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# Energetic and operational use of FlexCargoRail freight wagons in the single wagon load traffic

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**Abstract**

The FlexCargoRail system mainly focuses on electrical powered, radio controlled freight wagons which carry a rechargeable battery as a power source. The goal is to raise movement flexibility of the wagons for shunting operations and to increase efficiency of single wagon load traffic. There is also an advantage in energy efficiency in several dimensions: In contrast to diesel powered freight wagons, regenerative braking is possible. Compared to conventional operation on the ”last mile”, energy for operation of the shunting locomotive (including empty runs) is saved. Finally there is economization potential for mainline traffic operation because diesel mainline locomotives (actually only used due to the ”last mile”) can be replaced by electrical locomotives. With state-of-the art components, FlexCargoRail vehicles can be doubtlessly realized. However, due to economic aspects, it is reasonable to adapt the necessary components to the specific needs of FlexCargoRail: In most cases, industrial components can be used instead of the railway service specific ones, since the reliability requirements are much lower than for locomotives. Furthermore, the needs of FlexCargoRail suggest the development of an innovative kind of multi-receiver remote control. Presumably, FlexCargoRail vehicles and conventional freight wagons may be coupled to a freight train with distributed traction in future. A so called head car is then needed to supply the train with electric energy, to provide a cabin for the train driver and to carry the train’s control system. In that case, further economization potential can be exploited as a number of conventional locomotives become needless.

*Keywords: electric drive, electric vehicle, mobility, noise, regenerative braking*

## 1 Introduction

On the initial one-year stage the collaborative project FlexCargoRail, funded by the German Federal Ministry of Economics and Technology, has carried out an interdisciplinary investigation concerning the effects of the application of the electrical powered freight wagons in single wagon load traffic. For political-ecological purposes the single wagon load traffic is an important technique for shifting transports from road to rail. From the business perspective, block train traffic often has its seeds in the single wagon load traffic when the amount of goods to be transported grows accordingly on a certain distance. On the other hand, time-consuming delivery and sorting procedures in single wagon load traffic lead to high expenses, which could be compensated only by increasing the number of wagons. Consequently, in the past years it has brought about the situation when the customers with few wagons are increasingly less serviced by the railway traffic companies and the siding tracks are removed.

After giving a short introduction into the FlexCargoRail System, it will be dealt with economic and energetic advantages of the powered freight wagons, which could again arouse economic interest to the siding tracks that have become unprofitable in the past decades. Subsequently, the costs as opposed to the use of the powered wagons will be discussed, followed by the overall estimation of the system.

## 2 The FlexCargoRail System

The idea of a powered freight wagon is not novel, but still unestablished. The CargoMover [6] did not succeed due to operationally nonviable automation that, in addition, has lead to extremely high vehicle costs. The IVSGV survey [10] has introduced powered freight wagons with a diesel engine, which, apart from energetic disadvantages, are problematic in respect of fuel logistics. Therefore, the FlexCargoRail System focuses on self-powered freight wagons with an electric engine. They are designed in such a way that they can haul some conventional freight wagons and replace a shunting engine to a certain extent. The energy source is a battery which is charged either via a charging cable or mostly via the operation of the engines as generators during the main run. The wagon should be controlled with a radio remote control unit in shunting operation. Furthermore, it can be controlled with an optional control panel on the vehicle. For the main run a trip in a locomotive-hauled train is intended, because the wagon has neither control and safety technologies, nor a driver's cab. A sketch of a FlexCargoRail freight wagon with all essential components that distinguish it from a conventional freight wagon is represented in Figure 1.

## 3 Capacities of FlexCargoRail

As follows from the above description, the FlexCargoRail freight wagons can move autonomously during shunting operation, whereas in the main run they must be pulled in a locomotive-hauled train as conventional freight wagons. However, given a corresponding compatibility as to vehicle technology, the capacity of the powered freight wagon can be used in two ways in the main run.
Usually, the FlexCargoRail freight wagons are charged regeneratively in the main run. On a steep slope or at required intense acceleration the FlexCargoRail freight wagons can be employed as boosters, i.e. as suppliers of additional driving power. For this purpose a communication technology is necessary, which could transmit the request for traction assistance from the train driver or an assisting system. The remote control equipment, indispensible on the vehicles for the run on the last mile, could also perform this function in the main run. The booster function can be of special interest in the situation when a freight train needs to join the passenger traffic in a fixed cycle operation and must accelerate accordingly quickly.
Given a sufficiently large number of FlexCargoRail freight wagons in a freight train, the FlexCargoRail freight wagons provide enough traction capacity to do completely without a locomotive. However, the set of FlexCargoRail freight

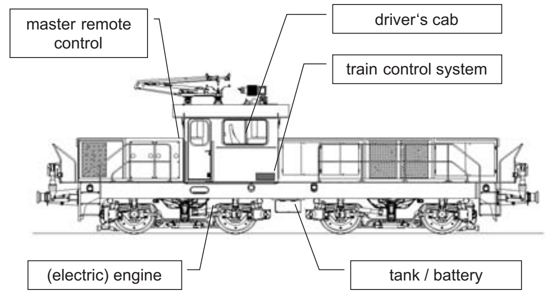


Figure 2: Sketch of a head vehicle

wagons and conventional freight wagons lacks permanent energy supply, a driver's cab and control and safety technology. Thus, a vehicle in the form of a small locomotive is needed, that possesses enough traction capacity to move itself. It should also provide electric energy - either with a diesel engine with a generator or with a pantograph and a converter – which is conveyed to the FlexCargoRail freight wagons via an energy coupler. Furthermore, this vehicle must be capable of control of FlexCargoRail freight wagons through a master radio remote control similarly to the above described case of a booster operation. Such a vehicle is called a head vehicle in the FlexCargoRail system and is demonstrated in Figure 2.
To make full use of the described potential of FlexCargoRail, first of all, a sufficient number of FlexCargoRail freight wagons is required. Therefore, the operation of FlexCargoRail with head vehicles will not be further dealt with in detail.

## 4 Operational use of FlexCargoRail

In this chapter the operational use of FlexCargoRail is described in detail. In [2] several settings are presented where electric powered freight wagons enhance the operational efficiency of the distributon of freight wagons to loading sites.
The most simple possibility of operation concerns the deposition of the wagons to be distributed on a transfer station, such that the rest of the train drives further on without any delay. A locomotive shunt driver of the railway company or of the loading station operator picks up the FlexCargoRail freight wagons at the transfer station and forces them to move with self-power in a shunting run to the nearby factory premises. There the wagons are distributed on the siding tracks. For this procedure no shunting engine is needed. The loading station operator has the following advantages: the time of pick-up and distribution of the wagons can freely be chosen and the operation is completely independent of the cycle of the shunting engine. Such an operation is basically possible, but realizable only given small distances between a transfer station and a loading station. On the one hand, the ac-

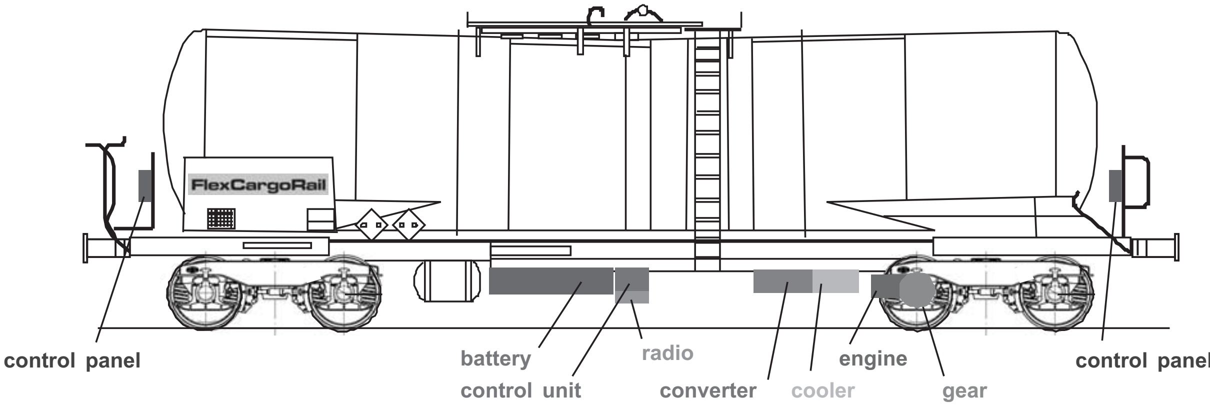


Figure 1: Sketch of a FlexCargoRail freight wagon

ceptable maximum speed of such a locomotive-free set would be low and thus the time of travel and the duration of the track blockade long. On the other hand, the run over bigger distances on a shunting step is hardly compatible on a regular basis with the actual requirements to working conditions of locomotive shunt drivers.
Another possibility for longer operational trips would be to combine the use of FlexCargoRail freight wagons and shunting locomotives. The railway traffic company locates the wagons nearby the loading station. The arrangement within the factory premises is carried out by a qualified assistant of the loading station operator. This procedure is called a postbox service. Thus, the operational trip of the railway traffic company is also reduced compared to the complete distribution of all wagons by the shunting locomtoive, and the pick-up and distribution of the wagons can be flexibly managed by the loading station operator. The advantage of this procedure for the loading station operator is that no locomotive shunt driver is needed, because the wagons are moved only within the factory premises.
The fact that a powered freight wagon can be moved quickly and flexibly anytime by the loading site operator should not be neglected. In case of conventional wagons a shunting locomotive or another shunting device is required. Movement within the factory premises is necessary if space must be made for another vehicle at the loading site. Furthermore, the loading site operator can use the powered freight wagon as a ”small shunting locomotive” to move conventional wagons, so that an extra shunting locomotive is needless. Finally, the wagons to be picked-up can already be presorted with a FlexCargoRail freight wagon, so that this task must not be implemented by the locomotive anymore and thus the time consumption is reduced.

# 5 Energetic use of FlexCargoRail

This chapter elucidates the advantages of the FlexCargoRail System concerning energy. A separate view will be taken of the shunting operation and the main run. The discussion of the polluting emissions closely connected with the energetic effects goes beyond the scope of the present paper and will be omitted here.

## 5.1 Energetic use in shunting operation

For the comparison of conventional shunting and shunting with FlexCargoRail it will be assumed that conventional shunting locomotives are diesel-powered. This assumption almost completely corresponds with reality in Germany, since siding tracks in Germany and in most European countries are electrified only in exceptional cases.
In the shunting operation it is particularly often accelerated and straight braked. During conventional shunting the kinetic energy when braking is completely transformed into frictional heat. In using the FlexCargoRail freight wagons, the electric motor can be applied as regenerative brake. Thus, at least a part of kinetic energy can be fed back to the battery as electric energy.
Moreover, a conventional shunting unit weights much more due to the heavy shunting locomotive, oversized for the most shunting moves, in contrast to a comparable shunting unit of the FlexCargoRail system. The mass to be accelerated is clearly lower in FlexCargoRail, which allows further energy saving.
The advantage of FlexCargoRail through regenerative braking has already been argued. It should not be neglected that the diesel motor of a shunting locomotive idles, even when the locomotive shortly stands still, and thus consumes fuel. In contrast, the electric motor of a powered freight wagon at a standstill consumes no energy. It should be noted that electrical powered vehicles have a certain requirement of power at a standstill as well which is caused by lighting and other auxiliary functions. This power requirement should however be disregarded here.
In [5] it was found out that a shunting locomotive idles about 65% of the operation time. The consumption of a diesel motor, typically used in a shunting locomotive, can be assumed to be 5 to 9 l/h. Thus, a shunting locomotive consumes 3.25 to 5.85 l of diesel per operation hour at idle, which with a heating value of 9.8 kWh/l and an

efficiency of refining of 94% (cf. [9]) corresponds to a regular average power consumption of 33.9 to 61.0 kW, relating to primary energy. This part of the whole energy consumption absolutely does not apply to the electric traction.
It should be noted here that there recently appeared prototypes of diesel-electric shunting locomotives with battery storage that make recuperative braking possible. However, all the other disadvantages of the use of a shunting locomotive (the mass, idle, complicated shunting moves) are completely the same.

## 5.2 Reduction of shunting moves

The previous chapter discussed the effects of applying an electric powered freight wagon during the shunting operation being advantageous as compared to shunting with a shunting locomotive. For that purpose a direct comparison has been made between an electric powered vehicle and a vehicle with a combustion engine. However, this would only hold true if a locomotive with a combustion engine is directly replaced with an electric powered locomotive.
The FlexCargoRail System presupposes, according to the above description, that freight wagons are electric powered. Empty runs that should be made in order to approach the wagons to be moved or to reach a distribution centre are inapplicable.
It can be estimated from the load profile for shunting locomotives, as well as from the "Siemens-Load Profile Shunting" in [5] that more than 50% of the operation time, when the locomotive does not stand still, the runs proceed without a hauled load. So, it can be assumed that empty runs make about 50% of the driving performance of shunting locomotives. Making a supposition, which is pessimistic for the FlexCargoRail System, that a diesel-powered shunting locomotive consumes 10 l/h in an empty run, the power of at least 98 kW is needed during an empty run. Given the 65% of standstill and 50% of the empty run rate, the average continuous power requirement for empty runs equals 18.2 kW in relation to primary energy. If freight wagons are powered and thus empty runs are dispensable, this power could also be completely saved.
This scenario can only be true if all the regarded freight wagons are electric powered. The FlexCargoRail System does not presuppose such a case. The intention, as described above, is to retain a number of conventional wagons that will be moved by the powered ones. Although the number of empty runs will be reduced thanks to a clever arrangement with the help of the numerous powered freight wagons, it should be kept in mind that the advantage of superfluous empty runs can not be fully realized to the extent described above.

## 5.3 Energetic use in the main run

The energetic use of the FlexCargoRail system is also obvious in various operational combinations in the main run. The booster operation (see above), when the FlexCargoRail vehicles can be used for supplying additional power, is not considered here in detail.
A trip of a freight train driven by a diesel locomotive will be examined as compared to a FlexCargoRail train with a head vehicle and FlexCargoRail freight wagons as it can be realized if a sufficient distribution of FlexCargoRail freight wagons is given (see section 3). Such a comparison is possible because especially small private railway traffic companies use only one single locomotive in the shunting trip in the sidings over the main run to the end station, due to the lack of available shunting locomotive to cover the area. Moreover, these locomotives must often be diesel powered due to the absence of electrification in the sidings.
To begin with, FlexCargoRail makes use of regenerative braking. Quantitative evaluation of the energetic advantages is still not easy to make, since this considerably depends on the dynamics of the trip (regular or conditional deceleration processes) and the topography of the line (slopes that force to brake).
It is equally difficult to quantify the energy consumption that the diesel locomotive has in the operational standstill periods in the main run, which is not the case with the FlexCargoRail train.
The quantitative evaluation should only be made here in the case when the traction is produced. Diesel motors used on the railroad have, under the most favourable conditions, a minimum diesel consumption of 180 bis 220 g/kWh (cf. [7]) in relation to the output of the engine. It should be noted however that these ideal conditions are seldom fulfilled by reason of overdimensioning of the versatile locomotives, as well as of the operationally conditioned trip in various regions of the engine characteristic map. Given a diesel heating value of 45.4 MJ/kg, the efficiency of the energy conversion from chemical energy (diesel) to mechanical energy is about 36% to 44%. Thus, with an efficiency of refining of 94% the overall efficiency equals 34% to 41% in relation to primary energy requirement.
In case of positive traction the energy requirement on the output of the engine of a FlexCargoRail train is equal to that of a train driven with a diesel locomotive. The average energy efficiency of electric power generation, which amounted to 41.7% in Germany in 2007 (see [3]) is opposed to the high efficiency of 95% of modern electric engines. The overall efficiency of the FlexCargoRail train is also about 40% in relation to primary energy requirement.
Taking into consideration the effects and polluting emission that have not been quantified here, it can be argued that even today the trip with electric energy of diesel traction is preferable, even if efficiencies related to the primary energy requirement also show no considerable difference, as is often supposed. Efforts in energy policy resulted in energy efficiency of electric power generation growing consistently through more efficient power stations and modifications of energy mix (see Figure 3). Thus, a continuing increase of energetic use of FlexCargoRail in the main run

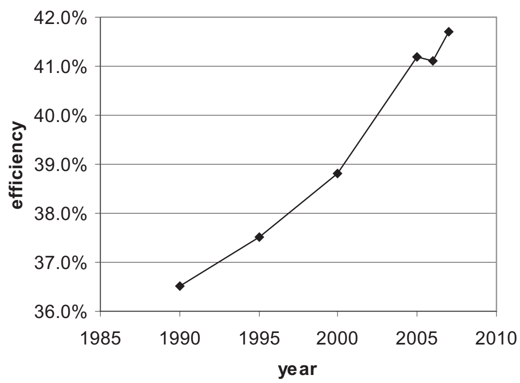


Figure 3: Average energy efficiency of electric power generation in Germany [3]

should also be expected for the future.

# 6 Costs consideration in FlexCargoRail

The previous sections have dealt with the use of FlexCargoRail in view of energy and operation. This section considers the costs of the use of FlexCargoRail, which fall under two categories. On the one hand, the analysis should be made of the technical realization of necessary equipment for the FlexCargoRail freight wagons and of the corresponding expenses for the acquisition and maintenance of the vehicles. On the other hand, it should be made clear that also new operational methods generate expenses, especially those concerning personnel.

## 6.1 Vehicle costs

First of all, it should be pointed out that the quantitative declaration of the costs of a FlexCargoRail freight wagon can not be made on the present stage. These costs substantially depend on the requirements to such a vehicle. For instance, the distance to be travelled by a powered wagon without battery charge influences the capacity and thus the costs for the installation of batteries; simultaneously, the mass and the correspondingly available load capacity at a constant axle load change. Furthermore, the prices for a fundamental component of the FlexCargoRail system, namely of the battery, undergo strong changes (in the past, as well as in the coming years), such that a quantitative assessment of the vehicle costs would only be valid for a given moment of time. Finally, for an efficient operation of the FlexCargoRail system the use of components is advisable, which are not yet available on the market and for which no costs could be defined. This is true, for instance, for the case of remote control that will further be described in section 6.1.3.

It should rather be discussed, which components with their characteristics can be applied for the FlexCargoRail vehicles. A competent reader could then specify the vehicle costs for a particular application.

### 6.1.1 Requirements for a case of chemistry logistics

In order to give an idea of the range of the components for the following observation, an application example has been taken from [1]. A tank wagon weighting 90 t is considered, which should be rebuilt to a FlexCargoRail vehicle. The vehicle must be able to move at a speed up to 25 km/h within the factory premises where the inclines do not exceed 12 ‰. It must be capable of running the distance to the transfer station of 3 km loaded and the same distance back unloaded without being charged meanwhile. Not each wagon has to be powered, and thus the next requirement is that the FlexCargoRail freight wagon should move with it one conventional tank wagon of the same weight.
A required capacity of the driving motor of 100 kW is calculated on the basis of these edge conditions. The battery capacity must be not less than 6 kWh , whereas a sufficient buffer should be definitely provided. For the most regarded applications a capacity of 10 up to max. 30 kWh is needed for longer sidings or an application of a powered wagon as shunting locomotive.

### 6.1.2 Necessary components

Figure 1 shows which components must be additionally reconstructed for converting a conventional freight wagon into a FlexCargoRail freight wagon. Some components (such as cooler, converter) can be seen as standard ones, so that there is no need to consider them in detail. The elaborate discussion will be devoted to central components.
A central element is naturally an electric drive to be integrated into the bogie. Basically, it is possible to fix a motor on the frame and connect it with a cardan shaft to the wheelset transmission. The drive shaft is though a high-maintenance element, sensitive to shunting crushes. For that reason a motor is integrated into the bogie. A construction with a shiftable gear box and a directly mounted motor is based on a conventional transmission Y-25 and is already used in construction vehicles and tunnel rescue trains (see also Figure 4).
Another novelty in the equipment of freight wagons is a traction battery. Conventional lead-acid batteries are not applicable in this case due to their particular heavy weight. On the other hand, the innovative lithium-ion batteries are not yet suitable for the application on the railroad, so they are rejected as well. NiCd and NiMH batteries show a big potential for exploitation in the coming years, which already today are used in the rail traffic for hybrid trams. It should be stressed that the energy storage with the mass

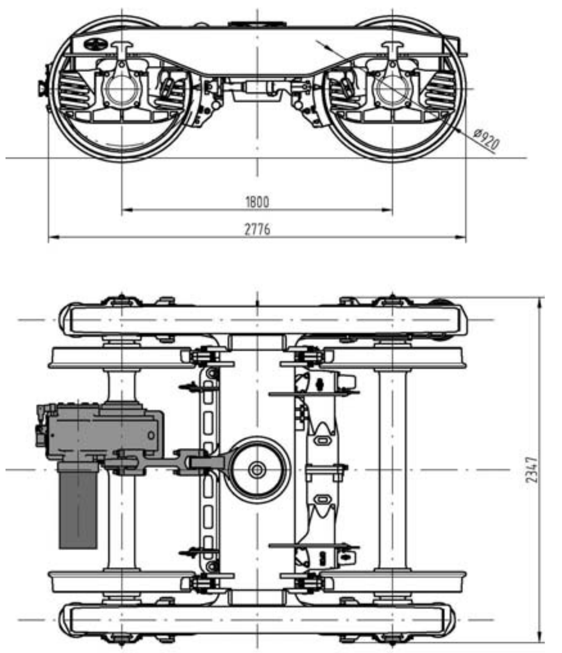


Figure 4: Electric powered bogie of the Eisenbahnlaufwerke Halle GmbH & Co. KG [8]

of 200 bis 600 kg (according to the required capacity) is an important factor influencing costs and weight, but it also reduces the load capacity. A developmental leap in battery technology as forecasted by experts (see also [4]) could also be helpful for the FlexCargoRail system as concerning costs and weight reduction and higher performance.
Finally, remote control will be dealt with in detail. Components available on the market are suitable for the FlexCargoRail vehicles. Modifications are essential in allocating the powered vehicles (one remote control should alternately control different vehicles) and require additional safety precautions (securing that the intended vehicle is moved and not another one out of sight of the shunter). Furthermore, an additional function of remote control in multiple unit could be reasonable. On the basis of these supplementary features and of the high expenses for remote control for the complete system it has to be balanced here whether an innovative approach for remote control should be found (see Section 6.1.3).

### 6.1.3 Economization potentials concerning the components

As already mentioned above, converting a conventional freight wagon into a FlexCargoRail freight wagon and its subsequent operation involves investment and operation expenses which are significant as compared to those of a conventional freight wagon. It is a normal practice in the railcar manufacturing industry to aim at high reliability, availability and safety in building vehicles. For the FlexCargoRail vehicles the question should be answered whether all these strong requirements to the usual specifications of railcars should be taken into account. Naturally, this should not concern some specifications like shock and temperature resistance or safety. Reliability and safeguarding against failure are elementary features of conventional locomotives, serving to prevent cases when the whole train remains lying on the track and blocks the way for other trains. The consequences of failure of a FlexCargoRail freight wagon are on the contrary much less dramatic. On the one hand, there are often runarounds on the blocked distance for other shunting units in a shunting area. On the other hand, a shunting locomotive or another FlexCargoRail freight wagon is normally available for towing the defective vehicle away. The failure of a FlexCargoRail freight wagon has no serious consequences even in the main run due to the redundancy of the multiple unit, so that the defective vehicle could further be moved on passively in the train like a conventional freight wagon.
In respect of costs it is profitable to resort to standard industry components, keeping the system safety. Thus, motors applied in commercial road vehicles could be used instead of a specially designed motor for the railway system. The sturdy three-phase asynchronous motor 1PV513 (Siemens) fulfils the necessary temperature and robustness requirements at a simultaneously low weight and correspondingly low costs. Further reduction of expenses is possible with other components, such as converter, through the use of standard industrial components. Prototypical trials must show how these components prove to perform in the everyday life operation.
As elucidated above, the currently available remote controls have to be upgraded as to certain functions for the application in FlexCargoRail. This individual adjustment could cause higher expenses as compared to the conventional remote control, with additional costs for the vehicle controlling computer. Here some costs could be saved as well again through resorting to industrial components. The currently available SIL3-capable SPS system could replace a special vehicle control for railcars. Besides, the radio remote control can directly be integrated into this vehicle control, which is also suitable for safety relevant functions, with the help of Industrial Wireless Local Area Network (IWLAN). By using modern standard protocols like, for example, ProfiSafe, the required safety level is preserved. Mobile devices of the SPS system , that are similarly obtained today and that have to be necessarily adjusted to the requirements to the shunting operations (robustness, serviceability in gloves, serviceability with one hand), are used today as transmitters for remote control.

## 6.2 Costs effects of the new operational method

The operational methods of the FlexCargoRail system, described in section 4, affect the expenses. Due to the fact that the costs depend on multiple parameters, no quantitative assessment

of the changes in expenses, as compared to conventional operation, can be made. Cost effects should rather be just elucidated here, for they correspond to particular application needs in each case.
In conventional shunting the shunt driver, in accordance with the system requirements, always stays at the just removed vehicles. If it is necessary to move the vehicles to another station, the shunt driver must also approach it in an empty run. In FlexCargoRail, on the contrary, individual motorization of each FlexCargoRail freight wagon allows a certain degree of freedom which enhances the flexibility, but at the same time poses a problem for the operator of covering the distances between individual vehicles to be moved. Such distances within the factory premises are rather moderate, whereas at the pick-up from a transfer station they can stretch to several kilometres. This obliges the personnel to cover these distances and creates extra costs.
The distance could still be reduced thanks to clever arrangement. For instance, the pick-ups from the transfer station could be preferably coordinated there with the delivery of vehicles, so that the shunt driver travels with one FlexCargoRail freight wagon from the factory premises to the transfer station and returns with another one. Furthermore, it is conceivable that a motorized road vehicle can be used, especially for the pick-up of wagons from the transfer station. Finally, FlexCargoRail freight wagons are also capable of remote control over large distances, especially in case of application of the innovative remote control (see also 6.1.3). The corresponding requirements, particularly the safety-related ones (like blockading or continuous monitoring of the travelled track), can not be discussed here.
It should also be noted that skilled employees are required as shunt drivers at the loading station operating centres, in case the pick-up have to be made by the operator. Similarly, a corresponding training is required for operating the FlexCargoRail freight wagons within the factory premises.

## 7 Evaluative summary

It has been shown in the above sections that FlexCargoRail freight wagons make the operation in the sidings considerably more efficient. The quick and flexible delivery of wagons in the sidings is realizable, and the shunting locomotive, so far indispensible, is immediately available for other operations. This helps to save efforts of shunting locomotives and the technical staff. Moreover, advantages in energy use during shunting operations are to be observed, which consist in reduction of the shunting trips, as well as in the fact that these trips can be made more efficient due to electric drive and regenerative braking. Advantages in energy in the main run are also to be expected, that will become more important due to changes in energy mix and innovation.
In order to convert conventional freight wagons into FlexCargoRail freight wagons, it is necessary to reconstruct numerous high-quality and partially highly innovative components in a vehicle. This requires investments into vehicle engineering. Maintenance of FlexCargoRail vehicles is likewise more complicated as compared to conventional freight wagons, and the maintenance rates are smaller. Finally, the new operational sequences lead to running costs, even though to another extent and for other purposes than in conventional operation. These aspects concerning the costs stand in opposition to the operational and energetic use of FlexCargoRail.
To sum it up, there exists a complex composition of the costs and use proportions, which makes an over-all statement about profitability difficult. The FlexCargoRail System does not at all claim to be able to penetrate all the application areas of single wagon load traffic through economic advantages. As a result of numerous communications with potential customers it has become clear that in certain branches a substantially higher use is expected, as opposed to the costs, due to the application of FlexCargoRail. Especially in the chemical logistics, an efficient, flexible and thus eventually a cost-effective operation is expected to be realized with FlexCargoRail. However no general conclusion can be made concerning specific industry sectors: in each potential application case separate efficiency tests must be conducted.

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