Task analysis of a shunting locomotive to derive use-cases for scenario based tests of ATO Functions

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Abstract: The automation of driving functions is one of the biggest challenges in automotive engineering. A common approach for validation and certification is scenario-based testing, executed in simulation environments and field tests. Besides advanced developments in the automotive industry, the interest of automation increases also in the railway sector. A scenario-based test methodology already applied in the automotive industry shall be adapted and further developed for validation of automatic train operation (ATO) functions. Less degrees of freedom due to guided tracks, differences in range of physical parameter values such as higher masses, longer system reaction times and lower coefficients of friction resulting in longer braking distances, as well as higher requirements of clearance tolerances, have to be considered in the methodology. Following the scenario-based approach in this paper a systematic derivation of use-cases is demonstrated. For rail applications the development starts from scratch. The scope of a shunting locomotive in general is defined by operational specifications. Out of those, the different shunting tasks to be fulfilled are elaborated and contain a wide set of parameters, leading to a huge variety of field tests. Accordingly, it is necessary to split up those shunting tasks to specific use-cases for more reliable and faster testing. These build the base for the scenario-based testing methodology. In further steps the use-cases are used to derive scenarios.

Keywords:
Automated driving functions, use-case based testing, use-case derivation, automatic train operation, scenario-based testing

1 Introduction

For the reduction of traffics impact on climate change it is necessary to optimize existing structures as well as developing new ones. In case of freight transport, rail traffic is already an ecologically rational option, which should be further expanded, [KA+18]. But depending on factors in different countries and regions, freight transport by train is not always the preferred method of transportation. High flexibility and comparatively low costs lead to a dominance of road freight transport in the modal split [UN17].
To address these problems, governments around the globe have proclaimed support programs. In 2014 the EU created the initiative "Shift2Rail" [SH14], with the aim of promoting new technologies to enable more ecological and economical rail transport. Similar processes can also be observed in the USA [Of20] and China [IX21].

One of those pushed new technologies is the automation of processes in combination with machine learning and artificial intelligence. This is expected to increase efficiency, reduce costs and lower emissions of rail freight transport. Single wagonload traffic, relevant for the transport of general cargo, has a bottleneck in the redistribution of goods at the shunting yards and causes one third of total cost of freight train operation. To address this issue, marshalling yards have become an important point in the ongoing process of automation and digitalization [Nü21].
The implementation of highly automated functions is slowly pacing up over the last years, for railway applications, [Nü21] but there are no standardized approval procedures yet. Therefore, it is necessary to develop a testing methodology, specified for railway systems, to deal with the increased complexity brought by the reduction of external boundaries, which enables test driven engineering and also contributes to the admissions process.

One approach used in the automotive industry to build such test methodologies is a scenario-based approach, on which the developed toolchain follows. Explicit use-cases that reduce the overall system to smaller components, serve as input variables for this test methodology [Pe20]. A methodological toolchain is developed for this purpose in the project VAL [Gr22], which features a virtual lab and a real field environment for testing an automated shunting locomotive.
In order to derive these use-cases for shunting operations, the processes and framework conditions at the shunting yard are analysed further below.

2 Shunting yard environment

The key task of a shunting yard is the decomposition of incoming trains into single wagons or sets of wagons to distribute and reorganize them into new trains depending on their destination. A shunting yard is divided in four subsystems (see fig. 1). A set of wagons is usually brought into the arrival tracks (1) by a track locomotive. In the next step the wagons are uncoupled and the track locomotive leaves the shunting yard. The uncoupling depends on the destination of the different wagons. Accordingly, there are singular wagons and groups of wagons left at the arrival tracks. To separate and distribute those wagons, they are pushed over a slight hill, that is called hump (2), by a shunting locomotive. Thereby, the wagons gain kinetic energy and roll downhill into the directional tracks (3) by themselves. Timed switch points and rail brakes are used to lead the wagons into the directional tracks for further distribution [Pa21], [He17].

In the next step there are loose wagons on the rail in the directional tracks (3), which have to be pushed together and coupled. This task is in general done by a shunting locomotive. State of the art shunting yards can also feature a double-pressure system for this step [Pa21], [He17].

Afterwards the coupled wagons are brought into the classification tracks (4), by another shunting locomotive. In the next step a track locomotive is attached to the wagons, brake hoses are attached and couplings are tightened. After this the main air pipe and control vessel is filled, to proceed brake test. Finally, documentary operations are carried out and the newly formed train can finally leave the shunting yard [Pa21], [He17].

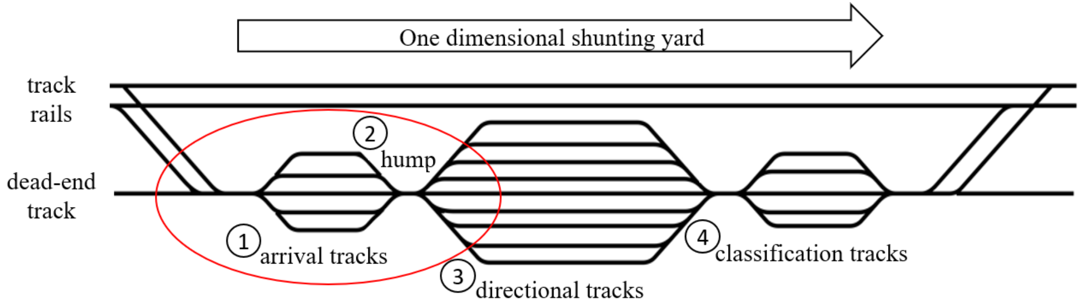

Figure 1: One-sided shunting yard (adapted from [un17])

For the automation of those processes or testing of an automated system executing them, it is necessary to gain a greater insight on the procedures of a shunting yard. The focus of the VAL project is on a hump locomotive, which has its working area in the red marked area (see fig.1). However, the methodology is structured in such a way that it can be extended to the rest of the shunting yard and, in the next step, to other elements of rail operations.

There are several persons and facilities needed to run a shunting yard. The main participants of a shunting process, are expediter, hump operator, shunting locomotive driver, switchman, shunting assistant and train dispatcher [DB19], [Bu67]. Their influences on the operational process must be known in order to be able to map any actions that may occur as an actor within a use-case.

The special feature of automation at the shunting yard is driving on sight. Accordingly, the automation must be able to map the driver's senses (primarily vision).

3 State of the art testing and use-cases

Testing of driving functions exists as long as driver assistance systems are established, however general differences between road and rail vehicles have to be considered.

Less degrees of freedom due to guided tracks, differences in range of physical parameter values such as higher masses, longer system reaction times and lower coefficients of friction resulting in longer braking distances, as well as higher requirements of clearance tolerances, have to be considered in the methodology.

Within the Pegasus Project [Pe20]a methodological approach was developed for a generally testing procedure to establish highly automated driving functions using a scenario-based test method. It was exemplary elaborated with one defined use-case, i.e. the highway assistant, that provides marginal conditions and basic information for the scenario definition. The basic information, that has to be provided for scenario based method is a use-case. Due to the variety of already existing ADAS systems, there is a wide set of use-cases that defines an automated driving vehicle.

For ATO functions especially on shunting yards there aren't any mentionable scientific approaches for defining necessary use-cases. In railroad technology, there are still few driver assistance systems and even fewer of them are designed for use in shunting locomotives. Within the project VAL a highly automated system has to be developed and tested, which has a high complexity in its entirety. In the preliminary project VAL2020 a functional demonstrator of a real shunting locomotive was presented [CS18] without systematic testing. The respective sub-functions are not sufficiently represented in any existing system. Consequently, use-cases have to be extracted from the operational framework and the additional knowledge available. Due to defined processes, structures and guidelines for working steps at the shunting yards, the ideal starting point for this are the shunting tasks provided by operational processes. The scope of the VAL project lies on testing the perception-based system decisions while executing shunting orders. It is assumed that the operational procedures around the shunting process are correct. If this is not the case, the reaction of the system to the operational error is tested, not its origin.

Before the shunting tasks can be examined in more detail the basic principles of use-cases are explained further in order to be able to assess the extent to which shunting tasks already correspond to a use-case or need to be further adjusted.

A use-case is defined as interaction with users that is visible beyond the system boundaries. These interactions are represented in a graphical system. For further usage each use-case parameter is specified within test-cases, which build the basis for system testing.

At the beginning of use-case definition, the system is observed as a black box. The system boundaries and interactions must be clearly defined. The stakeholders outside the system are automatically identified and their expectations of the system can be specified. With this it is possible in the next step to consider the subsystems [RQ12]. To generate a use-case, the expectations of neighboring systems and stakeholders for system behavior must be defined. The fulfillment of the expectations is checked in the resulting test cases. A use-case is basically described by the following parameters: name, actors, triggering event, short description, preconditions, essential steps, exceptions and postconditions. For the definition of the following test cases, it is helpful to reduce the complexity of the system as much as possible. Similar tasks may vary only within their pre- and post-conditions and thus form other test cases that need to be distinguished. [Fo20], [RQ14]

4 Functional analysis

The combination of the operational process regulation and the observation of tasks of the hump locomotive are used as a first functional analysis to derive the use-cases. In a first step, this results in shunting tasks, that break down the shunting process in subtasks. A shunting task is defined by a vehicle movement within a shunting process that must be tested. The tasks are based on guideline 408 §51 section 4 [DB14] in addition with own experiences. Also a typical proceeding is provided within [Sc21]. This procedure reduces the VAL System into smaller Subsystems, but some are still complex and widely. So there is still room for improvement, with regard to the further breakdown into more detailed subsystems.
The shown shunting tasks below (fig. 2) are based on the processes without automation affecting the locomotive.

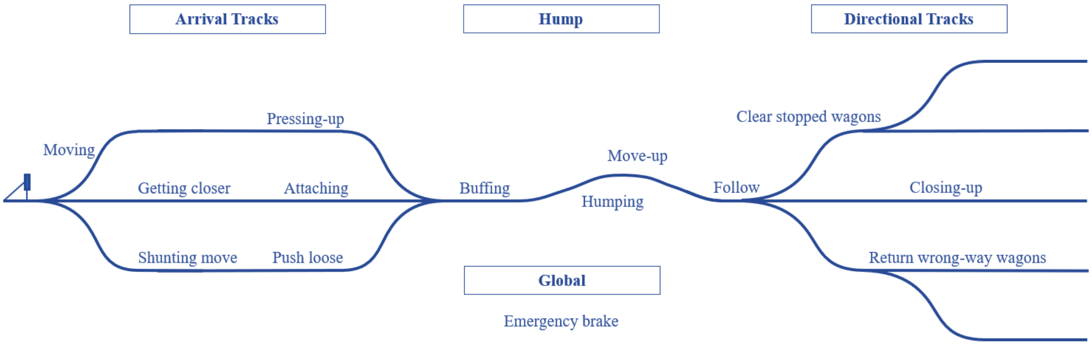

Figure 2: Shunting tasks and their possible area of execution at the shunting yard

The shunting task *moving* describes the process of carrying the locomotive into the operation track. The locomotive drives from the hump back through the arrival tracks into the dead-end track. After the switches are changed into the right direction and the light signal shows “drive”, the locomotive moves in its desired track. It usually appears after the locomotive finished the humping process.
For *getting closer*, the locomotive is already on the needed track and is moving towards the waiting wagons. The task ends, when a defined distance is undercut and the velocity has been reduced.
With *attaching* this process is proceeded. The locomotive drives to the wagon with a defined slow speed, until there is contact between the buffers of the first wagon and the locomotive established.
After *attaching* there are two options auf pushing the wagons. *Pressing-up* brings the wagons in the right distances for coupling or decoupling, while *push loose* enables the displacement of skids.
To start *buffing* the locomotive is attached to the wagons, couplings are loosened or closed and the skids are removed. In the next step the locomotive pushes the wagons towards the hump. When the first wagon reaches the top of the hump the process is called *humping*. The decoupled wagon is released by gravity and rolls into the

corresponding destination track. After the *humping* is finished the locomotive itself *moves- up* on top of the hump to await further tasks, as *moving* e.g..
In some cases the locomotive has to run over the hump for additional tasks.

Follow describes the process of moving down the hump to reach the directional tracks. In the directional track the locomotive usually comes to action, when errors occurred in the humping process. If wagons don't roll far enough, *clear stopped wagons* pushes the wagons further into the directional tracks.
If the switches where wrongly placed, due to human or system failure, the locomotive has to *return wrong-way wagons*. The locomotive drives to the wagon couples with it and moves them back up the hump, or into the right track.
Closing-up bridges the gaps of the running off groups of wagons in the directional tracks, in order to create free space at the beginning of the track.
Emergency brake is a feature, that has to be executed in every zone of the shunting yard. The locomotive has to be decelerated until standstill and brought in a safe state.
A *shunting move* describes a ride of a locomotive. This task is not strictly specified and is used to deal with specific exceptions, or rare tasks, that are not in the focus of the project yet.

The complete workflow of a hump locomotive can be described by the shunting tasks mentioned above. As is already apparent during the definition of these, some subtasks are repetitive and correspond to other shunting tasks, while other processes are not tightly enough defined to extract a reliable test case from them.

5 Use-case derivation

For the further definition of the use-cases within the project VAL, it has to be mentioned, that the shunting tasks buffing, humping and move-up are already automated at the Munich north shunting yard and not in the scope of this project. But they must be taken into account when extending the test methodology to other shunting yards.

A use-case is a work step to contribute a shunting task within an environmental setup. Each specific use-case is represented in different scenarios. To derive the use-cases, the shunting tasks are analyzed for intersections between them. Furthermore recurring and specific subtasks are identified as own work steps of the shunting task. This leads to small subsystem functions, that are repeatedly used to represent the functionality of a whole automated hump locomotive. The result of this procedure leads to the use-cases, further described in the following.

The derived use-cases are listed in Table 1 (p.7). Based on the functional analysis, the shunting task *shunting move* is left outside, but is still part of the methodology. The tasks *buffing, humping* and *move-up,* are directly transferred into use-cases, but are not considered further, because they are already automated in the test area. After the use-cases are derived, the stakeholders have to be defined. All operational participants are generally eligible for this. For the exact definition of the use-case, it is necessary to further subdivide into active and passive stakeholders.

VAL Use Case	Short description
check	Check system status and provide response
move	Drive over dead-end track into the required track
approach	Approach to wagons until a defined distance is under cut
attach	After approaching establish contact between wagon and VAL
pressing-up	Press wagons into the couplingposition
push-loose	Press wagons until skids are free to displace
follow	Move over hump from arrival tracks to directional tracks
closing gap	Close gap between wagons in the directional tracks
retreive wagon	Bring wrongly run wagon back to the hump
clear track	Push stopped wagons further into the directional tracks
emergency break	Stop Locomotive immediately and bring it into a safe state
buffing	Push disassembly unit towards the hump (Automated)
humping	Push disassembly unit over the hump (Automated)
move-up	Move on top of the hump after humping (Automated)

Table 1: Short description VAL Use-cases

The operational participants have different tasks within a use-case, making them active, passive or even not part of this use-case. Operational participants are the VAL-Operator, expediter, hump operator, train dispatcher, switchman and in case of an unautomated locomotive the shunting locomotive driver. Those interact with each other to fulfill the preconditions. Usually the VAL-Operator is the stakeholder, which actively engages by starting the processes. Train dispatcher and switchman, don’t have direct influence on the use-case, because they are only participated in the preconditions.

Fig. 3 demonstrates the procedure within the use-case *approach.* The operational stakeholders, together with the actor(s), establish the preconditions. “Start use-case” is triggered by the actor when the preconditions are complied. The serviceability is checked again with the included use-case *check*. Afterwards the defined procedure is executed under defined framework conditions. The post conditions follow from the end of the use-case.

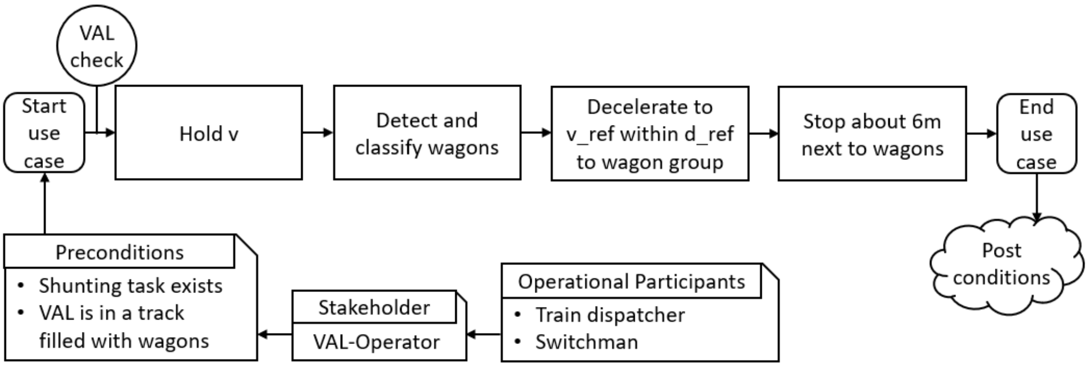

Figure 3: Example procedure of use-case approach

6 Conclusion

The derivation of the use-cases forms the basis for the further application of the test methodology.

Compared to the automotive sector, there are much less driver assistant systems for (shunting) locomotives, that can be used as basis for use-cases. Therefore, the use-cases had to be specially derived for further usage first. The approach of using clearly defined operational processes and framework conditions for a functional analysis offers a solid basis. The use-cases can be used further as an input parameter, to build a scenario based methodology.

Furthermore, it must be taken into account that the present use-case derivation is based on the processes with a human locomotive driver. It is assumed that the start command in an automated system is given by a VAL operator.

Changes in the operational process to simplify the automation of the locomotive are conceivable and to be expected. These can only be developed in parallel with commissioning. However, the use-cases developed here offer a solid first step towards the pre-development of automated shunting locomotives.

7 Acknowledgement

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