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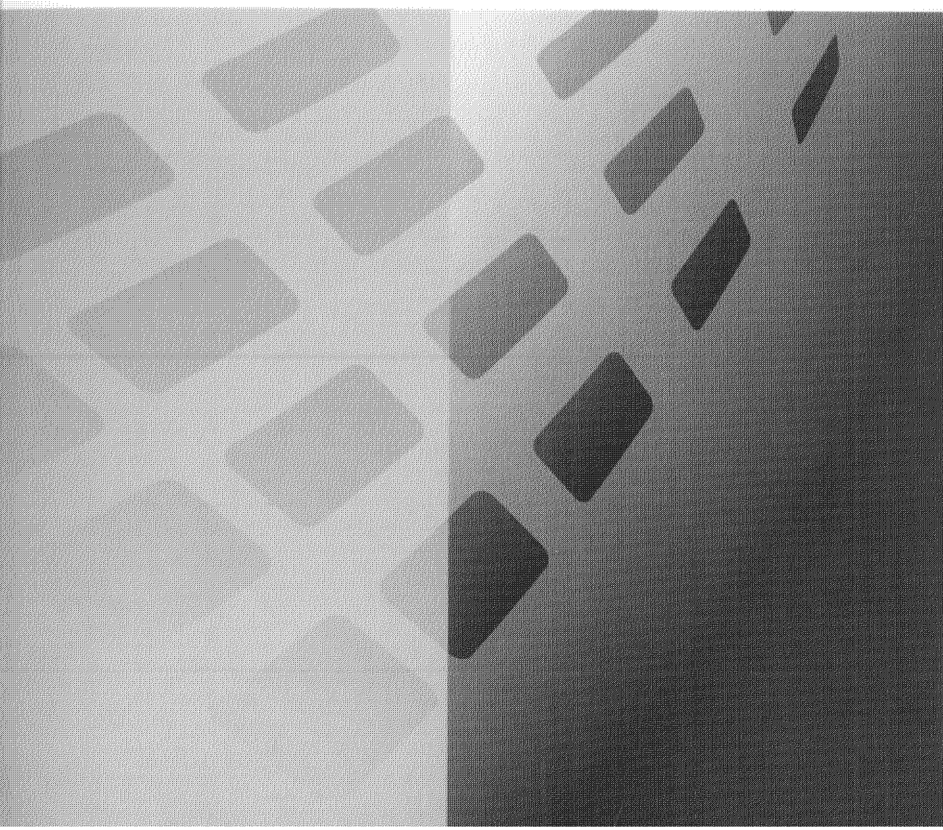
Wolfgang Kersten

Thorsten Blecker, Carlos Jahn and Wolfgang Kersten (Eds.)

# Maritime Logistics in the Global Economy

## Current Trends and Approaches



EUL VERLAG

# Modeling and Optimization of Transshipment and Waiting Times at Hubs

Adina Silvia Bruns

## Abstract

Transshipment between combined modes of transport is associated with time and efficiency losses on account of the transshipment process and waiting times. In the approach presented here, an optimization model is developed which minimizes the transshipment and waiting times at hubs. The modeling is based on knowledge from the field of operations research. The aim is to model a minimizing objective function with appropriate constraints to produce an optimization model. The literature surrounding this subject has various approaches which model logistic activities at hubs, but most of them fail to consider an optimization model to represent these activities. The approaches which do develop an optimization model have the following deficits: no optimization model explicitly minimizes the transshipment and waiting times in the objective function and considers in its constraints more relevant aspects such as different types of goods to be conveyed (standard and dangerous goods), different types of transport (main run, pre-carriage and on-carriage) and different forms of transshipment (reloading at the hub, passing through several hubs). Clearly there is a gap between the need for realistic modeling of real transshipment problems and the majority of existing mathematical optimization models in the relevant literature. This research study makes an initial attempt to close this gap.

**Keywords:** combined transport, transshipment and waiting times at hubs, optimization model

## 1 Introduction

Human exploitation of nature and irresponsibility towards the planet are changing the climate. The rising temperature on the earth (global warming) is largely attributable to increasing concentrations of $CO_2$ in the earth's atmosphere (Rahmstorf/Schellnhuber, 2007, p. 30) and the resulting greenhouse effect (Barth, 2002, pp. 46-47).

Over the past years, freight transportation has been growing on a worldwide scale, due in part to globalization, and is likely to continue growing in future. The rise in freight transportation is one of the main reasons behind climate-damaging $CO_2$ emissions. The increase in freight transport has been accompanied by a clear rise in transportation by road (Statistisches Bundesamt, 2011a and 2011b).

Transporting the majority of goods by road results in traffic congestion and excessive strain on the environment from $CO_2$ emissions (Eickemeier, 1997, p. 1). Rail transport of one barrel of freight over a distance of around 100 km consumes an average of 1.2 liters of diesel. By contrast, freight transportation by truck consumes an average of 5.2 liters of diesel for the same freight and same distance (Statistisches Bundesamt, 2004). This translates into average $CO_2$ emissions of 2.6 kg $CO_2$ to transport one barrel of freight over 100 km by train and 13.9 kg $CO_2$ emissions by truck (Statistisches Bundesamt, 2004). This clearly shows that transportation by truck creates significantly higher climate-damaging $CO_2$ emissions than transport by train. It is therefore desirable to disburden the roads and relocate freight to other modes of transport, in particular rail or waterways.

There is, however, a dislocation barrier here in that the forwarder and receiver of transported goods will almost always be served by roads, but often will not have their own rail or harbor connections for transport by rail or waterway. Combined transport by train or ship for the main run (at least 300 km (Vahrenkamp, 2007,p. 310)) and mostly by truck for pre-carriage and on-carriage therefore represents one of the most promising concepts for overcoming the aforementioned dislocation barrier. Under these circumstances, it is somewhat surprising that the combined transport is used far less (in 2007 combined transport accounted for just 6.6% of total freight transport (Reim, 2009, p. 586) than anticipated (Bundesministerium für Verkehr, Bau- und Wohnungswesen, 2001, pp. 3-4; Reim 2009, pp. 584-586).

Competitive disadvantages of combined transport are first and foremost transshipment and waiting times. By definition, combined transport involves at least two different modes of transport, between which the goods must be transshipped at least once. Where pre-carriage and on-carriage are involved, two transshipments are necessary. These transshipments usually take place at hubs and take time, which is

known as transshipment time. It is also possible that goods arriving at the hub by one means of transport cannot be handled immediately, because the resources or the subsequent means of transport are not free or available at the time. This can add to the waiting time and consequently extend the transport time as a whole. The main aim of coordinating logistics activities at a hub therefore consists in minimizing these losses of efficiency.

## 2 Definition of combined transport

*Combined transport* is defined as the transportation of goods or persons with the use of at least two different modes of transport. *Modes of transport* mainly refer to road, rail and waterway.

A general distinction can be made between direct and indirect transshipment of goods. In the case of direct transshipment, the loading unit will be handled a single time, meaning that it is transported by one crane from the starting point to the destination point of the hub. By contrast, in indirect transshipment the loading unit is handled several times by the same crane or different cranes, and where applicable by a driverless transport vehicle of the sorting system.

The present approach considers combined freight transport alone, in other words the transportation of goods, not of persons. In combined transport, the long transport route (main run) is by ship, train or airplane, with trucks used only on shorter distances (pre-carriage and on-carriage) (Bukold, 1996, p. 24; Bundesministerium für Verkehr, Bau- und Wohnungswesen, 2001, p. 5; European Conference of Ministers of Transport, 1998, p. 7; Koch, 1997, p. 64; Müller, 2005, p. 53; Organisation for Economic Co-operation and Development, 2002, pp. 15-16; Vahrenkamp, 2007, p. 309; Vrenken et al., 2005, p. 5). The change between the modes of transport, for example transshipment of the loading units from truck to train, takes place at hubs, also called combined transport hubs (Bundesministerium für Verkehr, Bau- und Wohnungswesen, 2001, p. 7; Martin, 2009, p. 293; Riedl, 1996, p. 13; Vahrenkamp, 2007, p. 309).

# 3 Study of the Current State of Research of Optimization Models

The relevant economics literature contains some models which deal with the transshipment and waiting times at hubs. In the following, five optimization models from the economics literature will be presented which – in the author's view – demonstrate a good approach to minimizing the transshipment and waiting times at hubs.

In his very detailed study, Alicke concentrated on working with the modeling and optimization of the Mega Hub. At this hub, containers, swap trailers and road semitrailers can be handled (Alicke, 1999, pp. 101-102). The necessary resources for the transshipment are cranes, driverless transportation vehicles of the sorting system and personnel (Alicke, 1999, p. 102).

The main aim is to minimize the maximum lateness $L_{max}$ of all arriving trains (Alicke, 1999, p. 102). To solve this problem it is necessary to clarify the sequence of the transshipped loading units, the definition of the crane areas (disjunct or overlapped), the size of the crane areas, the assignment of the cranes to the loading units at overlapping crane areas, and the assignment of the arriving trains to the rail tracks (Alicke, 1999, p. 102).

The author sets out to specify the objective function, which should result in a minimization of the maximum lateness of all trains whose loading units are to be transshipped at the hub in a given time horizon (Alicke, 1999, p. 124). Alicke formulates the objective function as a constraint which should ensure that the single lateness of all jobs is less than or equal to a precisely determined maximum lateness (Alicke, 1999, p. 124). A point of criticism here is that, contrary to the usual models from the field of operations research, the objective function presented does not have a minimizing or maximizing form, but is formulated as a restriction. In his model, what Alicke strictly speaking presents – contrary to the initial impression resulting from the aforementioned definition of a minimization aim – is not an optimization model, but "merely" a satisfaction model. The present study nevertheless considers this model, because the detailed modeling of time aspects is very useful for the intended purpose of significantly minimizing the transshipment and waiting times at hubs. It is also unusual that the objective function is not introduced until the end of the model, and all the restrictions are explained beforehand. From this author's point of view, these slightly detracting aspects are not so grave as to disqualify Alicke's model from further consideration, but it is necessary to be aware of this "abnormality".

Two groups of authors – Imai, Nishimura and Papadimitriou on the one hand and Cordeau, Laporte, Legato and Moccia on the other hand – concentrate on the transshipment of freight at a harbor. Their focus is on the optimal assignment of all arriving ships to the available berths (Cordeau et al., 2005, p. 1; Imai et al., 2001, p. 401).

As the optimization criteria serve the purpose of minimizing the transshipment time of all ships at the harbor. The transshipment time is the time, which lies between the arrival of the ships at the harbor and the end of the loading and unloading of the ships (Cordeau et al., 2005, p. 1; Imai et al., 2001, pp. 401-402). The assignment of the ships to their berths is important for the minimization of transshipment time, because the handling time of a ship can vary from berth to berth (Cordeau et al., 2005, p. 4; Imai et al., 2001, p. 402).

This depends on the one hand on the distances between the ships' berths and the transshipment place of the stored containers at the port, and on the other hand on the number of cranes which can be assigned to the various ships (Cordeau et al., 2005, p. 4; Imai et al., 2001, p. 404).

One point of criticism in this case is that modeling concentrates mainly on harbor transshipment, which is not sufficient for combined transport. Another criticism is that only the transshipment of containers is considered and not the transshipment of other loading units such as swap trailers. This model is nevertheless considered for the present study because it includes the time aspect.

In general, the scenario is as follows: the ships arrive at the harbor and wait to be assigned to a berth. Once on the assigned berth, the containers from the ships are transshipped by crane (Cordeau et al., 2005, p. 2). All this demands a high degree of coordination to achieve an efficient transshipment process (Cordeau at al., 2005, p. 2).

This model does not consider physical and technical restrictions (Imai at al., 2001, p. 404). From the author's point of view, this is unrealistic, as the depth of the water at a berth could be a crucial factor. The assignment of the ships to the berths must be considered, since arriving ships may have different draughts.

The main aim of the model is to minimize the sum of the waiting times of all ships for the berths and the handling times of all ships at the assigned berths (Imai et al, 2001, p. 404).

Guan und Cheung also consider the optimal assignment of ships to their berths in harbor. Their aim is to minimize the average processing time of all ships at a harbor, which is composed of the waiting times and the handling times of the particular ships (Guan/Cheung, 2004, p. 75).

In contrast to Imai, Nishimura and Papadimitriou as well as to Cordeau, Laporte, Legato and Moccia, Guan and Cheung allowed that a berth accommodate more than one ship (Guan/Cheung, 2004, p. 76). It is also assumed (as was already the case in Imai, Nishimura and Papadimitriou as well as in Cordeau, Laporte, Legato and Moccia) that ships have to wait for mooring if no free berth is available (Guan/Cheung, 2004, p. 75).

A berth is divided into different areas for modeling (Guan/Cheung, 2004, p. 77). Each berth area can at least be occupied by one ship at a time.

In their article, Guan and Cheung present two different mathematical models.

The basis of the first model is the so-called time and space diagram, in which the horizontal axis represents the time and the vertical axis the berth areas (Guan/Cheung, 2004, p. 77). The ships are depicted in this diagram as rectangles, whereby the length represents the handling time of the given ship and the height represents the size of the ship (Guan/Cheung, 2004, p. 77). The first model by Guan and Cheung is based on the aforementioned time and space diagram in that the positions of a ship on the time and space diagram form the basis of the formal-language demonstration (Guan/Cheung, 2004, p. 78). As already mentioned above, the objective function presents the minimization of the weighted average processing time of all ships. The objective function results from the difference between the departure time and the arrival time of a particular ship, multiplied by the weight of the particular ships (Guan/Cheung, 2004, p. 79).

The second model by Guan and Cheung has an identical objective function to the first model. The main difference is that the space required by a ship is considered in the time and space diagram (Guan/Cheung, 2004, p. 80). The area of the diagram is therefore divided into several blocks. Each block has the height of the berth area and the width of one time unit (Guan/Cheung, 2004, p. 80).

The container hub in Hamburg forms the basis of Hartmann's research. Hartmann wishes to eliminate even apparent processing problems regarding the coordination of the four kinds of resources – straddle carrier, automatic transportation vehicle, stacker crane, and personnel (Hartmann, 2004, pp. 51-52). One criticism here is that Hartmann only considers the use of containers and does not in any way consider other loading units such as bulk material.

In the model presented here, the four different kinds of resources should be planned optimally at a container hub by assigning arriving jobs to available resources (Hartmann, 2004, p. 52). The aim is to minimize the average lateness per job as well as the average setup time per job (Hartmann, 2004, p. 52).

The first step in formulating the model is to develop the objective function. The objective function expresses the above mentioned aim to minimize the sum of the average lateness per job and the average setup time of all jobs (Hartmann, 2004, p. 54). At this point it is important that the same time unit, for example seconds, is used for the lateness and setup times (Hartmann, 2004, p. 54).

The objective function is to be implemented on the four different kinds of resources named above.

A criticism here is that this model lacks the exact formal-language modeled restrictions typical of models from the field of operations research. While the objective function was modeled exactly by Hartmann, the restrictions are only presented verbally rather than in formal language, which would have been desirable.

In their article, Liu, Wan and Wang study the sequence planning of the use of quay cranes at a container hub (Liu et al., 2006, p. 60). Their main aim is to minimize the maximum lateness of the departure of the ships. This too is a point of criticism, since the focus lies on harbor transshipment, which is just one aspect of combined transport.

The aggregated workload of a berth is considered here. The workload consists of the numbers of transshipped containers and the average handling time required per container transshipment (Liu et al., 2006, p. 61).

The quay crane planning is based on the assignment of the ships to the berths (Liu et al., 2006, p. 61).

Liu, Wan and Wang's modeling focuses on the one hand on identification of the starting and completion time of the operation of each ship, and on the other on identification of the lateness of operations of each ship (Liu et al., 2006, p. 64).

Variables in the mathematical model of Liu, Wan and Wang are intended to model the non-overlapping of the crane areas, the necessary safety distances between the quay cranes, the route of the quay cranes and the capacity of the berths (Liu et al., 2006, p. 64).

The authors classify the problem mentioned here of the sequence planning for the use of quay cranes as NP-hard, and this must therefore be solved with the aid of a heuristic (Liu et al., 2006, p. 65). It is possible here to criticize the authors for not even attempting to develop an exact mathematical model and simplify it in a further step with heuristics. However, given the apparent complexity of this model and the fact that it appears barely possible to solve without a heuristic, the present author can appreciate the reasons for their decision.

The model for the sequence planning of the use of quay cranes is divided into two different levels (Liu et al., 2006, p. 65). On one level, decisions regarding the sequence of the handling of ships are modeled (ship level) on the assumption that a specific number of quay cranes is designated to handle each ship. On the other, decisions are modeled regarding the assignment of quay cranes for all ships to be handled (berth level).

On the ship level, the main aim is to minimize the handling times of the ships under consideration of the numbers of quay cranes assigned to each ship (Liu et al., 2006, p. 65).

In addition to the aforementioned partial model at ship level, Liu, Wan and Wang also developed a second model at berth level, which is based on the results of the ship level partial model (Liu et al., 2006, p. 67). This partial model on berth level defines the numbers of quay cranes assigned to every waiting ship. The main aim regarding the assignment decisions is to minimize the maximal lateness of the departure times of all ships (Liu et al., 2006, p. 67).

## 4 Development of an Optimization Model for Minimizing the Transshipment and Waiting Times at Hubs

The models presented here from the relevant economics literature seem unable to solve the problem of minimizing the transshipment and waiting times at hubs in a satisfactory way. This is in part because no optimization model formulates the minimization of transshipment and waiting times explicitly in its objective function. It can also be attributed to the fact that no other, from the author's point of view, relevant aspects such as different types of goods to be conveyed, different types of transport and different forms of transshipment are considered.

This research study therefore sets out to close the gap between the need for realistic modeling of real transshipment problems and the majority of existing mathematical optimization models in the relevant literature.

Before the optimization model for minimizing the transshipment and waiting times at hubs is developed, the variables used will be introduced and where applicable explained in detail.

For the model it is assumed that the planning started at point of time 1.

- $WT^{stan}$ : average waiting time of a standard good at a hub
- $WT^{dang}$ : average waiting time of a dangerous good at a hub
- $TT^{stan}$ : average transshipment time of a standard good at a hub
- $TT^{dang}$ : average transshipment time of a dangerous good at a hub
- stan: index for a standard good, where stan = 1,…,Stan
- dang: index for a dangerous good, where dang = 1,…,Dang
- $sp_{stan}$ : starting point at a hub of a standard good (stan), where $sp_{stan} = 1,\dots,SP_{stan}$
- $sp_{dang}$ : starting point at a hub of a dangerous good (dang), where $sp_{dang} = 1,\dots,SP_{dang}$
- $dp_{stan}$ : destination point at a hub of a standard good (stan), where $dp_{stan} = 1,\dots,DP_{stan}$
- $dp_{dang}$ : destination point at a hub of a dangerous good (dang), where $dp_{dang} = 1,\dots,DP_{dang}$

- TD: transshipment duration (interval during which a standard or dangerous good remains at the hub from the starting point to the destination point, conforms to the sum of the transshipment and waiting times of a standard or dangerous good)
- $\mathrm{TD}^{stan}$ : transshipment duration of a standard good
- $\mathrm{TD}^{dang}$ : transshipment duration of a dangerous good
- $\mathrm{Sched}^{stan}$ : schedule to be observed for a standard good (here: latest acceptable time at which a standard good must reach the destination point at a hub)
- $\mathrm{Sched}^{dang}$: schedule to be observed for a dangerous good (here: latest acceptable time at which a dangerous good must reach the destination point at a hub)
- $\mathrm{Cap}_{hub}^{stan}$ : capacity of a single hub for standard goods (measured in the numbers of transshipment activities; for example: = 500 transshipment activities per day at a hub)
- $\mathrm{Cap}_{hub}^{dang}$ : capacity of a single hub for dangerous goods

The decision variables will now be determined:

$$X_{sp.dp}^{stan} = \begin{cases} \text{1, if a standard good is transported from the starting to the destination} \\ \text{point at a hub} \\ \text{0, otherwise.} \end{cases}$$

$$X_{sp.dp}^{dang} = \begin{cases} \text{1, if a dangerous good is transported from the starting to the destination} \\ \text{point at a hub,} \\ \text{0, otherwise.} \end{cases}$$

$$\mathrm{Trans}_{di}^{stan} = \begin{cases} \text{1, if a standard good is transshipped directly,} \\ \\ \text{0, otherwise.} \end{cases}$$

$$\mathrm{Trans}_{ind}^{stan} = \begin{cases} \text{1, if a standard good is transshipped indirectly,} \\ \\ \text{0, otherwise.} \end{cases}$$

$$\mathrm{Trans}_{di}^{dang} = \begin{cases} \text{1, if a dangerous good is transshipped directly,} \\ \\ \text{0, otherwise.} \end{cases}$$

$$\mathrm{Trans}_{ind}^{dang} = \begin{cases} \text{1, if a dangerous good is transshipped indirectly,} \\ \\ \text{0, otherwise.} \end{cases}$$

$$\mathrm{Trans}_{comp}^{stan} = \begin{cases} \text{1, if a standard good is transshipped completely at a hub,} \\ \\ \text{0, otherwise.} \end{cases}$$

$$\mathrm{Trans}_{comp}^{dang} = \begin{cases} \text{1, if a dangerous good is transshipped completely at a hub,} \\ \\ \text{0, otherwise.} \end{cases}$$

To complete the optimization model, the objective function and the restrictions must be developed in the following steps:

Objective function: minimizing transshipment duration (TD)

$$\mathrm{TD}\,(X_{sp.dp}^{stan}\,;X_{sp.dp}^{dang}) = \sum_{stan=1}^{Stan}\sum_{sp_{stan}=1}^{SP_{stan}}\sum_{dp_{stan}=1}^{DP_{stan}} X_{sp.dp}^{stan}\bullet \mathrm{WT}^{stan} + \sum_{stan=1}^{Stan}\sum_{sp_{stan}=1}^{SP_{stan}}\sum_{dp_{stan}=1}^{DP_{stan}} X_{sp.dp}^{stan}\bullet \mathrm{TT}^{stan}$$

$$+\sum_{dang=1}^{Dang}\sum_{sp_{dang}=1}^{SP_{dang}}\sum_{dp_{dang}=1}^{DP_{dang}} X_{sp.dp}^{dang}\bullet \mathrm{WT}^{dang} + \sum_{dang=1}^{Dang}\sum_{sp_{dang}=1}^{SP_{dang}}\sum_{dp_{dang}=1}^{DP_{dang}} X_{sp.dp}^{dang}\bullet \mathrm{TT}^{dang} \quad \rightarrow \text{min!}$$

model restrictions:

(R1) $\sum_{sp_{stan}=1}^{SP_{stan}}\sum_{dp_{stan}=1}^{DP_{stan}} X_{sp.dp}^{stan} \leq 1$

(R2) $\sum_{sp_{dang}=1}^{SP_{dang}}\sum_{dp_{dang}=1}^{DP_{dang}} X_{sp.dp}^{dang} \leq 1$

(R3) $sp_{stan} \leq dp_{stan} \qquad \forall stan=1,\ldots,Stan\,;\forall sp_{stan}=1,\ldots,SP_{stan}\,;\ \forall dp_{stan}=1,\ldots,DP_{stan}$

(R4) $sp_{dang} \leq dp_{dang} \qquad \forall dang=1,\ldots,Dang\,;\forall sp_{dang}=1,\ldots,SP_{dang}\,;\ \forall dp_{dang}=1,\ldots,DP_{dang}$

(R5) $+ \quad =$

(R6) $+ \quad =$

(R7) $\sum_{sp_{stan}=1}^{SP_{stan}} \sum_{dp_{stan}=1}^{DP_{stan}} X_{sp.dp}^{stan} \bullet TD^{stan} \leq Sched^{stan}$

(R8) $\sum_{sp_{dang}=1}^{SP_{dang}} \sum_{dp_{dang}=1}^{DP_{dang}} X_{sp.dp}^{dang} \bullet TD^{dang} \leq Sched^{dang}$

(R9) $Trans_{di}^{stan} + Trans_{ind}^{stan} = 1$

(R10) $Trans_{di}^{dang} + Trans_{ind}^{dang} = 1$

(R11) $Trans_{comp}^{stan} = Trans_{di}^{stan} + Trans_{ind}^{stan}$

(R12) $Trans_{comp}^{dang} = Trans_{di}^{dang} + Trans_{ind}^{dang}$

(R13) $\sum_{stan=1}^{Stan} Trans_{comp}^{stan} \leq Cap_{hub}^{stan}$

(R14) $\sum_{dang=1}^{Dang} Trans_{comp}^{dang} \leq Cap_{hub}^{dang}$

(R15) $X_{sp.dp}^{stan} \in \{0;1\} \qquad \forall stan=1,\dots,Stan\ ; \forall sp_{stan}=1,\dots,SP_{stan}\ ; \forall dp_{stan}=1,\dots,DP_{stan}$

(R16) $X_{sp.dp}^{dang} \in \{0;1\} \qquad \forall dang=1,\dots,Dang\ ; \forall sp_{dang}=1,\dots,SP_{dang}\ ; \forall dp_{dang}=1,\dots,DP_{dang}$

(R17) $Trans_{di}^{stan} \in \{0;1\}$

(R18) $Trans_{ind}^{stan} \in \{0;1\}$

(R19) $Trans_{di}^{dang} \in \{0;1\}$

(R20) $Trans_{ind}^{dang} \in \{0;1\}$

(R21) $Trans_{comp}^{stan} \in \{0;1\}$

(R22) $Trans_{comp}^{dang} \in \{0;1\}$

The objective function developed above demonstrates minimization of the transshipment and waiting times. The first term of the objective function models the waiting times and the second term models the transshipment times, separated for standard and dangerous goods.

In general, a distinction is made in the optimization model presented here between standard and dangerous goods because the transport restrictions for dangerous goods may differ from the restrictions on standard goods. The transportation of

dangerous goods is subject to special protective measures, which affect the transshipment of these dangerous goods and must also be taken into account.

Restrictions R1 and R2 also refer to this difference, which can be found throughout the optimization model. These restrictions ensure that a standard or a dangerous good is transported from the starting to the destination point at a hub. It is clear with regard to these indices that standard and dangerous goods have different starting and destination points at the hub. In reality this could be different drive and exit gates at the hub, for example. Here there is a clear consideration of the differences between different kinds of goods.

Restrictions R3 and R4 guarantee that the starting point of a standard or dangerous good is equal to or less than its destination point.

Restrictions R5 and R6 ensure that the waiting times and the transshipment times of a standard or dangerous good must relate to the transshipment duration of a standard or dangerous good.

The two restrictions R7 and R8 guarantee that the transshipment duration of a standard or a dangerous good is less than or equal to the latest acceptable time at the hub in a given schedule.

Restrictions R9 and R10 furthermore ensure that a standard or a dangerous good is either transshipped directly or transshipped indirectly, so that the complete transshipment is composed of the direct and indirect transshipment (R11 and R12).

It must also be guaranteed that the complete transshipment of standard or dangerous goods conforms to the capacity of a hub for standard and dangerous goods (R13 and R14). The distinction between the two different kinds of goods is also relevant at this point, since the capacity of a hub for standard and dangerous goods can differ, for example with fewer specially equipped cranes or transportation vehicles available for dangerous goods than for standard goods.

Finally, restrictions R15 and R16 ensure that the decision variables are binary variables which can only have the values 0 or 1. The same applies to the direct and indirect transshipment of the standard and dangerous goods (see R17 to R22).

## 5 Future Research Directions

While the optimization model here presents the minimization of the transshipment and waiting times explicitly in the objective function, there is still scope for further research into various aspects. For example, different types of transport (main run, pre-carriage and on-carriage) could be modeled in the restrictions. The approach presented here considers the different kinds of goods, but it is also thinkable that they could be modeled in a more detailed and very formal-language way under different restrictions.

In this approach, the transshipment at the hub is modeled by considering direct and indirect transshipment, for example. Further research could, however, extend to include passing through several hubs.

The present optimization model forms a basis of further research – in addition to the aforementioned aspects – for example into implementation in the modeling and optimization software Lingo, Version 11. This would enable model evaluation with real business cases to be used to test the optimization model with regard to its adequacy in reality.

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