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"Development of a Concept for the EU-wide Migration to a Digital Automatic Coupling System (DAC) for Rail Freight Transportation"

Technical Report 'Simulation of Parallel Operation of Screw Coupling and Digital Automatic Coupling (DAC) in Train Formation Systems'

for the
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Disclaimer

This Technical Reports uses the masculine form to aid readability. Female and other gender identities are expressly included in this context, insofar as this is necessary for the statement.

Contents

Summary

Within the framework of the present study, the parallel operation of freight wagons equipped respectively with screw couplings (SC) and digital automatic couplings (DAC) was simulated for a train formation facility (TFF).

In single wagon traffic, the introduction of a DAC is seen as a key enabler for increasing the quality of transport and reducing operating costs – with the potential to digitise and automate operating processes in all European rail freight companies in the future. Pilot projects are already focusing on practical applications and technical testing of a DAC in operation.

One of the central questions is how migration can take place in the existing single wagonload transport system in Europe when the DAC is introduced. Several factors will have a significant influence on this decision, including the speed with which a DAC can be made available to system participants and the strategy for parallel operation of the SC and DAC over a longer migration period. A parallel operation phase is unavoidable because, with current technologies, the SC and DAC are not directly compatible without special adapter technologies.

In the present study, TU Dresden investigates the effects of such a parallel operation phase lasting several years on a TFF using different operating strategies.

The investigations were based on simulation techniques that used an experimental version of the tool “APP ZBA” (automated process planning in train formation facilities). As a result of a research cooperation with Deutsche Bahn, a refined version of this tool is in productive use in TFFs operated by DB Cargo AG. In agreement with the project participants, the 2019 configuration of the Munich North TFF was used as a model for the simulation in this study. The simulations were based of real operating data (train movements and wagon volumes) from March 2019.

The simulation uses scenarios that depict different points in time during a migration to a DAC based on the operational processes in a TFF. The decision regarding the selection of wagons to be retrofitted within an industry and the point in time at which this retrofitting takes place is random and therefore not controlled.

The two operation strategies studied are described as “mixed traffic” and “separate traffic”. The former means that two groups of wagons – with DACs and SCs respectively – are used within one train. This results in a time-consuming train formation process that involves shunting a coupler wagon, which is compatible with both coupling types, between the two groups of wagons. The second strategy considers trains with only one type of coupling. Processing these trains is easier, but a greater number of trains are required because pooling wagons is more difficult.

Under these conditions, the study shows that the “mixed traffic” operating strategy with conversion from an SC to a DAC over a migration period of several years rapidly leads to an overload of the TFF. The large number of mixed trains creates a great deal of additional shunting work. If the number of mixed trains is too high, traffic soon exceeds the capacity of the facility.

Simulations using a “separate traffic” operating strategy clearly show that only the scenarios for the conversion of one sector can be solved (here the automotive sector, and only without consideration of additional special operating processes and internal transports). However, even in this scenario, traffic already reaches the capacity limit of the TFF. No acceptable solution could be found in the scenarios for the subsequent conversion of wagons used by the

chemical industry and other sector. Above all, this is due to the rapid growth in the numbers of trains in these scenarios (separate SC and DAC trains), which overload the resources and infrastructure of the TFF.

Based on the simulation studies and evaluation of their results, it was found that there is potential for optimising both the ‘mixed traffic’ and the ‘separate traffic’ operating strategies.

In both cases, suitable measures must be introduced to limit additional shunting work and largely maintain the efficiency of the single wagon traffic system. In particular, measures for the temporal and spatial separation of wagon flows by coupling type should be investigated. For this reason, the authors recommend the use of a three-level model for a coordinated migration that can be managed at different levels:

- management of the migration process;
- management of network traffic;
- management of processes in the TFF.

Overall, the present study shows that considerable additional shunting work is to be expected in the TFFs if wagons are converted in an uncoordinated manner during the parallel operation phase of wagons with SCs and DACs. Without additional resources (infrastructure, personnel, locomotives) or functioning controls for the migration and daily operations (in the network, at single wagon traffic customers and in the facilities themselves), the TFFs quickly reach their capacity limits. The results of the study support the statement, that a migration phase should be as short as possible,.

In order to plan different approaches to the migration, further studies are required – on possible changes in the single wagon traffic network, and on the feasibility and effects of comprehensive controls for the network and TFFs. Single wagon traffic customers should also be involved in this process.

Intelligent control of the migration process in the network and TFFs will play a key role in maintaining the performance of single wagon traffic during the migration phase from the SC to the much-needed DAC.

1. Introduction

1.1 Starting situation

The introduction of a digital automatic coupling (DAC) is of outstanding importance and a key factor in the progressive development of rail freight wagons in Europe. In particular, the DAC closes the technological gap in the digitisation and automation of elementary operational processes in rail freight transport. This is why, since 2017, various demonstrator and pilot projects in Central Europe have been testing selected applications and specific effects when using the DAC (including the innovative freight wagon developed by DB Cargo AG and VTG AG on behalf of the German Federal Ministry of Transport and Digital Infrastructure[1] and SBB Cargo's 5L demonstrator train[2]).

A transition to widespread or full deployment of the DAC in European rail freight necessarily raises the question of how to develop and design a successful migration approach.

In the single wagon traffic system, the question of the migration approach is especially important and critical to the success of the system as a whole. This is due to two complex system interrelationships:

1. Speed of availability of the new DAC systems for the overall system (system components and system participants), and
2. Operation in the single wagon traffic production system when simultaneously using two incompatible coupling systems on rail freight wagons (SC and DAC).

The first of these raises the key question of whether migration can be achieved in days or months, or whether a longer period of several years should be stipulated. The significance of the second increases with the length of time required for migration.

So for a longer-term migration period, economic rail freight transport that is focused on customer benefit will require concepts that take into account the parallel handling of these two coupling systems in single wagon traffic both in transport, marshalling processes, in the facilities and service facilities, and on the 'last mile', including the customer interfaces.

The German Federal Ministry of Transport and Digital Infrastructure (BMVI) commissioned and is financing the development of an EU-wide concept for the migration to a DAC system in rail freight transportation.[3] The 'Simulation of Parallel Operation of Screw Coupling and DAC in Train Formation Facilities' sub-project, which is the object of this report, is aimed at creating transparency regarding the effects of a longer-term migration period. Its content focuses on conditions at the pain points in the single wagon traffic system: the TFFs. In the TFFs of the single wagon traffic system, arriving trains are broken up, the wagons are sorted, and formed into new outbound trains for onward transport.

In discussions on the further development of single wagon traffic it is repeatedly emphasised that without a DAC, essential processes in the breaking up and formation of trains will continue to require a great deal of manual effort, in each case combined with long process times[4]. In the TFFs, this applies to decoupling when handling inbound trains, and to the coupling of outbound trains with SCs, in particular. The introduction of a DAC is therefore also aimed at increasing the efficiency of these processes and improving occupational safety in the TFFs.

[1] See DB Cargo AG & VTG AG (2020).
[2] See SBB Cargo AG (2019).
[3] Cf. Federal Ministry of Transport and Digital Infrastructure BMVI (2020).
[4] See König & Hecht (2012); Technical Innovation Circle for Rail Freight Transport (2019).

For the migration to a DAC system, this study examines the effects of several years of parallel operation of SC and DAC on a TFF, when using different operating strategies.

The transition from an SCSC to a DAC represents a major challenge for the operating processes in a TFF. SCs and DAC are not compatible per se. Consequently, wagons with DACs and SCs cannot be coupled to each other directly. SC and DAC wagons can only be connected to each other by using adapters or coupler wagons.

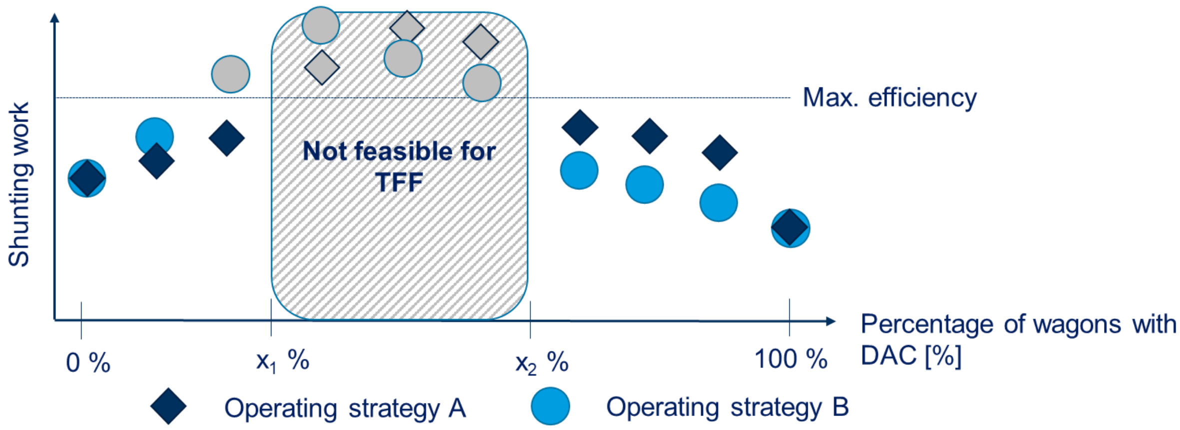
For the parallel operation of the SC and DAC in the TFF, fundamentally different operating strategies can be used. This study takes a closer look at two promising operating strategies:

'mixed traffic' and 'separate traffic'.

Besides being able to handle SC and DAC trains that use just one kind of coupling, a 'mixed traffic' operating strategy in the TFF allows for a simultaneous handling of mixed trains comprising one SC and one DAC group. In a 'separate traffic' operating strategy, only trains with one kind of coupling are operated to and from a TFF. SC and DAC wagons are separated in one TFF both in mainline traffic and in the operational processes. Other strategies, e.g. greater use of multiple collectors with one type of coupling to reduce the number of groups to be formed, are conceivable in principle, but not examined in this study.

In a study over a period of several years, it must be taken into account that at different points in time during the migration, the proportions of wagons with an SC and DAC respectively will change as the conversion programme progresses. The study therefore assumes that TFF operations will dynamically adapt to this. It can be expected that shunting work will initially increase as the degree of DAC conversion increases, and will only decrease again once a critical mass of DAC freight wagons has been converted (seeFig. 1).

Fig. 1: Expectations regarding the effects of operational strategies on shunting work in the TFF



Source: TU Dresden

The study uses a simulation program, developed at the Dresden University of Technology's Chair of Rail and Public Urban Transport, that is suitable for mapping different operating strategies in the TFF[5]. Different degrees of DAC conversion at certain points in time during the migration are defined as scenarios and simulated. For each simulated scenario and the quantity flows of trains and wagons used, a statement is made regarding the operational feasibility of the processes in the examined TFF. In addition, key indicators on resource expenditure and infrastructure requirements are produced for each scenario. The simulations

[5] See Eisold, Freitag, König (2017).

are carried out for a TFF using real data from 2019 (train movements and wagon volumes). The Munich North facility, one of the top-performing TFFs in single wagon traffic, was selected as the model train formation facility in its 2019 configuration.

1.2 Method

The procedure for simulating the parallel operation of the SC and DAC in a TFF involves four key steps:

1. Definition of the limiting conditions and data provision.
2. Definition of models and scenarios.
3. Simulation experiments.
4. Evaluation and conclusions,

A kick-off workshop[6] for project participants and protagonists from the single wagon traffic sector[7] initially discussed the statements to be provided based on the simulation experiments, the limiting operational conditions to be depicted in the simulation model, the simulation model's core properties, and the practical data required for the experiments. As a result of the discussion, the object of study was defined as the simulation of the parallel operation of the SC and DAC at the Munich North TFF, in its configuration and with model-relevant volume flows from 2019.

In designing the model scenarios, the study always considers two different operational strategies: 'mixed traffic' and 'separate traffic'. For both operating strategies, process chains are developed for operation in TFFs. These process chains are based on the real process chains at Munich North and the corresponding process time values. For new processes using a DAC, process times are assumed based on expert estimates. The process chains are then entered into the simulation tool: the experimental version of the "APP TFF" (Automated Process Planning in TFFs) tool developed by TU Dresden in a research collaboration with DB Cargo AG. A refined version of this tool is used productively during the operational planning phase in TFFs operated by DB Cargo AG. An experimental version of this tool is used for the simulation experiments. The studies are carried out on the basis of a real data set that extends over three days. This data set is provided by DB Cargo AG for the study and represents typical operating days at the Munich North TFF. The data set contains all train movements and wagon volumes for that period. As the railway undertaking, DB Cargo AG realises the incoming and outbound processes to be depicted in the simulation experiments with the breaking up and formation of trains, as well as the conversion and scheduling processes, on the infrastructure available at the Munich TFF.

To map the migration phase in the simulation, various scenarios are developed for both the 'mixed traffic' and 'separate traffic' operating strategies. In the above-mentioned kick-off workshop, an industry-oriented conversion of the wagon fleet was defined as a feasible approach for the migration and agreed as a basic procedure for the simulations. The scenarios comprise the step-by-step conversion of the wagons from the status quo to a full DAC conversion. With regard to the migration process itself, the simulation model considers the conversion of the wagons within an industry to be random, which is why the migration process

[6] Kick-off workshop, Frankfurt am Main, 17.07.2019.
[7] hwh Gesellschaft für Transport- und Unternehmensberatung mbH, TU Dresden, Deutsche Bahn AG, DB Cargo AG.

is defined as uncoordinated migration in the simulation experiments. A model for a controlled migration process over several years would only have been hypothetically possible at the present time. In practice, there would be a risk of it finding hardly any approval. For this reason, the train structure is not dynamically adapted according to a predetermined rhythm. A dynamic, controlled conversion could result in more favourable operating costs than a random conversion. Thus, a “worst case” scenario is assumed at this point.

For the simulation, a total of 31 scenarios were simulated for the ‘mixed traffic’ and ‘separate traffic’ operating strategies. In addition, another 16 scenario studies were carried out to analyse bottlenecks in the TFF. For this purpose, the simulation scenarios are each oriented to the degree of conversion and map the corresponding operational process chains under the given migration conditions and at the migration times of interest. The simulation experiments were carried out between October 2019 and March 2020 and were accompanied by a step-by-step interim presentation of the results to the client, the project team, and the above-mentioned protagonists from the sector.

The simulation experiments first consider whether the scenario is feasible, i.e. whether an acceptable marshalling schedule can be determined with the given infrastructure and a specific resource structure at the facility. If there is a feasible marshalling schedule for the TFF (realistic process chains with a specific sequence of operations in the scenario), the simulation results can be used to derive the required findings with regard to personnel, shunting locomotives, and infrastructure requirements in the selected model TFF. Based on these evaluations, specific recommendations and conclusions for a parallel operation of SCs and DACs in TFF are then made.

2. Limiting conditions for the simulation experiments and delimitation of the study

This chapter is devoted to the status quo of operations at the simulated TFF, the technical premises, and the delimitation of the study. In describing the premises on which the simulation is based, particular attention is paid to assumptions regarding the technical specifications of the coupling being described, and the equipment of relevant locomotives and coupler wagons with corresponding hybrid couplings. The characteristics of operation in the status quo and the transferability to other TFFs are also addressed.

2.1 Status quo in the simulated train formation facility

The simulation is performed using the example of the Munich North TFF. The underlying train structure is based on original data from three real, typical operating days from 2019. The infrastructure used in the simulation corresponds to the existing equipment status of the TFF in the period under consideration. The 40 sorting sidings available on these days should be mentioned as an important guideline for the performance of the facility. This circumstance is particularly noteworthy because from 2020 onwards, construction/conversion measures are planned for this facility that will affect the TFF's capacity (not part of the task in this simulation).

The examined TFF is well utilised in the 2019 study period, operating in the upper third of its capacity. The remaining capacity is used in the day-to-day operations to respond to possible network delays and fluctuations in traffic. In addition, it is sometimes necessary to reserve capacity for maintenance measures.

For newly defined processes (e.g. provision of a coupler wagon for combining a group of incompatible wagons when forming an outbound train), process times and resource requirements are defined on the basis of expert assessments.

For precise studies and facility-specific statements, the available resources must be considered, in particular the infrastructure, the process landscape of the respective TFF and the expected quantity structure.

2.2 Technical premises and delimitations of the study

Fundamental, technical limiting conditions are explained in more detail in the main report of this study (Hagenlocher et al., 2020) and in the technical report "DAC Technology" (Hecht, Leiste, Discher 2020). No basic DAC type could yet be specified for the simulation experiments. The DAC will be based on one of the currently known basic types (e.g. Scharfenberg, SA3, Schwab). The specific type to be adopted was still being clarified at the time of the project. The declared aim is to introduce a standard DAC throughout the EU. It is therefore assumed in the simulation experiments that all freight wagons equipped with a DAC are mutually compatible.

As already mentioned, the incompatibility between the SC and DAC poses a major challenge for operation under migration conditions. Wagons with SC and DAC cannot be directly coupled with each other. SC and DAC wagons be only be connected to each other using adapters or coupler wagons. The number and ready availability of appropriate devices is a prerequisite for a successful introduction of the DAC. In agreement with the protagonists present at the kick-off workshop, it was determined that in the simulation experiments coupler wagons should be provided for coupling SCs and DACs in mixed trains.

Furthermore, in a migration phase, additional design options are required to allow locomotives and wagons with different couplings to be connected. Hybrid couplings on locomotives (mainline locomotives and shunting engines) allow locomotives to be coupled to each other and to wagons despite their different coupling systems. It is therefore assumed in the simulation that all mainline and shunting engines are equipped with a hybrid coupler.

Based on this, the following premises apply for the simulation:

- Hybrid couplings can be coupled with each other;
- Coupler wagons have hybrid couplings on both sides.

There are several options for the constructive design of a DAC system, as described in the technical report “DAC Technology” produced for the present study. The variants presented here differ, among other things, in their degree of automation. For the simulation of parallel operation, the Type 4 DAC model variant was selected (with automatic coupling of the main brake pipe, power supply, and data bus, as well as semi-automatic decoupling) in the above-mentioned kick-off workshop (17.07.2019). With this variant, the operation of the DAC involves:

- Coupling: Automatic, after previous adjustment as the wagons come into contact.
- Decoupling: Manually on the wagon, e.g. by means of a cable pull;

A further premise is that the DAC changes from the buffer position to the coupling standby position during the procedure (considered in the simulation model). If this is not possible, local staff must be deployed during the pushing-off process at the peak of the hump (not included in the simulation).

Decoupling operations for all locomotive hybrid couplings are performed from the locomotive or via remote control or manually on the track (assumption for simulation model: equal time units in each case). Coupling takes place automatically as the wagons come into contact.

It should also be mentioned that automation solutions enabled by a DAC (e.g. automatic brake test) are not considered in this study.

The model and scenarios were defined on the basis of these technical premises.

2.3 Supplementary operational requirements outside TFFs

Outside the scope of this study, numerous limitations and new restrictions arise during the migration period which must be carefully considered when planning a conversion to the DAC. The following section describes some of the operational aspects that, in addition to the establishment of necessary production, maintenance, and repair capacities, should be urgently considered and investigated in greater depth as part of the migration process.

Any technical marshalling of freight wagons with DAC is only possible if either coupler wagons or suitable marshalling equipment, i.e. equipped with hybrid couplings, are available in sufficient numbers at the handling locations. Marshalling equipment primarily comprises shunting engines or mainline locomotives, but also shunting robots, road-rail vehicles, etc.

The scheduled handling locations are mostly sidings or connecting lines of the consignors and consignees where collection and distribution processes take place. In addition, there are satellite stations where trains are broken down and formed for short distance traffic, as well as maintenance areas. Unscheduled handling locations can also include any station where wagons have to be removed due to technical defects. If wagons cannot be handled due to a lack of shunting equipment with a suitable coupling, delays will result for all operating equipment and personnel involved. Under certain circumstances, these delays may cascade down to further transport services, e.g. by blocking a station track in the event of an unplanned handling operation.

For the above reasons, it is imperative that the coupling equipment is considered during wagon circulation planning. This applies not only to loaded and empty runs but also to maintenance, servicing, and repair. Special attention should be paid to coupler wagons.

When a wagon is equipped with a DAC, its area of application is limited to routes where suitable locomotives and marshalling equipment are available. This applies to both national and international traffic. As with the wagons, the couplings must also be taken into account in the management of locomotives and marshalling equipment.

3. Definition of models and scenarios

As the system-critical interface for single wagon traffic, TFFs have a key influence on the cost and success of a conversion. Based on the current state of technology and research, there is still a lack of knowledge about the behaviour of TFFs in a migration phase. Instead, TFFs are usually regarded as the black box of rail traffic[8]. The present study seeks to overcome this deficit with a novel simulation approach.

This chapter describes the simulation scenarios for the conversion from SC to DAC. First it provides an explanation of the ‘mixed traffic’ and ‘separate traffic’ operating strategies used in the simulation. It then briefly presents the resulting process chains and corresponding time values for the two operating strategies. In addition, it offers a definition of the quantity structure used in the simulation and discussion of the sector-oriented conversion of wagons.

It is important to note that the process chains defined below for the operating strategies examined were each defined for the specific conditions at the Munich North TFF (2019 configuration). They are not transferrable to other TFFs without adaptation. This includes process times and resource requirements. Thus, a direct transfer of the findings to other TFFs is not possible without additional analysis, since infrastructure and processes vary between facilities. The results of the simulation, however, still permit generalisations and general conclusions to be drawn for a migration.

3.1 Operating strategy models

Various constellations are possible for TFF operating strategies (see Table 1). Not all cases that are possible in theory are also relevant in practice. Only those cases that are most likely to be used are briefly discussed here.

In this study, a mixed train is understood to be a train formation comprising one group of SC wagons and one of DAC wagons. A ‘motley train’ is a train in which DAC and SC wagons are not separated into groups but can be distributed throughout the train formation.

[8] Cf. König et al., 2018.

Table 1: Possible combinations of inbound and outbound trains in the TFF with SC and DAC

	Outbound			
Inbound	DAC exclusively	DAC-SC separate trains	DAC-SC mixed trains	DAC-SC motley trains
DAC exclusively	Case 1	NA	NA	NA
DAC-SC separate trains	NA	Case 2	Case 5	Case 6
DAC-SC mixed trains	NA	Case 7	Case 3	Case 8
DAC-SC motley trains	NA	Case 9	Case 10	Case 4

Source: TU Dresden

The combination cases in Table 1 are briefly explained in the following.

Case 1: 'Separation of TFFs by coupling type'

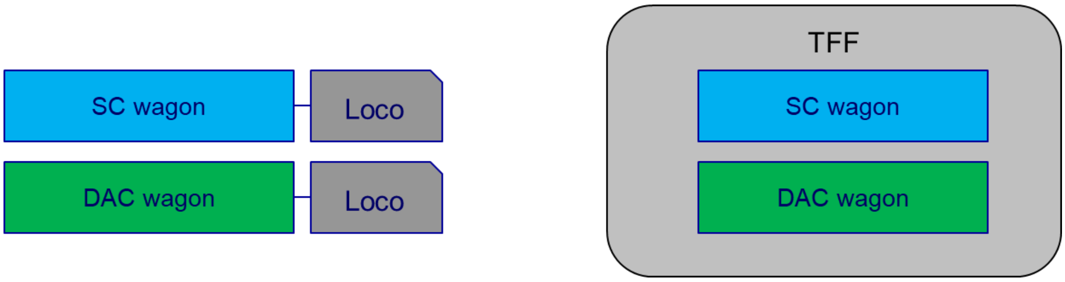
In this case, the TFFs would be designed for operations with freight wagons solely equipped with either SCs or DACs. In this case, with complete separation of the TFFs by coupling type, the processes and facilities for wagons with SC would remain unchanged. The facilities for handling DAC wagons would have to be adapted to reflect the associated process sequences.

A decision for this case should take into account the costs of providing, maintaining, and operating the separate facilities. In addition, there would be costs resulting from the longer times and travelling distances to/from the TFF for inbound and outbound trains.

Case 2: 'Separate traffic' operations

In this case, the mainline traffic to and from the TFFs would be separated into trains and wagons each with only one type of coupling (Fig. 2). If the TFF could process all trains and wagons regardless of their coupling type, the additional effort involved in managing the mainline traffic and trains as well as the provision of separate facilities would be eliminated.

Fig. 2: 'Separate traffic' operating strategy



Source: TU Dresden

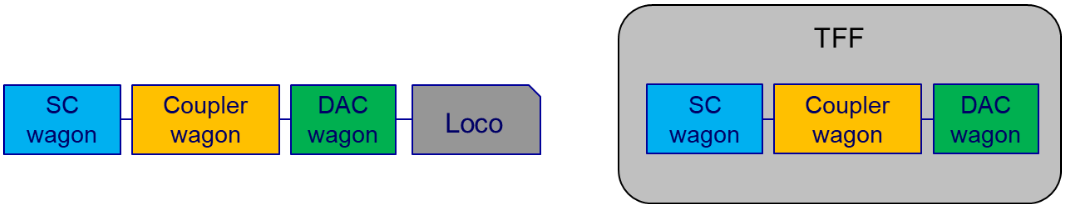
There would then be no need to couple wagons with different coupling systems within a train in mainline traffic. However, in all probability, the price for this advantage would be a lower level of train utilisation and associated increase in the size of train structures. In addition, an increase in wagon cycle times is likely, since it would take longer to achieve economically viable numbers of wagons per train.

Case 3: 'Mixed traffic'

As an alternative to Cases 1 and 2 outlined above, it would appear to make sense to use grouped, i.e. mixed, trains for the inflow and outflow of goods to the facilities ('mixed traffic'). This means that groups of wagons with the same type of coupling are positioned within a train (see Fig. 3). Thus, in a TFF, different couplings only meet at the separation points between the groups and at the locomotive. Hybrid couplings can be installed on the locomotives, allowing them to be coupled to wagons with either type of coupling. Coupler wagons, equipped with hybrid couplings on both sides, can be used between the wagon groups. In this case, too, wagons with different couplings are handled in a single TFF.

This approach would also eliminate the need to maintain separate facilities. Forming groups of trains in this way ensures better train utilisation. Compared with Case 1, a considerable amount of additional work/expense is involved in the necessary provision and management of the special coupler wagons. The expected statements regarding the effects on the operating processes will be relevant for the simulation experiments and their evaluation. For example, additional shunting operations are required to form the groups of wagons. Of course, the TFF can also process trains that use just one type of coupling – which in turn requires less work. This optimisation potential can be exploited given a sufficient number of wagons.

Fig. 3: 'Mixed traffic' operating strategy



Source: TU Dresden

In the simulations it is assumed that the wagons must be segregated according to coupling type for each line in the TFF's set of sorting sidings. This means that a greater number of sorting sidings is required. Currently, it is expected that damage will occur to technical systems if a wagon with an SC collides with stationary wagons with a DAC, or vice versa. Marshalling coupler wagons during the gravity sorting process is theoretically possible but would entail a high level of operational effort and expense and thus only rarely make sense.

Other cases

Cases 4 to 10, shown in Table 1, either contain sub-variants of the Cases 1 to 3, presented above, or are based on addition or removal of wagons with different coupling types but without grouping. For operational and economic reasons, ungrouped trains, i.e. 'motley trains' (see Cases 4, 6 and 8) only appear justifiable in exceptional cases since a coupler wagon would have to be shunted in each time different coupling types meet within the respective train. The considerable shunting work and large number of coupler wagons required would argue against this.

Simulation studies

With the above circumstances in mind, the simulation studies are therefore carried out for

- **Case 2 (separate traffic) and**
- **Case 3 (mixed traffic).**[9]

In the simulations for mixed traffic, it is assumed that inbound and outbound trains consist of two 'pure' groups of wagons, each with one type of coupling. The trains therefore usually have the following structure:

- Locomotive – group of wagons with SC – coupler wagon – group of wagons with DAC.

Consequently, three configurations are considered in the simulation:

- Trains with single-coupling, SC wagons only
- Trains with single-coupling, DAC wagons only (Fig. 2)
- Mixed trains (train formation scheme as shown in Fig. 3).

The following section presents the process chains for the cases of 'mixed traffic' and 'separate traffic' in greater detail.

[9] Kick-off workshop, Frankfurt am Main, 17 July 2019.

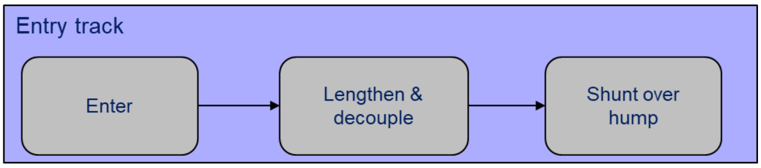
3.2 Process chains and process times

Status quo

Fig. 4 and Fig. 5 show the standard processes for breaking up and forming trains in the status quo – i.e. prior to a conversion of the freight wagons.

After the train has arrived in its inbound grouping, the locomotive is disconnected, and the wagons are separated according to their intended transition. This requires the SC to be unscrewed, the removal of the bracket from the draw hook, and disconnection of the brake hoses. The wagons are also vented to permit the wagons to roll of. A hump locomotive then shunts the wagons over the hump so that they are propelled by gravity and roll into the designated sorting siding in a controlled manner using rail brakes.

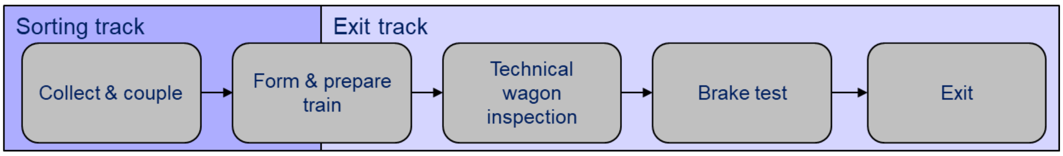
Fig. 4: Process chain for breaking up trains in the status quo with SC



Source: TU Dresden

Once collection has been completed, the wagons are coupled on the sorting track, the bracket is hooked into the draw hook, the coupling with the spindle is shortened, the brake hoses are connected and the valves are opened. A shunting engine then transfers the formed train to the set of departure sidings where the technical wagon inspection takes place to ensure the wagons' technical operability. The outbound train leaves the TFF after a brake test has been carried out with a mainline locomotive.

Fig. 5: Process chain for train formation in the status quo with SC



Source: TU Dresden

The process times assumed in the simulation for the status quo are listed in Table 2. The process times are calculated individually per train depending on the number of wagons. The durations consist of a fixed part (e.g. walking routes of the employees on site) and variable values per wagon (e.g. decoupling of a wagon). All process values listed here have been verified by protagonists in the rail freight sector.

Table 2: Assumed process times for status quo (pure SC wagons)

Process	Duration fixed [min]	Duration variable per wagon [min]
Entry into the entrance track	8.00	0.00
Lengthening & decoupling	9.05	0.55
Disconnection	1.00	0.43
Coupling the wagons	11.52	0.40
Preparing the train on the exit track	27.05	0.00
Wagon inspection	16.52	1.86
Simplified brake test	15.35	0.24
Departure from exit track	5.00	0.00

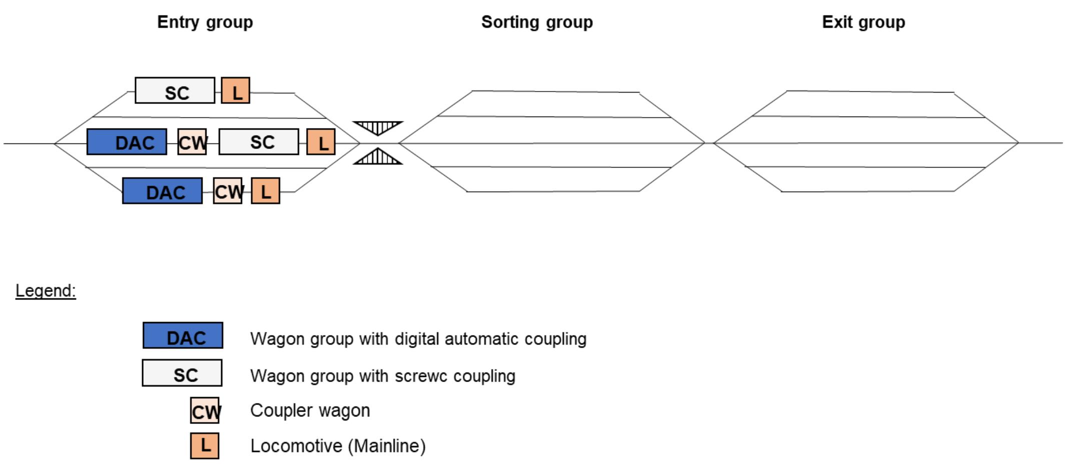
Source: TU Dresden

The following section looks in more detail at the process chains that take into account wagons with DAC. To avoid mixing effects, no other automation components besides the DAC are considered in the simulations (e.g. automatic brake testing, digital technical wagon inspection).

'Mixed traffic'

Trains that include wagons with SCs as well as wagons with DAC require a different process chain. Fig. 7 and Fig. 8 provide a schematic view of the process sequences, with track allocations, for breaking up and forming trains. An abstract overview is shown in Fig. 6.

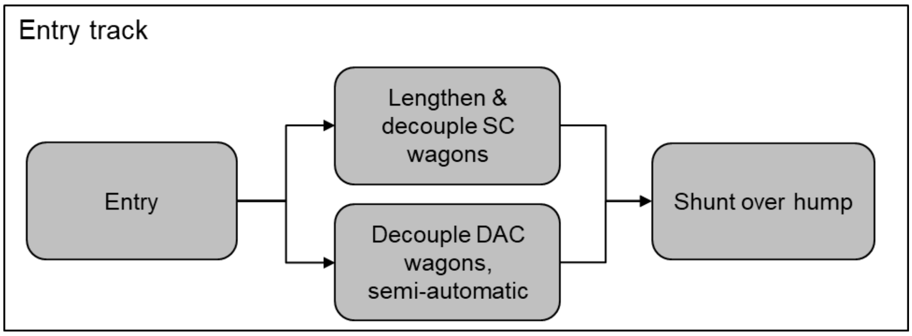
Fig. 6: Overview of forming and breaking up trains



Source: TU Dresden

For the section of the train comprising wagons with SCs, lengthening and decoupling is performed according to the description above. The other part of the train with wagons equipped with a DAC system is also separated on the entrance track. To do this, a local employee vents the wagons and disconnects the coupling system, e.g. using a cable pull.

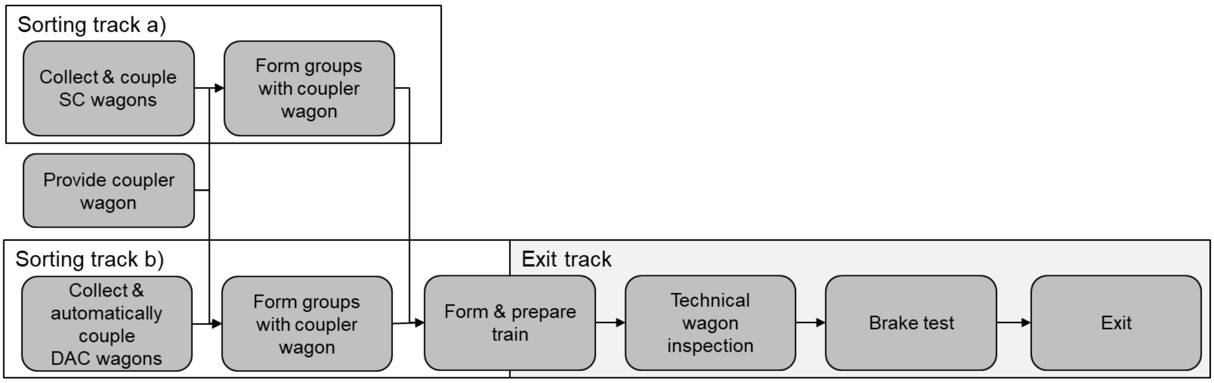
Fig. 7: Process chain for breaking up trains for 'mixed traffic' with SCs and DACs



Source: TU Dresden

Forming a mixed outbound train is a significantly different process from forming a train with only a single type of coupling. The wagons for the outbound train are collected separately on two sorting sidings, according to coupling type. The wagons with SCs are coupled by a local employee as described above. The remaining wagons with DACs automatically couple on contact – not just the mechanical coupling but also the couplings for the air and power/data lines. In addition, coupler wagons with hybrid couplings must be kept ready on another sorting siding. The following procedure is proposed to form the train according to the sequence defined in Section 3.1: a shunting engine pulls the coupled group of wagons with SCs out of the sorting siding *a* (Fig. 8) and shunts it onto a wagon with a hybrid coupling. This group, comprised of the wagons with SCs and the coupler wagon, is then attached to the wagons with DACs (on sorting siding *b*). The outbound train, which is now completely formed, is transferred to the exit tracks, where it undergoes outbound handling as described above.

Fig. 8: Process chain for forming 'mixed traffic' trains with SCs and DACs



Source: TU Dresden

The assumed process times are shown in Table 3. The process times, both for breaking up and forming the trains, depend on the mix of wagons with SCs and DACs.

Table 3: Process times for mixed trains

Process	Duration fixed [min]	Duration variable per wagon [min]
Entry into the entrance track	8.00	0.00
Lengthening & decoupling	9.05	0.35 per DAC wagon
		0.55 per SC wagon
Disconnection	1.00	0.43
Coupling the wagons, SC group	11.52	0.40 per SC wagon
Coupling the wagons, DAC group	0.00	0.00
Forming a mixed outbound train	25.20	0.00
Preparing the train on the exit track	27.05	0.00
Wagon inspection	16.52	1.86
Simplified brake test	15.35	0.24
Departure from exit track	5.00	0.00

Source: TU Dresden

‘Separate traffic’

In ‘separate traffic’ operations, each train has just one type of coupling. Accordingly, the process of breaking up and forming trains with SCs is the same as in the status quo (see Table 2 for estimated times). For trains with a DAC, the process of coupling is eliminated. The other processes remain the same. The assumed times for pure DAC trains can be found in Table 4.

Table 4: Process times for trains completely converted to DAC

Process	Duration fixed [min]	Duration variable per wagon [min]
Entry into the entrance track	8.00	0.00
Lengthening & decoupling	9.05	0.35
Disconnection	1.00	0.43
Coupling the wagons	0.00	0.00
Preparing the train on the exit track	25.20	0.00
Wagon inspection	16.52	1.86
Simplified brake test	15.35	0.24
Departure from exit track	5.00	0.00

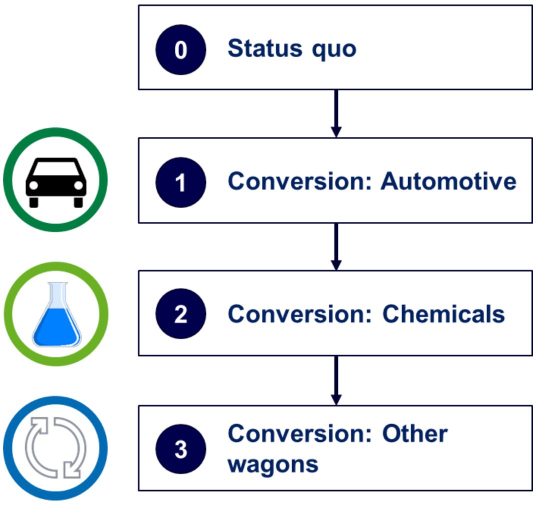
Source: TU Dresden

3.3 Quantity structure and industry definition

The data set provided by DB Cargo AG for the study comprises approx. 2,500 wagons that were in the facility during the period from 18 to 20 March 2019.

Simulating the migration at a TFF requires the development of different scenarios that illustrate the course of a migration and therefore the state of the wagon conversion at different points in the migration process. The scenarios are based on the basic idea of a gradual industry-driven conversion. This means that the sequence of conversions is based on the successive conversion of individual industries. Since freight wagons from the same industry tend to travel together in trains, this approach should be used to ensure that the complete conversion of individual trains/lines is achieved as quickly as possible. This has the advantage of limiting mixed operation of SC and DAC wagons on these routes and thus reducing the burden on the TFFs. It also minimises the duration of parallel operation for customers with sidings or connecting tracks. Based on the data set, the simulation identified two strongly represented industries for the Munich North TFF: the automotive and chemical industries. Thus, the simulation assumed the sequence of conversions shown in Fig. 9, which was chosen as an example for the Munich North TFF.

Fig. 9: Industry-driven conversion sequence



Source: TU Dresden

Due to limited workshop capacities, the conversion of the individual industries cannot be carried out completely at one point in time. It must take place in stages. In the scenarios defined here, discrete conversion points in time are considered and examined in 20 percent increments for each industry. The conversions of industries build on each other. The corresponding scenario definition is recorded in Table 5.

Table 5: Scenarios for simulations of parallel operation of SC and DAC

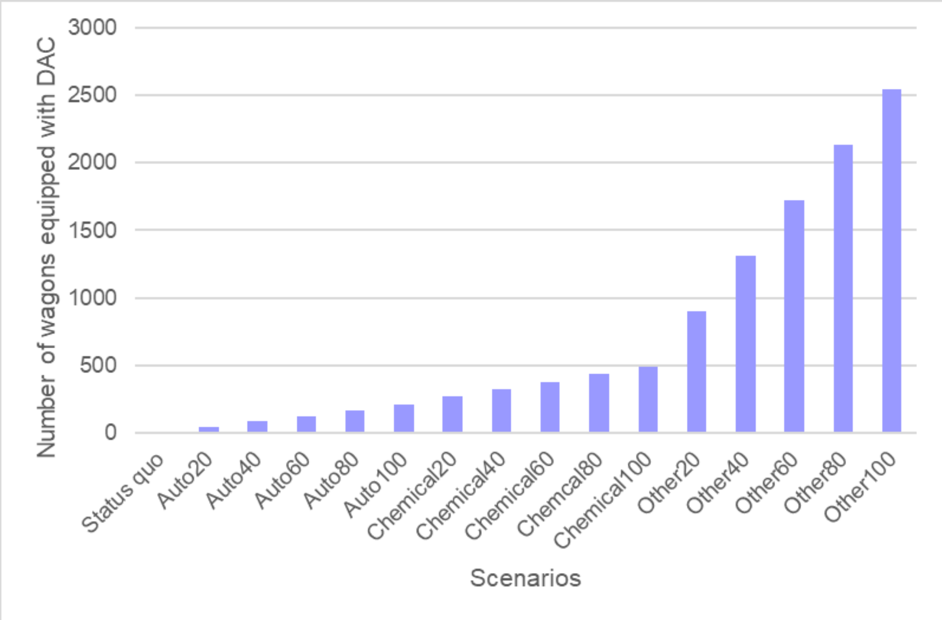
Scenario	Conversion status: Automotive industry wagons	Conversion status: Chemical industry wagons	Conversion status: Other wagons
Status quo	0 %	0 %	0 %
Auto20	20 %	0 %	0 %
Auto40	40 %	0 %	0 %
Auto60	60 %	0 %	0 %
Auto80	80 %	0 %	0 %
Auto100	100 %	0 %	0 %
Chemical20	100 %	20 %	0 %
Chemical40	100 %	40 %	0 %
Chemical60	100 %	60 %	0 %
Chemcal80	100 %	80 %	0 %
Chemical100	100 %	100 %	0 %
Other20	100 %	100 %	20 %
Other40	100 %	100 %	40 %
Other60	100 %	100 %	60 %
Other80	100 %	100 %	80 %
Other100	100 %	100 %	100 %

Source: TU Dresden

According to Table 5, this results in 15 scenarios each to be simulated for the ‘mixed traffic’ and ‘separate traffic’ operating strategies, plus the status quo simulation.

The conversion of the wagons within the industry conversion is random. This means that in scenario ‘Auto20’, for example, a random algorithm is used to select which specific automotive wagons are already equipped with a DAC. Due to this random component, the scenarios correspond to an industry-driven but uncoordinated conversion process. This represents a “worst case” scenario since the random element means that complete trains are not converted systematically; instead, individual wagons in the trains are usually equipped with a DAC, while a large proportion of them continue to run with SCs.

Fig. 10: Number of converted wagons (for the examined days of operation at the facility)



Source: TU Dresden

The scenario definition leads to a number of converted wagons equipped with a DAC for each scenario, corresponding to the number of wagons in an industry. These are shown in Fig. 10. The chart shows that the number of wagons converted in the scenarios increases according to the conversion sequence. The automotive and chemical industries account for approximately 20 percent of the total number of wagons. This means that the jumps in the 'remaining' scenarios are relatively large. For the simulations, this classification is sufficient to derive findings for a migration. In preparation for a specific conversion phase, however, a finer division of the steps may be appropriate. This is reserved for subsequent studies.

The scenarios presented in this chapter provide the basis for the simulation of parallel operation of the SC and DAC in the TFF. The results of the simulation are the subject of the following chapter.

4. Results of the parallel operation simulation

This chapter presents the results of the simulations of the scenarios for the 'mixed traffic' and 'separate traffic' operating strategies. In particular, it discusses the operational feasibility of the scenarios, as well as the resulting use of resources. This includes statements regarding the performance minutes required to implement the operating programme in each scenario. These relate both to personnel (marshalling workers for coupling and decoupling wagons) and shunting engines. In addition, evaluations of infrastructure requirements are carried out for the individual scenarios. Finally, it provides an initial estimate of the required number of coupler wagons for a selected scenario.

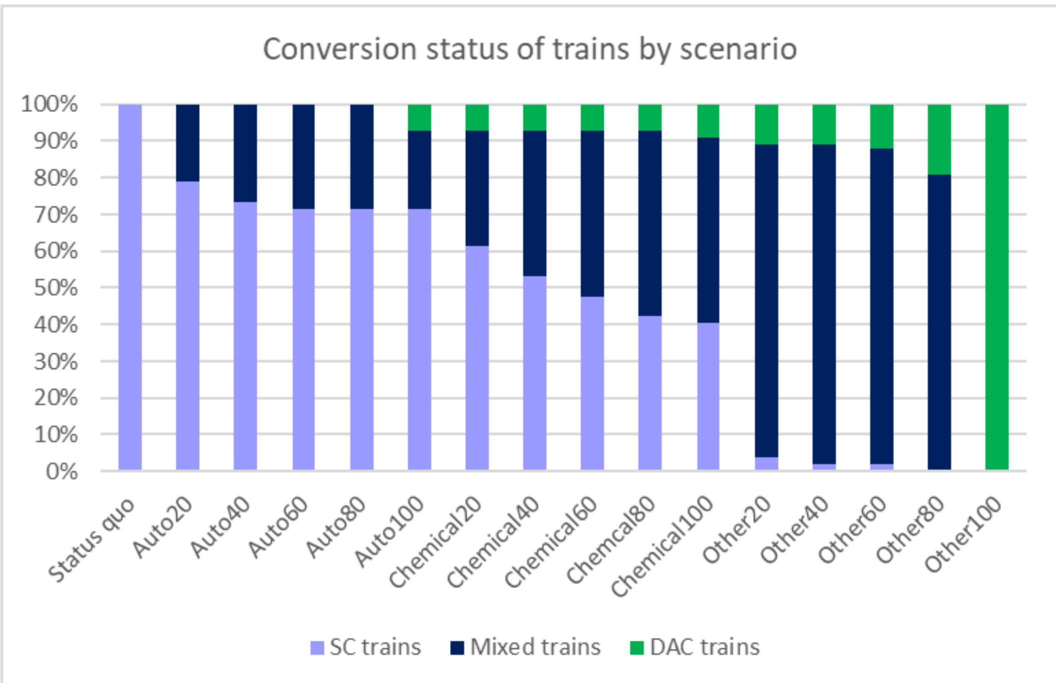
The results are presented separately for the two defined operating strategies.

4.1 Results for the 'mixed traffic' operating strategy

To help with evaluating the results of the simulation studies, please note, once again, that a mixed train consists of wagons equipped with DACs and wagons with SCs. In this operational strategy, trains are run as pure SC trains, mixed trains (SC and DAC wagons), and pure DAC trains. If a train contains SC and DAC wagons in a given scenario, this train is handled as a mixed train in the system. By the same reasoning, if only DAC wagons are present, the train will be a DAC train (analogous for purely screw-coupled wagons). This classification applies to both inbound and outbound trains in the TFF. It should be noted that 'through trains' are also considered in the simulation. However, their process chains are not changed because these trains are not broken up or formed in the TFF.

In the individual scenarios, the current conversion status can be determined for the division into SC trains, mixed trains, and DAC trains (see Fig. 11). It becomes clear that in the case of an uncoordinated conversion with 'mixed traffic', the number of mixed trains is very high until shortly before the conversion is complete – the reason this operational strategy results in a high level of additional shunting work throughout the migration phase.

Fig. 11: Conversion status of trains by scenario for 'mixed traffic', excl. through trains

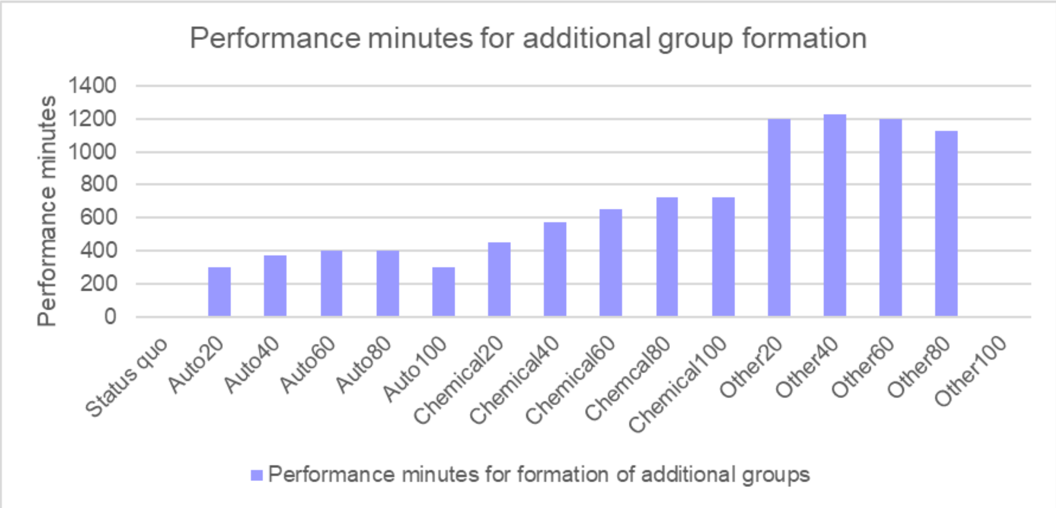


Source: TU Dresden

The large number of mixed trains means that a large number of additional groups must be formed in the system. The formation of groups to bring SC and DAC wagons together is performed by train formation locomotives and therefore strongly ties up their performance minutes. This connection is shown in Fig. 12. Depending on the scenario, this results in an increase of between 20 percent and 75 percent in the performance minutes for the train formation locomotives compared to the status quo.

In the 'mixed traffic' operating strategy, train formation locomotives must perform many additional tasks due to the processes involved in forming additional groups.

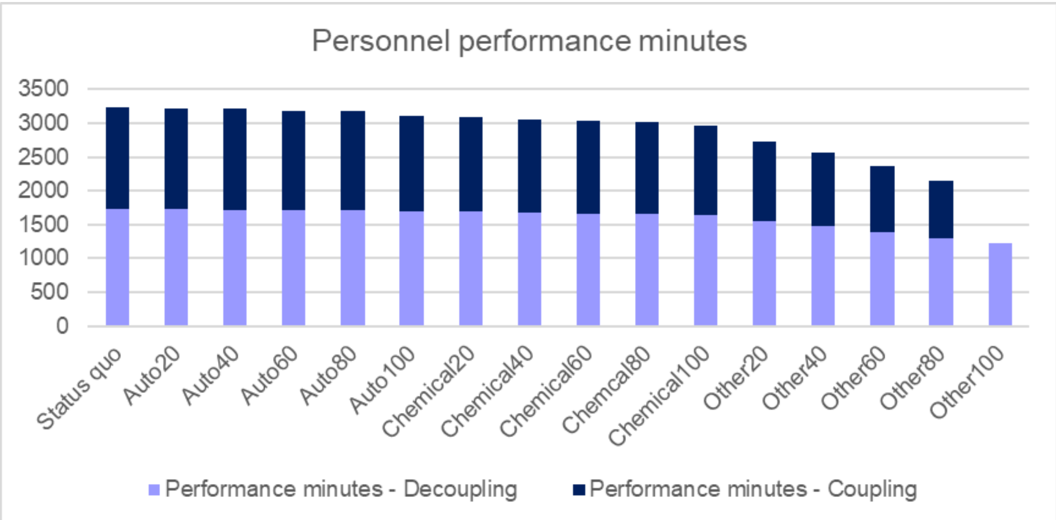
Fig. 12: Performance minutes of shunting engines due to additional group formation in 'mixed traffic' operation in the study horizon (three operating days)



Source: TU Dresden

The workload for the on-site staff is a different story. The performance minutes required for marshalling workers to couple and decouple wagons decrease with every converted wagon in the facility (see Fig. 13).

Fig. 13: Personnel performance minutes for 'mixed traffic'



Source: TU Dresden

Coupling and decoupling entail long and time-consuming walking routes in the facilities, which are considered in the process times. These large chunks of time can only be eliminated when no more manual processes are carried out on the train. If a train consists exclusively of DAC wagons, the process of coupling is completely eliminated for the marshalling operator. However, even if there is just one SC wagon to be coupled in the train, the high fixed time values for the walking routes also apply. Consequently, the process times for the couplers fall sharply only when whole trains are converted – until they drop to zero minutes in the 'Remaining100' scenario with 100 percent DAC wagons. As explained above, most savings in the area of performance minutes only occur when the last SC wagon of a train has been converted. Therefore, the performance minutes can only be significantly reduced in the 'Remaining100' scenario with 100 percent DAC wagons.

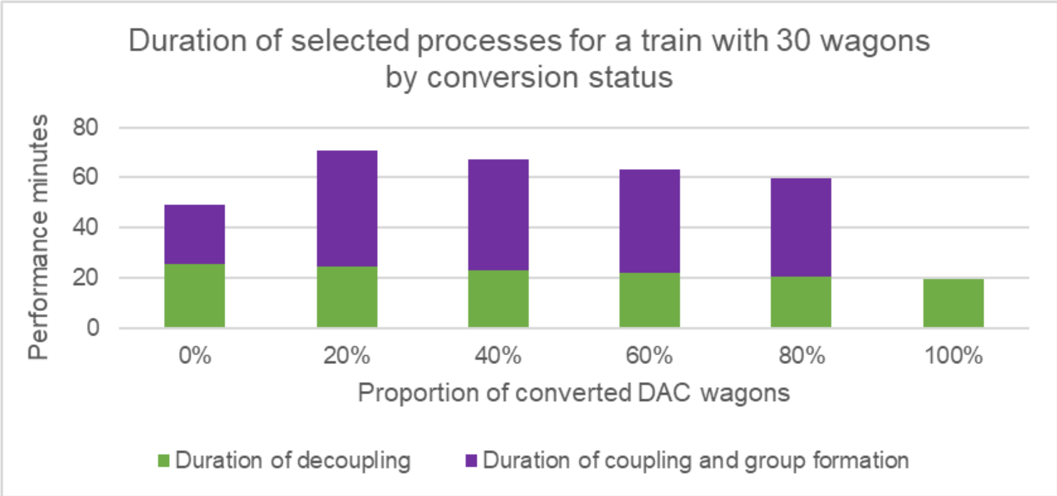
It should be noted that the process of decoupling is not completely eliminated, but still involves some manual intervention (see Chapter 3.2). So, although the time required is reduced significantly, this process cannot be eliminated completely yet because a Type 4 DAC decouples semi-automatically.

Based on these results, it can be shown that with the 'mixed traffic' operating strategy, the burden of coupling and decoupling for on-site personnel in the TFF decreases as the number of converted wagons increases.

To explain the operational relationships in more detail, and to help with interpreting the results shown in Fig. 12 and Fig. 13 the process times for a train with 30 freight wagons at different conversion statuses is provided as an example. Fig. 14 calculates the process times for lengthening and decoupling in the inbound group, as well as for coupling and, if necessary, group formation in the set of sorting sidings. The times are calculated using the methods described in Section 3.2. As the proportion of converted wagons increases, the handling time required for the inbound group (lengthening and decoupling) decreases. Since a large part of the process times is due to walking routes and processes that must be carried out independently of the coupling, the time savings are rather small.

A different effect becomes apparent when the time required for coupling and group formation is considered. Making up a mixed outbound train requires the formation of a group, which takes 25 minutes regardless of the number of wagons. This results in additional processing and work during the migration which can only be eliminated when the last SC wagon per train has been converted. Clearly, at the level of individual trains, mixed trains imply considerable additional effort and expense, and only the complete conversion of a train's wagon structure can generate the desired effects.

Fig. 14: Process times for a standard train with 30 wagons by conversion status



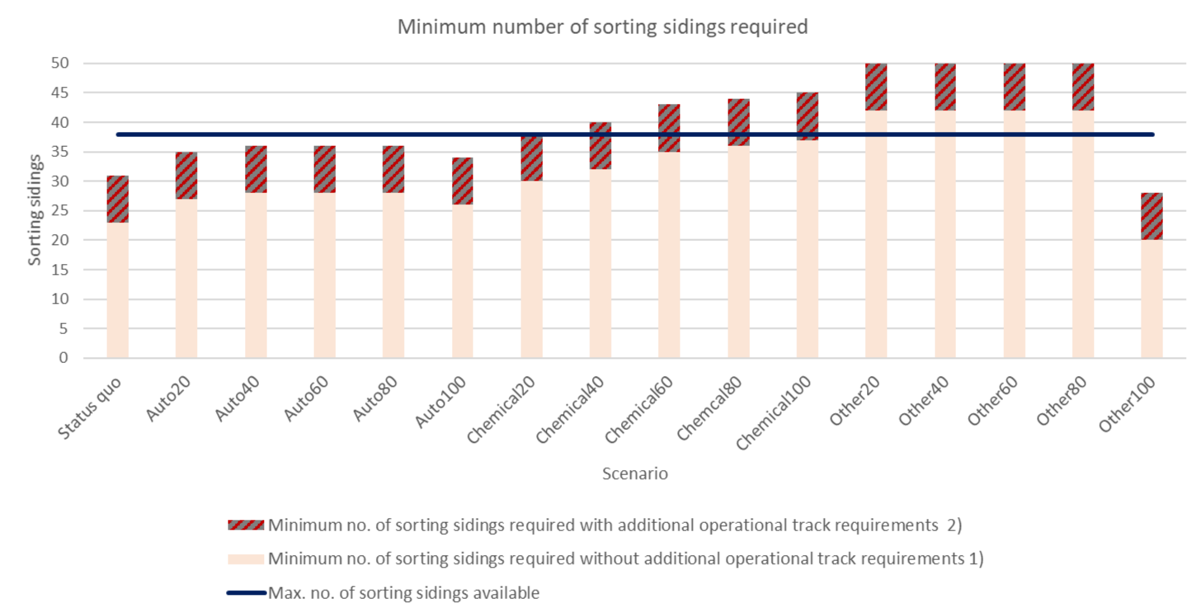
Source: TU Dresden

Given an uncoordinated conversion process and a ‘mixed traffic’ operating strategy, most of the effects of a DAC only become apparent in the TFF when the conversion is complete.

Since the simulations were based on real train structures and process times, the observation of the facility’s behaviour, with regard to utilisation of track infrastructure was of particular interest. It was shown that the key bottleneck for the ‘mixed traffic’ operating strategy lies in the number and length of the available sorting sidings. This bottleneck actually increases in practice, as additional tracks are required here for internal traffic, damaged wagons, and processes for groupage routes. This additional capacity requirement is not part of the simulation and must therefore be planned as additional operational track requirements.

The minimum number of sorting sidings required for each scenario is shown in Fig. 15. The maximum capacity limit has been set at 38 sorting sidings. In its 2019 configuration, the Munich North TFF had 40 sorting sidings, but two sorting sidings are reserved for the collection of coupler wagons. Fig. 15 also includes a constant value for additional operational track requirements. It should be pointed out, that the reservation of two sorting sidings for coupler wagons in the simulations is an operationally justified assumption. The precise estimate may require an integrated process analysis.

Fig. 15: Minimum number of sorting sidings required in 'mixed traffic' operating strategy



1) Based on train structure from March 2019 data set
2) Additional operational track requirements: internal traffic, damaged wagons and groupage routes.
Initial assumption as constant, to be specified in further studies.

Source: TU Dresden

Specifically, the results of the simulations show that the automotive and chemical industry conversion scenarios are feasible under the given assumptions. Taking into account the above-mentioned operational track requirements, however, only the DAC conversion scenarios for the automotive sector are readily achievable (211 DAC wagons). The 'Remaining20' (902 DAC wagons) to 'Remaining80' (2137 DAC wagons) scenarios, on the other hand, are not feasible in the case of an uncoordinated conversion because the sorting track capacity is insufficient to carry out the large number of group formations.

Due to the importance of having a managed conversion, it should be emphasised again at this point that this study on the parallel operation of DACs and SCs in TFFs assumes an uncoordinated conversion. Although the conversion is generally carried out in an industry-oriented way, the conversion of individual wagons in the industries is not controlled, but takes place randomly (see Chapter 3.3).

4.2 Rough estimate: Number of coupler wagons in a TFF

As explained above, the 'mixed traffic' operating strategy requires the use of coupler wagons. These wagons are the connectors between groups of wagons with SCs and DACs. At this point, an initial estimate of the number of coupler wagons required for operation is made on the basis of a scenario. Due to the high proportion of mixed trains, the 'Remaining80' scenario was chosen for this analysis. In this scenario, a 24-hour period is considered in order to estimate the required number of coupler wagons. This results in a train structure of 49 inbound trains and 40 outbound trains.[10] Of the 49 inbound trains, 38 run as mixed trains in the scenario. Of the 40 outbound trains, 34 are mixed (model day based on March 2019).

The analysis is based on the fact that, depending on the timing (arrival and departure times) of inbound and outbound trains, coupler wagons arrive at the facility with an inbound train or

[10] 'Through trains', which do not change their train configuration in the TFF, were excluded from the analysis.

leave it with an outbound train. A first approximation of the number of coupler wagons required can be calculated using a flow calculation.

First of all, the definition also states that a coupler wagon must be provided for each mixed inbound train in the considered time horizon. The inbound train is handled as an inbound train after entering the facility. After it has been disconnected, the inbound train's coupler wagon is made available in the sorting sidings to be used for an outbound train. If no coupler wagon is available for an outbound train at the time it is being formed, due to the timing of the trains, the number of additional coupler wagons required in the TFF is increased by one wagon. For this estimate, constant values were assumed for the time between the arrival of the trains and the earliest possible provision of the coupler wagon for an outbound train, as well as the last possible time for preparation and departure.

The number of coupler wagons required in the scenario is calculated as the sum of the number of mixed inbound trains and the additional coupler wagons to be kept in the TFF. Thus the 'Remaining80' scenario yields a requirement of 48 coupler wagons (38 coupler wagons from inbound trains, 10 coupler wagons as inventory in the facility).

It should be noted that an estimate of the coupler wagons required based on just one TFF can only provide a very limited picture of the interactions in the network. In addition to the TFFs, the use of coupler wagons also requires corresponding 'parking' capacities in all stations where these wagons are used or handled. Adequate wagon management is also necessary, in particular wagon circulation planning, monitoring, and control.

The flow calculation presented here should thus be understood as an initial indication and be elaborated upon with network-wide analyses. Other factors influencing the number of coupler wagons include variations in handling times and the frequency of damage to the wagons.

There is no analogous estimate for coupler wagons in the 'separate traffic' model, as this operating strategy does not require coupler wagons in the TFF.

4.3 Summary: 'Mixed traffic'

Overall, for an industry-driven conversion programme, the study yielded the following findings regarding the

feasibility of the 'mixed traffic' migration scenarios

(using the example of the Munich North TFF, 2019):

1. The uncoordinated conversion of the automotive wagons ('Auto20' to 'Auto100' scenarios) was successfully carried out. If the additional operational track requirement is added to the simulation values, a sufficient number of sorting sidings is available. The simulations show that the conversion of the automotive wagons is therefore feasible despite (and only with) additional work/costs in the marshalling yard.
2. The uncoordinated conversion of the chemical industry wagons ('Chemicals20' to 'Chemicals100' scenarios) was successfully implemented excluding special processes and without internal traffic. It clearly emerges that the TFF load limit is reached in these scenarios and that the necessary capacity described in Section 2.1 can no longer be kept free for operational necessities.

3. The simulations for the conversion of the remaining wagons ('Remaining20' to 'Remaining100' scenarios) show that an uncoordinated conversion of the remaining wagons is not feasible (given the assumed processes and resources).

On the basis of the results obtained in the above-mentioned simulations four core statements for the 'mixed traffic' operational strategy can be derived in a generalisable way:

1. An uncoordinated conversion over a migration period of several years will quickly lead to an overload of the TFF. The 'mixed traffic' operating strategy will result in considerable additional shunting work, which will exceed a facility's capacity if the number of mixed trains is too high.
2. The effects of the DAC in reducing shunting work only emerge once all the wagons within a train or system have been converted. Thus, the relationship between reductions in operating costs and the increasing degree of conversion at the TFFs is not linear, contrary to initial expectations.
3. The required number of coupler wagons for the implementation of the 'mixed traffic' operating strategy generates increased operating expenses at the TFF during the entire migration period.
4. There is potential for optimising the 'mixed traffic' operating strategy. In particular, it should be examined whether and at what cost the number of mixed trains can be reduced, since the shunting expenses they cause significantly exceed those of trains with a single type of coupling.

The simulation results and findings for the 'mixed traffic' operating strategy can be compared with the results and findings for the 'separate traffic' operating strategy.

4.4 Results for the 'separate traffic' operating strategy

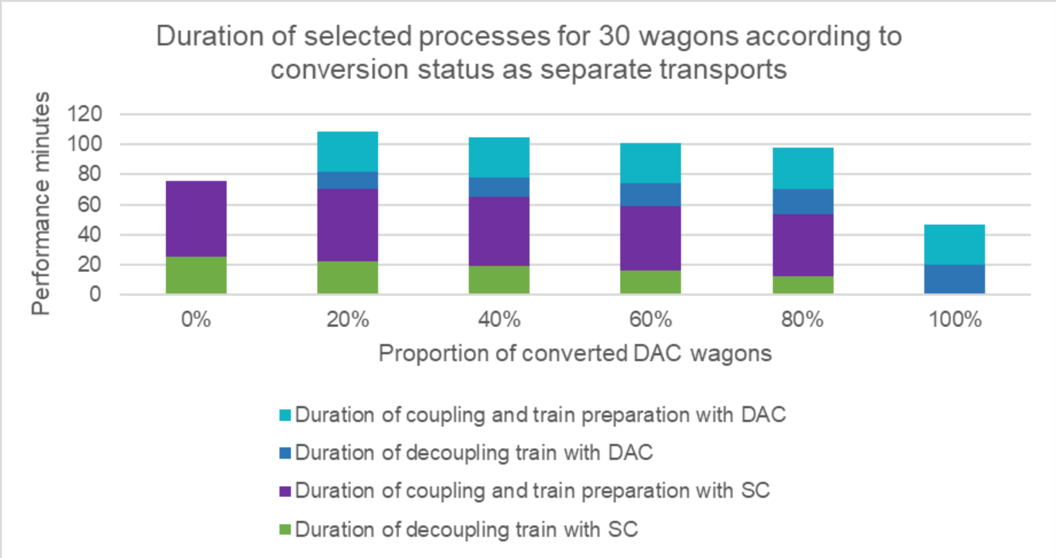
In the 'separate traffic' operating strategy, SC and DAC wagons are operated separately: a given train consists exclusively of SC or DAC wagons. Mixed trains are not permitted in this case. At the TFFs, the processes for SC and DAC wagons are operationally separated.

The advantage of this operating strategy is that there are no mixed trains, and therefore no coupler wagons need to be kept available. Consequently, the two sorting sidings reserved for coupler wagons in the simulations for 'mixed traffic' scenarios, can be additionally used for forming trains in the simulations for 'separate traffic' scenarios. This increases the capacity in the facility's set of sorting sidings. Furthermore, the processes for forming mixed groups of outbound trains are eliminated, along with the associated workload on train formation engines.

The disadvantage of this operational strategy is that individual routes can only be used at sub-optimal capacity, as the separation of wagons makes it difficult to pool wagon flows or prolongs the process for an unacceptably long period. For this reason, the simulations for this operating strategy also took into account the expected increase in the train structure (mentioned above). This entails increased expenditure on the deployment of locomotives and locomotive drivers in the network. In addition, the larger train structures for separate trains using SC and DAC respectively puts a strain on the TFFs, since trains must be broken up and formed. All the TFF's resources are utilised more heavily (infrastructure, personnel, and locomotives).

Fig. 16 shows selected examples of the process times required for an inbound train with 30 wagons at the TFF under the 'separate traffic' operating strategy. The separate handling of SC and DAC wagons (two trains) generates considerable additional work/expense compared to the status quo (0 percent DAC) and the target status (100 percent DAC). This results in high additional expenditure for train control and operation until the final SC wagon is converted.

Fig. 16: Duration of selected train break up and formation processes for a 30-wagon train, by degree of conversion

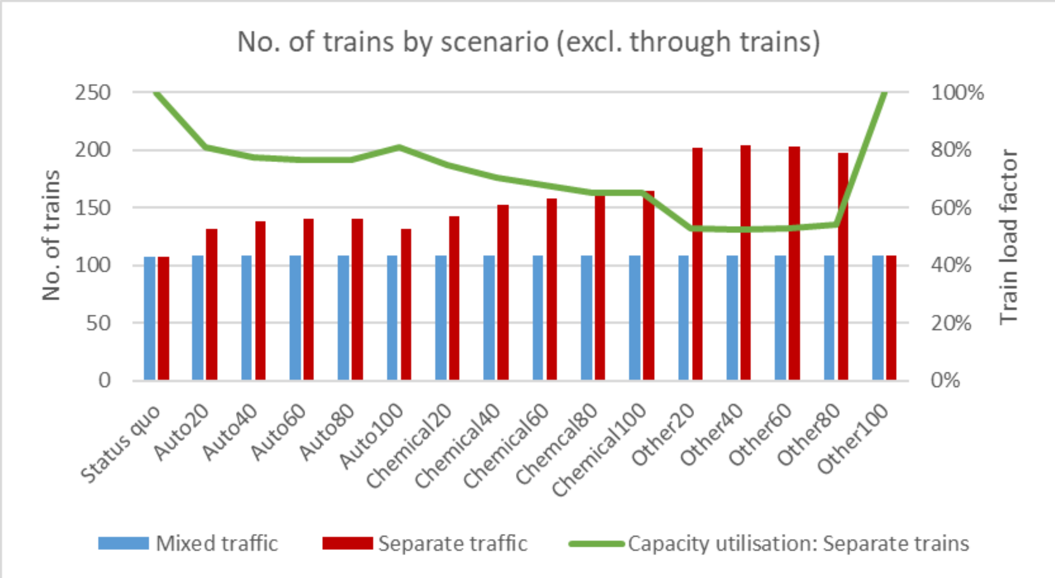


Source: TU Dresden

In the simulations for the ‘separate traffic’ operating strategy, the train structure from the original Munich TFF 2019 data set must be adapted for each scenario with a DAC. Once the first wagon in a train has been converted to a DAC, a DAC train is inserted into the simulation timetable in addition to the existing SC train. In the simulations, this train is entered in the same timeframe (arrival or departure). The converted DAC wagon must then be removed from the SC train and added to the DAC train. Afterwards, the process times are adjusted in accordance with the calculation rules listed above. Once all the wagons belonging to a train that was originally an SC train have been converted, the SC train is removed from the timetable and only the DAC train remains. Changed train/wagon allocations are not considered in the simulation due to the focus on a single TFF and not on the network.

Fig. 17 shows the described adaptations of the train structure for all scenarios and compares them with the ‘mixed traffic’ operating strategy. Due to the use of mixed trains with SC and DAC wagons, the train numbers remain constant over the entire migration period in the ‘mixed traffic’ operation strategy. In the ‘separate traffic’ operating strategy on the other hand, the number of trains increases significantly, especially in the ‘Remaining20’ to ‘Remaining80’ scenarios. This has a direct impact on the load factor of the trains compared to the ‘mixed traffic’ trains. The capacity utilisation of the trains decreases, in some cases considerably.

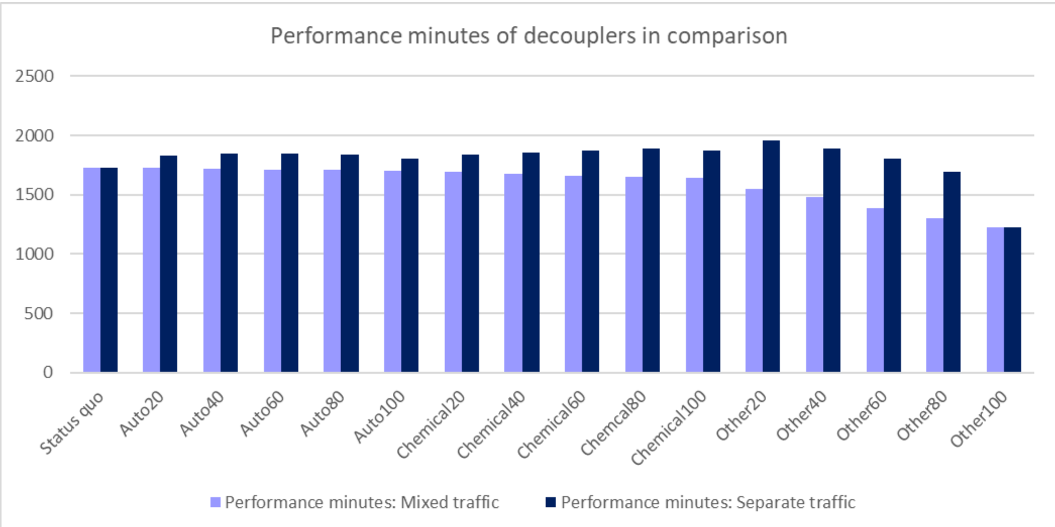
Fig. 17: Number of trains to be handled, by scenario (excl. through trains)



Source: TU Dresden

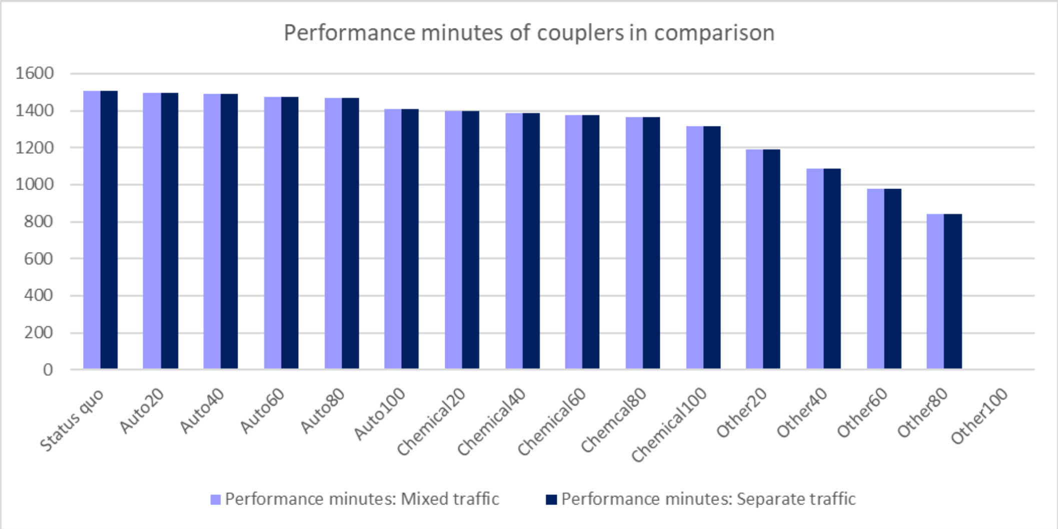
The sharp increase in the number of trains in the 'separate traffic' operating strategy means that a significant additional burden on the TFF can be expected during the migration period, as considerably more train formations and break-ups have to be carried out. This is also reflected in the workload on local staff (see Fig. 18 and Fig. 19).

Fig. 18: Performance minutes of decouplers in 'mixed traffic' vs 'separate traffic' operating strategies



Source: TU Dresden

Fig. 19: Performance minutes of couplers in 'mixed traffic' vs 'separate traffic' operating strategies



Source: TU Dresden

With the 'separate traffic' operating strategy, the number of minutes worked by shunting workers to decouple wagons increases during migration (in contrast to the 'mixed trains' operating strategy). Only when the migration is complete can the same effects be observed as with the 'mixed traffic' operating strategy, in the form of a significant reduction in performance minutes. This is because in the 'separate traffic' operating strategy, the same number of wagons must be decoupled and coupled as in the 'mixed traffic' scenarios. However, this number of wagons is divided between more trains because of the larger train structure. This increases the number of processes. For each process there is a certain fixed time value, which applies to walking routes to and from the train, for example. These fixed values must be considered for each process, so that overall, the 'separate traffic' operating strategy results in an increased demand for performance minutes. The amount of performance minutes for coupling is the same as in the operating strategy 'mixed traffic', which means that the effort is reduced by each retrofitted DAC wagon, but the major effects only incur, when all wagons are equipped with DAC.

4.5 Summary: 'Separate traffic'

Overall, for an industry-driven conversion programme, the study yielded the following findings regarding the

feasibility of the 'separate traffic' migration scenarios

(using the example of the Munich North TFF, 2019):

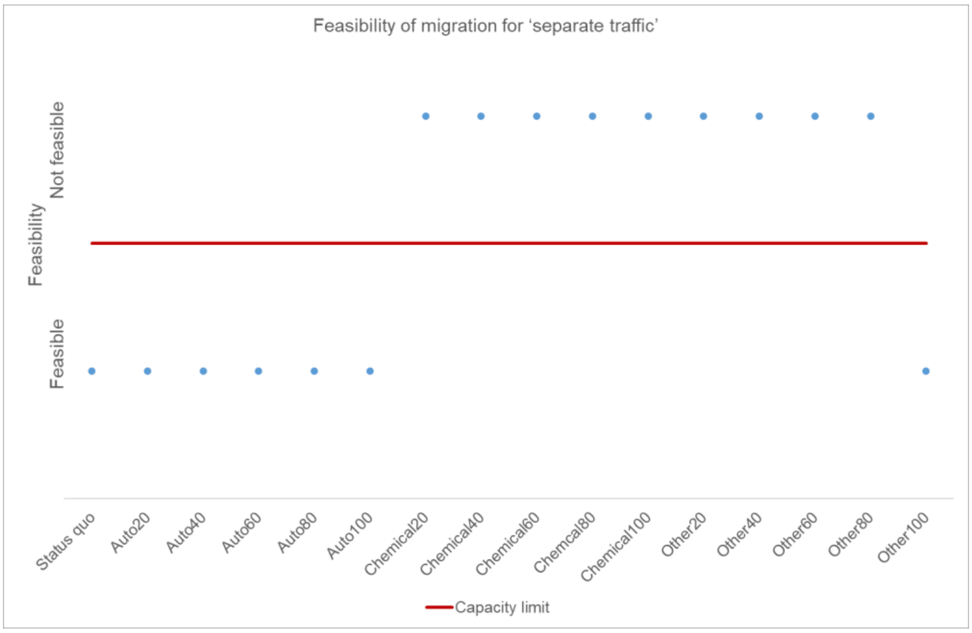
1. The simulation showed that only the scenarios for the conversion of the automotive industry could be solved without considering further operational track requirements. However, even here, the TFF's capacity limit is already reached.
2. No acceptable operating solution could be found for the conversion scenarios for wagons from the chemical industry and other wagons. This is due to the rapid increase in the number of trains in these scenarios, which overburdens the resources and infrastructure of the TFF.

3. With the 'separate traffic' operating strategy, it is difficult to locate the bottleneck directly (e.g. the set of sorting sidings in the 'mixed traffic' operating strategy), as there is a greater load on all track groups.

Further analysis of the bottlenecks in a TFF require more detailed studies due to the issue mentioned under point 3 (above). Only more detailed research into minimum track numbers can help in finding an acceptable solution with minimum resource requirements, as shown in Fig. 15 for the 'mixed traffic' operational strategy. These additional investigations are not part of this study on the parallel operation of SCs and DACs.

The results for the feasibility of the 'separate traffic' migration scenarios are summarised in Fig. 20. This clearly shows the capacity limit of the additional operational load for the simulated TFF.

Fig. 20: Feasibility of the 'separate traffic' operating strategy scenarios



Source: TU Dresden

Based on the results obtained in the above-mentioned simulations,

three core statements for the 'separate traffic' operational strategy

can be derived in a generalisable way:

1. In an uncoordinated conversion without adaptation of train structures, 'separate traffic' leads to a sharp increase in the number of trains. If the number of wagons remains the same, the result is lower train utilisation.
2. The increase in the number of trains leads to considerable additional shunting work at the TFF, and quickly overloads all of the facility's resources and infrastructure.
3. To implement the 'separate traffic' operational strategy successfully, it will be essential to avoid overloading the TFF. A number of accompanying measures will therefore be required to minimise the number of additional trains and the associated shunting work during the migration period. Possible measures for reducing shunting work are described in the following chapter.

5. Conclusions for a migration strategy

The present simulations examine the case of an industry-driven but uncoordinated conversion. This means that wagons for individual industries are converted successively over the migration period, in order to achieve clustering of DAC wagons at an early stage. Within these industries, however, there is a random selection (not controlled) of which wagon is converted at what time.

Under these conditions, the simulation experiments for the ‘mixed traffic’ operating strategy show that mixed trains with SC and DAC wagons lead to increased shunting work. In particular, this is expressed in increased sorting siding requirements and performance minutes of train formation locomotives. In the ‘separate traffic’ operating strategy, on the other hand, the separation of SC and DAC wagons causes the train structure to increase so much that the infrastructure, personnel and locomotives in the facilities as a whole are put under greater strain.

The results show that uncoordinated migration leads to a steep increase in shunting work in both the ‘mixed traffic’ and ‘separate traffic’ strategies. Under these conditions, most of the scenarios in the ‘separate traffic’ operating strategy cannot be implemented at the TFF without expanding the infrastructural basis. **A fundamental recommendation is therefore to reduce the migration period to a minimum (in short: necessity of ‘accelerated migration’) taking into account the limiting conditions described in the main report (Hagenlocher et al., 2020).**

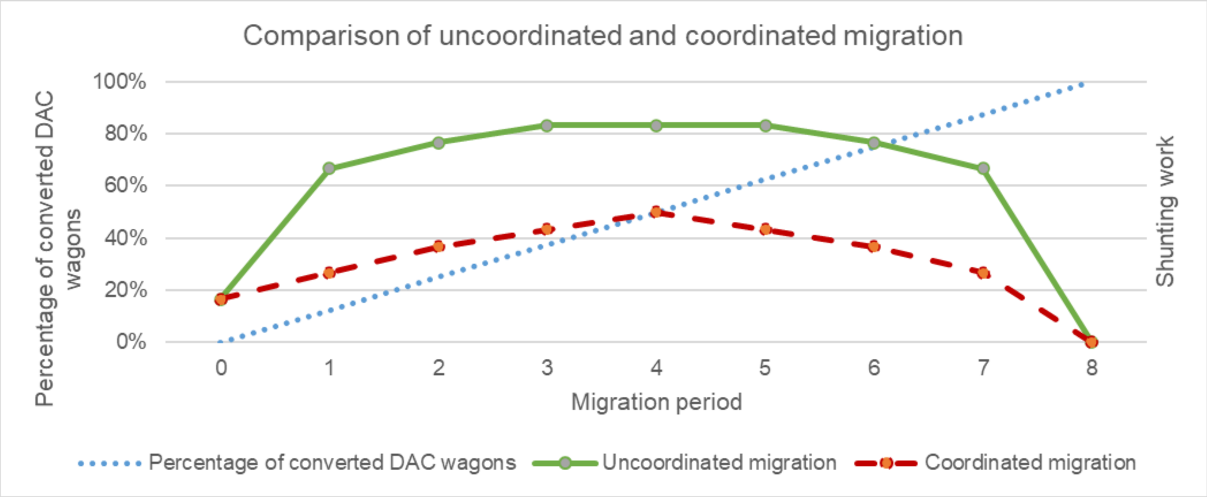
The additional shunting work for a parallel operation of SCs and DACs in the single wagon traffic system could be kept to a minimum by ensuring an extremely short migration time. This would require a highly focused conversion of all wagons in the shortest possible time. The corresponding production capacities for manufacturing the required number of DACs would have to be in place before an ‘accelerated migration’ could take place. Concerted action in terms of workshop capacities would also be necessary in both the freight and passenger transport sectors for accelerated installation of almost the entire volume of DACs. This could significantly reduce the expected additional operational costs of migration. An accelerated strengthening of this segment would become perceptible more quickly.

However, a migration planned over several years, and the inevitable parallel operation of SC and DAC wagons that results from this strategy, would allow the demand for coupling production and workshop capacities to be smoothed out over the migration period. In this case, the functioning of regular operations – with the described additional costs over a longer period of time – in the TFFs must be ensured, and overloading of the facilities must be avoided. Cleary, higher production costs are to be expected during a migration due to the increased shunting work required to provide the service (incl. the use of coupler wagons, increased use of resources).

If a longer migration period is chosen, measures must be taken to limit shunting work and thus achieve operational feasibility in the facilities. For this purpose, the term ‘coordinated migration’ is therefore introduced at this point.

The simulation shows that shunting work increases significantly even when relatively few wagons have been converted, and that they only fall when the conversion is nearly complete. A ‘coordinated migration’ should mitigate the sharp increase in shunting work and pass the apex at an earlier stage. This relationship is shown qualitatively in Fig. 21. The simulation results, which are based on an uncoordinated migration within a sector conversion, correspond to the solid green curve in this graph.

Fig. 21: Qualitative comparison of shunting work in an uncoordinated migration vs a coordinated migration



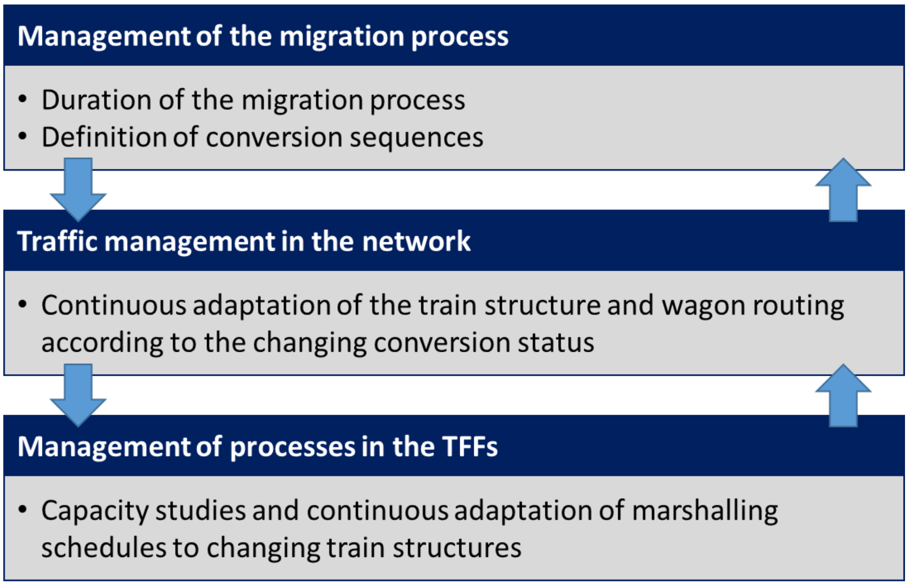
Source: TU Dresden

To ensure that the efficiency of the single wagon traffic system is largely maintained during a long-term migration period, a flattened expenditure curve is desirable. Based on the simulation studies and the evaluations carried out for this purpose, the authors propose controlling the migration on various levels for a migration process that lasts several years and flattens the expense curve. Fig. 22 shows three steps for controlling migration with a coordinated approach:

1. Management of the migration process.
2. Management of the traffic in the network.
3. Management of the traffic in the TFF.

and names the essential processes to be controlled (level model).

Fig. 22: Layer model for managing a migration



Source: TU Dresden

In this approach, the **first level** comprises an **overarching management of the migration process**. Here, the exact framework conditions of the migration must be clarified and defined. This includes determining the duration of the migration process as well as a sequence for converting the wagons over time. It is particularly important here to identify closed wagon groups, so as to focus on the conversion of entire trains and reduce mixed operation. Alongside the industry-driven approach used in the study, a route-based approach independent of the type of freight wagon can also be chosen, i.e. one that identifies which wagons run on the same routes. Through these measures, it may be possible to reduce the number of mixed trains during the migration phase in a ‘mixed traffic’ operating strategy. In the case of ‘separate traffic’, on the other hand, this measure could improve the capacity utilisation of individual trains and thus limit an increase in the train structure.

The **second level** comprises management of traffic flows in the network based on the basic migration conditions defined in Level 1. Traffic flow management here involves the continuous adaptation of the entire train structure in the network to reflect the changing wagon conversion status. Changing the train structure in the network also entails adapting the wagon flows in the network. Basically, no recommendation can be made at this point as to whether the ‘mixed traffic’, ‘separate traffic’ operating strategies or a hybrid variant should be used, as this must always be reassessed in relation to the current level of conversion.

There are, however, various options for separating wagons by coupling type in terms of time and geographical location. It is conceivable that different TFFs could be allocated different proportions of SC and DAC wagons (precisely defined to match the conversion status of a route). This means that some TFFs can handle mainly DAC wagons, while other facilities focus primarily on SC wagons. This would require adaptation of the current reference number system that determines the routing of wagons through the network. It would have to be expanded to include the type of coupling, in order to direct DAC or SC flows via certain facilities (for example, wagons from Munich to Gremberg are routed via Nuremberg with SC, and via Mannheim with DAC). Dividing the network into a DAC and an SC system within single wagon traffic can only be carried out at this point if there are defined interfaces between the systems that ensure customer access. This requires separate preliminary studies, accurate data for volume flows and the involvement of the customers of the single wagon traffic system.

Another option would be to **separate traffic flows according to time**. Here, specified intervals of the daily operations at the TFF could be earmarked for handling trains with a certain type of coupling. If inbound and outbound trains were coordinated in this way at network level, a high capacity utilisation of pure DAC trains could be achieved at an early stage, and mixed operation could be reduced. By then, this measure may be enough to delay the breaking up of trains that do not match the desired coupling type (capacity required in the inbound group and/or in the inflow). A best-practice example of this is SBB Cargo's three waves production.[11]

An essential factor in ensuring the success of network planning is the precise analysis of the facility capacities when adapting the train structures. If the system capacity is exceeded, changes at the network level are absolutely necessary to safeguard operations at the TFFs. In particular, the additional costs for forming mixed trains ('mixed trains' operating strategy), increased numbers of trains ('separate traffic' operating strategy), and the timing of train movements must be taken into account.

The **third level** is the **management of processes in the TFFs**. Due to the altered train structure in the network, TFFs must also continuously adapt their marshalling work plans and report capacity bottlenecks back to the network planning level. The details of the interaction between network planning and the TFFs require further investigation. It is evident that the additional shunting work identified in the context of a migration leads to greater resource requirements (personnel, locomotives, and tracks) which can vary locally depending on the train structure throughout the network as a whole. The resources required can be determined with planning and simulation tools as used in this study. This enables TFFs that bear a particularly heavy load during the migration phase to be targeted and strengthened.

Consequently, the **three levels** of the model **cannot be considered in isolation** but are strongly interdependent. An exchange of the results of coordination at the different levels is therefore a decisive factor in the success of a migration.

A coordinated migration requires a focused, consistent approach that is supported in the implementation by additional information flows. Based on the three-levels model presented for a migration phase, further network simulations are recommended to study the management of network traffic and scenarios regarding the effects of these changes in train structure on TFFs – also (and urgently) with the participation of single wagon traffic customers.

[11] SBB Cargo (2017).

6. Concluding remarks

In single wagon traffic, the introduction of a DAC is seen as a key enabler for increasing the quality of transport and reducing operating costs – with the potential to digitise and automate operating processes in all European rail freight companies in the future.[12] Pilot projects are already focusing on practical applications and technical testing of DACs in operation.[13]

One of the central questions is how migration can take place in the existing single wagon transport system in Europe when the DAC is introduced. Several factors will have a significant influence on this decision, including the speed with which a DAC can be made available to system participants and the strategy for parallel operation of the SC and DAC over a longer migration period. A parallel operation phase is unavoidable because, with current technologies, the SC and DAC are not directly compatible without special adapter technologies.

The present study therefore examined, for the migration to a DAC system, the effects of several years of parallel operation of the SC and DAC on a TFF, using different operating strategies.

The studies were based on simulation techniques that used an experimental version of the tool “APP ZBA” (automated process planning in TFFs). As a result of a research cooperation with Deutsche Bahn, a refined version of this tool is in productive use in TFFs operated by DB Cargo AG. In agreement with the project participants, the 2019 configuration and regulation processes of the Munich North TFF were used as a model for the simulation in this study.[14] The simulations were based on real operating data (train movements and wagon volumes) from March 2019.

The simulation uses scenarios that reflect different points in time during a migration to DAC, based on the operational processes in a TFF. The decision regarding the selection of wagons to be retrofitted within an industry and the point in time at which this retrofitting takes place is random and therefore not controlled.

Under these conditions, the **‘mixed traffic’** operating strategy shows that a conversion from SC to DAC over a migration period of several years quickly leads to an overload at the TFF. The large number of mixed trains results in considerable additional shunting work which exceeds a facility’s capacity if the number of mixed trains is too high.

Simulations using a **‘separate traffic’** operating strategy clearly show that only the scenarios for the conversion of one sector can be solved (here the automotive sector, and only without consideration of additional special operative processes and internal transports). However, even in this scenario, traffic already reaches the capacity limit of the TFF. No acceptable solution could be found in the scenarios for the subsequent conversion of wagons used by the chemical industry and other sector. Above all, this is due to the rapid growth in the numbers of trains in these scenarios (separate trains SC and DAC), which overload the resources and infrastructure of the TFF.

Based on the simulation studies and evaluation of their results, it was found that there is potential for optimising both the ‘mixed traffic’ and the ‘separate traffic’ operating strategies.

In both cases, suitable measures must be introduced to limit additional shunting work and largely maintain the efficiency of the single wagon traffic system. For this reason, the authors

[12] See König & Hecht (2012); Technical Innovation Circle for Rail Freight Transport (2019).
[13] See DB Cargo AG; VTG AG (2020); SBB Cargo AG (2019).
[14] Kick-off workshop, Frankfurt am Main, 17.07.2019

recommend the use of a three-level model in which a migration can be managed at different levels (management of the migration process, of network traffic, and of processes in the TFF).

Overall, the present study shows that considerable additional shunting work is to be expected in the TFFs if wagons are converted in an uncoordinated manner during the parallel operation phase of wagons with SCs and wagons with a DAC. Without additional resources (infrastructure, personnel, locomotives) or functioning controls for the migration and daily operations (in the network, at single wagon traffic customers and in the facilities themselves), the TFFs quickly reach their capacity limits.

The results of this study confirm the proposition that a migration phase should be kept as short as possible.

To plan different approaches to the migration, further studies are required – on possible changes in the single wagon load traffic network, and on the feasibility and effects of comprehensive controls for the network and TFFs. Single wagon traffic customers should also be involved in this process.

Intelligent management of the migration process in the network and TFFs will play a key role in maintaining the performance of single wagon traffic during the migration phase from the SC to the much-needed DAC.

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Glossary of acronyms

BMVI	Federal Ministry of Transport and Digital Infrastructure
DAC	Digital automatic coupling
SC	Screw coupling
TFF	Train formation facility
TU Dresden	Technical University of Dresden

Annex 1: Project team

TU Dresden

https://tu-dresden.de/bu/verkehr

Project management: Prof. Dr.-Ing. Rainer König

Project collaboration: Mr Tobias Pollehn, M.Sc., Mr Moritz Ruf, M.Sc.

The Faculty of Transport Sciences ‘Friedrich List’ is Germany’s largest academic centre of excellence in the field of transport sciences, with a tradition of over 60 years of research and teaching in Dresden. Its system-oriented approach focuses on the complexity of transport and communication networks and processes, therefore taking into account the dynamic challenges of the transport markets. With its interdisciplinary teaching and research network of transport economics, transport technology, transport infrastructure and traffic engineering, the faculty makes an important contribution to the sustainable development of all transport and infrastructure systems in order to meet the ever-growing mobility needs of society. The faculty comprises seven institutes with more than 20 professors and more than 250 employees. A total of around 2,000 students are enrolled in the faculty’s diploma, bachelor’s and master’s degree programmes, and in inter-faculty degree programmes.