operational Plan is modeled as an ordered list of planned operational events. The path is precisely defined for each Operational Plan. The order of the list is defined by the sequence of occurrence of events in the trains journey. Such an event describes a planned action, that should happen at the given location. An Operational Plan can be seen as an instruction list, defining the path and step by step the actions that should be performed on this path.

An Operational Plan is used to describe train runs, shunting movements, stabling and planned infrastructure restrictions, due to maintenance or construction work.

2.1. Operational Plan for a train run

To make schedule optimisations effectively, all movement of trains and vehicles must be considered in the planning and carried out as planned. Planning is a constant process that needs to detect deviations and determine if re-planning is necessary. Subsequently, Operational Plans for all movements of trains and vehicles might be (re)-calculated.

For each train run, an Operational Plan defines the precise, scheduled path of the train from the departure to the arrival point through the railway network. In case of commercial trains, the Operational Plan contains further operational actions (e.g., connecting trains, time constraints for stops), needed to operate the train.

The simplified example in Figure 2 shows the Operational Plan for the train number 392. The train is located at station A. The Operational Plan starts with the departure time on the given operation point (Station A). The Operational Plan defines the exact track route of the train through the track network (green line, defined by LeaveEdgeEvent, EnterEdgeEvent),). Optionally PassThroughEvents are defined, with a scheduledTime and earliestTimeConstraints where a train couldn't pass before at a defined location. Reading the Operational Plan further lets you discover, that train 392 will stop on station B but passes station C without stopping. The Operational Plan ends on station D. The different Events are described in [5].

The Operational Plan showed in the example is by far not complete. In a real scenario, an executable Operational Plan will carry a lot more information.

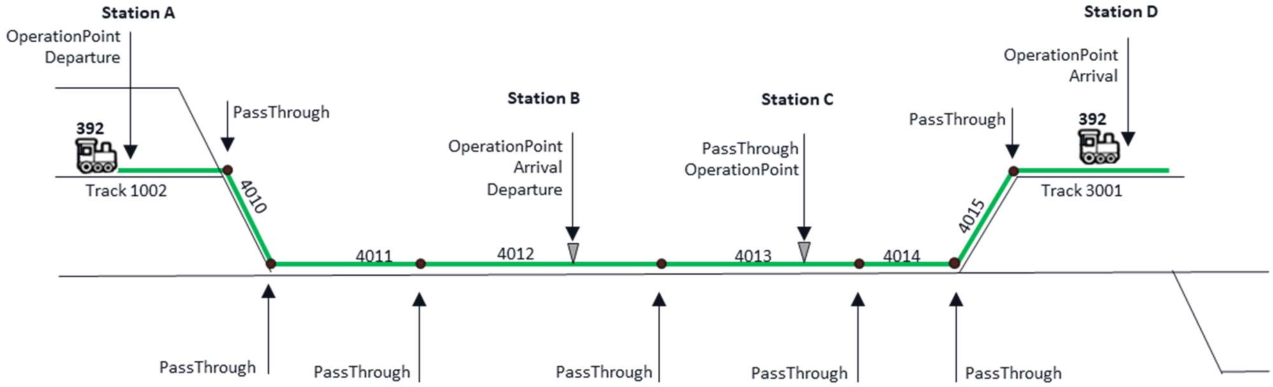


Figure 2 Simplified example of the concept of Operational Plan

2.2. Operational Plan for a shunting movement

Shunting movements are covered by the Operational Plan as well. There is no difference in the structure of the Operational Plan between shunting movements and train runs. A flag on the Operational Plan indicates which type of movement is described. Relationships between a shunting movement and a train run are structurally identical to the relationships from one train run to another train run.

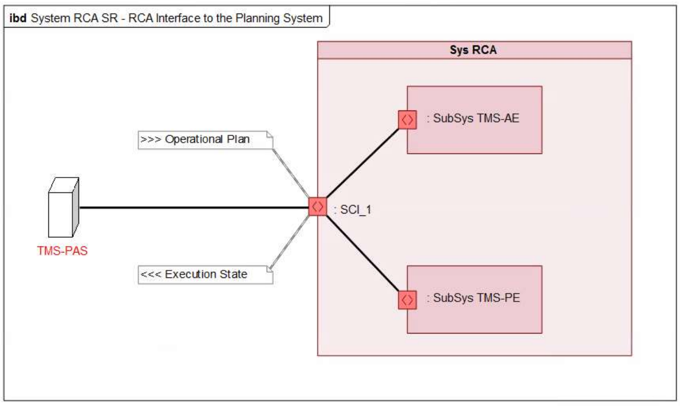
2.3. Operational Plan for stabling

The Operational Plan for stabling has not been defined yet. The basic idea is to define a start, end (timestamp) and location. With this Operational Plan, no movement is allowed. Velocity must be 0. Additional services could be possible, e.g., preheating, cooling, water filling, dumping wastewater, etc.

2.4. Operational Plan for usage restrictions

The usage of the railway infrastructure must be sometimes restricted. The reason for this could be for example maintenance or construction work. All plannable restrictions are considered in the traffic planning, since it reduces the railway capacity, but also monitored in the command and control system to ensure safe operations. The Operational Plan defines the track area affected, the planned start- and end time and limitations (e.g., speed reduction, track blockage). The Operational Plan for infrastructure restrictions has not been defined yet.

3. Operational Plan in the RCA Architecture



Speaking in systems, the Operational Plan is the message sent from the planning system to the command and control system. The Execution State is the message sent from command and control system to the planning system.

In RCA the planning system is called TMS-PAS. TMS-PAS communicates over interface SCI_1 with RCA. TMS-PE and TMS-AE are the RCA components, that are implementing SCI_1. Remember, that TMS-PAS is outside of the RCA scope and therefore not part of the architecture.

TMS-PE requests Drive Protection Sections and Movement Permissions according to the Operational Plan. TMS-AE generates instructions for ATO from the Operational Plan, so that the train autonomously drives as planned. TMS-PE and TMS-AE report back the execution progress of the Operational Plan with the Execution State.

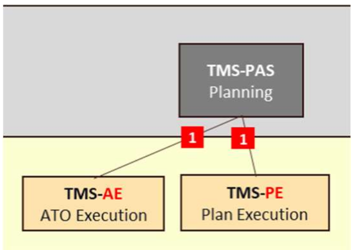
Since TMS-PE and TMS-AE are part of the RCA specification, they could likely be standard components. For TMS-PAS there will be IM specific solutions. SCI_1 connects standards components (RCA) with proprietary solutions.

3.1. The role of interface 1 in the migration

As mentioned in section 1.1 and 1.2, SCI_1 has a crucial role during migration. It bridges different worlds and provides interoperability for the involved systems. The following table shows different blueprints, how SCI_1 could be applied. SCI_1 provides the flexibility to connect a wide variety of planning systems to RCA and it allows to connect existing IXLs.

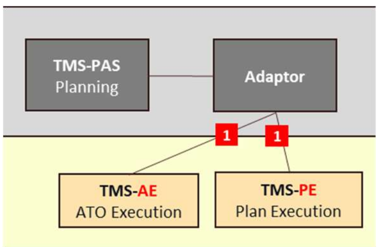
<table>
<tr>
<td>

Case 1: Planning System

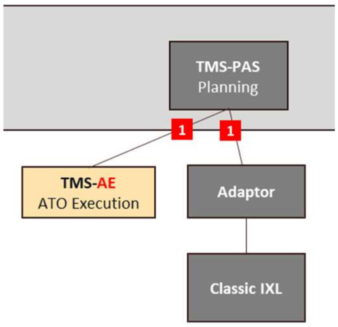


</td>
<td>This is the desired end state. Any planning system that implements SCI_1 can be connected to RCA.</td>
</tr>
<tr>
<td>

Case 2: Existing Planning System



</td>
<td>If the planning system cannot directly provide SCI_1, an adaptor could translate from the existing planning system interface to SCI_1. This allows to use many existing planning systems, that are used today by the IMs.</td>
</tr>
</table>

Case 3: Existing IXL	This case is primarily thought as a migration step. First SCI would be introduced between the planning system and the existing IXL by implementing an adaptor, that translates the Operational Plan to the language, which the IXL understands. In this case it would also be possible to use already the ATO components.
	

4. Structure of an Operational Plan

In the section Principles of the Operational Plan the idea of the Operational Plan was introduced. In this section the concept of the Operational Plan will be detailed further.

By definition, an Operational Plan consist of one to many Operational Segments. An Operational Segment refers to (a part of) a train run on which the same formation operates. Adding, changing or removing rolling stock from a train and changing the direction of the train alters the formation. Formation changes show up in new Operational Segments.

The Operational Segment contains a list of Operational Events ordered by their occurrence in the train journey. Each event defines an action that should happen on a certain position on the tracks. For example, a PassThroughEvent carries the scheduledTime and optionally an earliestTimeConstraint at what time a train should pass a certain position. The full list of available Operational Events is described in [2], [3]. This design should support future enhancements, since new Operational Events could be added not intrusively.

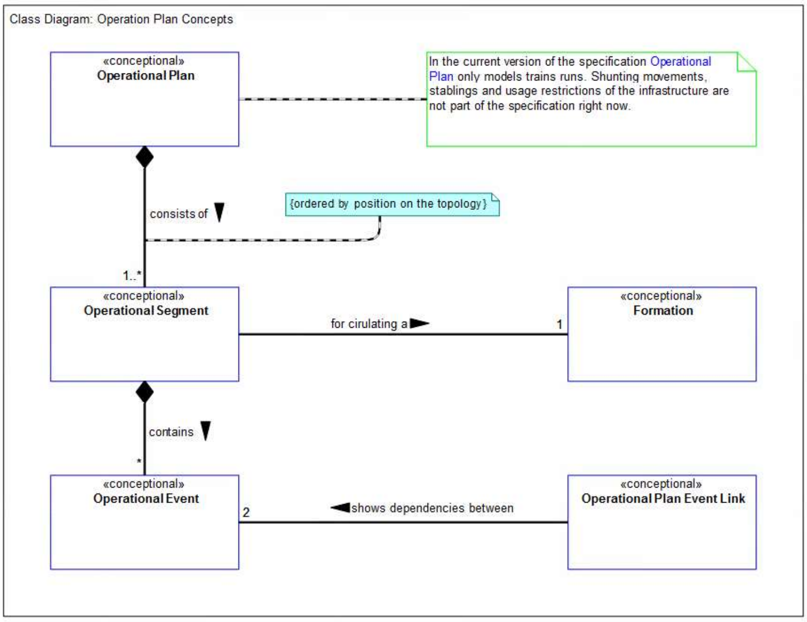


Figure 3 Domain model for Operational Plan

Name	Description
Operational Plan	The Operational Plan is the detailed plan of all track usage, including train runs, shunting movements, stablings and usage restrictions of the infrastructure (e.g., for construction and maintenance). Each train run is represented by a separate Operational Plan.
Operational Segment	The Operational Segment is the detailed plan that describes all track usage for exactly one Formation. Every Formation change will lead to new Operational Segment. A turnback is also considered a change in Formation due to the change of the direction of travel.
Operational Event	An Operational Event is a part of an Operational Plan. An Operational Event describes an planned action, that should occur at a defined location on the tracks.
Operational Plan Event Link	A Operational Plan Event Link is a relationship between two Operational Events which are part of Operational Plans. The linked Operational Events can be part of the same or different Operational Plans. Operational Plan Event Link are used for describing circulation of a rolling stock (split, join, change of OperationId) and turnbacks.
Formation	A Formation is an ordered sequence of vehicles in driving direction.

A train run can be precisely defined by creating a sequence of Operational Events. These Operational Events will be translated by TMS-PE and TMS-AE into instructions for trackside assets and locomotives. Figure 4 shows the sequence of Operational Events refining the Operational Plan of the example in the beginning of this document. The different Events are described in [5].

Remark: The example in Figure 4 shows, how the Operational Plan could be enhanced with proprietary Events to support migration. During migration the Operational Plan could contain additional proprietary Events such as the SignalEvent. These proprietary Events would be ignored by APS but are needed by existing interlocking systems. Such enhancements would make it then possible, to produce one Operational Plan that could be used in a mixed migration scenario with RCA and existing interlocking systems.

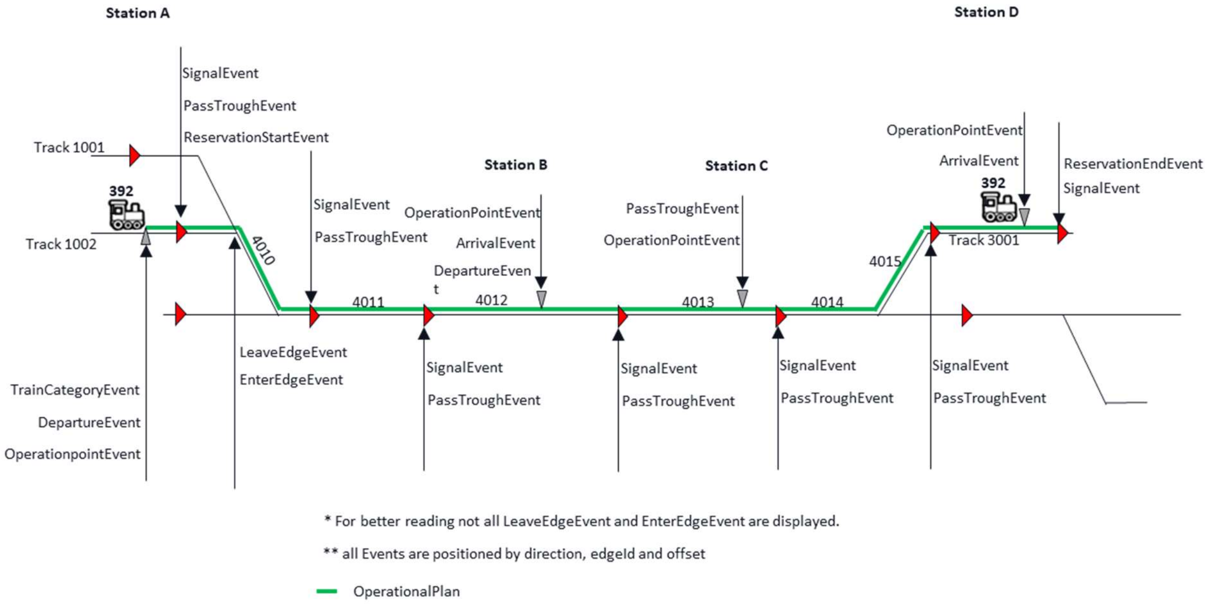


Figure 4 Example of an Operational Plan

The Operational Plan shown in Figure 4 can be easily transformed into a machine-readable format, such as json. An excerpt of an Operational Plan in json format is shown in Figure 5.

```
{
  "operationId" : {
    "operationalNumber" : "318",
    "operationalDay" : "2019-11-12",
    "infrastructureNet" : "Standard",
    "operationalPathId" : "318-001"},
  "description" : "SBBP-318-2",
  "type" : "TRAINRUN",
"operationalSegments" : [
{
"operatingType" : "OPERATIONAL",
"operationalEvents" : [
  {
  "type" : "TrainCategoryEvent",
  "position" : {
    "type" : "EdgePosition",
    "edgeId" : 35869,
    "offset" : 6735.500,
    "direction" : "OPPOSITE"
  },
  "constraints" : [ ],
  "category" : "EC"
  },
  {
  "type" : "PassThroughEvent",
  "position" : {
    "type" : "EdgePosition",
    "edgeId" : 35869,
    "offset" : 6735.500,
    "direction" : "OPPOSITE"
  },
  "constraints" : [
  {
    "type" : "EarliestTimeConstraint",
    "time" : "2019-11-12T13:43:30+01:00",
    "forced" : false
  } ],
  "scheduledTime" : "2019-11-12T14:02:28+01:00"
  },
  {
  "type" : "OperationPointEvent",
  "position" : {
    "type" : "EdgePosition",
    "edgeId" : 35869,
    "offset" : 6735.500,
    "direction" : "OPPOSITE"
  },
  "constraints" : [ ],
  "operationPointId" : 2338,
  "abbreviation" : "ALCA"
  },
  {
  "type" : "ArrivalEvent",
  "position" : {
    "type" : "EdgePosition",
    "edgeId" : 35869,
    "offset" : 3117.500,
    "direction" : "OPPOSITE"
  },
  "constraints" : [ {
    "type" : "LatestTimeConstraint",
    "time" : "2019-11-12T13:49:00+01:00"
  } ],
  "stopCode" : "COMMERCIAL_STOP",
  "scheduledTime" : "2019-11-12T14:08:16+01:00",
  "entryIntoOccupiedTrack" : false
},
…
```


Train Number 318

List of Operational Segment
Type: Operational

List of Operational Events

Event Type

Position of an Operational Event

List of constraints for the event

Figure 5 Example in json format

In real situations there are dependencies between trains, that need to be known by the systems, such as:

- Circulation of rolling stock
- Connecting trains
- Sequence of movements

These dependencies between trains can be expressed with OperationalPlanEventLinks. These Links establish a connection between two different Operational Event. Figure 6 shows how an OperationalPlanEventLink can be used to define that the same rolling stock will first circulate in Operational Plan 1 and after arrival it will circulate in Operational Plan 2.

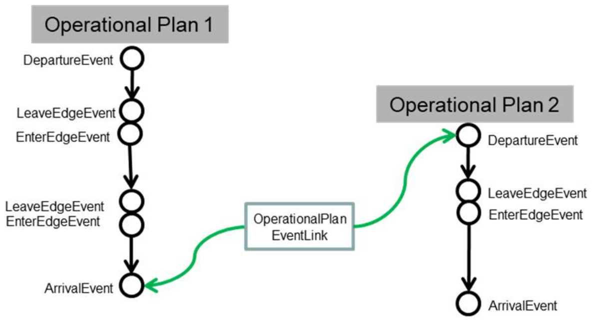


Figure 6 OperationalPlanEventLink

Remark: Stabling, shunting and infrastructure restrictions are currently not described in this chapter.

4.1. Operational Plans with unknown infrastructure

During the work on the Operational Plan concept in smartrail 4.0, we discovered, that it might be necessary to provide information about train runs that are not (entirely) handled by the IMs infrastructure (e.g., country borders, other railway infrastructure provider within a country). To do so, a new type (Type: Informational) of Operational Segment has been introduced. These informational Operational Segments only contain a subset of the Operational Events (TrainCategory, DepartureEvent/ArrivalEvent/PassThroughEvent, OperationPointEvent).

```
…
{
  "operatingType" : "INFORMATIONAL",
  "operationalEvents" : [ {
    "type" : "TrainCategoryEvent",
    "position" : {
      "type" : "LogicalPosition",
      "logicalPosition" : 1
    },
    "constraints" : [ ],
    "category" : "EC"
  }, {
    "type" : "DepartureEvent",
    "position" : {
      "type" : "LogicalPosition",
      "logicalPosition" : 1
    },
    "constraints" : [ {
      "type" : "EarliestTimeConstraint",
      "time" : "2019-11-12T13:10:00+01:00",
      "forced" : false
    } ],
    "stopCode" : "COMMERCIAL_STOP",
    "scheduledTime" : "2019-11-12T13:28:58+01:00",
    "actionReferenceTime" : "1970-01-01T01:00:00+01:00"
  }, {
    "type" : "OperationPointEvent",
    "position" : {
      "type" : "LogicalPosition",
      "logicalPosition" : 1
    },
    "constraints" : [ ],
    "operationPointId" : 3051,
    "abbreviation" : "MICL"
  }, {
    "type" : "ArrivalEvent",
    "position" : {
      "type" : "LogicalPosition",
      "logicalPosition" : 2
    },
    "constraints" : [ {
      "type" : "LatestTimeConstraint",
      "time" : "2019-11-12T13:21:00+01:00"
    } ],
    "stopCode" : "COMMERCIAL_STOP",
    "scheduledTime" : "2019-11-12T13:39:58+01:00",
    "entryIntoOccupiedTrack" : false
  },
```


Figure 7 Example of an Operational Plan with an informational segment

5. Design Principles

Principle: Every movement of a movable object has to be planned with an Operational Plan.

Rationale: For effective schedule optimisation, the planning system TMS needs to know every movement and every track usage. To use the tracks in the most efficient way, TMS creates Operational Plans and tracks the execution of these plans.

Principle: An Operational Plan defines exactly one train run.

Rationale: The granularity “one train run = one Operational Plan” has been chosen, because of several reasons. First, it represents a train or train run, that’s is a complete/self-contained entity. Second, the data of an Operational Plan needs to be consistent and can be checked on this level. Third, because of runtime efficiency. If a train run changes, only the affected Operational Plans must be recalculated and redistributed. This reduces the exchanged data volume and makes it easier for consumers (TMS-PE, TMS-AE) to handle the changes.

As a consequence, this means that running many trains simultaneously means to execute many Operational Plans at the same time.

Principle: Relations between Operational Plans are defined by links (e.g., connecting trains).

Rationale: There are commercial and operational relations between train runs. The most common case of such a relation is a connecting train. An Operational relation is for example a defined order in which the trains should pass a given location. The concept of Operational Links is an explicit way to defining such relations. These relations are standalone objects with their own lifecycle. Therefore, an update of relations is possible without updating the affected Operational Plans. Relations could be done also implicitly with timing point coordination, but this was considered as less robust and would result in much higher requirements for availability and accuracy of the planning system.

Principle: Abstraction Level and product independent interface definition

Rationale: For interoperability reasons, the Operational Plan and Execution State shall provide a good abstraction level and shall be product/system independent. Good abstraction means, that different concepts (e.g., different GoA-Levels, fixed block or moving block, aps and legacy interlocking systems) can be supported.

Principle: Enhanceability of the interface definition

Rationale: To support future changes, the design of Operational Plan and Execution State should be open for enhancements. To support a stepwise (for example regional) migration, additional and optional Operational Events could be introduced. This could allow to use Operational Plans with existing interlockings. Figure 4 shows an Operational Plan with additional Signal Events. These events are needed by the existing SBB interlocking (Iltis).

6. Open Points

These open points are known by the date of publication of this document:

- Shunting not covered in the current RCA specification
- Stabling (and Stabling Areas) not covered in the current RCA specification
- Usage restriction areas not covered in the current RCA specification
- Execution State not covered in the current RCA specification
- Timing specifications (e.g., update frequency of Operational Plan) and dynamic behavior not covered in the current RCA specification.
- Operational Plan could be quite big. Further investigations needed, if the whole plan or just a relevant part of it should be exchanged over SCI_1.
- Explaining the difference between Operational Plan and the “classical route” interface.
- Handover at country borders (first approach as described with informational and operational segments)
- Replace the principles mentioned by design rationales.