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DELIVERABLE D 5.1

IMPACT OF DAC ON PRODUCTION PERSONNEL AT MARSHALLING YARDS

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[1] PU: Public; CO: Confidential, only for members of the consortium (including Commission Services)

[1] https://projects.shift2rail.org/s2r_matrixtd.aspx

Document history

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02-11-2023	Peter Torstensson, Malcolm Lundgren, Peter Perstel	VTI, TRV, VIF	Project team members, PM	Final revision and resubmission

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1 Introduction

The current deliverable is an outcome of the EU-project titled DACcelerate part of WP4 (Infrastructure, capacity and modal shift/Green deal) in the European DAC Delivery Programme (EDDP, under the WP structure valid until end-2022). EDDP WP4 has been led by Trafikverket who is also in various leading positions/WPs in TRANS4M-R and EDDP neo. The overall objective DACcelerate WP5 is **to investigate the changes in work environment at marshalling yards that a transition from screw couplers to Digital Automatic Couplers (DAC) entails**. Production at the main marshalling yards of Sweden and Austria is analysed and compared. These two marshalling yards represent significant differences in terms of traffic throughput, physical design and organisation of production personnel. Job tasks performed by different professional roles at the marshalling yard has been surveyed as well as how personnel interact in accordance with current work processes. The research method applied in the current work has primarily involved workplace visits and interviews and hence the investigation has required a close collaboration with operators of marshalling yards. For the case studies in Sweden and Austria this has meant a comprehensive and trustful cooperation with the operator Green Cargo and the Austrian federal railways ÖBB. The current project has been integrated in WP4 of the EDDP programme as well as aligned with unions and other stakeholders through workshops held during the period when the project was carried out.

1.1 About DAC

In the current study, the impact of DAC at level 4 and 5 is investigated. DAC level 4 means that the physical coupling, and the connection of air pipes, power cables and data cables are managed without manual work by an operator. At decoupling, manual work is however required for example by pulling a handle at the side of the DAC resp. of the wagon. For DAC level 5, both coupling and decoupling are operated remotely by, for example, the train driver or personnel on the marshalling yard.

1.2 Objective

The impact of the introduction of DAC on work environment and working procedures at marshalling yards is studied with the objective to describe the changes in the work tasks, environment, and roles that this transition will entail. The current work focuses on human factors.

The work sets out from a current situation assessment on how work at marshalling yards is conducted and organised today. Involved professional roles including job profiles and qualification requirements are presented. The result provides an important baseline in the identification of future needs and challenges, as well as in the analysis of the impact of the introduction of new technology.

As a next step, work tasks and related professional roles believed to be affected by DAC are identified. These results are obtained through in-depth interviews with experienced production personnel from marshalling yards. In these interviews emphasis is directed towards the work environment that these personnel are exposed to and DAC’s potential to improve in this respect.

Finally, recommendations and suggestions to facilitate a future adoption of DAC at European marshalling yards are presented. Challenges and related prioritised questions that require further investigation are pointed out.

1.3 Method

The information used in this report is obtained from a review of documents, interviews, workplace visits, and workshops.

A number of documents were reviewed. These documents include a database on reported personnel injuries due to accidents in connection to marshalling in Sweden during years 2019–2021, provided by Green Cargo, and a report from the Austrian Federal Railways (ÖBB) comparing the marshalling yards at Hallsberg and Vienna (Wien Kledering).

The current work was carried out between years 2021-2022 during the period when the covid-19 pandemic hit the world. This represented a significant challenge during the execution of the project in such a way that site visits and in-person interviews were periodically impossible to carry out. Four in-depth interviews were conducted as part of the current work. One with a group leader at Green Cargo, who works in production at the marshalling yard in Hallsberg, and one with a senior researcher at Research Institutes of Sweden (RISE), who has worked with winter testing of DAC. Two supplementary interviews were conducted with a train driver and shunter employed at the Austrian operator Steiermarkbahn Transport and Logistics BmbH. The interviews included questions about the working environment as well as expected impact of DAC at level 4 and 5. As described in Section 3.2 and in the hierarchical task analysis of Section 4, the remote-control locomotive operator of Green cargo at Hallsberg's marshalling performs all tasks involved in the production at the site. This means that the interview subject of Green cargo has valuable experience of all different tasks conducted at the entrance-, classification- and departure yard as well as at the hump.

In terms of physical design, marshalling yards can be characterised into flat yards (with or without a hump) and gravity yards (Shift2rail, 2017). In particular, the construction of a marshalling yard with a hump allows for a significant increase in its effectiveness and capacity (Shift2rail ARC, 2016). This is an important reason why almost all gravity yards have been retrofitted with humps (Shift2rail SMART, 2016). Flat yards constructed without humps require shunting locomotives in order to move wagons forth and back during the train building process and are typically not used in countries that pursue single wagonload rail (SWL) freight (European commission, 2015). Two marshalling yards located in Hallsberg, Sweden, and in Vienna, Austria, were chosen for case studies as part of the current work. The selection was made based on the magnitude of their operation (both are the largest marshalling yard in their respective country) as well as layout. Regarding the latter, Hallsberg is a gravity yard whereas the site in Vienna is a flat yard. Both marshalling yards are constructed with humps which is consistent with the majority of marshalling yards in Europe. In addition, it can be noted that the research method applied in this work (based on workplace visits and interviews) is demanding and requires a great deal of participation from cooperating organisations and personnel. Well-established and trusting relationships between researchers and collaborating parties are a prerequisite.

At the marshalling yard in Hallsberg, the authors of the report met with the personnel and visited the site during scheduled production. During the marshalling, the personnel explained the process while we observed. We were also able to ask questions for further details. In Vienna, we met with the personnel and were taken on a tour of the marshalling yard. During the tour the work was described, and we were able to ask questions for further details.

Two workshops were held in connection with the workplace visits. Personnel at the marshalling yards in Hallsberg and Vienna, respectively, participated in the workshops where todays working environment as well as the expected impact of DAC at level 4 and 5 were discussed. In addition, a workshop with personnel from Hallsberg marshalling yard as well as from RISE was conducted to discuss the performed winter testing of DAC.

1.4 Outline of the report

An overview of selected relevant results from previous projects conducted as part of the activities in the development programme Shift2rail funded as part of Horizon 2020 is presented in Chapter 2. A key element of the current work is the detailed study of the working procedures at the largest marshalling yard in Sweden located at the city of Hallsberg. General information of this site is described in Chapter 3. Chapter 4 presents the so-called Hierarchical Task analysis (HTA) of Hallsberg. Chapter 5 and Chapter 6 discuss the impact of DAC on production at Hallsberg and work environment of personnel at the same site, respectively. The results obtained for Hallsberg are used as reference in a comparison with the conditions at the largest marshalling yard in Austria located outside Vienna. Chapter 7 presents a comparison between the marshalling yards in Hallsberg and Vienna. Final remarks are given in Chapter 8.

2 Overview of relevant projects performed as part of Shift2rail

Relevant projects and deliverables produced as part of Shift2rail are reviewed, see Table 1. Below results from these previous studies are related to the investigation carried out as part of the current work.

Table 1. Overview of projects and deliverables performed as part of Shift2rail that are relevant to the current work.

Name	Timeline	Involved parties	Main deliverables
ARCC (Automatic Rail Cargo Consortium)	01/09/2016-30/04/2021	DB, Bombardier, Trafikverket, Hitachi Rail STS, Slovenske železnice	D1.3, D2.1
FR8HUB (Real time information applications and energy efficient solutions for rail freight)	01/09/2017-28/02/2021	Trafikverket, DB, Bombardier, CAF, Hitachi Rail STS, Indra, ConTraffic, CEIT, DLR, Die bahnindustrie, Virtual vehicle, AVL, ÖBB	D1.2, D4.1, D4.2
FR8RAIL I FR8RAIL II FR8RAIL III FR8RAIL IV	01/09/2016-31/08/2019 01/05/2018-31/12/2022 01/09/2019-30/06/2023 01/07/2020-31/03/2023	Trafikverket, CTH, KTH, LTH, DB, Hitachi Rail STS, CAF, Bombardier, Virtual vehicle, Indra, Tatravagónka poprad, Knorr-bremse, SBB, ConTraffic, DLR, WBN, ACT, CEIT, Die bahmindustrie, MCL, PJM, SNCF, Faively, AVL	D5.1, D5.2, D5.3, D5.5, D5.6 D1.2 D3.3 D4.2

2.1 ARCC

The overall objective of the Automated Rail Cargo Consortium (ARCC) project was to conduct initial phase research to prepare for future automatic rail freight operations with increased levels of quality, efficiency and cost effectiveness.

ARCC suggests two different solutions for automated brake testing, one for partial automation (1) and one for full automation (2). Sections 4.2.2 and 4.2.3 of the current report present the procedures performed related to brake testing during production at Hallsberg's marshalling yard in Sweden. A full brake test requires the authorized person (most commonly the train driver) to walk along the entire train length six times which adds up to a total time for one test of about 60 min. Since brake tests are performed independent of time of the day and potential adverse weather conditions (heat, cold, rain, snow), work safety and comfort are also relevant aspects in this regard. Solution (1) eliminates four out of six inspection-walks of the full brake test and is associated with low implementation barriers. Solution (2), on the other hand, requires retrofitting of all wagons and locomotives with new sensors, electric power and data transmission (the later enabled through for example digital automatic couplers). Moreover, in correspondence with the discussion in Chapter 8 of the current report, the necessity to find technological solutions to account for tasks that are not carried out as part of the brake test as such, but nevertheless included in the associated work procedures (such as for example inspection) is commented.

As part of ARCC, operational procedures and decision processes at marshalling yards and terminals were investigated. This work considered operational management in a broad sense accounting for both traffic and personnel resources as well as interlinkage with network management. However, technological innovations to facilitate production such as automatic couplers were not considered. Similar to the work presented herein, Hallsberg in Sweden was selected for this study. In addition, the investigation included the marshalling yards Mannheim and München-Nord in Germany. The work illustrated the same principle difference in operation of marshalling yards located in Sweden and Germany, as is noticed in the comparison between Hallsberg's marshalling yard and the site located in Wien-Kledering, Austria, presented in the current report. Namely, that the production personnel at the German marshalling yards showed a significantly higher degree of specialisation as compared to their colleagues in Sweden. Typically, production personnel at Hallsberg rotate between the entrance-, classification- and departure yards which does not mimic the procedure at the considered marshalling yards in Germany. Further discussion on this topic is found in Chapter 4 and Chapter 7.

2.2 FR8HUB

The FR8HUB consortium engaged in different research activities with potential to increase the capacity, operational reliability and energy efficiency while at the same time reducing the LCC and noise emissions from rail freight operations. Their studies of so-called Intelligent Video Gates (IVGs) are of particular interest for the work in the current report. At its core, a video gate is an infrastructure that carries technologies (such as optical sensors) to enable automatic inspection of freight trains. As discussed in Chapters 6 and 8 in the current report, in order to realize the anticipated improvements with respect to both efficiency and work environment, automatic couplers need to be introduced in parallel to the implementation of technologies for automatic inspection of freight trains. IVGs are considered to promote operational efficiency mainly through:
Faster arrival processes through deviation management and identification of wagons and loading units with higher degree of automation during arrival processes,
More efficient and safer departure processes through higher degree of automation at departure.
With respect to (1) above, today's time-consuming manual inspection work carried out at the entrance yard of Hallsberg is described in Section 4.2.1.

FR8HUB put special emphasis on IVGs potential to improve the efficiency at intermodal terminals where today's operation is characterised by a large content of manual work. This includes for example manual inspection of both incoming and outgoing trains, each requiring up to 45 min. FR8HUB estimates that the introduction of IVGs at intermodal terminals leads to a reduction of this processing time to 15 min enabling an increase in the terminal capacity/throughput of about 15 %. At terminals, IVGs are intended to facilitate the transhipment where the liability of the freight units is transferred from the train to the terminal operator. As part of this process the operator collects information from the incoming train as for example UIC wagon numbers, wagon serialization, position of dangerous cargo, load units etc. and compares against data announced by the train operator on beforehand. As part of FR8HUB a proof of concept for an IVG was presented that verified the functionalities of technical equipment/sensors, logical modules, software and algorithms for a modelled train in a lab environment. The image processing functionalities were also tested with real photographs obtained on-site in a terminal.

2.3 FR8RAIL I-IV

FR8RAIL focused on six main areas/work packages to achieve the long-term objectives of 10 % reduction in costs of freight transport and a reduction in time variation during dwell times of 20 %. For the current work the work packages "Automatic coupling" (WP5) and "Telematics & electrification" (WP3) where, amongst other things, the Intelligent Video Gates (IVGs) were studied and developed, are of particular interest.

Migration plans for the transformation of rail freight from manual to automatic couplers was investigated as part of FR8RAIL I. During the migration period the interoperability of the automatic coupler design (to also be compatible with screw couplers) constitute an important feature and was selected as one key performance indicator (KPI) together with transmitted forces, weight, and data and power transmission. A technical evaluation of the KPIs and a complementary FMECA (Failure Mode and Effects and Criticality Analysis) of different available designs of automatic couplers were performed to give the most competitive solution. How to handle a failure in the automatic couplers during production at the marshalling yard was a question raised during the interviews performed as part of the current work, see Chapter 5. For the migration, a progressive implementation of the European freight wagon fleet over a time of 12 years is proposed. This way the market actors are given time to schedule retrofitting as part of regular maintenance and in a time perspective that meets the typical investment cycles.

Cost-benefit-analyses have been presented for automatic couplers at different automation levels, for transport chains with different characteristics (wagonload and intermodal) and at market environments with high and low labour costs. In most cases, a positive business case for automatic couplers result. This is especially true for automatic couplers type 4 (automatic mechanical coupling as well as of air pipe, power line, train data bus) and 5 (type 4 + automatic de-coupling) and for market environments with high labour costs. It is commented that the European freight wagon fleet of bout 600 000 wagons operating as part of the wagonload system, traffic interlaced and cross-border. This underlines the importance of the coupler interoperability as well as puts a level of complexity on the migration plan realising that many of the benefits and economic savings appear at first at a high deployment rate. The cost-benefit-analyses also discuss the importance to coordinate the introduction of automatic couplers with other related technologies to enable the sought-after automation, e.g. Intelligent video gates at terminals and marshalling yards. This is important given the large investment cost of automatic couplers (corresponding to up to a certain percentage of the cost of the wagon, depending on the later series product price) and the significance of this cost share especially in market environments with low labour costs. Automatic couplers at type 4 and 5 are currently under development in Europe. It is commented that a thorough long-term testing program is needed before deployment in large scale.

The IVG was installed by Trafikverket in Gothenburg was selected as case study performed as part of FR8RAIL III. Focus was on methodologies for the image processing and data sharing performed related to the automatic detection of e.g. wagon numbers, intermodal loading units as well as dangerous goods, their sequence, and wagon damages (such as for example graffiti). The evaluation showed room for improvements in the information extraction to meet the set goal of an accuracy level of 95 %. However, the concept also showed promise to become a building block for future automated and digitalized operation of terminals and marshalling yards.

As part of FR8RAIL IV, a Collision Avoidance System (CAS) for shunting locomotives has been developed and tested. The system was particularly adapted to conditions at marshalling yards with low-speed operations. It was developed to observe the gauge clearance area for straight and curved track, as well as in switches and crossings. Obstacles accounted for were persons (that may or may not carry safety vests) and other rail vehicles (especially other freight wagons or locomotives). Additional obstacles such as for example braking shoes were of particular interest given the application at the marshalling yards. Testcases were run both at day and nighttime. The evaluation showed that the system was well functioning, and the false positive warnings and alarms could be reduced to a minimum. Chapter 6 presents a further discussion on the working environment at marshalling yards based on descriptive statistics obtained from the rail freight operator Green cargo and interviews with production personnel.

3 Description of Hallsberg marshalling yard

The marshalling yard in Hallsberg is the largest in the Nordic countries and it is Sweden's largest railway junction, connecting the Western Main Line and the freight line through Bergslagen (see Figure 1) ("Hallsbergs station", 2022). The site also includes an intermodal terminal which has three railway tracks and connects to European highways E18 and E20. The infrastructure of Hallsberg's marshalling yard is managed by the Swedish Transport Administration (Trafikverket), while the company Green Cargo is responsible for operation. The intermodal terminal is run by the company Logent.

Green Cargo is Sweden's largest operator of railway freight with a market share of approximately 60 percent. It is owned by the Swedish State and managed by the Ministry of Enterprise and Innovation (Government Offices of Sweden, 2022). The company transport 21 million metric tons of freight annually and has approximately 1 900 employees. They serve almost 300 locations in Sweden, Norway, and Denmark, and run on an average weekday 400 freight trains. The Green Cargo freight train fleet includes approximately 5 000 wagons and 360 locomotives (Green Cargo, 2022).

Figure 1. Map of Sweden with the main railway lines outlined.

The Hallsberg marshalling yard covers an area of approximately 300 000 m^2 and extends a distance of more than 3 km. It has a consistent downwards slope of 0.3 percent from the entrance towards the departure yard. The marshalling yard is divided into four zones:

- the entrance yard (1 passage track and 8 line-up tracks),
- the marshalling zone (2 tracks over the hump),
- the classification yard (32 tracks),
- and the departure yard (12 tracks).

In addition, there are seven line-up tracks, ten tracks in the workshop, eight tracks at the locomotive depot, and a traffic control tower where the marshalling planners and operators are located. Green Cargo owns all the locomotives used for marshalling, but not the freight wagons. A principal sketch of the Hallsberg marshalling yard is shown in Figure 2. Figure 3 presents a schematic view of the yard with important components outlined.

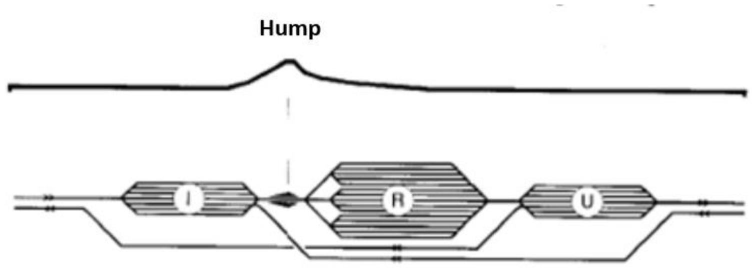


Figure 2. Principal sketch of Hallsberg marshalling yard including a hump. *I*=Entrance yard, *R*=Classification yard, *U*=Departure yard. Source: Nelldal & Wajsman (2014).

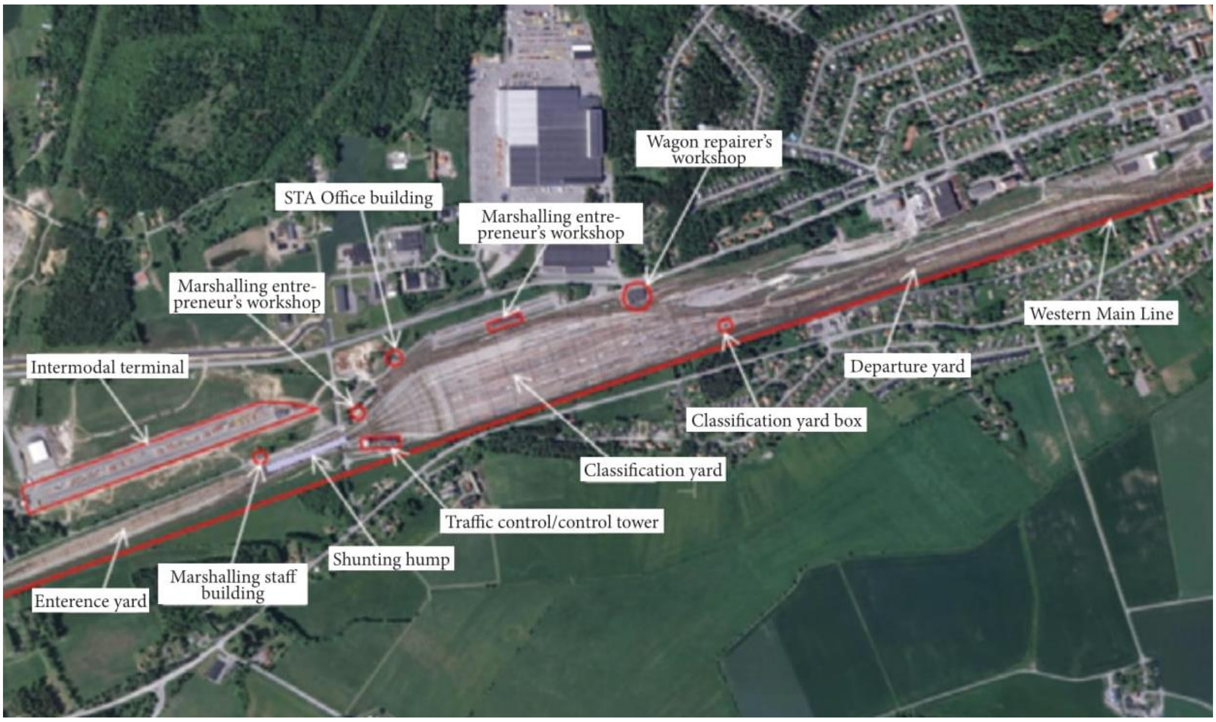


Figure 3. Overview of Hallsberg marshalling yard with important components of the physical design outlined. Source: The Swedish Transport Administration (2018).

Traffic flow through the main marshalling yards in Sweden is presented in Table 2. In 2013, approximately 35 trains were marshalled daily at Hallsberg. According to private communication, the current throughput at Hallsberg amounts to approximately 36 trains per day.

Table 2. Traffic flow at Swedish rail yards in year 2013. Hallsberg marshalling yard used for the case study in the current work in *italic*. Source: Nelldal & Wajsman (2014).

	Number of trains		Number of wagons	
Marshalling/freight yard	**Annually**	**Daily**	**Annually**	**Daily**
Hallsberg marshalling yard	*9 623*	*35*	*240 575*	*875*
Malmö freight yard	5 814	21	145 350	529
Sävenäs marshalling yard	5 777	21	144 425	525
Gävle freight yard	3 598	13	89 950	290
Ånge freight yard	3 307	13	82 675	286
Borlänge marshalling yard	3 194	12	79 850	275
Helsingborgs freight yard	2 494	9	62 350	327
Nässjö Central	2 122	8	53 050	193
Sundsvalls marshalling yard	1 265	5	31 625	115
Tomteboda	504	2	12 600	46
Västerås västra	465	2	11 625	42
Jönköpings freight yard	297	1	7 425	27
Trelleborg	291	1	7 275	26

3.1.1 Comparison to Wien Kledering marshalling yard

As described in Section 1.3, a workshop was held in Vienna with the Austrian Federal Railways (ÖBB).One objective was to comment on the performed hierarchal task analysis based on the operation in Hallsberg, see Section 3, and compare that to the operation at Wien Kledering. The report made by ÖBB in response to this workshop is an important basis for the content below.

In Table 3, physical and operational parameters of Hallsberg and Wien Kledering are compared. Wien Kledering is roughly three times the size, length and throughput compared to Hallsberg. An important difference in physical design is that Hallsberg has a continuous downwards slope whereas the classification yard at Wien Kledering is tub-shaped with a low-point between the hump and the departure yard.

Table 3. Physical and operational parameters of Hallsberg and Wien Kledering marshalling yards.

Parameters	Hallsberg	Wien Kledering
Area	300.000 m²	1.000.000 m²
Length	3 km	8 km
Topography	3 ‰ gradient from entrance yard to departure yard	Classification yard tub-shaped
Entrance yard	8 line-up tracks and 1 passage track	15 Tracks
Hump	2 tracks	2 tracks in front of the hump and one track after the peak of the hump
Classification yard	32 tracks	48 tracks
Side hump	No	Yes
Additional classification yard	No	13 tracks
Departure yard	12 tracks	10 tracks
Processed trains	36 trains per day	80 trains per day

3.2 Production personnel

The following professional roles are employed by Green Cargo to be involved in production at Hallsberg marshalling yard: remote-control locomotive operators, marshalling operators and marshalling planners. The number of personnel in different professional roles and associated requirement with respect to training are presented in Table 4. Marshalling planners and marshalling operators are located in the traffic control tower and oversee the marshalling; the planner is responsible for the scheduling of operations at the yard while the operator is involved in the ongoing operations by monitoring train movements and communicating with personnel at the yard. These tasks are often performed by the same person at other Swedish marshalling yards, but. The remote-control locomotive operator is responsible for shunting and driving the locomotives on the site.

Table 4 summarises qualification requirements for the different professional roles involved in production at the Hallsberg marshalling yard. The recruitment process for all professional roles includes requirement test, personal meeting, health test and psychological evaluation. Candidates who pass these tests are then subjected to training located to the current site in Hallsberg. Details regarding the requirements, with respect to training, are outlined in Table 4. It can be noted that for a remote-control locomotive operator to be allowed to drive outside of the marshalling yard, a one-year education at a vocational university is generally required. For all personnel, health check-ups are scheduled every three years up to the age of 55 years, after which they are performed annually. In addition, annual competence tests are performed. Table 5 presents the personnel at the marshalling personnel in Hallsberg during a typical day.

Table 4. Number of personnel in different professional roles involved in production at Hallsberg marshalling yard. Required qualifications/training for respective professional role are outlined.

Professional role	Number of personnel	Required qualification
Remote-control locomotive operators	58*	13 weeks basic training (theory and practice). After 1 year of work, a possibility to take 3 weeks further training to be allowed to drive locos at the yard
Marshalling operators	9	Basic requirement for qualifications and work experience as a remote-control locomotive operator at Hallsberg marshalling yard. An additional requirement of 10-weeks of training.
Marshalling planners	5	Basic requirement for qualifications and work experience as marshalling operator at Hallsberg marshalling yard. An additional requirement of 5 weeks of training.

*Including 15 personnel able to perform level shunting and 9 personnel working the loco depot

Table 5. Number of personnel a typical day, categorised by time-of-day and workplace.

Time-of-day	Team leader	Entrance yard	Classifica tion yard	Control tower	Flat yard shunting	Total
Morning	1	2	1	2		**6**
Afternoon/evening	1	5	2	2	2	**12**
Night	1	5	5	2		**13**

3.2.1 Comparison to Wien Kledering marshalling yard

Table 6 presents a mapping between the different professional roles at the marshalling yard located in Hallsberg and Wien Kledering. This is part of the results from the workshop held in Vienna with ÖBB, see Section 1.3. The report made by ÖBB in response to this workshop constitutes the main basis.

Professional roles and job profiles among production personnel differ significantly between the marshalling yards of Hallsberg and Wien Kledering. In general, at Wien Kledering a high degree of specialization (up to 33 distinct roles) is used while at Hallsberg a few professional roles perform a lot more of the tasks as described in the hierarchal task analysis of Section 4.2 below. Typically, remote-control locomotive operators at the Hallsberg marshalling yard rotate between the entrance-, classification- and departure yard as well as the hump. The same does not occur at Wien Kledering.

Table 6. Professional roles of marshalling personnel in Wien Kledering compared to in Hallsberg.

Role in Wien Kledering	Tasks	Role in Hallsberg
Wagon technician (Wagenmeister)	Responsible for the wagon technical inspection and the full brake tests	Remote-control locomotive operator
Shunting worker	Coupling and uncoupling of wagons.	

(Verschieber)	Detachment of wagons on the hump. Bleeds the brakes of the wagons. Sets protection against roll away of the wagons. Simplified brake test.	
Leader of shunting operations with traction vehicle operation (Verschubleiter mit Triebfahrzeug-bedienung)	Can do the same tasks as a shunting worker. Responsible for the safe execution of the shunting operations.	
Dispatcher (Fahrdienstleiter)	Monitors the train movements from the control tower	
Assistant of the Dispatcher (Fahrdienstleiterassistent)	Monitors especially the train movements on the hump	Marshalling operator
Leader of shunting operations / hump master (VL Bergmeister)	Coordinates and super-vises the operative activities on the hump from the tower.	
Shunting coordinator (Verschubkoordinator)	Coordinates the shunting operations from the tower	Marshalling planner

The vocational training process at ÖBB consists of evaluations of physical and mental fitness/health, a requirement of more than three years of active experience (e.g., with assistant dispatchers) and an interview with the recruitment and assessment centre – with evaluations of social skills, how the recruit handles different situations, a stress test and a small exam. Those who pass are put into a pool of trainee prospects.

To become a shunting worker, one must go through 7 weeks of training and pass an exam. With additional training, one can become a shunting operation leader (“Leader of shunting operations”). This training including a practical part where one follow more senior colleagues, do independent work and takes an exam, and takes an additional 32 weeks. For those who wishes to advance, the next step is multifunctional shunting training, which gives the workers the ability to perform more functions on the yard and takes an additional 20 weeks of training. Finally, there is a role which takes an additional 15 weeks to complete called “Leader of shunting operations with traction vehicle operation”.

4 Hierarchical Task Analysis (HTA)

4.1 About HTA

VTI has conducted a task analysis (HTA: Hierarchical Task Analysis). This means that activities during marshalling are studied, and actions carried out to achieve a goal surveyed. The term goal is used to describe the overall what it is that is supposed to be performed. Based on the task analysis and the activities that are described therein a good understanding can be developed of when (the order of specific tasks) and how shunting at Hallsberg marshalling yard is conducted. The task analysis is thus used as a basis for understanding how the overall task (goal) is reached. Through this understanding a company, for example, can create ideas about, and understanding of, the consequences of changes in technical, organizational, or social systems on processes involved in their business. Figure 4 presents a schematic example of an HTA.

The overall aim of the task analysis is to present activities to achieve a goal. To achieve the overall goal, different subgoals must be accomplished, which subsequently requires additional sub-subgoals to be attained, etc. In very complex activities, there can thus be a large hierarchy from goal to sub-sub-subgoal, and so forth. As the activities studied usually contains an interaction between several actors, the HTA typically outlines who (role/actor) that carries out a specific subgoal.

The question is What specific task can be resolved, When and by Whom.

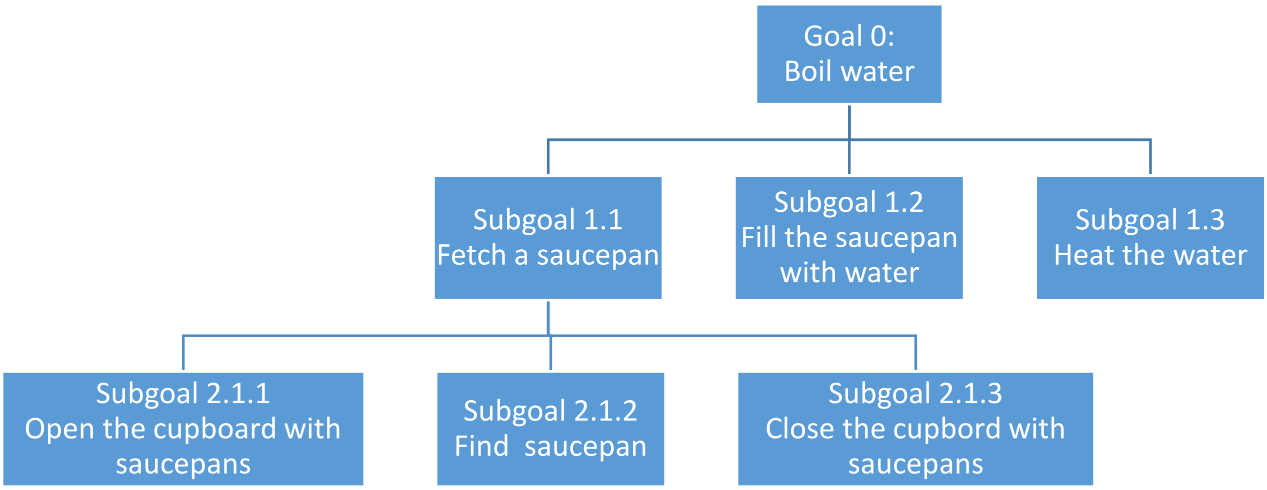


Figure 4. Description of a simple Hierarchical Task analysis (HTA).

4.2 HTA for production at the Hallsberg marshalling yard

A HTA usually becomes very complex and difficult to oversee. One difficulty is to determine the sufficient level (breakdown) of subgoals. For the current work, three levels have been deemed to be sufficient. In the example above (Figure 4), it is possible that 2 levels are sufficient, i.e., level 0 and 1. If, on the other hand, you come to an unfamiliar kitchen, you may need three levels. The more complex the task to be analysed; the more levels are needed for the task analysis to become clear. It has been deemed that shunting with a hump requires three levels of subgoals for readers with a limited understanding of shunting to understand the different activities. The 4th level, where the different steps for how e.g., the train driver actually manages the locomotive is thus not relevant for the present purpose. Figure 5 presents level 0 and level 1 of the HTA for production at the Hallsberg marshalling yard. The following subgoals are described in separate sections.

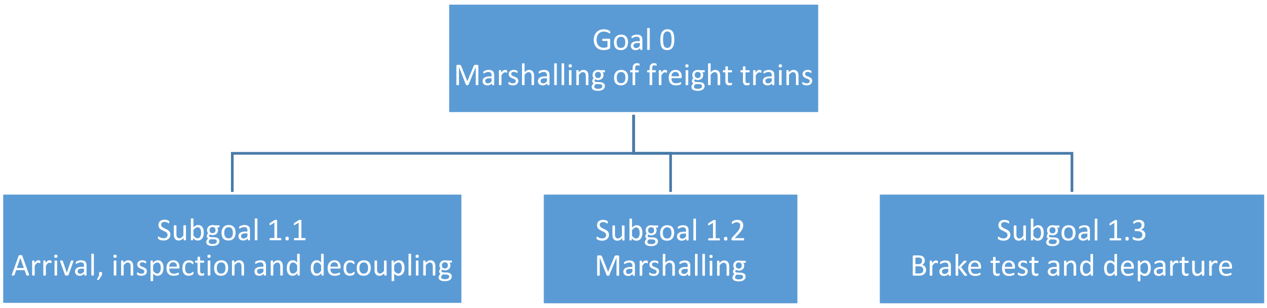


Figure 5. Levels 0 and 1 in HTA for production at the Hallsberg marshalling yard.

4.2.1 Subgoal 1.1: Arrival, inspection and decoupling

This section describes the activities performed associated with subgoal 1.1 “Arrival, inspection and decoupling” of the HTA for production at Hallsberg marshalling yard, see Figure 5. Figure 6 presents the breakdown into subgoals at level 2. Below the tasks performed are described separate for each subgoal.

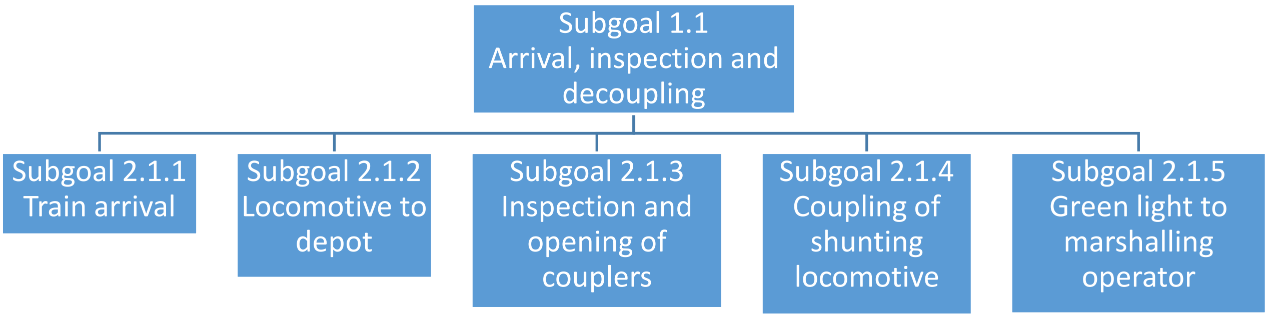


Figure 6. Level 2 for subgoal 1.1 “Arrival, inspection and decoupling” in HTA for production at the Hallsberg marshalling yard.

Subgoal 2.1.1 Train arrival

Trainsets containing wagons for marshalling is left at the entrance yard by the regular train drivers, see Figure 7. A remote-control locomotive operator places a brake shoe in front of the first wagon (closest to the hump) and then disconnects the locomotive by disconnecting the air pipes and open the brake pipe cock. The coupler is then unscrewed and detached.

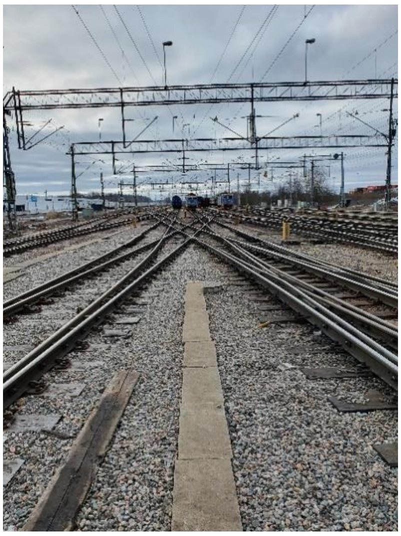


Figure 7. Photograph of the entrance yard.

Subgoal 2.1.2: Locomotive to depot
The regular train driver moves the locomotive to the locomotive depot. The locomotive that is closest to the hump thus leaves the wagon set to be marshalled. One remote-control locomotive operator remains at the entrance yard.

Subgoal 2.1.3: Inspection and opening of couplers
One or two remote-control locomotive operators are involved in this subgoal activity. It happens that the order of subgoal 2.1.3 and subgoal 2.1.4 is reversed, that the shunting locomotive is connected before or at the same time as the inspection and opening of screw couplers are performed.

The work in subgoal 2.1.3 requires a "detachment bill" that specifies the wagons to be detached. The detachment bill is usually identical to the "release bill" used in subgoal 2.2.2, but it happens that changes take place between the time the trainset enters the entrance yard until it passes the hump. Each wagon is inspected to ensure that nothing is broken or that, for example, graffiti hides any important information. Damaged wagons receive a red card and are sent to the workshop. A damaged wagon that is missed during inspection and discovered when the wagons are at the departure yard causes large additional costs.

From the sixth wagon (counted from the hump), the remote-control locomotive operator pulls the triple valve to vent the pneumatic air system and release the brakes, see Figure 8(a). Based on the release bill, the remote-control locomotive operators also prepare the detachment of wagons by unscrewing the couplers at the correct places in the wagon set. This is done by the remote-control locomotive operator who bends under the buffer, disconnects the brake pipes and laying them up, and closes the brake pipe cock before unscrewing the coupler, see Figure 8(b). In the event that two remote-control locomotive operators cooperate during inspection, they start at each end of the wagon set and when they meet, they go over to the other side of the wagon set and inspect the other side on their way back. When the inspection is complete, a green light is given to the remote-control locomotive operator in the shunting locomotive. In cases when screw couplers are frozen or rusted and could not be loosened at the entrance yard, the wagon set is stopped on the hump where there are levers to be used (see subgoal 2.2.2). In this case, the remote-control locomotive operator at the entrance yard reports this to the marshalling operator in the traffic control tower.

(a) (b)

Figure 8. (a) The triple valve (red handle) found on all wagons. (b) The coupler is unscrewed, the brake pipe is disassembled and suspended, and the brake pipe cock (red lever) is closed.

Subgoal 2.1.4: Coupling of shunting locomotive

A remote-control locomotive operator brings a shunting locomotive to the current track at the entrance yard. The locomotive is connected to the wagon that is furthest from the hump. The driver of the shunting locomotive reports to the remote-control locomotive operator who performs the inspection (subgoal 2.1.3) when the locomotive is connected. The remote-control locomotive operator onboard the shunting locomotive may thereafter participate in the inspection of the wagon set, see subgoal 2.1.3.

Subgoal 2.1.5: Green light to marshalling operator

The remote-control locomotive operator in the shunting locomotive drives forward (from the hump) so that the entire wagon set is stretched, to check that the wagons are still “coupled”. At the same time, the remote-control locomotive operator on the entrance yard places himself at the sixth wagon (from the hump) to check that the wagon set is stretched. When this happens, the brakes on the first five braked wagons are released by pulling the triple valve (see Figure 8(a)) at the same time as it is checked that the couplers are stretched.

When this is performed, and the same remote-control locomotive operator also has removed the brake shoes, he/she communicates a “go-ahead” to the remote-control locomotive operator in the shunting locomotive. The driver in the shunting locomotive in turn reports to the marshalling operator in the traffic control tower. The final green light for marshalling is given by the marshalling operator in the traffic control tower. When this has been received, the remote-control locomotive operator in the shunting locomotive begins to reverse towards the hump (by charging the brakes on the wagon set).

4.2.2 Subgoal 1.2: Marshalling

This section describes the activities performed associated with subgoal 1.2 “Marshalling” of the HTA for production at Hallsberg marshalling yard, see Figure 5. Figure 9 presents the breakdown into subgoals at level 2. Below the tasks performed are described separate for each subgoal.

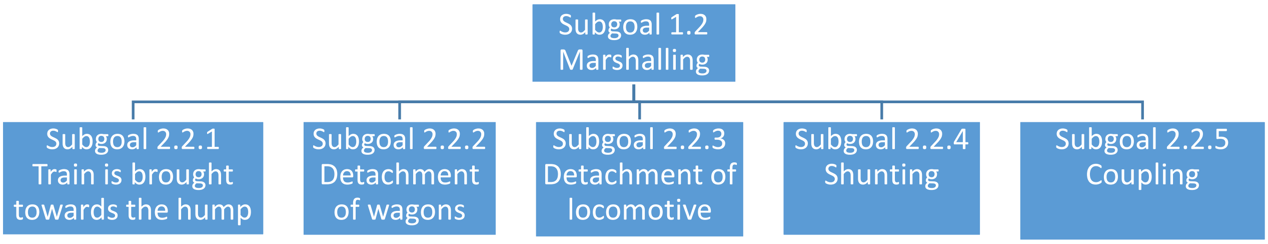


Figure 9. Level 2 for subgoal 1.2 ”Marshalling” of the HTA for production at Hallsberg marshalling yard.

Subgoal 2.2.1: Train is brought towards the hump

After green light is given by the marshalling operator located in the traffic control tower, the remote-control locomotive operator starts to bring the train towards the hump at a speed of maximum 4.2 km/h. Figure 10 shows a photograph of the hump at Hallsberg marshalling yard.

Figure 10. Picture of the hump at Hallsberg marshalling yard.

Subgoal 2.2.2: Detachment of wagons

Wagons are detached in accordance with the release bill (see subgoal 2.1.3). It is required by the remote-control locomotive operator who mans the hump to read this simultaneously as detaching couplers, using the so-called detachment stick, see Figure 11. This is performed while the train is in continuous motion. Dependent on the time of the day, it may be the same personnel who makes the inspection at the arrival yard (subgoal 1.1) that also detach couplers at the hump. In the case of couplers that are stuck because of for example rust or ice, there are level arms that can be used at the hump, see Figure 11(b). After the crest of the hump, wagons roll individually or in groups downwards towards the classification yard. The final destination of each wagon determines to which track on the classification yard it should be directed. Switches are manoeuvred automatically from the traffic control tower from where the marshalling operator monitors the operation. Rail brakes mounted in the infrastructure are used to reduce the speed of the wagons.

(a) (b)

Figure 11. (a) The coupler is detached while the train in continuous motion using a "detachment stick". (b) Lever arm tools to use for the case if a screw coupler could not be released at the arrival yard.

Subgoal 2.2.3: Detachment of locomotive

The shunting locomotive is detached by the remote-control locomotive operator located pressing a button onboard the shunting locomotive, see Figure 12. The detachment of the shunting locomotive is performed between the two final dwarf signals in front of the hump.

Figure 12. The remote-control locomotive operator makes the detachment by pressing a button in the driver compartment.

Subgoal 2.2.4: Shunting

Figure 13 shows free rolling of individual, or groups of, wagons from the crest of the hump towards the classification yard. The wagon speed is reduced with rail brakes mounted in the track superstructure. The first wagon to enter a specific track on the classification yard rolls onto the stop buck. This is followed by all wagons with similar destination which are stopped by the buffers.

Figure 13. Wagons roll individually or in groups from the hump down towards the classification yard.

Subgoal 2.2.5: Coupling

The remote-control locomotive operator at the classification yard uses an air pipe to connect the wagon at the stop buck to the permanent brake test facility, see Figure 14. Wagons are thereafter coupled and inspected by one or two remote-control locomotive operators. The number of personnel depends on the time of the day. To connect wagons the remote-control locomotive operator bends under the buffers, mounts, and tightens the screw coupler, connects the air pipe, and opens the brake pipe cock. When coupling the final wagon, the remote-control locomotive operator ensures that air is present in the entire trainset by inspecting so that the block brakes are mounted as the brake pipe cock of the final wagon is closed. Then the remote-control locomotive operator that mans the permanent brake test facility is given a go-ahead to perform a brake test using the terminal shown in Figure 16.

Figure 14. A wagon stopped by the stop buck and connected to the permanent brake test facility through an air pipe.

4.2.3 Subgoal 1.3: Brake test and departure

Activities related to subgoal 1.3 “Brake test and departure” (see Figure 5) of the HTA for production at Hallsberg marshalling yard are described below. Figure 15 presents the breakdown into subgoals at level 2. Below the tasks performed are described separate for each subgoal.

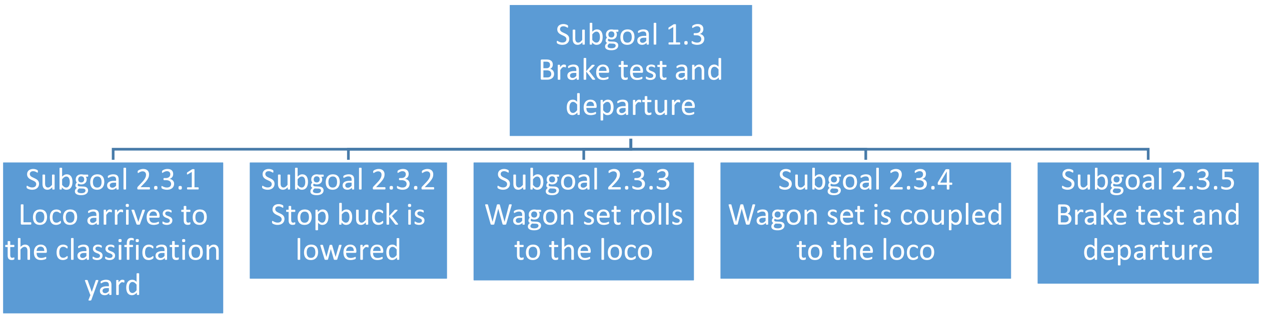


Figure 15. Level 2 for subgoal 1.3 ”Brake test and departure” of the HTA for production at Hallsberg marshalling yard.

Subgoal 2.3.1: Loco arrives to the classification yard

A locomotive arrives to the current track on the classification yard and stops at the opposite side of the stop buck as compared to the coupled wagon set. The remote-control locomotive operator at the brake test facility requests lowering of the stop buck through the terminal shown in Figure 16. The stop buck is lowered when the top three lights on the terminal light up green.

Figure 16. Terminal for performing brake test and communicating with the traffic control tower as well as manoeuvring the stop buck.

Subgoal 2.3.2: Stop buck is lowered
By using the terminal in Figure 16, the remote-control locomotive operator at the classification yard requests a lowering of the pressure in the brake system and hence brake blocks are released, whereupon the wagon set rolls towards the locomotive. At a certain distance (learned through experience) between the wagon and the locomotive, the remote-control locomotive operator requests the brakes to be charged in order for the wagon set to reach the locomotive at a very low speed.

Subgoal 2.3.3: Wagon set rolls to the loco
When the wagon set meets the locomotive, the remote-control locomotive operator bends under the buffers between the first wagon and the locomotive, closes the brake pipe cock, closes the valve to the permanent brake test facility, and detaches the wagon set from it.

Subgoal 2.3.4: Wagon set is coupled to the loco
To couple the locomotive to the wagon set, the remote-control locomotive operator bends under the buffers, mounts the screw coupler and tightens it, attaches the brake air pipe, and opens the brake pipe cock.

Subgoal 2.3.5: Brake test and departure
Two different brake tests are performed. First the train driver in the locomotive requests the brake pressure to be lowered, whereupon the remote-control locomotive operator on the classification yard inspects (ocularly and by hitting the brake blocks), so that the brake blocks on the end car are charged. Secondly, a leakage test is performed by requesting a brake pressure of 5 bars. When this is reached, the input of air is interrupted whereafter the air leakage of the brake system is estimated by assessing the speed at which the brake pressure is lowered. If these two tests are passed, the train is allowed to leave. If the current track on the classification yard is required for

the shunting of subsequent traffic the train is moved to the line-up at the departure yard. If so, an additional short brake test is performed at a later stage before the train leaves the departure yard. This is conducted by the train driver who lowers the brake pressure and inspects so that the brake blocks on the wagon closest to the locomotive are charged.

5 Impact of DAC on production at Hallsberg

Below are minutes from the workshop with production personnel from Hallsberg marshalling yard as well as people from Research Institutes of Sweden (RISE) involved in winter testing of DAC . The workshop was arranged in order to discuss practical challenges related to the adoption of the production at Hallsberg to DAC.

Trafikverket has commissioned RISE to perform winter tests of DAC. From the beginning, four DAC by different manufacturers were selected for the investigation. Preliminary results show that couplers work fine also for harsh winter conditions. Coupling occurs over a minimum speed of 0.6 km/h, but successive coupling tests have been performed for speeds up to 10 km/h. Good results, with respect to ability to couple, have been found also for cases with bad track alignment. It was explained that DAC is designed to show if decoupling has occurred via an observable physical indicator at the side of the DAC, and do, therefore, not require the operator to go under the buffer to check. Currently, the coupler is operated by a handle, and the standard requires it to be reachable from outside the buffers.

Subgoal 2.2.2 "Detachment of wagons" at the hump was discussed. It was explained that decoupling with DAC is easy when it is under compressive forces. However, to decouple under tensional forces is more complex. DAC level 4 uses – in a prototype/demonstrator version existing at the time of this study - a splint that needs to be manually mounted in order for the DAC not to couple under compressive forces. As explained in subgoal 2.1.3, screw couplers that are to be detached at the hump are opened during inspection at the entrance yard. However, it is essential that the entire wagon set remains coupled (as is also verified in subgoal 2.1.5 before start of marshalling) to prohibit wagons to run away on the downwards sloping yard. Hence, Hallsberg does not allow for DAC to be put in non-coupling mode by mounting the splint at the entrance yard.

Also related to subgoal 2.2.2 "Detachment of wagons", and for the case of decoupling at the hump without first putting the DAC in decoupling mode by mounting the splint, couplers may reconnect again when exposed to low magnitude compressive forces. It will be a difficult task for the remote-control locomotive operator at the hump to request decoupling of the DAC at the exact instant when the force in the couple goes from compressive to tensional.

It was underlined that there are still much to consider with respect to operation and safety during marshalling with DAC. The case of DAC level 5 was discussed and particularly who will be remotely responsible to release/decouple the wagons at the hump.

It was discussed how to manage a DAC that is malfunctioning and not able to couple. How to move such a wagon from the track? In response it was mentioned that DAC is already in operation for passenger traffic and hence this question should already have been accounted for. However, the question could not be answered by the participants in the meeting.

Regarding subgoal 2.1.3 "Inspection and opening of couplers", the many activities not directly related to handlsing of the screw couplers were discussed (checking rolling stock, cargo, signs, etc.). In order to increase productivity of marshalling, these activities need to be assessed by other technological solutions than the DAC (e.g., image monitoring, wheel damage indicators, etc.). The participant from the Hallsberg marshalling yard explained the important proportion of tasks not directly related to handling of the couplers.

Subgoal 2.1.3 describes that the brakes of the five wagons closest to the hump are charged by closing the brake pipe cock at the coupler between the fifth and sixth wagon. It was uncertain how to accommodate this procedure for DAC. The participants from the DAC winter test announced that the brake pipe cock will remain also for DAC but were unsure if it will allow usage in this way. Another question regarded the possibility for automatic sensing of brake pipe cocks in DAC. It is essential to be able to vent individual wagons/wagon groups using the triple valve which in turn requires use of the brake pipe cocks. These questions were not able to be resolved during the meeting.

In subgoal 2.2.4 "shunting" the wagons enter the classification yard and are stopped at the stop buck. The design of the stop buck needs to be changed in order to allow for DAC, see Figure 14.

It was consensus that DAC conveys significant advantages in the classification yard as it enables wagons to connect automatically (see subgoal 2.2.5 "coupling"). This, however, presumes that the DAC is not put in "decoupling mode" using a splint, see above.

Table 7 gives an overview of the impact of DAC on the different work tasks/subgoals in the Hierarchical Task Analysis of the production at Hallsberg marshalling yard presented in Chapter 3. As is noticed in the comparison with production at the marshalling yard at Wien Kledering, working procedures and professional roles differ largely. From private communication with Green Cargo, the authors have been told that working procedures may differ significantly also between marshalling yards located in the same country. Therefore Table 7 shows the impact of DAC with respect to the task analysis of Hallsberg marshalling yard rather than professional roles.

Table 7. Summary of the subgoals of the Hierarchical Task Analysis and how they would be affected by the introduction of DAC.

Subgoal	Affected by DAC?*	How would the task be affected?	Implications on work environment
2.1.1 Train arrival	No		
2.1.2 Locomotive to depot	No		
2.1.3 Inspection and opening of couplers	Yes	To prohibit runaway of wagons, DAC level 4 cannot be put in non-coupling mode at the inclined entrance yard of Hallsberg. On the other hand, without this setting, the decoupling at the hump becomes very difficult. However, when these technological challenges have been overcome, DAC will impact the current subgoal or even making it obsolete (especially for DAC level 5). It is uncertain how to accommodate the breaking of the five wagons closest to the hump. Even if the brake pipe cock will remain for DAC, it is unsure if it will allow usage in this way. The introduction of DAC will not affect the manual inspection of wagons and rolling stock.	Removing the requirement of bending under buffers and reducing exposure to high pitch noises when working with the compressed air will make the work less physical demanding. With video-gates for digital inspection, the need for ocular inspection and walking along the tracks are also reduced. This could reduce injuries connected to e.g., falling and collisions.
2.1.4 Coupling of shunting locomotive	No		
2.1.5 Green light to marshalling leader	No		
2.2.1 Train is brought towards the hump	No		
2.2.2 Detachment	Yes	Given the physical design of Hallsberg marshalling yard and	Pulling a handle positioned at the side of the wagons instead of using

of wagons		today's functionality of DAC level 4 it is difficult to understand how to accommodate this new technology at the site. DAC reconnects under compressive forces. But decoupling under tensional forces is also not allowed. In DAC level 4, a splint can manually be mounted in order for the DAC not to couple under compressive forces. But at Hallsberg this would lead to runaway of wagons. Entirely new procedures need to be developed for this task to allow introduction of DAC. It will be a difficult task for the remote-control locomotive operator at the hump to request decoupling of the DAC at the exact instant when the force in the couple goes from compressive to tensional. For DAC level 5 it is also unsure who will be responsible to remotely release/decouple the wagons at the hump.	a so-called detachment stick for DAC level 4 will reduce the need to reach in between the wagons. This could reduce the risk of being squeezed/crushed. However, depending on the release mechanism, a twisting motion could be introduced which could bring other health-related risks, e.g., back strains and sprains. With DAC level 5, no manual release is needed.
2.2.3 Detachment of locomotive	No		
2.2.4 Shunting	Yes	The design of the stop buck needs to be altered in order to allow for DAC.	
2.2.5 Coupling	Yes	DAC enables wagons to connect automatically. This, however, presumes that the DAC is not put in "decoupling mode" using a splint. It is uncertain how the brake test is affected.	Removing the requirement of bending under buffers and lifting heavy couplers will make the work less physical demanding. In addition, the risk of personnel waiting between the buffers for approaching wagons, are removed.
2.3.1 Loco arrives to the classification	No		

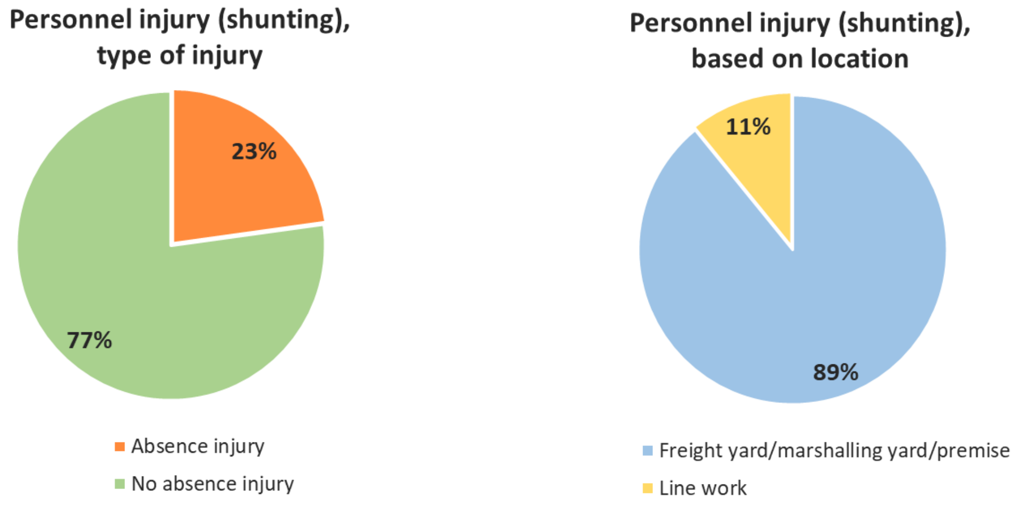
yard			
2.3.2 Stop buck is lowered	No		
2.3.3 Wagon set rolls to the loco	Yes	For the authors of the report, it is still unclear how DAC will enable the wagon to be connected to the permanent brake test facility simultaneously as the DAC is allowed to couple with the loco. This, however, presumes that the DAC is not put in “decoupling mode” using a splint.	
2.3.4 Wagon set is coupled to the loco	Yes	DAC enables the first wagon to connect to the train automatically. This, however, presumes that the DAC is not put in “decoupling mode” using a splint. Also see the comment related to subgoal 2.3.3.	Removing the requirement of bending under buffers and lifting heavy couplers will make the work less physical demanding. It is uncertain how the brake test is affected.
2.3.5 Brake test and departure	No		

*: Allows to answer a dichotomous Yes or No. It should however be noted that it is not always the case that the answer is as clear cut as this. The answer (Yes/No) is based on the understanding of the present development phase of DAC. Several challenges exist and oncoming research and developments of DAC might alter the answers to some extent.

6 Impact of DAC on work environment at Hallsberg

Production personnel in marshalling yards have a physically demanding work with substantial amount of walking, repeated bending under the buffers, heavy lifting of couplers, and exposure to high pitch noises when working with the compressed air. When the couplers are covered in ice or sheaves for other reasons, the work gets extra strenuous. In addition, the environment is dirty and the ground is sometimes slippery (due to for example rain, snow, and ice) and filled with obstacles at the same time as trainsets are frequently in motion. Moreover, in the entrance yard, trainsets could approach from both directions, which is especially precarious in darkness. This kind of physical work takes its toll on the body, while the risk of accidents also is present.

Descriptive statistics of reported personnel injuries, due to accidents in connection to marshalling in Sweden during years 2019–2021, have been provided by Green Cargo. It is important to note that the data cover accident reports and therefore do not cover other negative health effects that occur over longer periods of time, like repetitive straining injuries, hearing loss, mental health etc. According to Figure 17(a) and Figure 17(b), nearly one quarter of the cases led to absence from work and roughly 90% of cases occurred at the marshalling yard, respectively. Figure 18 presents how accident reports are distributed over different categories. It may be observed that falling while on ground level is the most common injury, followed by being squeezed/crushed, being hit and falling while disembarking.



(a) (b)

Figure 17. Distribution of personnel injuries at Green Cargo due to shunting during years 2019-2021 on absence/no absence (a) and locations (b). Base: 193 cases.

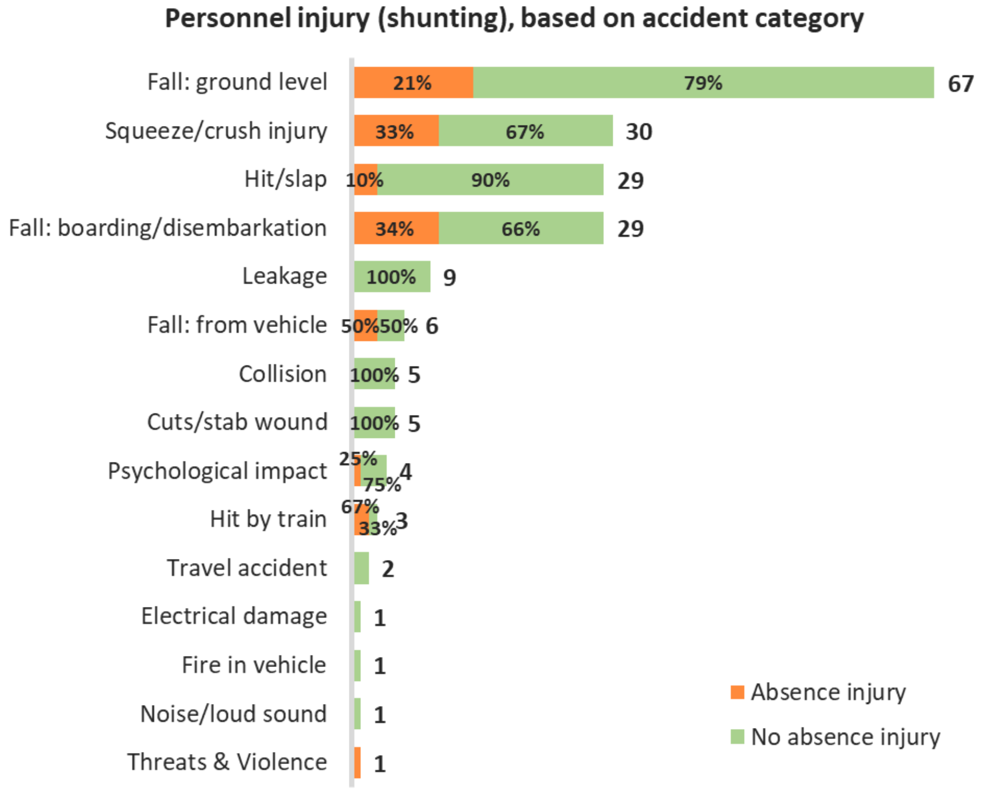


Figure 18. Personnel injury at Green Cargo due to shunting, based on accident category and type of injury (2019–2021). Base: 193 cases

To further investigate the working environment for the production personnel at the marshalling yards, as well as the effect of the introduction of DAC, two interviews were conducted. The first person interviewed was a group leader at the marshalling yard in Hallsberg and the second was a senior researcher at Research Institutes of Sweden (RISE), who has conducted winter testing of DAC in Sweden.

The first scenario discussed in these interviews were the introduction of DAC level 4, where the coupling, as well as the connection of cables, are managed automatically. The decoupling, on the other hand, is still done manually by, for example, pulling a handle at the side of the DAC.

In terms of preparing for decoupling, the introduction of DAC level 4 would significantly improve the working environment, as some of the tasks in subgoal 2.1.3 "Inspection and opening of couplers" will be completely removed. The production personnel will still need to do a substantial amount of walking for ocular inspection of the wagons, but test with video-gates for digital inspection is already being conducted. If these video-gates are introduced, most of the inspection will be done digitally with occasional ocular inspections in unclear cases. Furthermore, the production personnel will no longer need to bend under the buffers to disconnect cables and unscrew the couplers, as that will automatically be done with DAC. Removing the bending under buffers and exposure to high pitch noises when working with the compressed air will make the work less physical demanding. The problem with sheaving couplers will probably also decrease, but when it happens it will be harder to solve as the more technical advanced DAC cannot be handled as roughly (using for example sledgehammers), as could the simpler manual couplers.

In terms of decoupling, the introduction of DAC level 4 would partially change the working environment, as the task in subgoal 2.2.2 “Detachment of wagons” will be adjusted. The production personnel will still have to detach the couplers, but instead of using a so-called detachment stick they will, for example, pull a handle positioned at the side of the wagons so that they will not need to reach in between the wagons.

In terms of coupling, the introduction of DAC level 4 will constitute the largest improvement of the working environment, as some of the heavy and precarious tasks of subgoal 2.2.5. “Coupling” will be completely removed. With manual couplers, the production personnel need to bend under the buffers to connect cables and lift the couplers. It is not allowed to stand between the buffers when another train approaches. However, during the interviews there have been reports of observations when this occurs. This is to avoid bending under the buffers and reduce the strain on the body. This procedure constitutes an apparent risk for accidents and will be completely removed by the introduction of DAC, where buffers are no longer present. The lifting of the heavy couplers will also be removed as this will automatically be done with DAC.

The second scenario discussed in the interviews were the introduction of DAC level 5, where the coupling as well as the decoupling, including connecting and disconnecting the cables, are managed automatically.

At the entrance and departure yards, the introduction of DAC level 5 will affect the same tasks as the introduction of DAC level 4 will. At the hump, the tasks in subgoal 2.2.2 “Detachment of wagons” will however be completely removed. The production personnel will no longer need to detach the couplers, as this will automatically be done with DAC level 5. The detaching of couplers could even be done remotely, but this might constitute a safety risk for the production personnel still present at the marshalling yard as they will have less control over where and when the trainsets and wagons will be moving.

If, and in that case how, marshalling yards like the one in Hallsberg needs to be redesigned to facilitate the use of DAC is still unclear. How the introduction of DAC level 4, and especially level 5, will affect the existence of different professional roles of the production personnel, as well as their responsibilities, knowledge, and skills for these roles is also uncertain. Finally, specific problems such as fixing sheaved or broken couplers and moving wagons with broken DACs also need to be resolved. This aspect was particularly highlighted in the interviews with the representatives from the Austrian operator Steiermarkbahn Transport and Logistics BmbH who pointed out the countless malfunctions (for example related to slow and ice) that they had to deal with today and what this means for the future introduction of DAC. Furthermore they stressed the need for DAC to allow coupling in tight curves with radius below 300 m often present at the small shunting yards visited in their operations.

7 Comparison of HTA to the main marshalling yard Wien Kledering

As mentioned in Section 1.3, partners at ÖBB has used the HTA of Hallsberg marshalling yard in Section 4.2 as basis to evaluate differences in work procedures at Wien Kledering, see Table 8. Their differences in physical design and topography requires that different working procedures are applied. For example, on the levelled entrance yard in Wien Kledering, it is sufficient with only two braked wagons to secure the train set from run-away (the brake system of all other wagons of the train set is vented).

The differences in physical design of the classification yard means that at Wien Kledering, wagons are braked to a full stop by gravity (up-wards slope) in combination with a track mounted hydraulic brake system. Further, the first wagon that enters the classification yard is immediately connected to the permanent brake test facility in order to mount the brakes. At Hallsberg, the speed of wagons is reduced by two steps of rail mounted brakes and the final stop is brought by the stop buck located at each track of the classification yard. At Wien Kledering it is allowed to build several trains on the same classification track, which is not allowed at Hallsberg.

Table 8 shows that the marshalling performed at Hallsberg and Wien Kledering are, for the most part, quite similar in their specific tasks. The differences stem mainly from the fact that the latter marshalling yard is larger and have a different topology (which primarily affects subgoals performed on the classification yard). Another big difference is the higher degree of specialisation of professional roles at Wien Kledering as was discussed in Section 3.2.1.

Table 8. Differences in tasks between Hallsberg and Wien Kledering marshalling yards.

Subgoal	Differences between Hallsberg and Wien Kledering
2.1.1 Train Arrival	Differences in the way and location of protection against roll away. At Wien Kledering the wagon set is secured by full break of the locomotive driver. After decoupling of the locomotive, wagons are secured with brake shoes and by blending the air line of the last two wagons.
2.1.2 Locomotive to depot	No differences.
2.1.3 Inspection and opening of couplers	Also at Wien Kledering, the order of subgoals 2.1.3 and 2.1.4 can be reversed. Wagon technical inspection at the entrance yard is only performed on demand at Wien Kledering. At Wien Kledering the pneumatic air system is vented and the brakes released except for the last two wagons. It is also possible that the work is performed by two shunting workers. There are rarely problems with frozen couplers in Wien Kledering, therefore no specific procedure described. “Detachement bill” (Zerlegeliste) is also used for the decoupling procedure.
2.1.4 Coupling of shunting locomotive	No differences. It is possible that the leader of shunting operations with traction vehicle operation supports the shunting workers.
2.1.5 Green light is communicated to marshalling leader	The check if the wagons are coupled with the shunting locomotive, is only performed by the locomotive driver, by hearing the sound of the pulled wagons. The completion of the train preparation for the hump process is announced by radio

	communication.
2.2.1 Train is brought towards the hump	Decoupling is allowed during a locomotive speed of 1,5 m/s (5.4 km/h) at Wien Kledering.
2.2.2 Detachment of wagons	A special shunting worker, who is dedicated only for the decoupling on the hump, is used in Wien Kledering.
2.2.3 Detachment of locomotive	No differences.
2.2.4 Shunting	The brake system on the hump (retarder) is only passable downhill. The first wagon to enter a specific track on the classification yards is secured by brake shoes, who are only allowed to be removed, when the wagons are leaving the track.
2.2.5 Coupling	The first wagon on the track is immediately connected to the permanent brake test facility by a shunting worker. The wagon technical inspection as well as the brake test with permanent brake test facility is performed by a wagon technician of ÖBB Production GmbH.
2.3.1 Loco arrives to the classification yard	Locomotive of the outbound train drives directly to the wagon set.
2.3.2 Stop buck is lowered	Does not occur.
2.3.3 Wagon set rolls to the loco	Does not occur.
2.3.4 Wagon set is coupled	No differences.
2.3.5 Brake test and departure	This kind of brake test is called simplified brake test (“Vereinfachte Bremsprobe”) in Austria and is performed by a shunting worker and the locomotive driver. In special cases it is performed only by the locomotive driver.

8 Recommendations, guidelines and challenges

The current report presents the importance of DAC with respect to work environment and working procedures at marshalling yards. The information used in the project constitutes mainly knowledge bound to the interpersonal cooperation among production personnel at marshalling yards and can partly be referred to as part of the 'workplace culture'. To the extent that there are written sources, these documents contain information regarding internal work processes that are sensitive for operators to share. Therefore, the research method applied has had to mainly rely on interviews, workplace visits and workshops. The detailed description of the production process at the largest marshalling yard in Sweden, located in Hallsberg, presented in Section 3 constitutes a cornerstone of the project. With this as reference, the impact of DAC on work procedures and work environment are investigated in Section 5 and Section 6, respectively. Moreover, the observations from Hallsberg marshalling yard were used to assess differences in working procedures compared to a marshalling yard with approximately double the capacity located in Vienna, Austria. Two supplementary interviews were conducted with a train driver and shunter employed at the Austrian operator Steiermarkbahn Transport and Logistics BmbH. Below follows an overall discussion on recommendations, guidelines and challenges related to the introduction of DAC based on the results obtained in the project.

8.1 Transition to a healthier work environment

An in-depth interview with focus on the work environment at marshalling yards were performed with a production group leader of Green cargo at the Hallsberg marshalling yard. In the production at Hallsberg, the personnel rotate across all different parts (i.e. entrance yard, hump, classification yard, etc.) of the marshalling yard which means that the respondent has knowledge and experience from all different tasks involved in marshalling, see Section 3.2. Taking into consideration that the majority of marshalling yards in Europe are constructed with a hump, the interview results are considered relevant also from a European perspective.

The respondent from the production at Hallsberg described a physically demanding work that contains a substantial amount of walking and heavy lifting performed outside around-the-clock with exposure to potential harsh weather conditions and a dangerous working environment. This is consistent with the description that was obtained from the two employees of the Austrian operator Steiermarkbahn Transport and Logistics BmbH (STL), who particularly pointed out the demanding task containing a substantial amount of walking when coupling a long freight train (> 600 m) during nighttime in bad weather conditions. With the courtesy of the operator Green Cargo, the project got access to historic data on accidents which have occurred during shunting in Sweden. These aggregated data consisting of almost 200 accidents reported over several years, make an important contribution to understanding the main causes of accidents and injuries during marshalling. To the authors' knowledge, similar information has not been published in literature before. It is notable that approximately half of the reported accidents are related to falling either on ground level during walking on the uneven and sometimes slippery track area or during boarding/disembarkation of shunting locomotives. This indicates that the introduction of DAC level 5 at Hallsberg has potential to significantly reduce the risk of accidents for production personnel. Especially if the introduction of DAC is accompanied by other innovative technology for remote inspection of wagons and cargo (e.g. video-gates). During the interviews with the representatives from STL, the need for new solutions to carry out brake testing were particularly highlighted.

Unless the introduction of DAC is combined with automated brake testing, the significance of the walking distance that the shunting workers need to cover will be small. Given the high degree of specialization of production personnel at Wien Kledering, the reduced risk for accidents will primarily affect a few selected professional roles at this site.

The discussion on accidents related to shunting contained in the previous paragraph only partially captures relevant aspects with regard to the introduction of DAC. In addition, it is a reasonable assumption that the introduction of DAC will impact on wear and tear damage developed during working life such as straining injuries and hearing loss. A development where repetitive bend under buffers and handling of heavy couplers no longer is required will mean a significantly less physically demanding work as compared to the situation currently for production personnel at marshalling yards. Initial attempts to account for these aspects as part of the current project were cancelled due to difficulties to obtained relevant data and information. It is an important remaining task for future research to investigate the long-term effects of the current work environment on the health of production personnel at marshalling yards. In the longer perspective, the presumption is that DAC level 5 combined with technology for remote inspection and monitoring will partly transform current professional roles while at the same time create need for new competence, e.g. the field of engineering. All together, these changes in physical and social work environment are expected to bring new challenges, for example related to mental workload, which also remain for future research to investigate. Related to this, the interviews with representatives from STL stressed the importance of performing working tasks seen as meaningful. The respondents raised question marks whether a future, when manual tasks have been transformed to monitoring/controlling automatic operation, will offer this.

8.2 Introduction of new professional roles with new competence

Today, disruptions in marshalling are often handled manually. In Hallsberg, for example, screw couplers that cannot be released at the arrival yard, due to rust or ice, is released at the hump instead. There, sledgehammers and level arms are used to unstick the couplers. When DAC is introduced, disruptions are more likely to be caused by technical problems and, even in cases with couplers stuck due to rust or ice, the solutions are more likely to require technical knowledge. The transition from manual to technical solutions require new competence. At this point, it is hard to know if this could be solved by further education of the current personnel or if technicians, with higher education, needs to be recruited. Furthermore, the handling of disruptions may also need to be organized in a different way. While today's manual solutions can be performed directly at the hump, more technical solutions may require the wagons to be redirected to the wagon repairs workshop. How, and by whom, this should be arranged will probably differ between different marshalling yards but must be considered.

The introduction of DAC is predicted to improve the work conditions for especially production personnel. However, the introduction of DAC, especially with video-gates, will also have an impact on the command-and-control chain. When new technology is introduced, it is well known that how a goal and subgoals (see HTA above) are reached will be affected in a socio-technical system (Merat, & Lee., 2012; Schmid, D., & Stanton, 2020). Surveillance (Endsley, 2021), decision making (Klein, 2008) and communication (Clark, 2021), will be affected and the role for production personnel will therefore also be affected. It is outside the scoop of this project to investigate how the introduction of DAC will reveal itself in terms of the command-and-control chain. The literature from other sectors that introduced automation is however rather clear, the roles for the existing personnel will change and new roles (competences) will most certainly be needed (cf. Merat, & Lee., 2012). Even if it is difficult to predict how the DAC will change the tasks to perform, two principal barriers will need to be considered (Reason, 2005). The first barrier concerns security. If the production could have consequences for society, the automation needs to be secured from attacks from actors outside the command-and-control system. It should not be possible for unauthorised personnel to decouple wagons. The second barrier concerns the interaction and collaboration between authorised personnel within the command-and-control chain. **Who** is doing **What** and **When**. This report has indicated pros with the introduction of DAC from a work condition perspective for the production personnel, but it should be highlighted that the introduction of automation will need to develop an understanding of how the socio-technical system will work in reality. The three W:s (Whom What, When) will need to be considered before an implementation of DAC will work in reality. Hence, a command-and-control analysis of the production task (shunting at marshalling yards) is needed.

8.3 The necessity to consider the system perspective

To investigate the potential of DAC as an enabler for increased efficiency, a reduced work force or improved work environment for production personnel, it is necessary to understand that there are technical, organisational and social developments that need to be implemented simultaneously for this to be possible. For example, video-gate for visual inspections of the wagon set, additional automated workflows, knowledge and skills needed for the new tasks and job profiles in addition to the understanding of how the technology and personnel interact at the marshalling yard. It is important to regard the system as a whole and not only focus on the implementation of DAC or other technologies individually. There will be a need for research that assesses DAC in a human-technique perspective.

As described in Section 5, the downward slope at Hallsberg marshalling yard makes it impossible to put the DAC level 4 in non-coupling mode at the entrance yard. Further, the operation at the classification yard is based on the use of stop bucks that are not adopted for DAC. To enable DAC level 4 in its current design at Hallsberg would require significant infrastructural investments. Also, during discussions with personnel at the Wien Kledering marshalling yard, questions have been raised regarding the feasibility to implement of DAC level 4 at the site. In planning of the long transition period when DAC will gradually be implemented, but the use of screw couplers still widespread, this report raises the importance to also take related needs with respect to the infrastructure at marshalling yards into account.

The marshalling yards accounted for in the current project were selected based on their size and importance with respect to rail freight in Sweden and Austria. The current work has demonstrated significant differences between the sites with respect to physical design (e.g. consistent vertical gradient at Hallsberg as compared to the tub-shape at Wien Kledering) and organisation of production (e.g. few professional roles and large rotation between work places in Hallsberg as a contrast to the opposite relationship in Wien Kledering). According to private communication, the working procedures at marshalling yards operated within the same country, and even by the same operator, can also differ to such extent that personnel cannot easily move between sites. These large local variations in how production is carried out at different marshalling yards put high demands on the design of DAC to enable for the technology to be adopted across the entire

European transport system for rail-borne freight. To facilitate a future successful transition to DAC it is recommended that a thorough mapping of work procedures at European marshalling yards will be conducted.

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