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OptiYard - Optimised Real-time Yard and Network Management

Deliverable D3.2

Functional and Technical Specification for the OptiYard Simulation Environment

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Executive Summary

This Deliverable represents an important milestone in the OPTIYARD project, as it reports on the work conducted in OPTIYARD Tasks 3.2, 3.3 and 3.4 in order to develop the functional and technical specifications for the selected OPTIYARD simulation environment. It builds on work reported in OPTIYARD Deliverables 2.1, 2.2 and 3.1 which have identified and categorised the range of operations conducted in railway terminals and yards and have examined the information and data requirements for successful yard operation. This work is used here in order to develop a fuller understanding of the yard processes, the operational interfaces between the yard and the rail network and the challenges of managing these more proactively through real-time information.

Section 2 reports on the work undertaken in Task 3.2 to develop a definitive and structured list of yard functions that will be required in the simulation model to represent the key elements of the OptiYard eco system, and discusses the processes and behaviour in the real-time operations and management of yards and surrounding networks.

Section 3 then reports on the work undertaken in Task 3.3 to specify the technical aspects in the selected simulation and optimisation environment VILLON, for the implementation of the required functions and structural composition specified in Task 3.2. The simulation environment will be sufficiently flexible to adopt future technology developments and computationally efficient enough to facilitate real-time decision-making.

Section 4 then reports the work undertaken in Task 3.4. Following on from the previous functional and technical specifications, this sets out a range of key requirements and characteristics for real-time data management and information exchange to enable successful real-time communications between the yard simulation environment and the surrounding network, in order to support semi or fully automated operation processes in rail freight yards and networks.

Table of contents

List of figures

Abbreviations and acronyms

AGV	Automatic Guided Vehicle
PCS	Path Coordination System (RNE tool) or Port Community System
RMG	Rail Mounted Gantry cranes
RNE	RailNetEurope
SWL	Single Wagonload
TAF	Telematics Applications for Freight
TIS	Train Information System (RNE tool)
TSI	Technical Specification for Interoperability

1. Scope and Purpose

To meet the ambitious objectives of the S2R and Horizon 2020 research programmes and address the challenges raised in S2R-OC-IP5-01- 2017 (Real-time yard and network management), OptiYard proposes to design a simulation and optimisation tool based on the real-time information exchange between railway yards and the relevant network. It will provide decision support for real-time operation and management in railway yards and networks, to improve the capacity, punctuality and reliability of both single wagon load and blocktrain freight transport.

In detail, OptiYard will define an improved information and communication process, simulate intelligent real-time yard operations, provide automated optimisation algorithms for yard management, and use a technical demonstrator in the form of a fully functional software module to show the capability of intelligent real-time simulation for the co-ordination of decision-making within the yard. OptiYard will also directly support projects S2R-CFM-IP5-02-2015 (Start-up activities for Freight Automation) and S2R-OC-IP5-01-2015 (Freight automation on lines and in yards).

The overall aim of WP3 is to define the simulation model of the real-time operations in yard and the relevant network eco system, in two deliverables. Deliverable 3.1 reviews a variety of existing yard and terminal infrastructures in Europe, assesses the capability and future development of the Villon simulation environment in the integrated yard and network simulation and optimisation in OptiYard, outlines the data exchange requirement in the OptiYard framework, and further defines the suitable simulation environment for real-time yard and network management. Directly built on Deliverable 3.1 and summarising the results from Tasks 3.2, 3.3 and 3.4, Deliverable 3.2 will set up the functional, technical and data management specifications that need to be considered in setting up the simulation/optimisation model and demonstrators in the following WPs. More specifically:

- Task 3.2 will specify the functions required in the simulation model to represent the key elements of the OptiYard eco system, as well as the processes and behaviour in the real-time operations and management of yards and surrounding networks.
- Task 3.3 will specify the technical aspects in the selected simulation and optimisation environment, for the implementation of the required functions and structural composition specified in Task 3.2. The simulation environment should be sufficiently flexible to adopt future technology development and computationally efficient to facilitate real-time decision-making.
- Task 3.4 will be developed based on Task 2.4 to specify the requirements and characteristics of real-time data management and information exchange for communications between the yard simulation environment and the surrounding network, to support the semi and fully automated operation processes in rail freight yards and networks.

2. Functional Specification

The functional specification sets out in detail the functions that the integrated yard and network simulation system must perform. The functional specifications focus on the behaviour, interactions and processes involved in yard operations and in the integrated yard and network management systems. The development of the functions will be based on the full listing and understanding of the

operations in yards and terminals as well as the wagon movements in the railway network given by the outputs of both the initial stages of OptiYard and other European projects.

Yards, terminals and surrounding networks are the basic facilities of the OptiYard eco system, and the operations of these components rely on the associated facilities (infrastructure, asset and personnel) and technologies used. Wagons and trains are the basic units moving/handled in these facilities. Therefore, the OptiYard simulation should include functions to represent these facilities and basic units, as well as the characteristics required of them for the activities and processes of yards, terminals and networks. This composes Section 2.1, the first half of the functional specification, on the information and characteristics of facilities, wagons and trains.

On the other hand, the activities and behaviours in yards, terminals and surrounding networks should be clearly specified, both covering the basic operations in these facilities and also presenting flexibility for the extension of the model in the future. The integrated modelling framework should include simulation modules, which reflect the current systems, and optimisation modules, which make decisions automatically or provide decision support to the managers. This leads to Section 2.2, the second half of the functional specification, on the process and behaviour of yards, terminals and surrounding networks.

2.1. Functional specification of facilities, wagons and trains

Section 2.1 specifies the required data relating to facilities (yards, terminals and surrounding networks), wagons and trains in the OptiYard simulation and optimisation environment.

2.1.1. Yard facilities

The yard facility data should include:

- Type of the yard: hump yard, flat yard, gravity yard
- Infrastructure layout of yard
  - Receiving yard, classification bowl and departure yard: tracks and switches
  - Hump
  - Maintenance track, repair track, etc.
  - Sorting bowl and the associated hump for the secondary shorting/marshalling (if provided)
- Characteristics of tracks
  - Running direction
  - Speed limit
  - Gradient
  - Curvature
  - Signal
  - Electrification
- Classification bowl: deceleration technology
- Asset: shunting and line locomotives
  - ID
  - Weight
  - Length
  - Number of axles
  - Electric or diesel traction

  - Traction and braking characteristics
  - Signalling system compatibility (required for line locomotives)
- Personnel
  - ID
  - Qualification, i.e. type of work that each staff can do, including: yard operations, dispatching/disposition processes, inspection of incoming/outgoing trains, brake test and related preparation work, shunting engine driving, incoming/outgoing freight train driving, etc.

2.1.2. Intermodal terminal facilities

Data relating to intermodal terminal facilities should include:

- Infrastructure layout of terminals
  - transhipment tracks
  - non-transhipment tracks
  - switches
- Characteristics of tracks
  - Running direction
  - Speed limit
  - Gradient
  - Curvature
  - Signal
  - Maximum permissible weight per axle and per metre
  - Electrification
- Equipment
  - Type: ship-to-shore cranes, portal cranes, straddle carriers, reach stackers, etc.
  - ID
  - For cranes: location and tracks they serve
  - Capabilities of each piece of equipment used
- Cost per unit of weight for loading/unloading of goods
  - Monetary cost
  - Energy cost
  - Environmental cost

2.1.3. Surrounding network infrastructures

The infrastructure data in the surrounding rail network should include:

- Infrastructure layout: tracks, junctions, switches, stations, tunnels, etc.
- Railway signalling system and the regulation rules:
  - Multi-aspect signalling (arrangement of blocks, number of aspects, and the associated temporary speed limits)
  - ETCS (implementation level, arrangement of blocks if fixed-block, and location of balises)
- Characteristics of tracks
  - Running direction

  - Speed limit
  - Gradient
  - Curvature
  - Maximal weight per axel and per unit of train length
  - Restriction on the type of good transmitted
  - Profiles of static and temporary speed limits
  - Electrification

2.1.4. Wagons and wagon groups

The wagon data should include:

- Wagon ID
- Owner
- Length
- Weight
- Net weight of cargo
- Number of axles
- Maximum speed
- Braking characteristic
- Wagon content
- Trip plan
  - Origin terminal, intermediate yard(s), and destination terminal
  - Scheduled arrival and departure times at terminals and yards
  - Train ID and the ordering of wagon on the train when transhipped between yards
- Preferred arrival time at the destination terminal and the penalty for late arrival

2.1.5. Freight and passenger trains

The common data for freight and passenger trains should include:

- Train ID
- Type and priority
- Maximum speed
- Traction and braking characteristics
- Running resistance characteristics
- Train control system on board: fixed-block, ETCS (and level), etc.
- Train route and schedule
- Train driver ID

The extra data of freight trains should include:

- Composition: block train or single wagon load
- For SWL trains, Wagon ID and ordering
- Wagon content
- Status: incoming, waiting to be decoupled, waiting to be coupled, ready-to-depart
- ETA time at the yard or ETD time from the yard

2.2. Functional specifications of activities and real-time management

2.2.1. Yard activities and real-time management

Railway yards manage a multitude of complex and time-critical operations. The main tasks include: the reception of arrival trains, shunting and marshalling, dispatch of departing trains, management of locomotives and personnel, and so on (Figure 1). The function specification for yards includes three parts: the basic information of the yard activities, the yard simulation model and the yard management activities. The yard activity information specifies the basic characteristics of different activities conducted in yards, the yard simulation model simulates the activities and processes in yards, and the yard management model manages the progress of activities and processes.

The information of yard activities includes

- Working hours of the yard
- Required quantity and time (mean and standard deviation) of personnel and asset for each operation
- Way of secondary sorting/marshalling: e.g. pulling back over hump and roll over again, or flat shunting (i.e. using shunting engine)
- Method used for formation of multigroup trains:
  - Consecutive forming of multigroup trains: single-stage sorting method, Futhner's method, general method, special method, unified group method, Japanese method,
  - Simultaneous formation of multigroup trains: elementary method, triangular method, geometrical method

The yard simulation model should

- Simulate the train and wagon processing in the yard
  - For block/transit trains, the process includes
    - Arrival: reception of the arrival train to the arrival track
    - Decoupling and changing locomotive (if needed)
    - Commercial and technical inspection
    - Brake test and other preparation
    - Train departure
  - For SWL trains, the process includes
    - Arrival: receiving the arrival train to the arrival track(s), decoupling and moving the locomotive to the loco tracks, commercial and technical inspection, decoupling the wagons
    - Sorting/marshalling: moving shunting loco to the arrival yard, push wagons over the hump
    - Secondary sorting/marshalling (if required): pulling the wagons over the secondary shunting hump or via the shunting locomotive
    - Shunting: move wagons to the classification bowl track or the departure track, coupling, inspection, brake test and other preparation
    - Departure: add line locomotive, brake tests, departure
    - Other activities such as documents exchange and train identification
- Simulate the randomness in the processing time of the above-mentioned activities
- Be able to estimate the ETD of a train from the yard

The yard management and optimisation model should manage the processes and activities in:

- Arrival: determining the time and track(s) in the arrival yard to accept the arrival train
- Sorting/marshalling: scheduling the sorting/marshalling procedure, including
  - Track(s) allocation for assembly of wagons for each outgoing train
  - Enquiring the network model about the restrictions of network infrastructure which may affect the composition of the outgoing trains
  - Assigning wagons to outgoing trains
  - Ordering wagons in the outgoing trains
  - Ordering and time of propelling each wagon over the hump
  - Schedules and routes of the yard locomotives on the yard tracks
- Secondary sorting/marshalling: scheduling secondary sorting/marshalling procedures
- Shunting: schedule the shunting procedure, including
  - Assign track in classification bowl or departure yard to the outgoing train
  - Determine the sequence and time to pull locomotive, each wagon and each wagon groups to form the train
  - Schedule and route the yard locomotives on the yard tracks
- Departure
  - Coordinating with network/terminal management model to determine the departure time from the yard
  - Assign line locomotive to the train
  - Preparation and checking activities prior to departure
- Schedule personnel and asset in all above-mentioned processes and activities

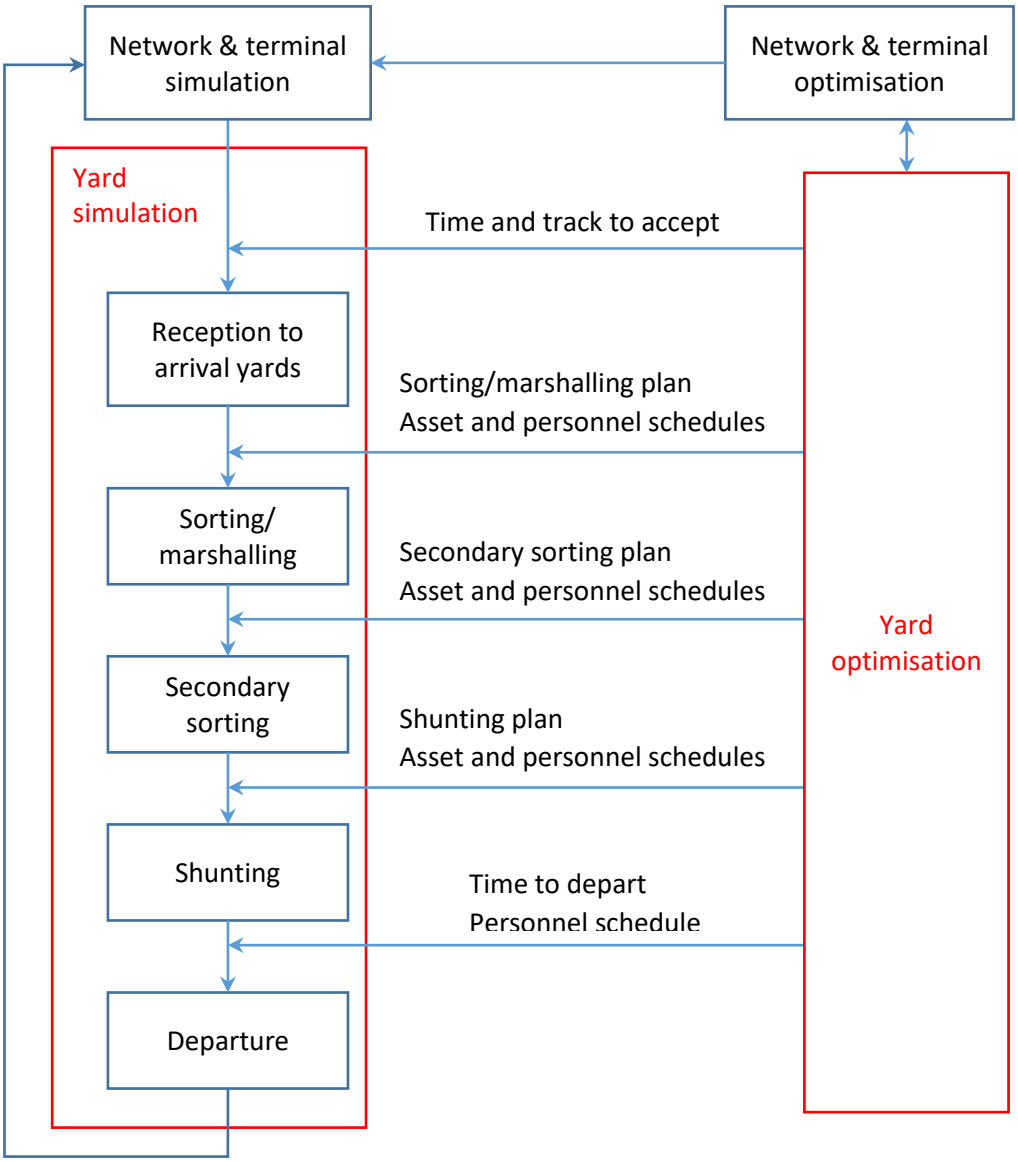

Figure 1: Yard processes

2.2.2. Terminal activities and real-time management

Railway terminals provide the interface of interaction between railways and other freight transport modes such as maritime and road. The main activities of such terminals are the loading and unloading of wagons. The functions for yard activities and management also include three parts, namely, basic information, simulation and management.

The information of yard activities includes

- Working hours of the terminal
- Required quantity and time (mean and standard deviation) of each piece of equipment for wagon loading and unloading

The terminal simulation model should

- Simulate the process of moving loads from other modes to trains
- Simulate the process of moving loads from trains to other modes
- Simulate the movement of empty trains in the terminal network, which move to and from the terminal for loading wagons
- Simulate the movement of loaded trains in the terminal network, which move from terminals to the yard/network
- Simulate the random fluctuations in
  - Availability and arrival of vehicles of other modes
  - Processing time of wagon loading/unloading
- Estimate the ETD of the train from the terminal.

2.2.3. Network activities and real-time management

The network simulation model should be able to

- Simulate the movement of passenger and freight trains in the network, according to the schedule
- Plan the speed profile for each train according to the schedule
- Estimate the ETA time at yards
- Provide the train location, speed and ETA to yards on request
- Simulate the random delays occurring when trains are running on the line and/or dwelling at stations

The network management and optimisation model should be able to

- Decide the train priority when two or more trains request to access the same resource at the same time
- Conduct ad-hoc rescheduling and rerouting triggered
  - on request
  - by delay
  - at fixed time moments
  - when a path request is sent by the yard
  - when a train is ready to depart
- Determine the path for a waiting-to-depart freight train and the associated schedule in response to the path request considering the associated train and track characteristics

3. Technical Specification

The technical specification deals with requirements on the simulation framework to implement the functions specified in Activity 3.2.

The simulation tool Villon (Simcon, 2012), provided by Simcon, is selected as the core of the simulation framework. Villon is a generic simulation model, which allows microscopic modelling of various types of transportation logistic terminals containing railway and road infrastructures (e.g. marshalling yards, railway passenger stations, factories, train care centres, depots, airports, etc.). The simulation tool Villon is based on flexible agent-oriented simulation architecture ABAsim (detailed description of its properties can be found in (Kavička et al. 2007)), which enables trouble-free extension of its functionality as well as cooperation with other software modules (e.g. railway network module or optimization module).

In Villon, the modelled system (e.g. railway yard or container terminal) is considered as a service (queueing) system, composed of three subsystems, each with a specific role in the system: resource subsystem, customer subsystem and control subsystem.

- **Resource subsystem** includes *Stable (fixed) resources* (set of tracks, signalling system, interlocking system) and *Mobile resources* (shunting or train locomotives and personnel). These resources are utilized during the service of systems' customers.
- **Customer subsystem** represents in the model the trains or parts of trains, which have to be served (e.g. technical inspection, shunting of a set of wagons, etc.). The arrival of customers into the terminal is modelled by the input generator.
- **Control subsystem** consists of elements that model decision making activities and handling activities related to execution of defined service of each customer in the terminal. Technological procedures of serving customers are defined by user-definable flowcharts. This enables the tool to model railway yards with varying operational procedures and thus guarantees the ability to cover the needs of OptiYard in this respect.

In order to model all functions as defined by functional specification, data defining the entities and operations of all subsystems have to be properly defined. Required data are listed in functional specification part of this document. The following text describes the method of data definition and formats used in the respective subsystems of the simulation framework.

3.1. Resource subsystem

3.1.1. Infrastructure

The infrastructure model of a railway yard or container terminal combines geometry data about the infrastructure (physical layer) and the role assignment for each infrastructure element (logical layer).

The geometry of track layout in Villon is accurate and respects all important physical properties (such as shape, length, diameter or slope) of infrastructure elements. The infrastructure model is drawn to a scale (not schematic). In order to prepare the physical infrastructure model of railway yard or container terminal, the following data are required:

- Track – polyline (set of segments with different length and radius) bounded by switches or adjoining tracks. Two geometric types of segments in track polyline are used:
  - Lines
  - Arcs

  Further properties of tracks segment are required:

  - Slope
  - Speed limit (more speed profiles per segment are possible)
  - Other equipment on segment
  - Electrification
  - Type of communication between train and interlocking system (via track loop, radio)

  For tracks which belong to the same group in interlocking system, the same ID of isolated circuit has to be set. If one of these tracks is occupied by a railway vehicle, the interlocking system model then automatically occupies all tracks in this group.

- Switch – set of 2 or 4 segments (line or arc) connected in one common point. Depending on the switch type, 2 or 4 segments are used (Fig 1):
  - Single switch – 2 segments
  - Double slip switch, Single switch or Crossing – 4 segments. For this kind of switch drive-through possibilities have to be defined.

Figure 2: Switch types

- Signal – limits the useful length of tracks, indicate aspects and type of interlocking system. The following signal types can be placed to a track (position and assignment to tracks is defined):
  - Earnest signal
  - 2-aspect signal
  - 3-aspect signal
  - 4-aspect signal
  - Balise
  - Marker (ETCS L2)
  - Shunting signal
  - Limit

The initial aspect on some signal types must also be set, e.g. Stop or Go on 3-aspect signal. Depending on placement of the signal (on main line, in a station) the role of the signal is also required (home, exit, block, cover).

- Building – this geometry is usually used as an addition to the track infrastructure model to support better understanding and orientation in modelled environment. In case of service personnel, a building can define a position where the personnel are stationed. The duration of personnel movement from this starting point to served customer can be calculated. The geometry of building is represented with a closed polyline.

The railway infrastructure layout can be prepared in two ways:

- Drawing in infrastructure editor, integrated in simulation software Villon
- Importing from an external source (Figure 3). AutoCAD standard data exchange format DXF is supported for direct import. Import from other sources (MicroStation, railML) is possible after transformation.

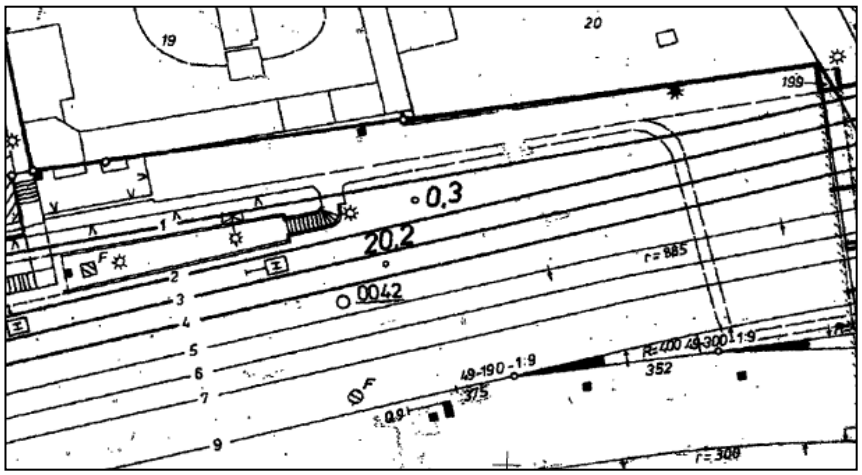

Figure 3: Example of railway infrastructure layout

After the creation of the physical infrastructure model all tracks are considered to be equal in their purpose – a railway vehicle can move on them under specified conditions. To distinguish various different purposes of tracks in a yard (e.g. sorting sidings, reception tracks, departure tracks, etc.), the tracks have to be assigned to track groups (Figure 4). This assignment defines the so-called logical infrastructure layer. These groups with predefined (or user defined) functions are then used for various activities in simulation, e.g. when a train arrives, one of tracks from group “Reception tracks” is requested and assigned to the train for arrival.

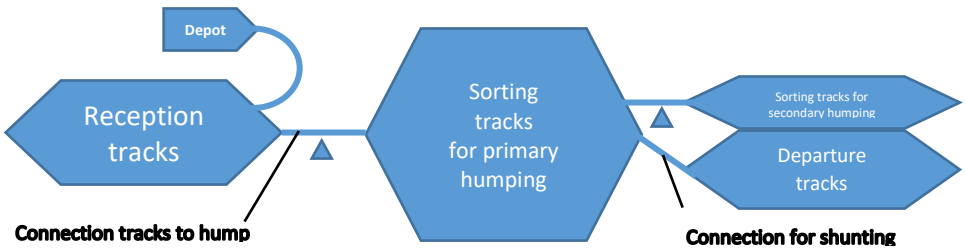

Figure 4: Track role assignment

The number and kind of track groups/roles needed in a railway yard or container terminal depends on trackage configuration and type of operation.

3.1.2. Locomotives/engines

In a simulation model of railway yard or container terminal, primarily the work of shunting locomotives is observed. The shunting locomotives are considered as mobile resources of the modelled service system. Their main role is to transfer sets of wagons between track groups in the yard.

Usually, the following types of locomotives (distinguished by role in railway yard or container terminal) are used:

- Hump engine/locomotive – responsible for sorting of incoming trains over the hump
- Formation engine/locomotive – responsible for formation of new outgoing trains in classification yard
- Pushing engine/locomotive – responsible for wagon compression on sorting track after humping or before train formation
- Shunting engine/locomotive – executing shunting operations as required in the yard as a whole.

The ability or specialization of shunting locomotives to execute some tasks in a yard or container terminal is defined by assignment to specific groups of locomotives.

For proper modelling of shunting locomotives following input data are required:

- Number of locomotives of each specific type
- Type of engine, to know physical properties (selected from engine catalogue)
- Work area (e.g. reception sidings, or just departure sidings, or the whole yard)
- Availability schedule (e.g. resource available between 9 am and 4 am)
- Starting/waiting track (e.g. hump or depot track, where the shunting locomotive waits for next assignment)
- Resource management settings (e.g. after work always return back to starting position; the way, how to return to waiting/depot tracks…)
- Gap on waiting track (by parking)

In the case of train locomotives, the situation is different, because these locomotives do not belong to the resources of railway yard or container terminal. The train locomotives are resources of the railway network, which has to properly manage them over whole railway network. From the point of view of the yard or container terminal, the train locomotive is considered as a customer that is to be served (uncoupling, coupling, transfer to/from locomotive shed or directly to another train).

3.1.3. Personnel

In the simulation tool Villon the personnel resources of a railway yard or container terminal are understood as mobile resources – resources belonging to the yard which are changing their location

in time. The main focus is put on employees servicing the trains and shunting units outside in the trackage, e.g. the action is clearly bound to a certain train or shunting unit standing on a track. The personnel is specialized in different professions (similar to other resource types, the profession is defined by assignment to groups) – each profession represents ability of a resource to execute a defined task. Typical modelled railway employees in a yard or container terminal are:

- Engine driver as a resource needed for the train/shunting movement
- Technical inspector (technical inspection, brake test)
- Data collector (to collect missing data directly from wagons)
- Shunter (person engaged outside with shunting/switching operations, coupling/uncoupling of engines)
- Coupler (wagon coupling in classification yard)
- Uncoupler (wagon uncoupling during sorting on the hump)
- Other personnel servicing trains in the trackage (custom service)

For each modelled employee type in trackage following data are required:

- Number of employees of each specific profession
- Work area (e.g. reception sidings, departure sidings)
- Availability schedule (e.g. resource available between 6 pm and 4 am)
- Starting position for work (shelter or building, where the employee waits for next assignment)
- Resource management settings (e.g. after work always return to starting position).

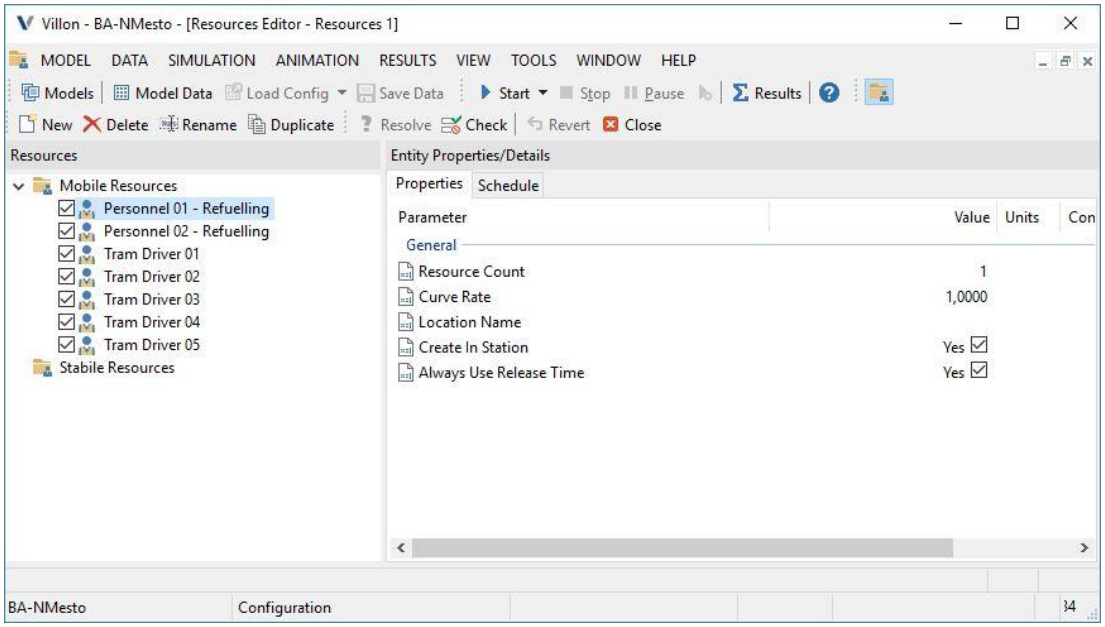

Figure 5: Definition of personnel resources

3.2. Customer subsystem

Elements (objects) to be served are represented in the model by trains or by parts of trains. The service they are subject to is for example technical inspection, shunting of a set of wagons, etc.

The arrival of customers into the terminal is modelled by the input generator, which allows modification of parameters corresponding to the time schedule and to the train composition. The documents needed for acquisition of these data are the timetable for freight trains and wagon lists of arriving trains. The data can be statistically processed and probability distribution tables can be created for each relevant train characteristic. Another way of modelling the input flow is to precisely reflect the real situation by means of exact definition of every train composition and parameters (arrival time, train groups, type, etc.).

3.2.1. Vehicle catalogue

To model properly the railway vehicle, technical data about engines and wagons must be entered. Based on this data the wagon list for each train will be prepared (train formation list).

- Engine parameters (for train and shunting)
  - Engine Length: 20 Meters
  - Engine Weight: 40 Tonnes
  - Axle count
  - Tractive effort diagram (for calculating the dynamic movement)
  - Resistance coefficients
  - etc.

- Wagon parameters
  - Wagon Length
  - Wagon Weight
  - Axle count
  - UIC wagon type code - 5th to 8th position in wagon number (31 80 0691 235-2 => 0691)
  - Allowed freight weight
  - Maximal speed
  - Storage type (universal, for container, for palettes)
  - etc.

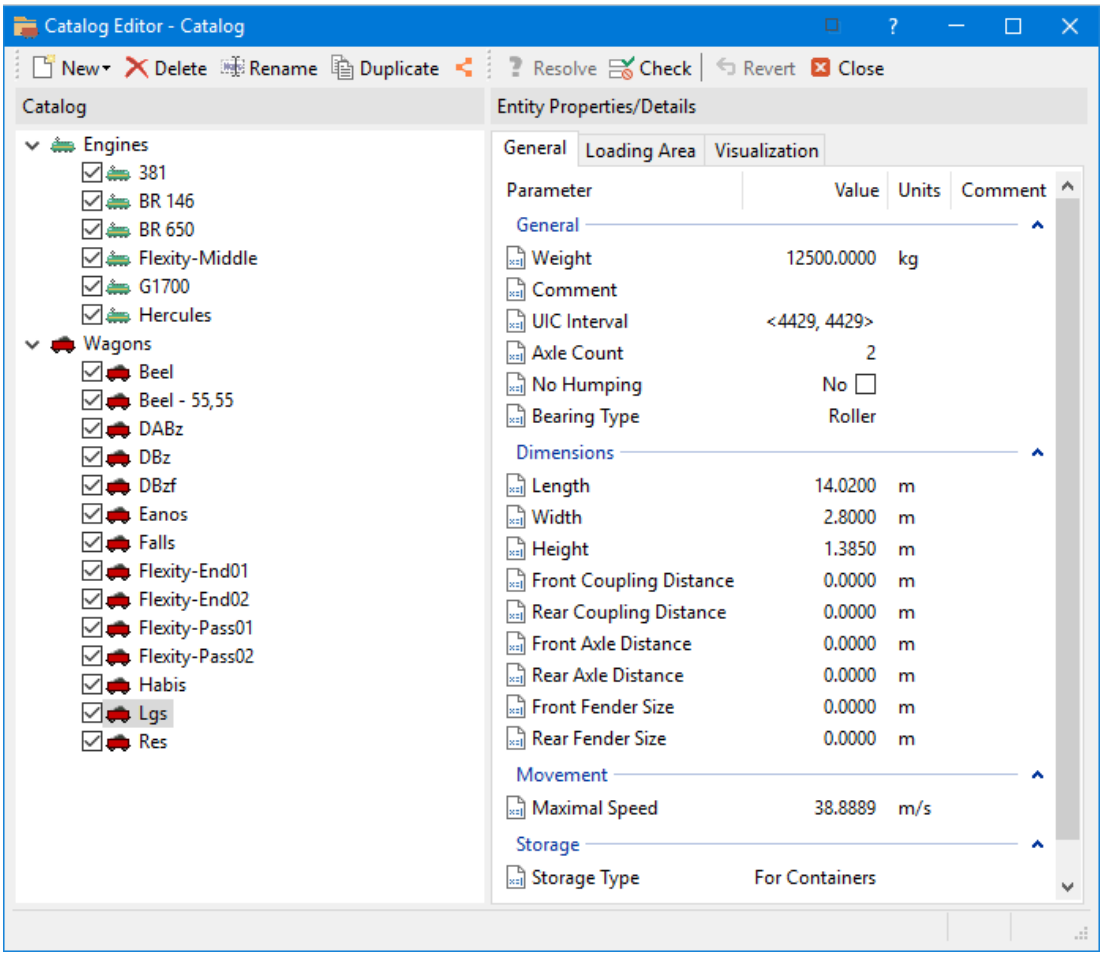

Figure 6: Vehicle catalogue

3.2.2. Train and shunting formation

Based on available data from the investigated railway yard or container terminal (export, statistic evaluation) the wagon list for each train will be prepared (train formation list). The train formation can be fixed or randomly generated.

For fixed train formation following data has to be entered:

- Type of railway vehicle from wagon catalogue
  - Locomotive
  - Wagon
- Destination of wagon
- Name of vehicle (UIC name or wagon number can be used)
- No humping (set by default based on wagon type, but also be modified depending on dangerous or fragile freight)
- Freight

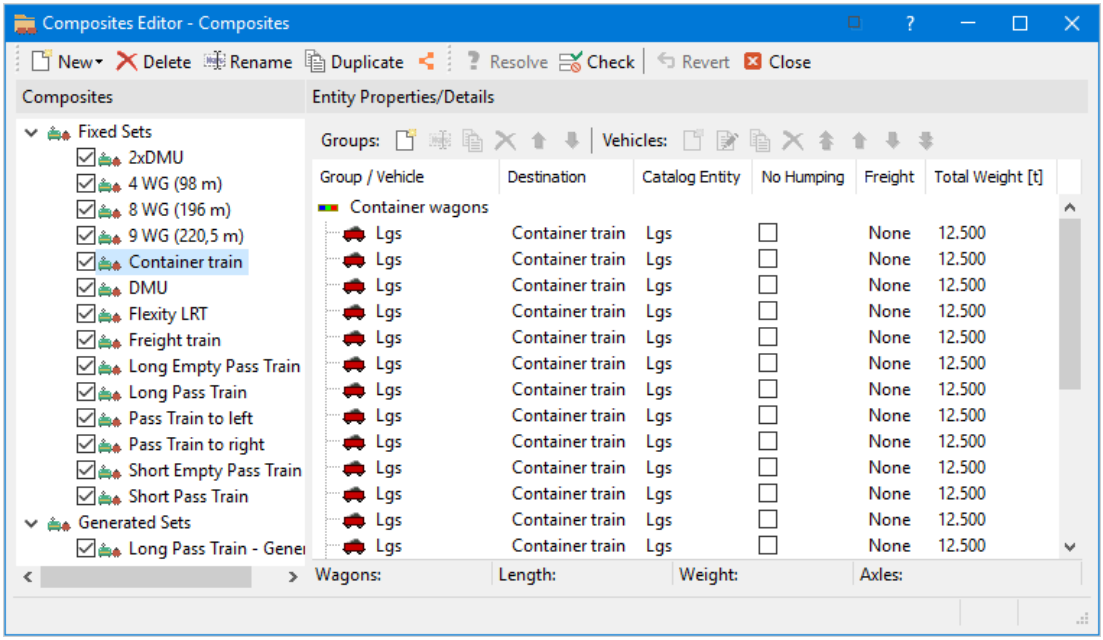

Figure 7: Container train formation (list of wagons)

In case of generated train composition the frequency for all data or value interval are required.

3.2.3. Inbound trains

Input flow represents all incoming trains into the marshalling yard or container terminal. Two basic types of incoming trains have to be considered: incoming train with sorting and transit trains (part of train will be uncoupled and sorted, rest of the train leaves the marshalling yard).

For each incoming train following data are necessary:

- Train number
- Operating days
- Planned entry time
- Average delay and random distribution
- Train engine
- Train formation (list of wagons)
- Entry track on the main line
- Output track on the main line (for transit train only)
- Handling technology – defines how to serve the train
- Average deceleration rate (for calculating the dynamic movement)
- Interlocking equipment (ability to read loop, ETCS L2)
- etc.

Train	Train type	Operating day	Input track	Output track	Entry time	Data about delays	Engine type	Handling technol.	Avg. dec. rate	Formation (reference to train composition)	Train resistance	Interlocking Eqp.
65754	Reg.	Mo	InTr01	-	19:54	Avg. 35 Min; exp.	1016	InTrain01	0,3	Form. 65754 on Monday	T	ETCS

Table 1: Example of incoming train with sorting

3.2.4. Outbound trains

All outgoing trains from the marshalling yard are usually created in classification sidings. For the marshalling yard the list of outgoing trains represents the available time slots on the railway network for specific direction, i.e. when the trains, for example to Prague, can leave the marshalling yard. There are two types of outgoing trains: regular and exceptional (on demand). Regular trains operate usually according to a regular schedule, exceptional trains only operate if too many wagons have arrived for given relation (direction), i.e. when regular trains have insufficient capacity for all sorted wagons.

For each outgoing train, the following data are necessary:

- Train number
- Train type (regular, exceptional)

- Operating days (Mo-Sa)
- Planned accumulation finish (when the accumulation has to stop to prepare the train for planned departure)
- Planned departure time (time slot on the railway network)
- Train engine for outgoing train (diesel, electric engine)
- Relation – set of destinations that the train will collect wagons for (to Prague, Vienna)
- Maximal train length/weight (limit of railway network)
- Minimal train length/weight/wagon count/axle count (if the minimal value is not reached, the train will be cancelled)
- Output track on the main line
- Handling technology – defines how to serve the train
- Average deceleration rate (for calculating the dynamic movement)
- Humped trains (list of incoming trains, which must be sorted before the train can reach its accumulation finish)
- etc.

Train	Input track	Output track	Accumulations finish	Departure time	Engine type	Handling technol.	Avg. dec. rate	Relation	Max Weight (To)	Max. Length (m)	...
54567	-	450	01:20	03:30	1016	OutTrain03	0,3	Prague	1400	580	
61222	-	610	15:20	17:00	2048	OutTrain05	0,2	Vienna	1800	620	

Table 2: Example of two outbound trains

3.3. Control subsystem

The control subsystem defines the operating procedures of the modelled yard or terminal. The main operating procedure inside logistic terminals (similarly as in any other service system) is serving of customers entering the system. Technological procedures of serving customers differ not only between various types of transportation terminals (e.g. marshalling yards vs. container terminals), but also between terminals of the same type (every company has its own operating procedures). In addition, the technological procedure may differ even between customers of the same terminal (e.g. each train in a marshalling yard can have slightly modified handling procedure or some tasks can take longer time, etc.).

The utilized simulation environment has to be able to support modelling of these various types of operating procedures without modifications of software, i.e. on the logical level, it must not hard-code any pre-defined operating (service) procedures – as these have to be easily defined by the model designer during the creation of the model. The chosen simulation tool Villon complies with these requirements, utilizing flexible flowcharts that are composed of activities, representing tasks in operating procedures of modelled systems.

3.3.1. Modelling of activities

Villon contains a set of predefined, so-called template activities, which are prepared by programmers and cover the whole spectrum of functions found in operation of transportation terminals. At present time, there are around 30 template activities. Template activities are not to be used directly, they serve only as a template for creation of derived activities. Template activities define parameters and mandatory resources for each type of derived activity. User can create a practically unlimited amount of derived activities and customize them by modification of their parameters and resources.

Each derived activity contains:

- **Set of resources**, required for the activity to be executed. For example, activity 'Simple movement' defines resources such as Infrastructure type (e.g. electrified tracks) and Engine type (e.g. shunting engine). Besides mandatory resources defined in template activity, user can specify additional resources. Resources are identified using resource groups. Resource groups contain a collection of ordered individual resources. Every resource from the group can be utilized for the execution of the activity. Of course, it is possible to create single resource groups, which enables modelling of specific assignment of resources at an individual level.
- **Set of parameters**, which specify the activity execution in more detail. For example, in activity 'Simple movement' we have to, among other things, define parameters 'Move speed' or 'Priority'. For 'Technical inspection' activity, a completely different set of parameters has to be defined – e.g. 'duration per wheel' or 'duration per car'.

The following is the list of the most important activities available and their parameters.

General activities				
Name	Description	Typical parameters	Resources	Usage
General activity	Activity with fixed duration or depending on amount wagons …; Resources may be required	Fixed duration, Duration per Wagon/Length /Axles /Loaded Wagon /Empty Wagons, Random duration	Personnel, Locomotive, Tractor, Crane, reach-stacker, …	Simple brake test, full brake test, technical inspection, commercial inspection, check-in at the gate. Some disturbances can be taken in account (bad weather, broken part…)
Uncouple trains	To split a train in 2 parts (not sorting a train into the classification yard)	Fixed duration	Personnel, Locomotive	Splitting double EMU/DMU, Uncoupling wagon group with status NO HUMPING
Couple trains	To couple two trains together (not coupling a train in a sorting sidings)	Fixed duration	Personnel, Locomotive,	Coupling two single EMU/DMU, Coupling two wagon groups
Movements				
Name	Description	Typical parameters	Resources	Usage
Railway movement	Train and shunting movements from A to B	Max. speed, Speed limit profile, Route restrictions, dynamic movement	Locomotive, Personnel	Train or shunting movement depending on interlocking system; taking into account dynamic movement (power, slope, weight…),
Road movement	Road vehicle movements from A to B	Max. speed, Speed limit profile, Route restrictions, average acceleration and	Personnel	Movement of road vehicle on line-based infrastructure

		deceleration		
Route setting	Route setting for train/shunting movement in advance – movement doesn't start immediately after route setting	Route restrictions, Fixed time for route settings, Time for route settings per switch, …	Personnel, Railway tracks	Between route setting and the start of train movement other activity has to be executed
Management of infrastructure				
Name	Description	Typical parameters	Resources	Usage
Track assignment	Requesting target track for service (occupation)	Input side, Route restrictions to target track…	Tracks	Assigning reception/platform/stabling track
Road assignment	Requesting target road place for service (occupation)	Input side, Route restrictions to target road place…	Road infrastructure	Assigning parking/loading/unloading/check-in place
Enter model	Entering of vehicles from network into the model	Input speed, Input side	Tracks	Moment, when a vehicle will be put into the model (placed on the infrastructure)
Leave model	Leaving the model on the network			Vehicle will be removed from the model
Management of personnel				
Name	Description	Typical parameters	Resources	Usage
Personnel assignment	Requesting personnel for service	Starting side of work	Personnel	Assigning the coupler, inspector, shunter, driver, cleaner…
Personnel movement	Movement from starting position to served vehicles	Fixed duration, walking speed …	Personnel	Moving the coupler … from starting position to the served train, truck, ship
Personnel release	Release and return of personnel to starting position	Fixed duration, walking speed …	Personnel	Release the coupler, inspector, shunter, driver, cleaner after a work is done.
Management of locomotives				
Name	Description	Typical parameters	Resources	Usage
Locomotive assignment	Requesting locomotive for service	Train side of the assignment, Route restrictions	Locomotive	Assigning the hump/formation locomotive
Locomotive movement	Movement from starting position to served vehicles	Speed, route restrictions	Locomotive	Moving the locomotive from starting position to the served train
Locomotive coupling	Coupling the locomotive	Fixed duration	Locomotive, Personnel	Coupling the locomotive to a train or shunting unit
Locomotive uncoupling	Uncoupling the locomotive	Fixed duration	Locomotive, Personnel	Uncoupling the locomotive from a train or shunting unit
Locomotive release	Release and return of locomotive to starting position	Speed, route restrictions for return	Locomotive	Release the locomotive after a work is done.
Management of Lifting equipment (cranes, reach-stackers, forklifts)				
Name	Description	Typical parameters	Resources	Usage
Lifting equipment assignment	Requesting Lifting equipment for service	Route restrictions	Lifting equipment	Assigning the crane, reach-stacker, forklift
Lifting equipment movement	Movement from starting position to served vehicles	Speed, route restrictions	Lifting equipment	Moving the Lifting equipment from starting position to the served vehicle
Lifting equipment	Release and return of Lifting equipment to	Speed, route restrictions for return	Lifting equipment	Release the Lifting equipment after a work is

release	starting position			done.
Transloading				
Name	Description	Typical parameters	Resources	Usage
Simplified unloading vehicle	Unloading vehicles into a storage area without using lifting equipment	Fixed duration, Duration depending on number of loads		Unloading coal, pallets, containers …
Simplified loading vehicle	Loading vehicles from a storage area without using lifting equipment	Fixed duration, Duration depending on number of loads		Loading coal, pallets, containers …
Unloading vehicle	Unloading vehicles into a storage area with using lifting equipment	Fixed duration, Duration depending on number of loads and parameters of the cranes …	Cranes, forklifts, reach-stackers, front loaders …	Unloading coal, pallets, containers … with cranes, forklifts …
Loading vehicle	Loading vehicles from a storage area using lifting equipment	Fixed duration, Duration depending on number of loads and parameters of the cranes …	Cranes, forklifts, reach-stackers, front loaders …	Loading coal, pallets, containers … with cranes, forklifts …
Special activities				
Name	Description	Typical parameters	Resources	Usage
Preparing for humping	Activity with fixed duration or depending on amount wagons, cuts to prepare the train for sorting – loose the coupling, Resources may be required	Fixed duration, Duration per Wagon/Length /Axles/Loaded Wagon /Empty Wagons /Cuts, Random duration	Personnel	Typical for marshalling yards with sorting over a hump or using flat humping
Humping	Sorting the wagons over a hump or using flat humping.	Avg. hump speed, Avg. cut speed in the switch and in sorting tracks, valid relation assignment to the sorting tracks	Personnel, Locomotive, railway infrastructure	Typical for marshalling yards with sorting over a hump or using flat humping
Coupling cuts in sorting sidings	Activity for coupling the wagons in a sorting track	Fixed duration, Duration per Wagon/Length/Axles/Loaded Wagon/Empty Wagons/Cuts	Personnel, Locomotive	Typical for marshalling yards with sorting over a hump or using flat humping
Regroup operation	Interchange of wagon groups between more trains	Synchronization of trains	Personnel, Locomotive, railway infrastructure	Two fast freight trains have to interchange wagons groups
Queries				
Name	Description	Typical parameters	Resources	Usage
Number of wagons	Requesting how many vehicles are in the train sets			To make a decision how to continue (train set has less than 20 wagons => Answer YES/NO
Is requested track occupied?	Asking before entering into the model to choose proper alternative			Request in advance to prevent deadlocks
…				
System activities				
Name	Description	Typical parameters	Resources	Usage
Client Name Change	Train, shunting unit, road vehicle, ship have to have a unique number/name	New number/name, or incrementing the number		Train number or road vehicle name change for easier identification
Client	Changing the destination	New destination		In MY the sorting of

destination change	of wagons, trucks, container …	station		wagons is based on destination stations
Stay in station	For modelling train stops at railway stations and halts	Minimal stay in station, Taking in account the route setting		Used for modelling movement on railway network – train operation based on timetable
Waiting for …	Waiting	Departure time, specific time		For control the proceeding of handling technology – waiting until…

Table 3: List of important technological activities

3.3.2. Definition of operating procedures

Parameterized derived activities are composed into flowcharts (called technologies), which define succession and mutual dependence of activities in a service process. Each customer in the system (trains/trucks/ships/etc.) gets a technology assigned and executed. The handling technology can be prepared for a group of customers (the execution will however differ according to actual customer and parameters defined) or just a single customer. In order to modify the service of a customer, the user can modify parameters or resources of activities, change mutual dependency of activities (change the flowchart shape) or even exchange the whole technology at once (simply by assigning another technology from the list of defined technologies to the customer).

Figure 8 shows an example of a technology flowchart defined for serving an inbound train in a marshalling yard. Blue rectangles represent activities with defined parameters and resources. Oriented connecting edges represent mutual functional dependencies of activities, the execution flows as defined by these edges. The execution of each activity can last some time. In order to start an activity, all activities that are connected with this given activity with incoming edges, have to be already finished.

The variety of defined handling technologies depends on infrastructure layouts, level of details, scope of the model, etc. Below are some examples that demonstrate the main activities executed for various types of service in different types of yards or terminals.

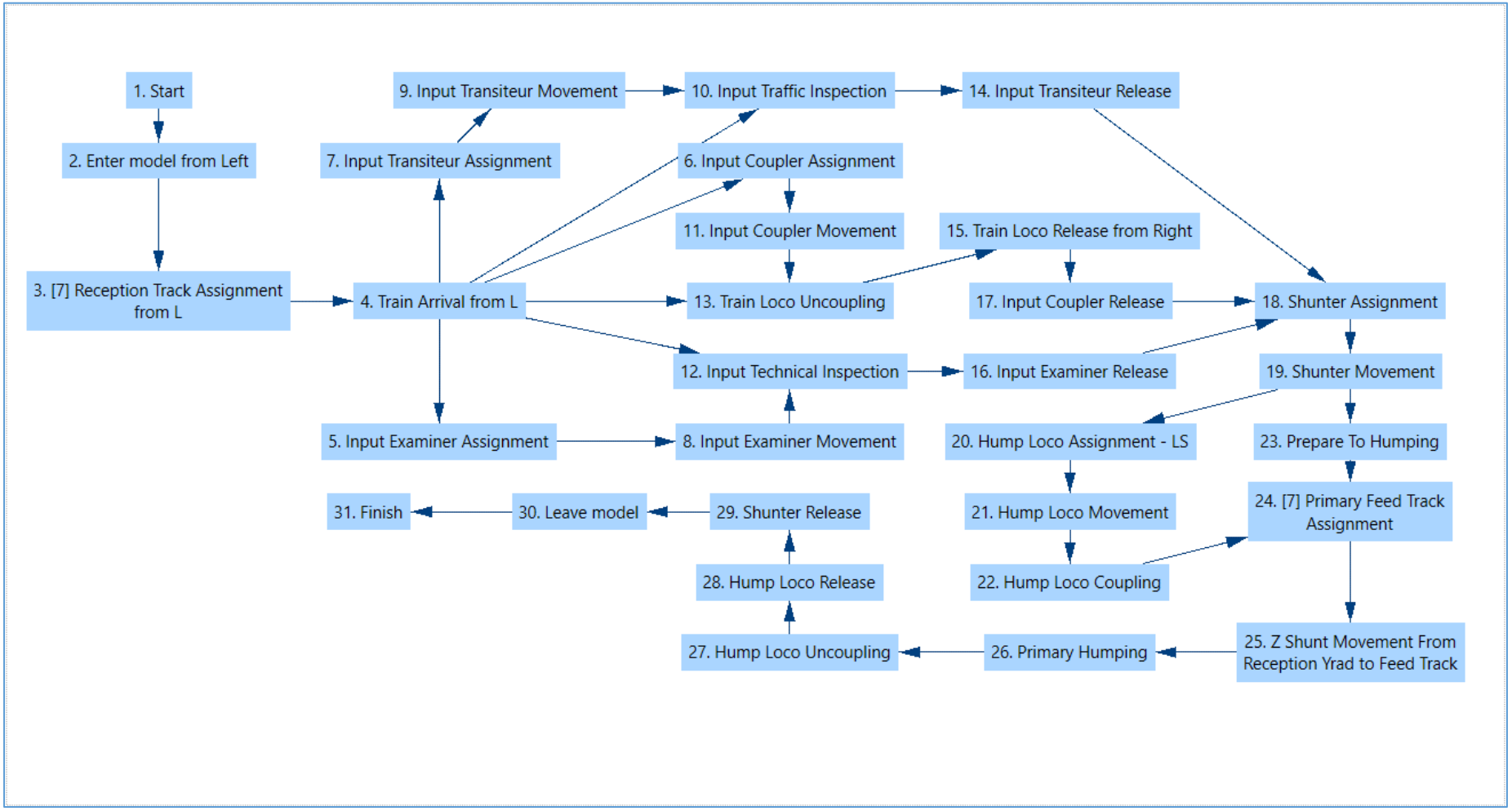

Figure 8: Example technology of incoming train in a marshalling yard with sorting over a hump

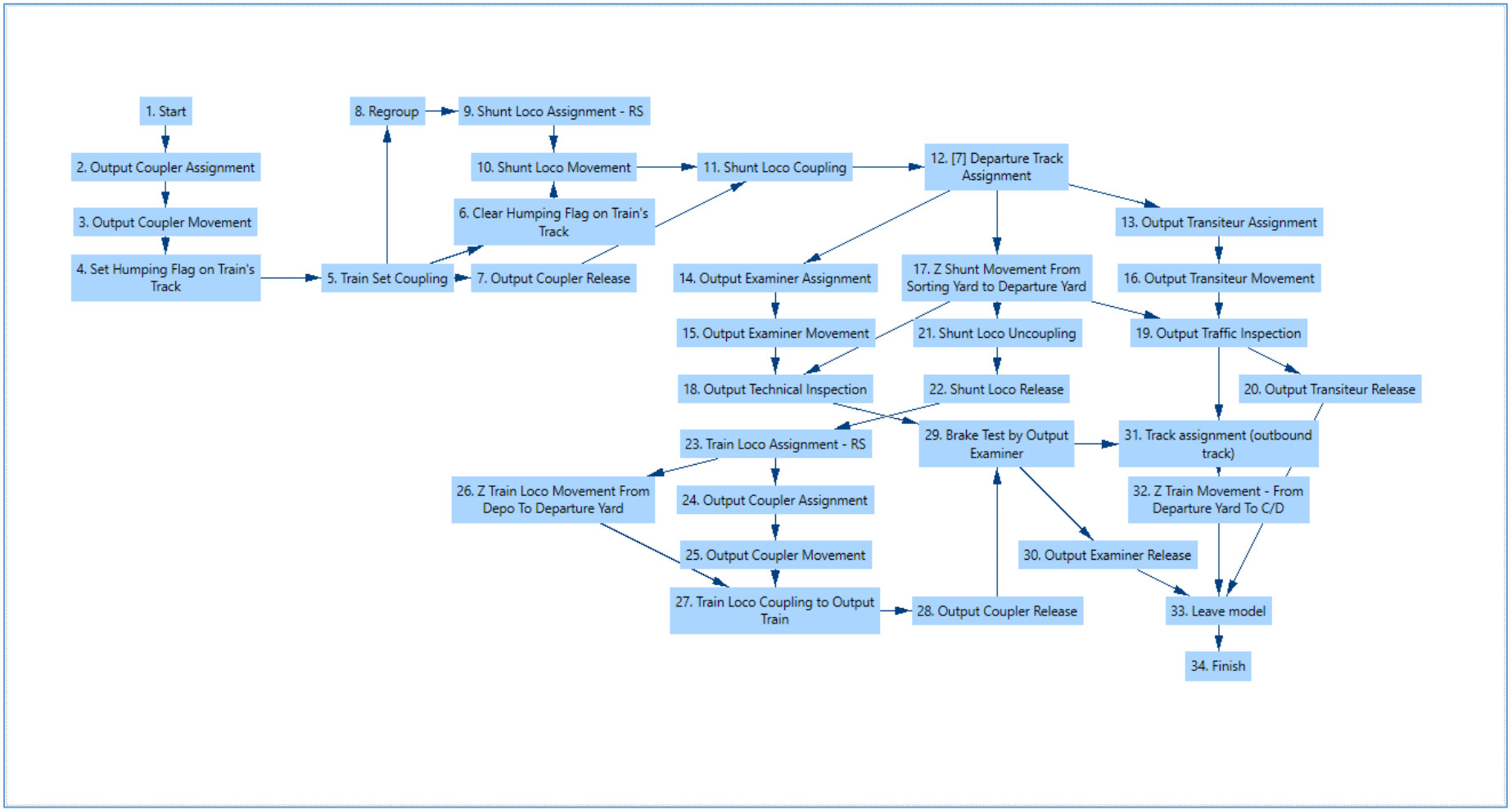

Figure 9: Example technology of outgoing group train in marshalling yard (coupling with other collected wagon groups)

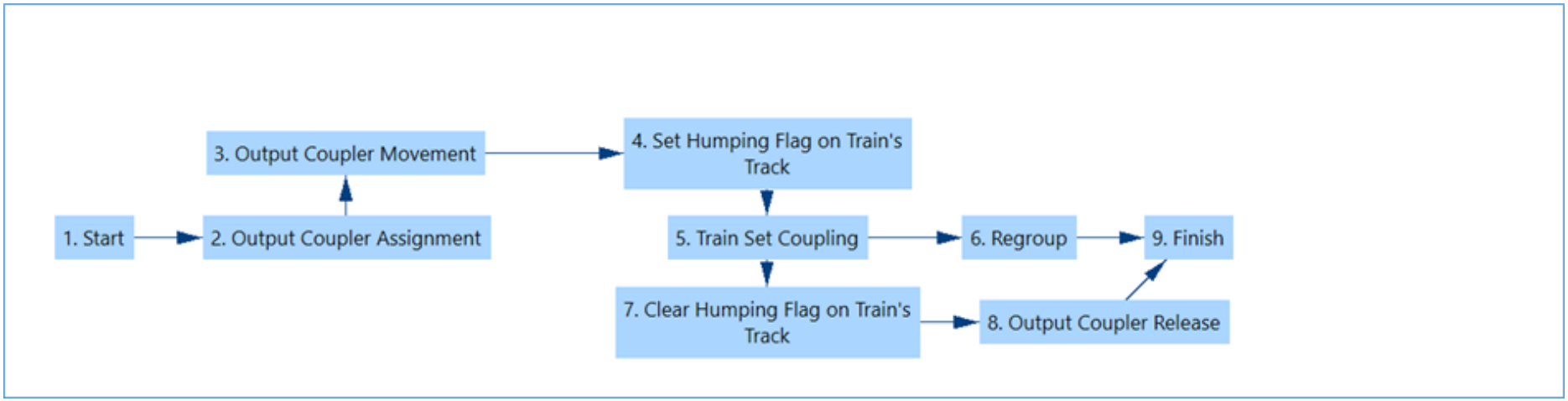

Figure 10: Example technology for coupling of wagon groups for outgoing group train (coupling with main train is needed)

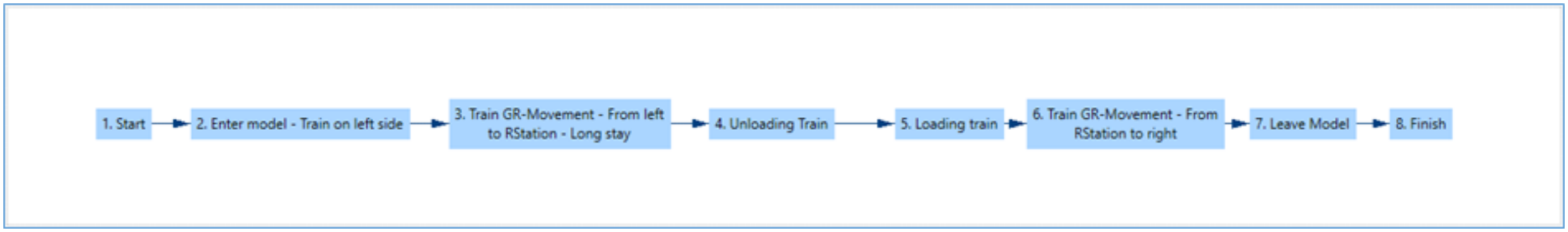

Figure 11: Example technology of train with unloading and loading in terminal

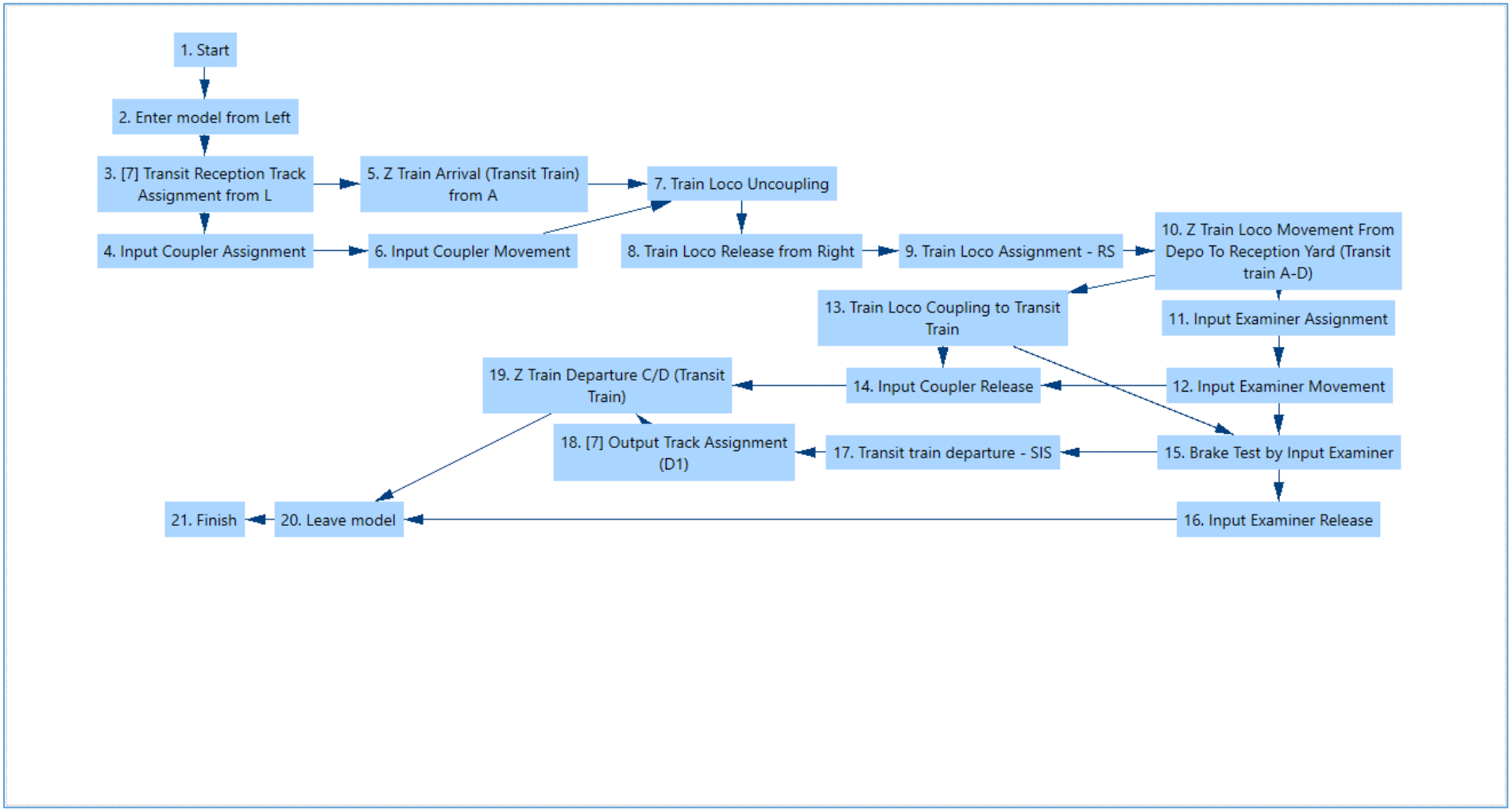

Figure 12: Example technology of transit train with stop in marshalling yard to change the main line locomotive (diesel to electric)

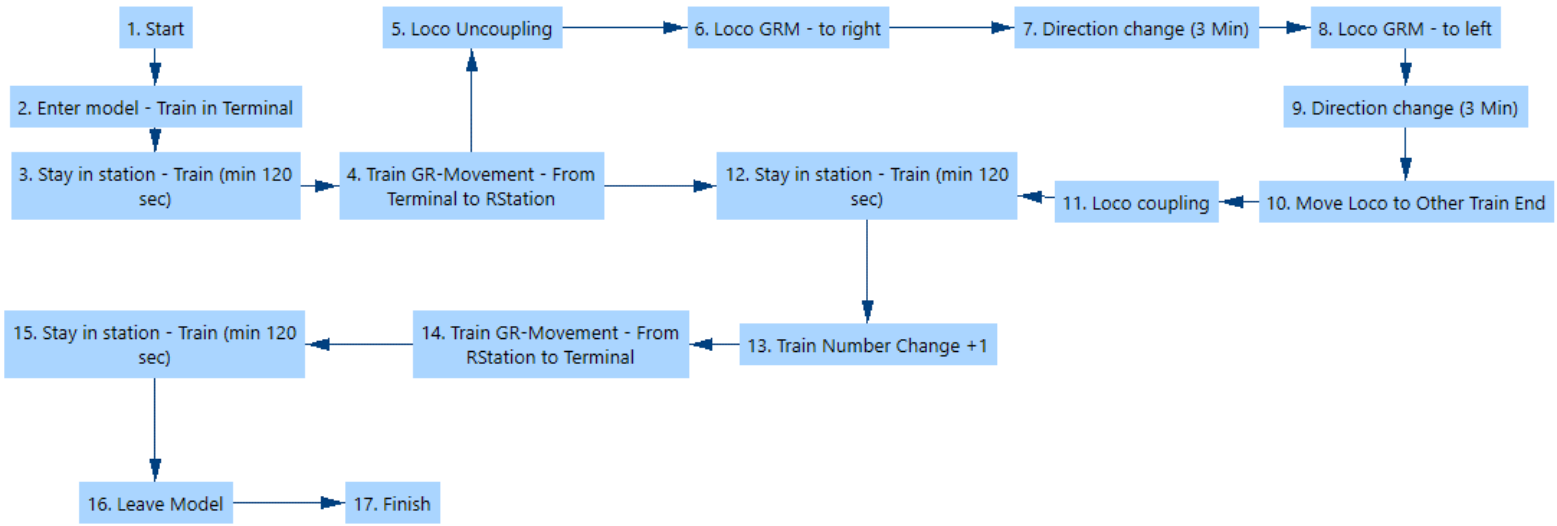

Figure 13: Example technology of transit train with stop in marshalling yard to change movement direction on the main line

3.3.3. Decision making and control algorithms

In order to execute modelled activities, the simulation environment has to employ specific algorithms to model decision-making tasks and execute specific activities found in marshalling yards.

3.3.3.1. Decision making tasks

The simulation environment must support automatic solutions of decision-making tasks (e.g. during resource assignment activity, the simulation executive has to select the resource that will be assigned to the customer) as well as have the ability to cooperate with the optimisation module to query for an optimised solution to the current decision-making task. The details of achieving this are briefly discussed in section 3.8 and will be elaborated in work package 5.

3.3.3.2. Other control algorithms

Besides purely decision-making algorithms, the simulation environment has to contain specific algorithms to execute some non-trivial tasks encountered in such complex service systems as marshalling yards. One of the vital tasks in a marshalling yard is sorting of wagons to sorting sidings. To sort the incoming wagons into outgoing trains in a marshalling yard, each wagon has to have a destination station defined. Further, a sorting table that includes relations must be defined. Relation is a set of destination stations (mostly for the same geographic direction). Relations are assigned to specific sorting tracks, whereas at the same time, one relation can be assigned to only one sorting track. Based on this sorting table, each wagon will be distributed to the respective sorting track, where a new outgoing train is being assembled.

The following points summarize the data required for proper definition of sorting operations in a marshalling yard:

- List of all destination stations, which can be sorted in the marshalling yard (Prague, Prague-South, Berlin, Vienna, etc.)
- List of all collected relations (relation = set of destination stations collected on one sorting track), e.g. relation Prague collects for the following destination stations (Prague, Prague South, etc.)
- Maximal length and weight of outgoing trains for each relation, e.g. relation Prague has length limit 620 Meter and weight limit 1800 Tonnes
- Assignment of relations to sorting tracks – initial assignment and change rules if modifications of the assignment are necessary.

3.4. Simulation run control and abilities

The simulation environment supports standard controls of simulation run execution, i.e. Start, Stop, Pause, furthermore the selection of simulation speed is possible. The presentation of simulation run execution using on-line animation and visualisation is a vital part of the validation and evaluation process of simulation runs. The simulation environment should therefore support detailed presentation of the status of the simulation model and all its components/elements (infrastructure, vehicles, resources, etc.).

Besides an animated output of modelled activities in 2D or 3D presentation (Figure 14), Villon also offers the presentation of the execution status of serving procedures. Users can immediately recognise the current state of the attendance; colour coding makes it possible to distinguish between already executed activities, activities being executed right now and activities which will be executed in the future. By pointing the mouse on the activity, user can see all defined resources, values of all parameters as well as the starting and finishing times and duration of the activity (if the activity has been executed already).

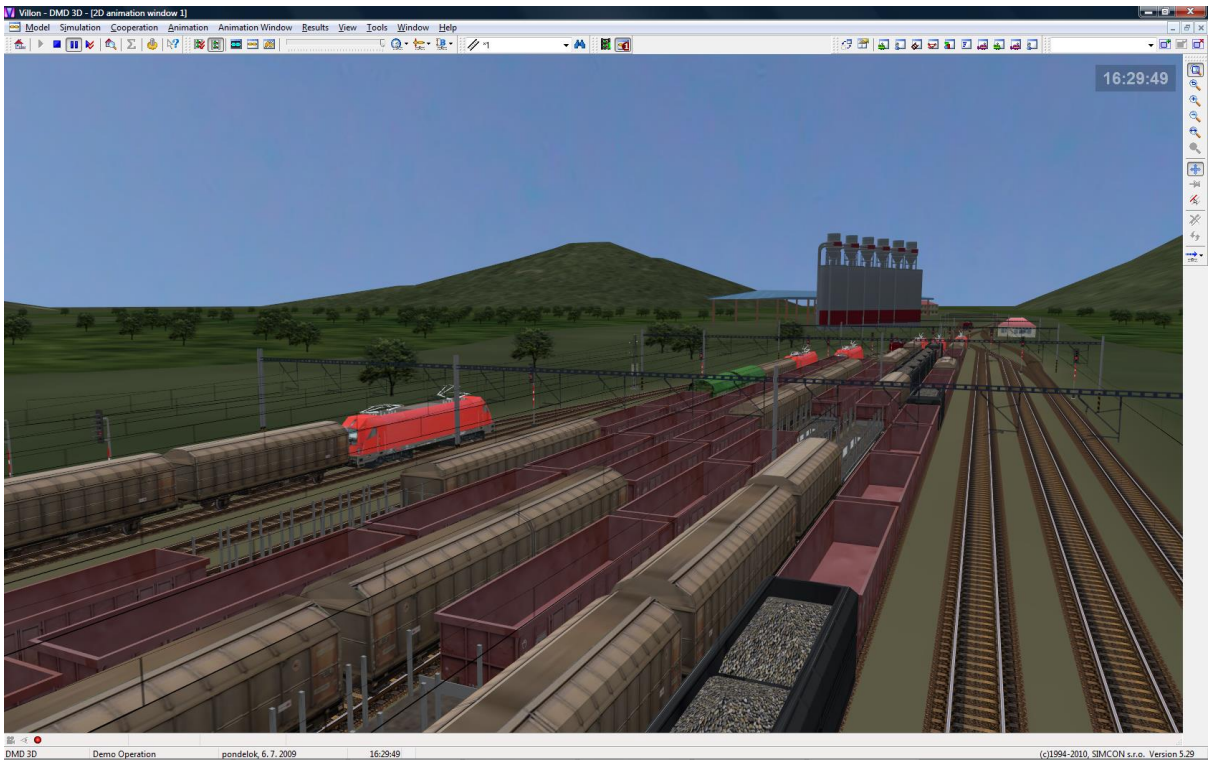

Figure 14: Example of 3D visualisation in Villon

To ease the debugging of the simulation model, the user is able to set a breakpoint flag on any activity. Breakpoint can be set during definition of activities, during definition of operating procedures (technologies) and even during a simulation run. In cases where an activity with a breakpoint flag set is executed, the simulation run is paused and the user is presented with a window showing the status of the technology.

3.5. Evaluation of simulation run

To be able to verify the ability of optimisation to improve the operation of investigated system, the simulation environment has to support various evaluations of conducted simulation experiments. These evaluations should provide users with statistics about utilisation of resources, delays of trains, dwell times, and other selected important key performance indicators (KPI).

Simulation software Villon provides a set of post-run evaluations that make it possible to analyse executed operating procedures. To this purpose, a detailed protocol on simulation is recorded during the simulation run. These protocols are processed after the simulation run and information can be retrieved from them, e.g. statistics in the form of tables, graphs and charts and detailed time-dependent reports on utilization of resources, waiting times, etc.

3.6. Structure and storage of simulation model data

All data about the simulation model, all defined experiments as well as protocols of executed simulation runs are stored in a single folder. This approach guarantees simple portability of models and all related files. The simulation environment supports creation of zipped model archives (utilising standard ZIP compression algorithms that are extractable by the majority of archive software tools).

Besides the main model file (with .MDL extension) that contains general information about the type of the model and references to all data files, the folder contains subfolders belonging to stored simulation protocols (records or simulation run). Each subfolder also contains a local copy of all relevant model files that were used to produce the simulation run. This guarantees future replicability of model runs and their results, even after the original data have been modified.

The internal data structure of Villon can be divided into Model Data, Run Properties and Scenarios (called Configurations).

The internal model data structures in Villon do not strictly reflect the distinction into three main categories – resources, customers and operation. There are multiple data sets in each category, thus providing a flexible approach to the definition and future changes of model data. Villon model data contains around 30 physically distinct types of data that completely describe modelled system infrastructure and operation. Data are organised in a hierarchical manner (Figure 15) based on their mutual dependencies (starting with infrastructure, followed by other resource types, service activities, service procedures and finally customers).

The Run Properties portion of model defines attributes of simulation run – duration, animation settings, simulation protocol options and cooperation (breakpoints, warnings, interrupts, etc.) options.

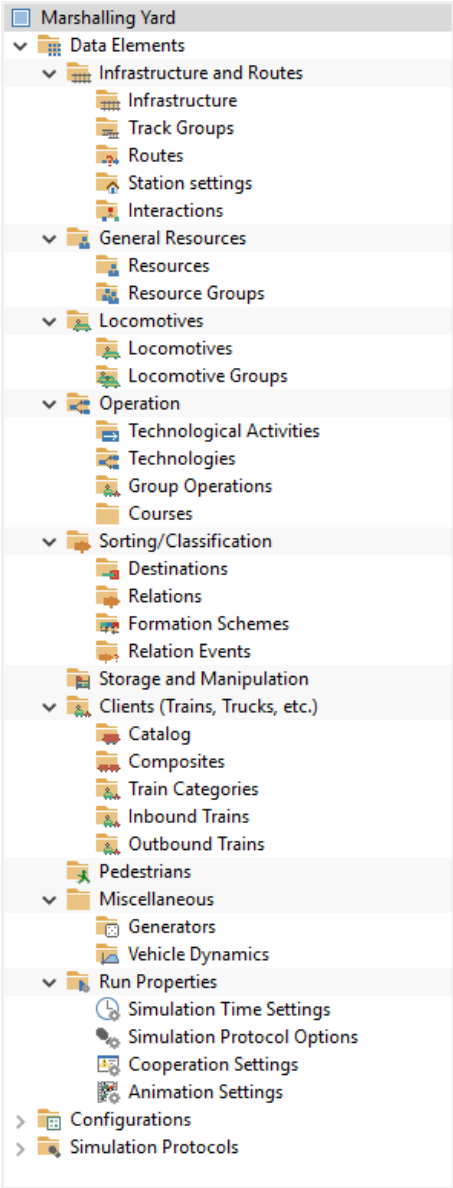

Figure 15: Data organization of simulation environment

The user has the ability to create many variants (represented by distinct data files) of every data type. The simulation scenario is then simply created by selection of a single variant of every data type (e.g. the user selects one variant of infrastructure, one variant of personnel and so on). A scenario created such a way is associated with a specific name and can be stored in the database of scenarios (configurations). This way it is possible to prepare data for multiple different experiments within a single model data set, while sharing many common data files.

3.7. Hardware and software requirements

The simulation framework requires an IBM PC compatible personal computer with the following hardware requirements (or better):

- CPU: Intel i3 or equivalent
- RAM: 8 GB
- Graphics: 2 GB of video memory
- Storage: 200 MB of free space

Software requirements are as follows:

- Operating system: Microsoft Windows 7, 8 or 10, 32-bit or 64-bit

3.8. Enhancement and cooperation with optimisation module

The simulation and optimisation environment comprises two modules, which will play key roles in the decision support process – an optimization module and a simulation module. Within the frame of the project, the simulation environment will be utilised for two distinct purposes.

- **Virtual yard model** will act as a substitute of the real yard, currently not equipped with a real-time information system ("virtual yard/terminal software"), i.e. it will be capable of supplying real-time information via a simulated real-time information system, and of receiving final recommended decisions from the Optimisation module, that have to be applied in the simulations. The transfer of a current state (identified in the simulated yard) from the virtual yard model to the Optimisation module will be ensured.
- **Validation of decisions provided by optimization module.** Each time a decision is to be made in the modelled yard (for example assignment of a reception track for an arriving train), the optimisation module will be queried and asked for a decision (in this case for the track number that has to be assigned for the incoming train). After the simulation run, key performance indicators will be evaluated to validate the decisions and identify improvements made.

Essential upgrades of the Villon environment are necessary to guarantee:

- real-time functionality and
- communication with the Optimisation and Network modules in the OptiYard architecture.

These enhancements will be analysed, designed and implemented at later stages of the project.

4. Specification for Data Management Interface

Real–time data analytics should provide instant responses for yard and traffic managers. Therefore data availability, consistency and compatibility are key components for real time rail freight management. The data management interface defines the functional interface that different applications will use to create, display, retrieve, update and delete data elements. It is also used for administrative and management applications to facilitate accuracy, security access and monitoring of information. In this section, we look at some of the key elements for real-time data management interface between the yard simulation environment and the wider network. Specifically, we make an effort to identify the sources that describe the main requirements and characteristics of the specification for this interface, to ensure compatibility with AIDC technologies and other applications identified as suitable for managing semi and fully automated operation processes in rail freight yards and networks in real time.

It is crucial to consider the sources that build on previous developments to incorporate the aspects of the wider network into the functional and technical specifications developed in previous tasks. Specifically the specification for real-time data management interface needs to be aligned with the strategies developed for real-time yard and network management.

The purposes and objectives of the specification for real-time data management interface between the simulation environment and the wider network need to be clearly defined and introduced. Methodology for setting up the interface between the simulation environment and the network would be of interest to capture and incorporate the needs and characteristics of AIDC technologies, software development and architecture. It is also of interest to understand the potential for designing, installing and maintaining a web-based interface for a real-time management between simulation environment and the network.

Other key elements include:

- Real-time graphing, which is crucial for real-time decision making. It should be based on time series data analytics, and facilitated by flexible tools for implementation in new locations and onward transmission of real-time data between yards in a network.
- Clear specification of metadata sets.
- Production of online reports giving estimates for the productivity of the rail freight system using suitable measurement units, such as MoPs and KPIs, as well as a valuation report based on download statistics which should be available at any time.
- Guaranteed IT security in accordance with ISO 27001:2013. ISO/IEC 27001:2013 specifies the requirements for establishing, implementing, maintaining and continually improving an information security management system within the context of the organisation. It also includes requirements for the assessment and treatment of information security risks tailored to the needs of the organisation. The requirements set out in ISO/IEC 27001:2013 are generic and are intended to be applicable to all organisations, regardless of type, size or nature, hence they are suitable for rail freight yards and networks.
- Guaranteed arrangement for administration and access to any created database.
- Clarification and full documentation of performance monitoring arrangements and the frequency of updates. The interface specification should also include a computer-based facility

for validation of suggested outcomes. Data management policy regarding provision of backup and archiving facilities needs to be in line with ISO 27001:2013.

- Search facilities for viewing of metadata should be available.
- The use of a common data structure is crucial for accuracy in data exchange and display by different applications. In the past, specialised interface programmes have been developed to transfer data between different applications; this has proven to be inefficient and time-consuming. Several specialised interfaces between programmes currently exist, but as the number of applications grows this solution becomes less reliable. To exchange data between two particular applications, two different interfaces need to be developed (one for each direction of transfer). As the number of applications increases, the number of possible data exchanges also increases. For this purposes we recommend that the same application should be used for real time data management by both the yard and the wider network.
- A common specification for real time management interface. RailML is being developed as an open source data format. The specification of data management interface should be centred on interfaces that use the RailML format to import and export data for real time management between applications. This approach would be far more practical if the same application is used for real time data management by both the yard and the wider network.

5. Conclusions

OptiYard will produce an output at TRL levels 3-4. The deliverables of the project will support future IP5 efforts by providing a framework environment within which processes for both real-time yard operations and real-time network operations can be optimised. These results (and subsequent optimisation tools) may then be integrated into on-going and future IP5 projects that will further develop these tools for application at higher TRL levels.

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SMART - Smart Automation of Rail Transport. Deliverable D4.2 - Overall framework architecture and list of requirements for real-time marshalling yard management system.

S2R-CFM-IP5-02-2015 (Start-up activities for Freight Automation), Real-Time Yard Management. D2.1 - Description of automation/optimisation requirements and capabilities of decision making process in Marshalling yards and Terminals.

S2R-CFM-IP5-02-2015 (Start-up activities for Freight Automation), Real-Time Yard Management. D2.2 - Description of business processes of a network management system and the interactions/interfaces with a Real-time Yard Management System.