Shunt-E 4.0—Autonomous Zero Emission Shunting Processes in Port and Hinterland Railway Operations

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Abstract: The port railway operation in Germany and Europe is not least due to its long history of technological and regulatory developments characterized by a high number of players and a lack of comprehensive planning and optimization of all relevant processes. Innovative technologies and business processes are therefore useful and needed to achieve key steps on the way to an overall optimization of rail transport within global supply chains. A substantial part of the European rail freight transport has its origin or its destination in an inland or sea port. Considering the railway system, ports play a more important role for urgently needed innovations than the pure interfaces between sea and land transport. Especially ports with their own railway system have an own responsibility in this matter. Insofar the goal of the Bremen Port Railway—which already now has a leading share of railway in modal split in Europe—is to exploit the opportunities offered by digitalization. Significant steps for this are the optimization and gradually automatization of rail operational processes on the last mile including modern and transparent IT systems and the designing of autonomous shunting processes. Together with research partners ISL (Institute of Shipping Economics and Logistics Bremen), BIBA (Bremen Institute for Production and Logistics) and IVE (Institute for Transport, Railway Construction and Operation in Brunswick) and in connection with associated business partners the project Rang-E has been applied for at the Ministry of Transport in the funding initiative IHATEC (Innovated HARbour TEChnologies)—and had won a grant to perform the proposed work. Basic thoughts are outlined in the following.

Key words: Port development, port technology, port railway, port connectivity, hinterland traffic, autonomous rail operation, shunting operations.

1. Preamble

Hinterland connectivity on road, rail and inland waterways is one of the most competitive distinguishing factors for today’s sea and dry ports. Therefore innovations with a clear focus on autonomous and emission free port and logistics operations are crucial to safeguard a prosperous future of global ports. In this context the German Federal Government set up a program to support innovative port solutions and thus supports the project “Shunt-E 4.0—Autonomous Zero Emission Shunting Processes in Port and Hinterland Railway Operations.” This practical research program focuses on improvements in last mile rail operation. It is conducted together with Bremen’s port railway which is regarding the modal share of rail hinterland transport already as one of the leading European port railway systems. This article describes the overall objectives, ambitions and expected outcomes of the Shunt-E project.

2. Rail Transport—A Competitive Advantage Not Just for the Environment

From the early days of railway operation towards today it has always been a success factor to many European ports that there were direct rail connections and a dense rail network between the ports and their hinterland. As a result we find some of the most focused rail ports in the so-called North-Range, a comparatively short coastal stretch in northwestern
Europe between Le Havre in France and Hamburg in Germany which serves some of the strongest industrial and consuming areas within Europe.

Right there the four largest European container ports to date Rotterdam, Antwerp, Hamburg and Bremerhaven (Fig. 2) are concentrated. All of them have a significant rail share in their container hinterland transport with the German ports clearly in the lead. Fig. 1 demonstrates the development of container numbers in million TEU (twenty feet equivalent unit) transported by rail to and from the leading EU seaports over the past 15 years.

As the figure shows the modal share of rail in hinterland transportation reaches in ports like Hamburg and Bremerhaven already 50 percent and gives these ports a very high score regarding their environmental performance. Regarding the overall number of containers transported by rail to and from the seaports of Hamburg and Bremerhaven these ports are by far the leading rail-ports on the European continent although there are some smaller ports like Gothenburg in Sweden or Koper in Slovenia which have a slightly higher rail share.

Compared to the total rail share in EU land based transport these figures are more than twice as high as the average, which demonstrates that the European maritime transport chains as part of global supply networks are the forerunners in the climate change driven necessary transport shift.

3. Historical Development of Rail Cargo Transport—A Burden for a Modern Industry

Aside from this successful status port and hinterland railway operations today are comparably complex processes. The reasons are manifold and may first of all be seen in the long historical development of rail transport on the European continent both in terms of technology as well as in regulation. Within the more than 150 years of railway development processes every single European nation and also the state for a long period of time mainly owned railway undertakings and

Fig. 1 Container hinterland traffic to and from leading EU seaports on rail in mill. TEU.
Source: Port Authorities of Hamburg, Bremen, Rotterdam and Antwerp.
infrastructure providers, which were typically integrated organizations, “invented” their own rules and regulations, technical and regulatory requirements, operating procedures, organizational structures and so on.

Even if there were no specific needs may be except from the unspecified intention to protect the national rail markets each European country and each national railway organisation created explicit procedures that varied more or less from those of the neighbors. Key words like interoperability and intermodality only popped up recently and thus the European rail cargo sector today appears more than just a bit antiquated [1, 2].

4. The General Rail Cargo Process within EU Ports

The general process which involves many different partners like railway undertakings, shunting operators, infrastructure providers, energy providers, terminal operators, port management organizations etc. is on the example of a typical European railway system (Bremen’s port railway) divided in various steps as follows:

(1) Separation of main-line locomotives (electrical) after train arrival in the port area;

(2) Transport of train section or wagons with shunting locomotives (diesel or hybrid) towards forwarding groups and later on to the terminals (Fig. 4);

(3) Terminals have to conduct control and supervision works on the train and on the cargo (i.e. seal-check).

The first point means that the physical rail transport between EU seaports and hinterland destinations which may be cargo villages, inland or dry ports is typically conducted by railway undertakings. In some cases they are the owner of wagons and locomotives and sometimes they are operating with chartered or leased equipment. Over the longer transport legs rail transport within the EU is in most cases electrified, so that a typical cargo train between the ports and the hinterland destinations operates with a total length of 740 meters including one or two electrical locomotives. These locomotives are not able to operate on the non-electrified last mile, which is why they have to be separated from the wagons after arrival within the port area.

In the ports area step two starts. Typically fossil fuel powered shunting locomotives with separate drivers take over. They manually couple to and push the wagons into the loading terminals. Before this process starts physical checks of the wagons and the cargo are being carried out. Therefore specifically qualified wagon technicians are needed. The shunting locomotives, their drivers and the wagon technicians are typically provided by dedicated port shunting companies. Depending on the size of ports there are different companies in competition to each other active in the shunting business.

Fig. 2 The port of Bremerhaven as a testbed for autonomous shunting processes.
Source: Bremen’s Ministry for Economic Affairs, Labour and Ports.
When the wagons with the containers or other kind of cargo finally have made it to the loading terminal tracks additional checks for the cargo, the seals and the papers accompanying the train section or wagons are being conducted, typically by terminal operators staff. For that port workers go along the up to 710 meter long wagon units and back to report the status and their findings. If everything corresponds to the expected standards the unloading process by highly efficient rail mounted gantries, rubber tyred gantries or other types of equipment can finally begin. As a consequence of these steps the first cargo movements can and do only start hours after train arrival in the port area.

A comparable long procedure is also needed after completion of train loading process. Cargo trains with import goods also need to have specific checks, brake tests and load control works with following shunting processes. Just by these rules already technically ready cargo trains typically remain in the port area for an average of two more hours before they can start their trip back towards the national and European hinterland destinations. As a result port railway operation in Europe today is much more complex than truck and barge processes, which gives the rail mode a competitive disadvantage. The reasons are as mentioned mainly sector, country and or company specific rules and regulations.

5. Need for a Modernization of Rail Procedures More Than Obvious

Real innovations within the European rail cargo sector are rare, even if good ideas do exist and pop up again and again. Many previous projects on automatization and process optimization failed or were stopped by various reasons like the comparatively small market for cargo railways, the long-lasting lack of political support for the sector and the complex and long-lasting approval procedures. In fact technical solutions like automatic clutches, automatic brake tests, remote train control systems, automatic load controls, obstacle detection and many more rail related optimization measures are technically for a long time feasible and were already successfully tested in the past. But, they did not make it to the broader European market. One reason lies in the typically decades long life span of locomotives, wagons, steering and control equipment with consequently very long innovation cycles. Another reason is the comparatively small number of new locomotives that can be sold within the European market in combination with only very few technology providing companies. For them it is simply not lucrative enough to spend much money and efforts on research and innovation.

As a consequence rail transport of cargo until today is in many European regions very traditional and old-fashioned. Especially in comparison to truck transport the rail sector is falling back. Ongoing innovative projects like truck-platooning in combination with autonomous trucks endanger the overall system advantage of rail and thus the future perspective of rail transport.

So, if global and especially European ports want to improve railway transport they strongly need innovative port and hinterland railway systems and processes. The aim for the sector must be that trains that arrive in port will spend a maximum of 30 minutes before the first containers or other commodities will be discharged and loaded to and from the wagons. After completion of the loading procedures in the terminals trains should be ready to leave the port area without any additional treatments or checks within minutes. Only if this is reached there will be a level playing field between railway and truck or barge operation and a prosperous future for rail cargo transportation.

6. Long-Term Perspective Autonomous Emission Free Shunting Processes in Port Railways

With the support of Germans Ministry of Transport Bremen’s port railway has been selected as a test bed for autonomous emission free shunting processes. The port railway network in Bremerhaven is
non-discriminatory accessible and part of the public infrastructure company “Bremische Hafeneisenbahn” who belongs to the Free Hanseatic City of Bremen which takes care of its infrastructure with related operational and technical service providers.

Currently the tracks are regularly used by over 30 European railway companies with almost 100 having license agreements. These companies connect the ports of Bremen with national and international hinterland traffic. Several competing shunting companies take the task of transporting the trains and wagons—which are usually loaded with vehicles or containers in Bremerhaven—from the starting rails to the receiving terminal and vice versa. They carry out the tasks on behalf of the corresponding railway company which in return make sure to provide the electrical operated mainline locomotives including their destined train drivers for entering and leaving the port area right on time. Currently there are 13 shunting locomotives of different type and age—all Diesel operated—being active 360 days a year in a 24/7 system.

To operate a shunting locomotive a train driver and a shunting worker are needed. Shift planning for them is done by the on-site managing clerk of the respective railway company. The actual driving and shunting operation is based on the regulations of Bremen Port Railway. Their managing staff organizes the track use and their dispatcher at the signal box sets and authorizes the driving route. The handling companies set with their loading and unloading processes the pulse for the train movements. In Bremerhaven, loading and unloading containers as well as automobiles follow slot times specified beforehand. The processes also take into account the load levels of the specific wagons to avoid idle and waiting times. There is no direct contractual relationship between the terminals, the port train operator and the shunting companies so that communication and coordination between the involved parties is of major importance. Actors agreed on autonomous shunting as long-term objective, also because of the expected shortage of train drivers.

Bremen’s port railway system is demonstrated in Fig. 3.

The port railway plan in Fig. 3 highlights not to scale all rail tracks within the port area. The yellow marked tracks are electrified and the purple lines stand for non-electrified tracks. The overview shows that almost every corner of the port has a direct rail connection and

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**Fig. 3** Railway network within Bremerhaven port.
Source: Bremen’s Ministry for Economic Affairs, Labour and Ports.
the track arrangement in the upper area of the container terminal furthermore demonstrates the general technical development over the past decades. Whereas it was state of the art in the early days of containerization to place the rail tracks directly under the ship to shore (STS) cranes, it later turned out that rail tracks should be better placed in the middle of the yard. Nowadays modern rail operation takes place behind the yard with dedicated rail handling terminals, which can be seen here in the upper right area. The main-line transport between Bremerhaven and the national and European hinterland is currently conducted by railway undertakings which also take care that enough train drivers and wagon technicians are in place at the time when they are needed for the port leave.

The railway undertakings are the purchasers and contract partners for shunting services. The shunting companies in Bremerhaven to date operate 13 shunting locomotives, most of them decades old and all running on fossil fuels. They operate 24/7 like the loading terminals within the port and despite the fact that they compete to each other to have a cooperation agreement for cases of unexpected locomotive failures or shortages in personnel. The overall rail traffic within the port is controlled and steered from a control tower in the center of the port, where dispatchers on behalf of the Free Hanseatic City of Bremen, the overall owner of the ports infrastructure fulfils their duties.

Even if the port organisation, structure, ownership and responsibility within EU seaports differ from port to port, the general system of port railway operations is pretty much comparable. It is depending on many different actors, their communication and collaboration and it depends today much more on people than on technology. Automatization and digitalization therefore are needed for the long-term perspective of autonomous emission free shunting processes in port railways.

7. Expected Effects of Autonomous Shunting Operations in Ports

The description of the status quo of typical port railway procedures has shown that the aim of a totally autonomous shunting operation can and will only be reached with intermediate steps like process automatization. In general the expected effects of autonomous emission free shunting operations to date are the following:

1. Simplification of operational processes;
2. Avoidance of empty-drives;
3. Reduction of the overall shunting stock (savings of about 30 percent are expected);
4. Avoidance of communication-interfaces;
5. Optimization of infrastructure use with savings on future investments;
6. Reduction of operational efforts and costs (on the locomotive and in the offices) through reduction of personnel;
7. Safety-improvements;
8. Disruptions reduction in port railway operation \[3, 4\].

A fully autonomous shunting operation is a long-term perspective which is preceded by many intermediate steps of process automation and generation of corresponding structures of infrastructure, processes and legislation. An essential step will be the implementation of a centralized remote-controlled shunting operation. With the active commitment of all involved parties this is possible within the upcoming decade.

Basic consideration will be to organize the entire port train shunting operation process autonomously. As a result a smaller number of locomotives would be needed. The electrical operated shunting locomotives Shunt-E would be able to almost completely avoid the empty runs currently caused by lack of interaction and overall optimization.
Completely interlinked and optimized IT interfaces between terminal operators and port train operator—as well if necessary also with the DB Netz AG (managing the majority of the railway infrastructure throughout Germany) and train operators—are building blocks contributing to process optimization in rail freight transport. Concepts in current innovation areas such as Industry 4.0, Internet of Things, digitalization in ports and self-controlled logistic units find a grateful application field.

An autonomous operating shunting locomotive Shunt-E must have access to all status information of railway infrastructure companies, such as Bremen Port Railway, port terminals but also to DB Netz AG, to always receive a complete overview over the current operational situation. At the same time it is necessary to secure for continuous access to information on plans and malfunctions, loading and unloading time schedules in terminals, planned slots, actual arrival and departure of trains, availability of train drivers and so on via standardized IT interfaces.

On this basis an autonomous operating shunting locomotive Shunt-E would be able to always know which shunting tasks are next as well as the order of the following ones which would subsequently result in an optimized usage of rail tracks (infrastructure optimization). It would coordinate itself autonomously with other shunting locomotives (in sense of an auction as already used for optimizing multi agent systems), book the necessary infrastructure and by extent—in case of a problem—find a solution by co-operating with her “colleagues” by herself. Compared to today’s train operating procedure in port areas Shunt-E would not need resting time and would run emission-free. Certainly, it is necessary to generate answers to multiple questions of operational, railway law, entrepreneurial, financial and organizational nature before implementing such an autonomous shunting operation on the grounds of Bremen’s Port Railway.

8. Outlook and Relevance for the Global Port Community

As outlined the goal of a fully autonomous operated shunting service on one of the most important European port railway systems is still—a fictional picture but with this vision it is possible to achieve noticeable efficiency gains by consistently implementing interim steps. Remote controlled
locomotives as well as the automation in the area of testing breaks, coupling, train handling, train configuration, identification of rear of a train etc. are important elements on that route. There are technical solutions for all these areas; the objective is to combine them step by step in an intelligent way for the sake of the entire rail sector—and to achieve a joint breakthrough. Hence it is necessary to break up the very common rail sector approach of “keep the proven” and to lead it to a clear innovation orientation as it is daily business for other transport sectors.

“Shunt-E 4.0—Autonomous Zero Emission Shunting Processes in Port and Hinterland Railway Operations” is of high relevance to the global port community as it combines the necessary innovation approach for future port development with a sustainable greenports strategy. The above described aim of highly efficient last mile railway procedures and productions will therefore be seen in ports from the year 2028. It is most likely that first installations will become operational in new green port projects, whereas the upgrading of existing ports with autonomous shunting systems will take longer due to the higher complexity.

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