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INCREASING CAPACITY UTILIZATION OF SHUTTLE TRAINS IN INTERMODAL TRANSPORT BY INVESTING IN TRANSSHIPMENT TECHNOLOGIES FOR NON-CRANABLE SEMI-TRAILERS

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ABSTRACT

For shuttle trains with a fixed transport capacity which are the dominant operating form in intermodal transport, increasing capacity utilization is of crucial importance due to the low marginal costs of transporting an additional loading unit. Hence, offering rail-based transport services for non-cranable semi-trailers can result in additional earnings for railway companies. However, these earnings have to compensate for the investment costs of the technology. Based on a dynamic investment calculation, this paper presents a simulation model to evaluate the economic profitability of transshipment technologies for non-cranable semi-trailers from the railway company's perspective. The results depend on the capacity utilization risk faced by the railway company. In particular, if the railway company does not sell all the train capacity to freight forwarders or intermodal operators on a long-term basis, investing in technology for the transshipment of non-cranable semi-trailers can be economically profitable.

1 INTRODUCTION

Freight volume is predicted to increase in the years to come and the majority of this growth is expected to even increase the road freight transport volume. According to forecasts the total road freight transport volume in the European Union will grow to 2442 billion ton kilometers (tkm) in 2030 which is an increase of 43% compared to 2005 (Rich and Hansen 2009).

These trends put a high pressure on the road infrastructure and are considered to be environmentally disadvantageous due to the high external costs of truck transportation. Therefore, one of the goals of the EU transport policy is to shift 30% of road freight over 300 km to other modes of transport like rail or waterborne transport by 2030 (European Commission 2011). Hence, intermodal transport is of increasing importance. According to the definition of the European Commission intermodal transport is "the movement of goods in one and the same loading unit or road vehicle, which uses successively two or more modes of transport without handling the goods themselves in changing modes" (UN/ECE 2001). Intermodal transport chains can be separated into at least three legs: pre-carriage, main-carriage and on-carriage (Stedieseifi et al. 2014). While local pick-up and delivery operations in pre- and on-carriage are often performed by truck, transport modes characterized by economies of scale are used for the main-carriage (Bektas and Crainic 2007; Bontekoning, Macharis, and Trip 2004). Since the focus of this paper is on rail-based intermodal transport chains, intermodal transport refers to the combination of road (pre- and on-carriage) and rail (main-carriage) using the loading units containers, swap bodies and semi-trailers. While containers and swap bodies are the dominant loading unit in intermodal road-rail transport, semi-trailers are commonly used in road transport.

In Germany, about 70% of the road freight transport volume (310 billion tkm) in 2014 was performed with semi-trailers (German Federal Motor Transport Authority 2015). Therefore, they are of focal importance for a shift from unimodal road transport to intermodal transport. Semi-trailers can be further separated in non-cranable and cranable semi-trailers which are equipped with grappler pockets and can be lifted by conventional transshipment equipment (reach stackers and portal cranes) in terminals. However, the majority of semi-trailers in Europe (over 85%) are non-cranable. Based on this shortcoming, several transshipment technologies for the horizontal or vertical transshipment of non-cranable semi-trailers have been developed.

However, depending on the technology, investments in terminal infrastructure and/or additional transshipment equipment are necessary. From the perspective of the railway company undertaking investments in the transshipment technology, the economic profitability of these investments must be ensured. The additional demand generated from attracting new customers by offering transportation services for non-cranable semi-trailers can increase the capacity utilization of shuttle trains which are the dominant operating form for railway transport in intermodal transport (Woxenius 2007, Macharis and Bontekoning 2004). Shuttle trains consist of a fixed number of wagons and run according to a predefined schedule. Since the costs for rail transport are mainly fixed costs (Woxenius, Persson, and Davidsson 2013), increasing the capacity utilization directly results in additional profit. This profit must be compared with the investment costs and possible additional costs (e.g. for handling and/or maintenance).

The perspective of the railway company which has to decide about the investment in transshipment technology has not been considered in research so far. This paper addresses this research gap and investigates this investment decision subject to various risk scenarios for the capacity utilization faced by the railway company. The three investigated scenarios differ according to the percentage of capacity sold on a long-term basis to the customers of the railway company which are intermodal operators and freight forwarders.

Therefore, the research question is the following: Under which risk scenarios for the capacity utilization is the investment in transshipment technology for non-cranable semi-trailers economically profitable from the perspective of the railway company? To account for the temporal distribution of the cash flows, the economic profitability is evaluated based on a dynamic investment calculation. The net present value (NPV) method is used to discount estimated future cash flows for different investment periods. However, the cash flows can be considered as uncertain and differ according to the risk scenario for the capacity utilization, the availability of necessary transshipment equipment at the terminals and the demand for intermodal transport services for non-cranable semi-trailers, and other operational influences.

Therefore, a simulation approach is used to model the operation of shuttle trains capable of loading non-cranable semi-trailers to estimate the cash flows for the dynamic investment calculation. The developed model follows the agent-based modeling approach that allows one to model complex systems consisting of autonomous entities called agents, which have their individual behavior and interact with other agents (Macal and North 2010). Agent-based modelling allows one to precisely model the various entities (e.g. train, orders, transshipment equipment) which are part of the transport process in a detailed manner. The model was developed in cooperation with a leading railway company and validated with industry experts. In this paper, it is used to conduct a case study for a specific origin-destination (O/D) pair.

The remainder of this paper is structured as follows. In the next section, relevant literature regarding simulation in intermodal transport is reviewed and research concerning the transshipment of non-cranable semi-trailers is summarized. Furthermore, details on the investment decision along with different risk scenarios for the capacity utilization faced by the railway company are presented. In Section 3, the simulation model and its agents are described before an illustrative case study is conducted in Section 4. In Section 5, the paper closes with conclusions and highlights the need for further research.

2 RESEARCH BACKGROUND

2.1 Simulation in Intermodal Transport Chains and Transshipment Technologies for Non-Cranable Semi-Trailers

Various literature reviews exist categorizing strategic, tactical, and operational planning problems in intermodal transport (Crainic and Laporte 1997; Macharis and Bontekoning 2004; Bontekoning, Macharis, and Trip 2004; Caris, Macharis, and Janssens 2008; Caris, Macharis, and Janssens 2013; Steadieseifi et al. 2014). Since there is a high number of literature reviews in this field, this overview focuses on literature dealing with simulation-based approaches in intermodal transport. Sophisticated simulation models are described in the literature which often consist of connected layers which either subsume various decision-making entities or physical transport/transshipment processes.

Baindur and Viegas (2011) introduce an agent-based modelling approach to estimate the modal split of competing transport modes (road and waterborne intermodal transport) between trading regions. While the transport processes are encapsulated in a physical layer, shippers and carriers interact on a market layer through simulated contracts. A regulatory layer forms the framework conditions for the market and physical layer. The model can be used to estimate the impact of policy measures on the modal split.

Gambardella, Rizzoli, and Funk (2002) present an agent-based simulation model for intermodal transport chains simulating the flow of intermodal terminal units (ITUs) among inland intermodal terminals connected by rail corridors. Each terminal has its user catchment area connected to it by the road network. While an agent-based system coordinates the transport process, discrete-event simulation is used for the terminal and corridor simulation. The model can also be applied to evaluate different policy measures. Rizzioli, Fornara, and Gambardella (2002) focus on the terminal simulation included in the aforementioned simulation model. Based on a discrete-event model the operation of intermodal rail-road terminals can be simulated. The impact of alternative input scenarios (e.g. processing times) on performance criteria (e.g. mean residence time of ITUs) can be tested for user defined terminal structures.

Ballis and Golias (2002) estimate cost versus volume curves for various rail-road terminal configurations using a simulation-based approach. Main design parameters of a terminal are discussed and efficient terminal configurations are recommended for specific cargo volume ranges. Based on the fact that the efficiency of time savings due to efficient terminal operations depends on the applied rail operating form, Ballis and Golias (2004) broaden the scope of the investigation. By implementing the terminal simulation and cost curves into a macro freight transport model simulating different rail operating forms, different terminal configurations can be tested in a transport network.

Holmgren et al. (2012) developed the Transportation And Production Agent-based Simulator (TAPAS) which is able to simulate various transport chains to analyze transport-related policy and infrastructure measures. They also differentiate between a physical (production and transportation) and a market layer (decision making and interaction between actors). The decisions taken by agents on the market layer lead to actions on the physical layer. TAPAS does not exclusively focus on intermodal transport, but the agents included in the model can be composed to replicate intermodal transport chains.

Macharis and Pekin (2009) present a location analysis model for Belgian intermodal terminals (LAMBIT) which can be used to compare intermodal (rail and inland waterways) and unimodal road transport. Various policy measures like the introduction of new terminals and subsidies can be analyzed.

Technologies for the transshipment of non-cranable semi-trailers are only addressed in a few papers. Chiara, Deflorio, and Spione (2008) investigate the probability of selecting an intermodal transport alternative to unimodal road transport enabled by horizontal transshipment technologies for non-cranable semi-trailers. For the Modalohr technology, they estimate the modal split for unaccompanied as well as accompanied (tractor and semi-trailer are loaded on the train) intermodal transport and unimodal road transport between the Italian and French Alps. Based on random utility theory, the calibrated modal split model estimates that about 4% of the total shipments would use intermodal transport when four journeys per day are offered which increases to 9% in case of a frequency of ten services per day.

Truschkin and Elbert (2013) explore the modal split between intermodal transport and road transport for the German transport market enabled by the extensive introduction of horizontal transshipment technologies for non-cranable semi-trailers. A discrete choice model is combined with a bass diffusion model to estimate the modal split using a system dynamics simulation. The model analyzes the impact of transport-related policies on the modal split. Enabled by the direct subsidization of rail line hauling a maximum market penetration ratio of 42% for intermodal transport is estimated.

Ballis (2014) investigates the adaptation of operative terminal processes for the transshipment of non-cranable semi-trailers. Based on a discrete-event simulation for a specific technology for vertical transshipment he analyzes parameters affecting the performance of the system.

Existing studies in the field of transshipment technologies for non-cranable semi-trailers mainly focus on the transport demand which can be potentially shifted from unimodal road transport to intermodal transport. The corresponding transport capacities are approximated by the number of journeys per day (Chiara, Deflorio, and Spione 2008) or are assumed to be infinite as in the case of Truschkin and Elbert (2013). The perspective of the railway company hauling the trains and responsible for the investment decision regarding the transshipment technology has not been considered in research so far.

2.2 Relevant Framework Conditions for the Investment Decision

This paper focuses on vertical transshipment technologies since they regularly do not require additional investments in new terminals and can be used in existing large-scale transshipment terminals. In particular, a system consisting of a transport platform and a terminal platform is investigated in this paper. The transport platform is a metal frame which is placed under a semi-trailer to load it on the train and remains under the semi-trailer during rail transport. In order to position the semi-trailer on the transport platform, an additional terminal platform is needed. Regarding the investment costs the purchase prices for the transport and the terminal platforms have to be included in the analysis. Additional running costs can stem from additional handling effort as well as maintenance work. However, additional running costs for transshipment and maintenance are neglected in this paper. Based on the description of the technology, the duration of the transshipment process for non-cranable semi-trailers (up to 5 minutes per loading unit) is only slightly longer (about 25%). Furthermore, due to the simple construction the technology can be considered as robust.

In this paper the demand due to non-cranable semi-trailers is considered as an additional demand to increase the capacity utilization of existing train connections with fixed capacities. Because of high capital investments, railway companies usually plan and fix rolling stock capacity and train schedules for several months in advance (Jaržemskienė and Jaržemskis 2009). Hence, the scheduling of additional trains is not included in the analysis.

To evaluate the economic profitability of the transshipment technology, the NPV method is used in this paper. This method has been applied in the logistics context, e.g. to estimate the economic profitability of transshipment technologies (Kim 2010) and returnable packaging (Rosenau et al. 1996). As a dynamic investment calculation method, it accounts for the temporal distribution of cash flows and discounts them by an interest rate which can be defined based on the cost of capital. The resulting NPV can be seen as the investment's absolute value in terms of today's value of money (Rosenau et al. 1996). Hence, the tipping point for economic profitability (break-even point) is an NPV of zero.

Regarding the positive cash flows (additional earnings), different risk scenarios can be differentiated according to the proportion of the capacity risk faced by the railway company. In the first scenario (referred to as "outsourced risk") the whole capacity of a shuttle train for an O/D pair is sold to freight forwarders or intermodal operators on a long-term basis. Hence, capacity usage is at their risk, i.e. unused loading space on the train has also to be paid, and investing in transshipment technology for non-cranable semi-trailers cannot increase the capacity utilization from the perspective of the railway company. In this case investing in the technology is only economically profitable if loading space for non-cranable semi-trailers on a shuttle train can be sold at a higher price to intermodal operators and freight forwarders.

In case loading space on shuttle trains is regularly sold only partly to intermodal operators and freight forwarders (referred to as "own risk"), investing in technology for non-cranable semi-trailers can lead to new customers for the railway company. In this case, the investment can also be economically profitable if the additional earnings due to the higher capacity utilization are more than the investment costs of the technology.

A last scenario can be considered as a combination of the two aforementioned scenarios and will be referred to as "shared risk". Like for the first scenario, the whole capacity of the train is assumed to be sold to freight forwarders and intermodal operators. However, in case loading space equipped for non-cranable semi-trailers (referred to as non-cranable loading space in the following) is not used by a freight forwarder or intermodal operator, the railway company partly refunds them for the unused space and can sell it to other customers. In this scenario, additional earnings can be generated by reselling unused space.

3 SIMULATION MODEL

3.1 Model Structure

The agent-based simulation model is suited to simulate the transport of non-cranable semi-trailers for multiple O/D pairs between two transshipment terminals served by shuttle trains. The model allows simulating the availability of non-cranable semi-trailers at the terminal either based on probabilities or based on a more complex approach consisting of the interaction of a market and a physical layer. Since this paper focuses on rail-based main-carriage, the approach of approximating the availability of non-cranable semi-trailers by probabilities is chosen. In this case, a random number of semi-trailers are available for loading at the terminal at the time of departure and the physical layer of the simulation covers the main-carriage. The description of the agents in the next section focuses on this case.

The extended market interaction model covers the whole intermodal transport chain including pre- and on-carriage by truck and main-carriage by rail. The main-carriage can also be performed by truck as an alternative to rail transportation. On the market layer the transport mode for the transport chain can be selected by the shippers. This extended model is briefly described at the end of this paper.

3.2 Agents of the Simulation Model

Five different agents are integrated in the simulation model: Train, TransportPlatform, Terminal, TransportOrder and TrainOrder. The train agent performs rail-based transport services for the main-carriage between transshipment terminals and runs according to a predefined schedule. The origin and destination terminal of the transport process are determined by a TrainOrder. A train agent can comprise several TransportOrders, each of them relating to a single semi-trailer. Additionally, it contains a specific number of transport platform agents. One important parameter of the train agent is its capacity in terms of loading units. The speed of the train is defined by the schedule which contains the time of departure and time of arrival.

A transport platform agent refers to the equipment needed to load a non-cranable semi-trailer on the train. Transport platforms are loaded and unloaded in terminals and can be transported in trains with and without a semi-trailer (cranable or non-cranable) on top of it. A transport platform must be available in a terminal to load a non-cranable semi-trailer on the train. Based on the parameter settings, transport platforms can be stored in terminals or they can be linked to a specific train. In the latter case, transport platforms run with this train whether or not they are needed to transport non-cranable semi-trailers.

The terminal is a physical object in the simulation model, but also has decision making capabilities. Based on a schedule, it calculates the necessary number of trains for a specific O/D pair and initiates TrainOrders to run these trains between itself and a destination terminal. Based on the applied probability to approximate the availability of semi-trailers, the terminal generates transport order agents containing the semi-trailers and stores them until the next scheduled departure of a train. Before the departure, depending on the availability of transport platforms, non-cranable semi-trailers and other loading units are loaded on the train and the transport order agents are handed over to the train agent. After the train arrives at the destination terminal, semi-trailers are unloaded and the TransportOrders are stored by the terminal agent. One main parameter of the terminal agent is its individual transshipment cost. Every terminal agent contains a single terminal platform for the transshipment of non-cranable semi-trailers.

A TransportOrder comprises a single loading unit and is generated by the terminal. It has an origin and a destination which are terminal agents. It tracks the time needed between the various physical locations of the transport chain. The total transit time between the origin and destination as well as the time on board a vehicle are stored and it saves the costs associated with the overall transport process.

A TrainOrder initiates a train journey. Train order agents are generated by the schedules implemented in the terminal agents. Besides the destination terminal, it can contain an intermediate stop where the train stops for a predefined time. The journey of the train is visualized using GIS-data in the simulation model.

3.3 Development of the Computer-based Simulation Model

The computer-based simulation model was implemented using the software AnyLogic 7.2 which offers various modeling approaches (discrete-event, system dynamics and agent-based simulation). In this paper, the agents and their behavior are modelled using state charts and custom Java code which allows incorporating the conceptual model in a detailed manner. This flexibility can be seen as one of the most important features of simulation software (Law 2013). The computerized model has to be verified to assure that the computer programming and implementation of the conceptual model are correct (Sargent 2013). Complexity was added piecewise. At every step, the code was checked rigorously in order to debug the individual elements concurrently with model development (Sargent 2013). The outputs of the submodels as well as the outputs of the overall model were checked (degenerate tests). Furthermore, operational graphics displaying the performance measure of the model and additional model variables were used to observe the dynamic behavior of these indicators during model execution (Sargent 2013).

4 CASE STUDY

4.1 Case Study Overview

A case study for a selected O/D pair is described in this section. Based on this case study, the research question of this paper is addressed. However, the sensitivity analyses performed at the end of this section allow generalizing the results to other O/D pairs. The assumptions of this case study were discussed with logistics experts and managers from a railway company.

Shuttle trains running between Verona (Italy) and Lübeck (Germany) were selected for further investigation. First, this O/D pair was chosen since intermodal transport is a competitive alternative for this trans-Alpine traffic route. Second, the necessary structure gauge for transporting semi-trailers is available on this route. Third, a major percentage of the trucks arriving by ferry in Lübeck are equipped with non-cranable semi-trailers. Due to different train length restrictions, trains get shortened before crossing the border to Italy. In the other direction, additional wagons are coupled to the train. However, these additional wagons are neglected in the following since handling non-cranable semi-trailers at an intermediate stop was not considered as possible due to the limited terminal space. Based on the discussion with the railway company, storing the transport platforms in the terminals was not considered as an option.

4.2 Dependent and Independent Variables

Since the objective of the simulation model is to evaluate the economic profitability of investing in transshipment technology for non-cranable semi-trailers, the NPV is the dependent variable.

The analysis is performed for different investment periods (independent variable InvestPeriod). Due to different sources for additional earnings, further independent variables differ for each scenario. For the first scenario (outsourced risk) only higher prices for non-cranable loading space are a possible source of additional earnings. Thus, the price of this loading space relative to the price for loading space for a conventional loading unit (cranable semi-trailers and other loading units) is used as an independent variable (PriceNonCranable). To estimate the target costs for the transshipment equipment for this scenario, the investment costs for the transport platforms are varied (CostsTransportPlatform). Since no uncertainty is present in this scenario, the results are deterministic.

Because other sources for additional demand are investigated in the second and third scenario, the price for non-cranable loading space and the investment costs for transport platforms are fixed. For the second scenario (own risk) the capacity is only partly sold to freight forwarders and intermodal operators on a long-term basis. The remaining wagons subject to utilization risk from the perspective of the railway company are assumed to be equipped for non-cranable semi-trailers. Based on the case study assumption that no storage of transport platforms takes place in the terminals, they are linked to specific trains. Hence, the number of wagons equipped for non-cranable semi-trailers is fixed for a train. Since non-cranable or cranable semi-trailers can be loaded on the train together with a transport platform, available cranable semi-trailers can be also used for non-cranable loading space. Hence, in the first step for every loading space not sold on a long-term basis, the availability of a cranable semi-trailer is determined by a Bernoulli distributed random variable. This distribution was chosen since it easily allows evaluating the feasibility of realizing the resulting break-even points in practice. The corresponding success probability is an independent variable of this scenario (SuccessProbCranable). The value of this independent variable depicts different average levels for the capacity utilization without consideration of non-cranable semi-trailers. The resulting earnings constitute the reference value which will be compared with the higher earnings after accounting for the additional demand due to non-cranable semi-trailers. In the second step, for every remaining loading space the availability of a non-cranable semi-trailer is determined by a separate Bernoulli distributed random variable (SuccessProbNonCranable).

In the third scenario (shared risk) the whole capacity of the train is assumed to be sold to freight forwarders and intermodal operators like in the first scenario. However, in case non-cranable loading space is not used by a freight forwarder or intermodal operator, the railway company partly refunds them for the unused space and can sell it to other customers. Hence, in the first step for every loading space not sold on a long-term basis (equipped for non-cranable semi-trailers), the non-use probability is determined by a Bernoulli distributed random variable which is the first scenario-specific independent variable (SuccessProbNonUse). The amount refunded relative to the price for this loading space is a second scenario-specific independent variable (AmountRefunded). Additional earnings can be generated if the amount refunded to intermodal operators or freight forwarders is lower than the realized price for reselling the loading space. However, not in every case non-used space can be resold. Thus, the success probability (Bernoulli distributed) of reselling non-used loading space is the last independent variable of this scenario (SuccessProbReselling).

4.3 Data Input and Validation

The realistic train schedule for the O/D pair was implemented in the simulation model. According to the schedule, six trains run in each direction per week. To operate this schedule, four trains (four sets of wagons) and two locomotives are necessary. The relevant capacity of the shuttle train is 26 loading units. Based on the discussion with the railway company, six out these 26 spaces are assumed to be equipped for the transport of non-cranable semi-trailers meaning that 24 transport platforms in total have to be bought. Earnings per loading space were approximated by distance-dependent earnings. The distance between Verona and Lübeck is 1289 km. The costs associated with operating a train are assumed as fixed and independent of the number of loading units on the train. The input data was discussed and validated with the railway company in workshops and interviews. In addition to data validation, the suitability of the model for its intended purpose has to be validated. Since the transshipment technology for non-cranable semi-trailers has not been implemented yet, no data relating the usage of the technology and the capacity utilization was available. For non-observable systems, the primarily used method for operational model validation is exploring the output behavior of the model (Sargent 2013). Hence, the simulation output was reviewed with logistics experts and managers from the railway company for reasonableness to address the model's face validity (Law 2013).

4.4 Simulation Experiments

To analyze the three scenarios a full factorial design was chosen. The parameter variations are summarized in Table 1 resulting in 485 system configurations. For each system configuration five replications (scenario 2 and 3) were performed (fixed sample size procedure) and different random number streams were used to obtain independent replications (Law 2013). The five replications resulted in confidence intervals for the means ($\overline{X}(n) \pm t_{n-1,1-\alpha/2}\sqrt{S^2(n)/n}$ where $S^2(n)$ refers to the sample variance, α=0.05) which were comparatively small. The estimated relative precision, defined as the confidence interval half-width divided by the estimated mean of the performance measure (Bienstock 1996), was regularly lower than 10%. According to the investment period, different run lengths of the simulation were chosen. To reduce the number of necessary simulation runs for the second and third scenario, CostsTransportPlatform was fixed to 25,000 € and PriceNonCranable was set equal to 100%. For the third scenario only an investment period of two years was investigated. The costs for a single platform which is needed in every terminal at least once (terminal platform) are assumed to be 30,000 €.

Table 1: Configuration of the simulation experiments.

Scenario 1: Outsourced risk	**Scenario 2: Own risk**	**Scenario 3: Shared risk**
InvestPeriod: 2, 5, 10, 15 yrs.	InvestPeriod: 2, 5, 10, 15 yrs.	InvestPeriod: 2 yrs.
PriceNonCranable: 100%-120% (step 5%)	SuccessProbCranable: 0%-83.3% (step 16.67%)	SuccessProbNonUse: 12.5%, 25%-100% (step 25%)
CostsTransportPlatform: 5,000 €-30,000 € (step 5,000 €)	SuccessProbNonCranable: 10%-100% (step 10%)	AmountRefunded: 0%-100% (step 25%)
		SuccessProbReselling: 0%-100% (step 25%)

4.5 Numerical Results

For every parameter configuration, the mean $\overline{X}(n)$ of the dependent variable (NPV) was calculated based on five replications. Since the confidence intervals were comparatively small, they are not depicted in the following graphs to improve readability. For every scenario and parameter set the NPV of the investment is determined by the simulation model. Based on the results, the relevant break-even points (NPV equal to zero) of the investments are interpolated based on a curve fitting approximation and the corresponding values of the independent variables for these points are provided in the following figures. Hence, points in the graphs do not always correspond to the levels of the independent variables shown in Table 1.

For the first scenario (outsourced risk) the break-even price for non-cranable loading space (relative to the price for a conventional loading unit) is depicted in Figure 1 for different investment costs for a transport platform. For a longer investment period the necessary price premium decreases. Furthermore, the price premium increases linearly with the costs for a transport platform. In case of investment costs in the range of 20,000 € to 30,000 € a price premium starting from 2% (15 years investment period) up to 15% is necessary. Based on the discussion with the railway company, realizing a price premium for the transport of non-cranable semi-trailers was not considered as feasible due to the stiff competition with unimodal road transport. The results rely on the fact that six loading spaces are equipped with transport platforms. In case less loading space is prepared for non-cranable semi-trailers, the price premium increases since the lower additional earnings also have to compensate the costs of the terminal platforms.

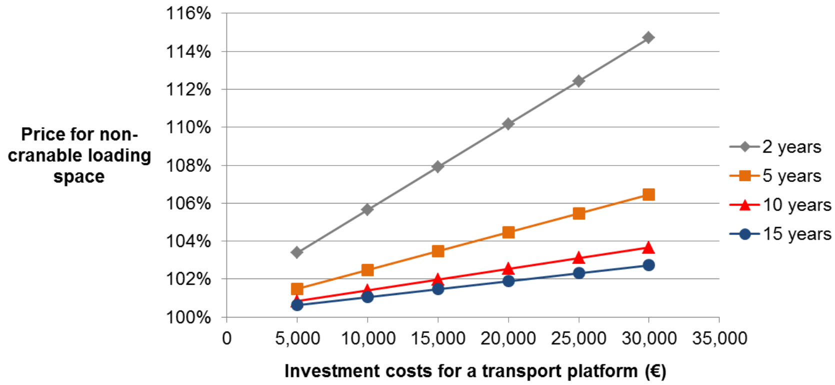

Figure 1: Scenario 1 – Break-even calculations for different investment periods.

In the second scenario (own risk) loading space not equipped for non-cranable semi-trailers (20 loading units) is assumed to be sold on a long-term basis. In a first step, the success probability for cranable semi-trailers was fixed to a specific value (see Table 1) to depict different current average capacity utilization levels of shuttle trains before considering the additional demand due to non-cranable semi-trailers. E.g. setting the success probability for cranable semi-trailers to 0.5 for every non-cranable loading space (6), results in a current (i.e. without considering non-cranable semi-trailers) average capacity utilization of 23/26=88.5%. Thus, three non-cranable loading spaces remain. The availability of non-cranable semi-trailers for each of these loading spaces is determined by the success probability for non-cranable semi-trailers. Based on these results, the success probability for non-cranable semi-trailers to reach the break-even point is interpolated. Figure 2 presents the necessary break-even success probabilities for different current average capacity utilization levels. For instance, to reach the break-even point for a current average capacity utilization level of 88.5% (success probability cranable semi-trailer=0.5) every of the three (on average) remaining non-cranable loading spaces must be occupied by a non-cranable semi-trailer with a success probability of 25% (investment period two years). In case the current average capacity utilization is low (e.g. 76.9%) the necessary success probabilities for non-cranable semi-trailers are comparatively low for all investigated investment periods. This probability increases significantly for an investment period of two years for a rising current average capacity utilization. However, in case of a high current average capacity utilization, the necessary success probabilities apply to less non-cranable loading spaces which have to be occupied by non-cranable semi-trailers (see dashed line in Figure 2).

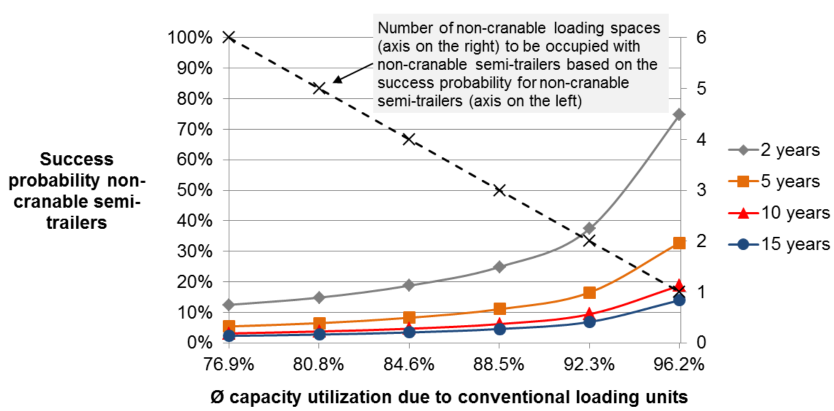

Figure 2: Scenario 2 – Break-even calculations for different investment periods.

The results for this scenario highlight the economic profitability of investing in the technology in case the current average capacity utilization is comparatively low. In contrast to the first scenario, the required success probabilities for non-cranable semi-trailers can be regarded as being achievable.

For the third scenario (shared risk), the necessary break-even probabilities for reselling of non-used non-cranable loading space, given various values for the non-use probability, are depicted in Figure 3 for an investment period of two years. This investment period is applied, since this scenario can be seen as a starter product for intermodal operators and freight forwarders to offer transport services for non-cranable semi-trailers to their customers in case the actual demand for this transport service cannot be easily estimated. Due to the amount refunded, the capacity utilization risk for the intermodal transport or freight forwarders is lower since it is shared with the railway company. Hence, additional earnings are highly uncertain for the railway company and the technology should amortize the investments in a short time frame. Since some of the system configurations investigated (e.g. amount refunded 100%) require higher success probabilities than 100% to break even, only reasonable combinations are depicted in Figure 3. The break-even probability for reselling increases with a falling probability for non-use. Since reselling at a higher price than refunded is the source of additional earnings in this scenario, having less possibilities for reselling (lower non-use probability) increases the required success probability for reselling. As expected, the required success probability for reselling increases with a rising amount refunded.

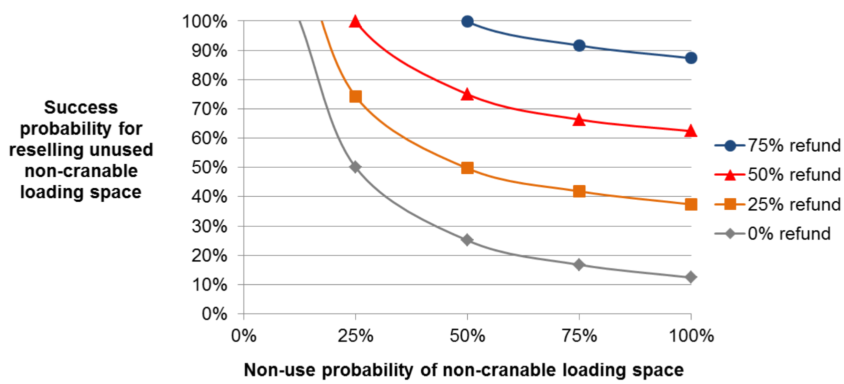

Figure 3: Scenario 3 – Break-even calculations for different amounts refunded (investment period 2 yrs.).

In case, on average 50% of the non-cranable loading space of a train (3 loading units) is not used and the amount refunded equals 50% of the price, vacant loading space has to be resold in about 75% of the cases. Since non-usage of non-cranable loading space can take place on short notice, reaching these values can be challenging. However, in case longer investment periods are accepted by the railway company, this scenario can be considered as an enabler of the market launch of the technology.

5 CONCLUSIONS

The results show that investing in transshipment equipment is economically profitable in case a comparatively high percentage of the capacity is not sold on a regular basis to freight forwarders or intermodal operators (scenario 2). In such a situation, empowering shuttle trains for the transport of non-cranable semi-trailers can increase the profitability of shuttle trains significantly. In case the whole capacity is sold to freight forwarders and intermodal operators on a long-term basis (scenario 1), investing in this technology is only reasonable from the perspective of the railway company if a comparatively high price premium for non-cranable loading space can be achieved. The shared capacity risk addressed in the third scenario is suitable in case the whole capacity is sold on a long-term basis, but the railway company wants to incentivize the transport of non-cranable semi-trailers.

Several practical implications can be drawn from the results. First, the railway company should base its investment decision for different O/D pairs on the current capacity utilization of the shuttle trains. In case the capacity can be sold on a long-term basis to intermodal freight forwarders or intermodal operators, investing in the technology does not seem to be economically profitable. Second, if the usage of the technology is supposed to be incentivized, offering a risk sharing approach (scenario 3) can be beneficial for the intermodal operators/freight forwarders and the railway company. However, this result depends on the ability of the railway company to resell non-used loading space.

The analysis is limited to a specific O/D pair. Assumptions about the price for loading space (distance-dependent in this paper) directly influence the results. However, the results can be extended to other O/D pairs exhibiting a similar distance and price structure. In case only lower prices can be realized for loading space, the break-even probabilities increase since the investment costs remain identical.

The approximation of the availability of non-cranable semi-trailers based on probabilities can be mentioned as another limitation of this paper. For a more detailed analysis, the extended version of the simulation model (market interaction) mentioned in Section 3.1 can be considered. It covers the whole intermodal transport chain including pre- and on-carriage by truck and main-carriage by rail as well as unimodal road transport. On the market layer the shippers either select intermodal transport or unimodal road transport based on their individual preferences and performance criteria of both transport options (e.g. costs, delivery time and punctuality). Shippers and receivers are modeled as agents in the vicinity of the terminals (catchment area). Based on the shippers' mode choice behavior the availability of semi-trailers for intermodal transport can be approximated. However, this behavior has to be explicitly captured for specific O/D pairs. Further research is also necessary to design strategies for the management of the platforms in case storage in terminals is considered and the usage of the platforms for different O/D pairs is analyzed. In particular from a network point-of-view, the interdependence between the availability of transport platforms and the local demand for rail-based transports of non-cranable semi-trailers should be considered in the design of repositioning strategies for the equipment.

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