FUTURE DEVELOPMENTS FOR THE WOOD-BASED INDUSTRY

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THE FUTURE OF INDUSTRY AS SEEN FROM A SOCIAL SCIENCE AND ECONOMIC PERSPECTIVE

Der durch die *Austrian Marshall Plan Foundation* unterstütze Forschungsaufenthalt von Jänner bis März 2020 am *Institute of European Studies* der *University of California* in Berkeley, ermöglichte effizientes Verfassen (Februar), Überarbeiten (Anfang März), Einreichen (Mitte März) und Einarbeiten der drei positiven Reviewer-Feedbacks (Ende März) des Artikels *Contingency Plans for the Wood Supply Chain Based on Bottleneck and Queuing Time Analyses of a Discrete Event Simulation* (https://doi.org/10.3390/f11040396). Dieser wurde am 2. April im renommierten Schweizer Forests Journal (5-Year Impact Factor: 2,453; Q1 im *Scimago Journal & Country Rank* in der Kategorie *Agricultural and Biological Sciences: Forestry*) unter CC BY 4.0 publiziert. Zusammen mit den früheren Artikeln *Discrete event simulation of multimodal and unimodal transportation in the wood supply chain: A literature review* (Kogler & Rauch 2018, https://doi.org/10.14214/sf.9984) und *A discrete-event simulation model to test multimodal strategies for a greener and more resilient wood supply* (Kogler & Rauch 2019, https://doi.org/10.1139/cjfr-2018-0542) komplettiert dieser Artikel die Dissertation *Decision support by discrete event simulation for the wood supply chain*, die am Insitut für Produktionswirtschaft und Logistik der Universität für Bodenkultur Wien erarbeitet wurde.

Großer Dank geht an die *Austrian Marshall Plan Foundation*, im Besonderen an Herrn Dr. Markus Schweiger und Frau Claudia Kraif, die diesen Aufenthalt ermöglichte. Dank gebührt auch der Österreichischen Forschungsgemeinschaft für die Kofinanzierung im Rahmen des Programmes Internationale Kommunikation, dem *BOKU Vienna Open Access Publishing Fund* für die Finanzierung der Open-Access-Publikation, sowie der Sigsim Gesellschaft, die durch die Verleihung des *Student Travel Award* die Teilnahme an der *Winter Simulation Conference 2019* ermöglichte. Darüber hinaus geht Dank an das *Institut für Produktionswirtschaft und Logistik der Universität für Bodenkultur, Wien*, wobei insbesondere Prof. Manfred Gronalt und Hon.-Prof. Peter Rauch wesentlich zum Gelingen dieses Forschungsaufenthaltes beigetragen haben. Abschließend geht großer Dank an das *Insitute of European Studies der University of California, Berkeley*, das ein wunderbarer und vorbildlicher Gastgeber war, wobei Prof. Jeroen Dewulf und Dr. Julia Nelsen bemerkenswert engagiert bei allen Herausforderungen unterstützen. Hier sei exemplarisch die Organisation des *Symposium on Wood Supply Chain Management in Austria and California* herausgegriffen, bei dem die – im Rahmen der oben genannten Dissertation erforschten – Inhalte mit namhaften Experten (Department of Industrial Engineering; Department of Environmental Science, Policy and Management; Haas Business School; Berkeley Forests; Institute of Transportation Studies; European Commission) diskutiert wurden. Insbesondere wurde das Holzlieferkettenmanagement in Österreich (Vortrag Christoph Kogler) und Kalifornien (Vortrag Dr. William Steward, Director Berkeley Forests) verglichen und zukünftige Herausforderungen, wie das vermehrte und intensivere Auftreten von Naturkatastrophen in Folge des Klimawandels behandelt. Hierbei wurden interessante Ähnlichkeiten in den Lieferkettenauswirkungen nach Waldbränden in Kalifornien und Windstürmen in Österreich erkannt, die es ermöglichen, vorhandene Modelle der verschiedenen Forschergruppen zu kombinieren und gemeinsam an neuen Projekten zu arbeiten. Unterschiedliche Forschungsansätze und Methoden wurden diskutiert, wobei insbesondere die *Diskrete Event Simulation* (Vortrag Prof. Lee Schruben) als dafür besonders geeignet empfunden wurde, und das Fundament für den nachfolgenden Forschungsartikel bildet.

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Contingency Plans for the Wood Supply Chain Based on Bottleneck and Queuing Time Analyses of a Discrete Event Simulation

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Abstract: Wood supply chain performance suffers from risks intensified by more frequent and extreme natural calamities such as windstorms, bark beetle infestations, and ice-break treetops. In order to limit further damage and wood value loss after natural calamities, high volumes of salvage wood have to be rapidly transported out of the forest. In these cases, robust decision support and coordinated management strategies based on advanced contingency planning are needed. Consequently, this study introduces a contingency planning toolbox consisting of a discrete event simulation model setup for analyses on an operational level, strategies to cope with challenging business cases, as well as transport templates to analyze outcomes of decisions before real, costly, and long-lasting changes are made. The toolbox enables wood supply managers to develop contingency plans to prepare for increasing risk events and more frequent natural disturbances due to climate change. Crucial key performance indicators including truck to wagon ratios, truck and wagon utilization, worktime coordination, truck queuing times, terminal transhipment volume, and required stockyard are presented for varying delivery time, transport tonnage, and train pick-up scenarios. The strategy BEST FIT was proven to provide robust solutions which saves truck and train resources, as well as keeps transhipment volume on a high level and stockyard and queuing time on a low level. Permission granted for increased truck transport tonnages was evaluated as a potential means to reduce truck trips, if working times and train pick-ups are coordinated. Furthermore, the practical applicability for contingency planning is demonstrated by highly relevant business cases such as limited wagon or truck availability, defined delivery quota, terminal selection, queuing time reduction, or scheduled stock accumulation. Further research should focus on the modeling and management of log quality deterioration and the resulting wood value loss caused by challenging transport and storage conditions.

Keywords: contingency planning; discrete-event simulation model; forest-based industry; logistics; multimodal transport; natural calamities; risk; supply chain management

1. Introduction

Wood is the only sustainable natural resource available in Austria [1]. Consequently, the forest-based industry is a crucial economic sector profiting from Austria's abundant forests, well-developed infrastructure, highly skilled workers, and a rich research environment, which enables export rates of 87% in the paper industry [2] and 70% in the wood industry [3]. For every additional 100 m^3 of wood harvested, a new green job is added to the 300,000 existing ones (i.e., 1/10 of Austria's working population: 175,700 forestry, 40,000 joineries, 27,900 wood industry, 23,000 timber trade, 11,400 timber construction, 8100 paper industry, 6000 forest management) [4]. To ensure economic success and sustainability and to secure the existing jobs, the industry is dependent on a stable wood supply. The current challenges of the Austrian wood supply chain include decreasing numbers of both crane-truck drivers and train terminals, rapid market price fluctuations, as well as long lead and queuing times. These challenges are reinforced by supply chain risks that may be technical (e.g., machine and truck breakdowns), managerial (e.g., delivery stops at mills and reliability of rail wagon delivery), or inclement weather (e.g., high snow cover, heavy rain, and low temperature).

Climate change increases the frequency and impact of extreme natural calamities which results in high volumes of salvage wood (more than 50% of the harvested wood in Austria in 2018 [5]) and an intensification of risk in the wood supply chain. The Austrian government in its Forest Strategy 2020+, recognized the risks to productivity and the economic deployment of Austria's forests and set the strategic goal of building and developing resilient risk management instruments and contingency plans [1]. Natural calamities such as windstorms, bark beetle infestations, and ice break treetops produce high volumes of salvage wood, which have to be quickly transported out of the forest to limit further damage or wood value loss. Train terminals have proven to be effective in securing a stable wood supply to the industry as they provide the high transport capacity of railroads and connected storage areas. In Austria there are 153 active train terminals (i.e., 60 wood industry terminals, 65 wood shipping terminals, seven private terminals, 12 temporary terminals, nine terminals with special status), and a considerable number of inactive but recoverable terminals, where wood can be transhipped from truck to train [6]. The management of such a multimodal wood supply chain is more challenging than that of a unimodal supply by utilizing trucks only. However, it reduces the effects of climate changes (e.g., CO_2 emissions), supply chain risks (e.g., buffer capacity to supply industry when harvesting is not possible), and supply chain challenges (e.g., reducing the bottleneck of crane truck capacity by limiting their operation to unavoidable short distance wood transport by trucks to terminals).

To provide decision support for the management of a multimodal supply chain, many companies in the forest-based industry have been trying to digitalize. Concepts such as Industry 4.0 and the internet of things (IoT) have inspired companies to collect large amounts of data, but in most cases they are not analyzed, shared, or used for the decision making process required to mitigate risks. For this reason, industry representatives are considering the development of digital twins of their supply chains. The term digital twin is used as an umbrella term and can be further divided in a wide range of maturity levels. Based on an earlier framework [7] steps for a virtual factory were defined [8], which are also generally appropriate for virtual supply chain models. They define a digital model as a virtual representation that reaches a connected model state (also designated as digital twin), if it is supplied with real-time data. Others define a digital twin as a "virtual representation of a real-world system and its status", distinguishing it from simple simulation models by "the ability to determine the state of a specific object", which is "achieved by combining current data from the subject with its simulation model" [9]. Based on these definitions, Austria's forest-based industry is a long way from creating a real digital twin or virtual supply chain. However, the first step in this direction can be made by creating digital models, which reduce uncertainty at a reasonable cost. This leads companies away from educated guesses and gut decision making based on rule-of-thumb estimates to decision making based on data already collected but not properly analyzed.

In the literature, digital models for multimodal wood supply chains including terminals have been delivered in the form of discrete event simulation (DES) models. DES fits perfectly for modeling the wood supply chain in a dynamic (i.e., variables change over time), discrete (i.e., system changes occur at specific events), and stochastic (i.e., random observations) way [10]. The wood supply chain covers growing, harvesting, extraction, transporting, storing, (pre-)processing, (re)using, and recycling of wood. Wood supply chain management deals with relevant decisions to plan, design, operate, control, and monitor material-, service-, financing-, and information flows within and between various actors [10]. Appropriately, the wood supply chain can be represented by standard DES elements such as entities or resources (e.g., wood, trucks, trains), delays (e.g., processes, tasks, service times), queues (e.g., waiting lines to enter terminal or industry stockyards), or system capacities (e.g., transport or stockyard capacity). Furthermore, DES is appropriate for advanced contingency planning because complex interdependencies can be modeled and visually illustrated in animations to demonstrate model internals to stakeholders. DES models for wood transport were reviewed and the suitability of multimodal DES models for building efficient, resilient, green and socially sustainable wood supply chains was confirmed [10]. Existing multimodal DES models including train terminals [11–15] cover timber, forest chip, or biomass transport at an operational level. They use different supply chain network configurations for regional case studies in Austria or Finland. Other multimodal DES models also consider vessel terminals [16–19]. These multimodal DES studies are important contributions to obtain a better understanding of the complex interdependencies of multimodal wood supply chains, yet none have focused on risk mitigation and generalizable contingency planning.

Especially after extreme natural calamities, when decisions have to be made quickly, there are neither coordinated plans nor elaborated management strategies available. As a result, supply chain performance suffers and will suffer even more due to risks intensified by more frequent and extreme natural calamities driven by climate change. Consequently, a research gap exists to derive concrete contingency plans for wood transport. To help close the current research gap, this study delivers elaborated contingency planning for train terminals based on DES. In particular, this study sets up a DES model to deliver crucial key performance indicators (KPIs) and develops transportation templates for different delivery time, tonnage, and train pick-up scenarios as a basis for contingency planning. Furthermore, contingency planning is illustrated by practical and highly relevant business cases. Consequently, it answers the research questions "Which parameters are critical for multimodal contingency planning?", "How many trucks and wagons are needed for short-, medium-, and long delivery times, respectively, with one or two train pick-ups to perform best", and "How many truck trips can be avoided, if the maximal transport tonnage increases and how would this effect the terminal performance"?

2. Method and Model

Simulation models facilitate understanding of complex systems and their behavior in a variety of scenarios. They provide superior benefits for managerial contingency planning in nonstationary systems under uncertainty in contrast to mental, conceptual, physical, or mathematical models. In simulation modeling, methods such as DES, agent based simulation (ABS), and system dynamics (SD) are general frameworks for mapping a real-world system [20]. DES focuses on manmade systems, where large and complex operations can be broken into a sequence of straightforward tasks or processes, which are often illustrated in flowcharts [21]. Moreover, different model configurations and what-if analyses show the effects of decisions before real, costly, dangerous, inefficient, or long-lasting changes are made and therefore provide valuable decision support for today's challenges.

The applied DES model is an extension of Kogler and Rauch [15] including a new generic model structure enabling generalizable results for various train terminals. The model was sufficiently validated including expert involvement, appraisals, real life case study data, input (e.g., restrictions, decision variables, case study settings), and output checks (e.g., transportation plans, volumes). Moreover, the identification of critical parameters resulted in the design of new scenario settings taking into consideration different delivery times, transport tonnages, and number of train pick-ups. Additionally, refined parameterizations, as well as an enhanced system logic now enable advanced contingency planning. The parameterizations of Kogler and Rauch [15] included only one broad triangular distribution for delivery times, which, for this study, was split into narrow triangular distributions for short, medium, and long delivery times to provide more appropriate configurations for different train terminals with various delivery times. This approach was also used for the parameterization of low, moderate, and heavy transport tonnages to evaluate permissions granted for higher truck transport tonnages. The implementation of a second train pick-up per day expanded the system logic, but required coordinating truck working times with train pick-ups to ensure a solution quality of both a truck utilization rate over 95% and no empty wagons at the time of train pick-up. Comprehensive sensitivity analyses for the decision variables (i.e., number of trucks and number of wagons) provide advanced multimodal transport plans which outperform the simple expert-based heuristic of Kogler and Rauch [15]. Furthermore, this study defines and calculates new KPIs, which are especially relevant for contingency planning.

The model maps the flow of wood entities through the supply chain by facilitating processes for wood harvest, storing at forest landings, truck transport to terminal, storing at terminal stockyard, transhipment to wagon, and train transport to industry (Figure 1).

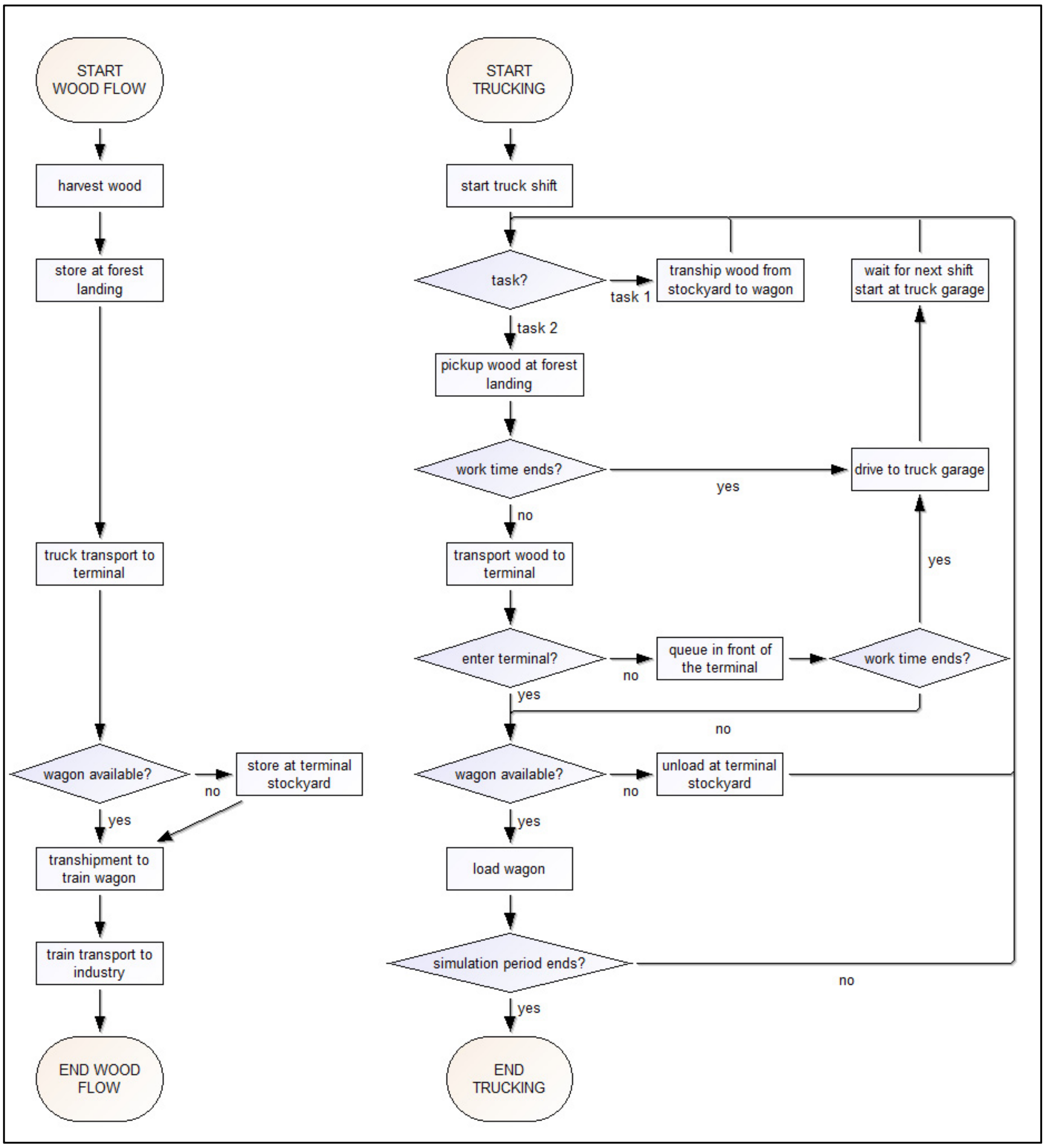

Figure 1. Flowcharts of the wood and transporting flows of the simulation model.

Trains and trucks move the wood during their working hours through the supply chain. Trucks fulfill the tasks of picking up wood at the forest landing and transporting it either directly to wagons or via terminal stockyards. The processes at the terminal are modeled in detail and close to reality, which enables the tracking of truck queuing times. Thus, the following activities are covered: Queuing in front of the terminal, removing safety belts, loading wagon, securing wagon load, unloading at stockyard, cleaning truck platform, and completing delivery documentation. Consequently, a complex logic controls the transhipment process from trucks to stockyard or wagons, as well as the potential truck queuing at the terminal. Trains pick up fully loaded wagons, transport them to industry, leave empty wagons for loading, and sort wagons according to their loading status at the terminal. For a detailed description of the DES model refer to Kogler and Rauch [15].

Sensitivity analyses of preliminary simulation runs indicated that results are sensitive to changes in delivery time from forest to terminal, number of train pick-ups at the terminal, and the transport tonnages. Consequently, these parameters were critical for multimodal contingency planning. Based on input data analysis (e.g., process times) of Austrian case studies and consultation with experts (i.e., foresters as well as wood, transport, and logistic managers), realistic parameter settings were specified, which lead to the formulation of scenarios to cover small-scale train terminals with similar layouts: One loading siding, no overtaking at the roughly elliptical inbound truck driving route, loading track length of maximum seven wagons, and two truckloads filling one wagon (Figure 2). This represents the majority of Austria's train terminals for wood transhipment.

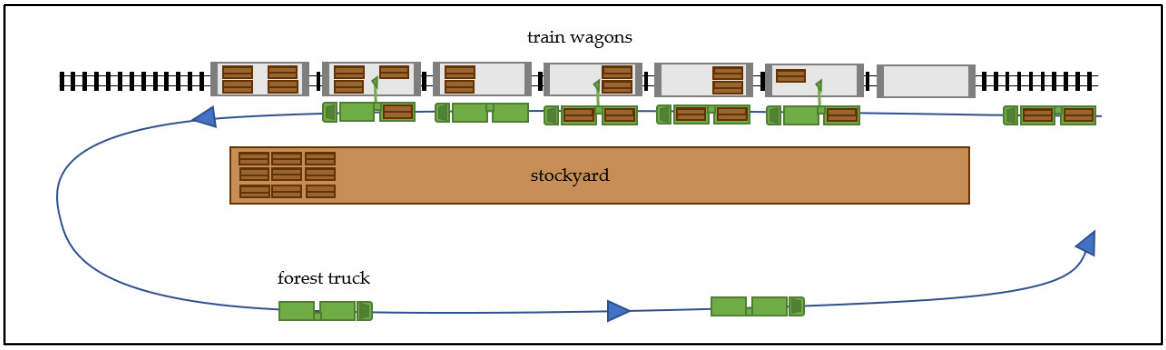

Figure 2. General layout of small scale train terminals displaying loading track, stockyard, and truck driving route.

Thus, simulating 18 scenario combinations (Table 1) covers a broad range of potential logistic cases and facilitates the generation of generalizable results as a basis for the development of robust transport strategies for contingency planning.

Table 1. 18 scenario settings for simulation.

One Train Pick-Up (P1)				Two Train Pick-Ups (P2)			
	Delivery Time (D)				Delivery Time (D)		
Tonnage (T)	P1D1T1	P1D2T1	P1D3T1	**Tonnage (T)**	P2D1T1	P2D2T1	P2D3T1
	P1D1T2	P1D2T2	P1D3T2		P2D1T2	P2D2T2	P2D3T2
	P1D1T3	P1D2T3	P1D3T3		P2D1T3	P2D2T3	P2D3T3

P = train wagons pick-ups: P1 = one a day, P2 = two a day. T = tonnage of forest trucks equipped with crane: T1 = low (MIN = 23 t/MODE = 24 t/MAX = 25 t), T2 = moderate (26/27/28), T3 = high (29/30/31). D = delivery time to train terminal: D1 = short (MIN = 5 min/MODE = 10 min/MAX = 15 min), D2 = medium (35/40/45), D3 = long (65/70/75).

The truck delivery time covers categories representing regions with short-, medium-, and long delivery times between forest landings and terminal. Triangular distributions were used to take into account different street and traffic conditions and possible process delays (Table 2).

Table 2. One way truck delivery time.

Delivery Time	Drive Time (min)			Number of Trips Per Truck Per Day
	MIN	MODE	MAX	
short	5	10	15	3–4
medium	35	40	45	2–3
long	65	70	75	1–2

Scenarios for low, moderate, and high truck loads were designed to consider actual weight limits (e.g., 44 t in Austria) for forest trucks equipped with a crane, as well as exemption clauses granted by the authorities after massive windthrows with bark beetle burdens or potential future liberalization. For heavier tonnages one additional minute of loading/unloading time per additional ton was assumed. A truck driver cannot exactly estimate the weight of the loaded wood due to natural variations in bulk density and moisture content, as well as a lack of crane scales in the majority of Austrian forest trucks. Consequently, the variation was implemented applying triangular distribution of tonnages and dependent process times (Table 3). General truck tasks at the terminal such as removing belts (i.e., MIN = 7 min/MODE = 10 min/MAX = 12 min), securing wagon loads (i.e., 5/8/10), cleaning loading platform (i.e., 3/5/10), as well as completion of delivery documentation (i.e., 10/13/15) are the same in all scenarios [15].

Table 3. Truck tonnages and dependent process times.

Transport Tonnages	Tonnage (t)			Load Truck Time (min)			Unload Time at Stockyard/Wagon (min)		
	MIN	MODE	MAX	MIN	MODE	MAX	MIN	MODE	MAX
low	23	24	25	30	35	40	35	45	55
moderate	26	27	28	33	38	43	38	48	58
high	29	30	31	36	41	46	41	51	61

Once or twice a day, a locomotive picks up full loaded wagons and provides the number of ordered empty wagons. Train pick-up times are fixed by the train carrier at 9 am and 3 pm (i.e., for two pick-ups). The start of truck shifts was coordinated with delivery times and train pick-ups resulting in a high ratio of fully loaded wagons at the time of a train pick-up. This ensures high truck utilization, as well as high terminal handling volume. Trucks start their shift at 7 am (adjusted to 5 am for medium and long delivery time scenarios with two train pick-ups) giving them enough time to fill the wagons before the first pick-up at 9 am. This approach of working time and train pick-up coordination was validated for its practical usability by terminal managers of the Austrian Federal Forests (i.e., largest forest owner in Austria) and Rail Cargo Austria (i.e., main cargo operator on Austrian railways), who confirmed similar strategies, if high terminal handling volume was needed after natural calamities. In accordance with European law, truck shifts were set to 8 h a day for five days a week.

Extensive test runs were performed to understand the interdependencies of the system and to select and track the most important KPIs for contingency planning. The resolution time was set as minutes and the simulation period as one week in order to both match manager's requirements and follow common scientific practice [10]. To ensure the predefined solution quality necessary for practical usability, all results that satisfy a truck utilization of over 95%, allow no empty wagons at the time of train pick-up and allow fewer than 20 half loaded wagons per week for one train pick-up (i.e., respectively 40 half loaded wagons for two train pick-ups). The simulations were replicated 52 times for every scenario to cover a full year of observation time. This resulted in 936 single simulation runs consisting of 52 weeks for a total of 18 scenarios.

2.1. KPIs and Transport Strategies

Four KPIs were identified as necessary to provide decision support for contingency planning. The KPI "terminal transhipment volume" defines the maximal amount of wood in solid cubic meters, which can be transhipped at the terminal from truck to wagon per week for a given truck and train wagon configuration. The KPI "required terminal stockyard" shows the amount of wood in solid cubic meters which is stored to guarantee a high truck and wagon utilization, as well as smooth wood flow from forest to the industry. The KPI "average queuing time" reports on the average truck waiting time in minutes at the terminal, which consists of the waiting times to enter the terminal, remove the safety belts, load the wagon or unload at the stockyard, and clean the loading platform. The KPI "maximal queuing time" reveals the longest waiting time in minutes for trucks to pass through the processes at the terminal.

Contingency planning requires the consideration of those KPIs, as well as reflection on the different, often competing objectives. In order to provide decision support for different planning objectives, various sets of KPI rankings were developed with stakeholder participation and analyzed for low tonnages and short, medium, and long delivery times. After extreme natural calamities the contingency planners are challenged to transport the wood out of the forest as fast as possible to avoid wood value loss. Consequently, the first strategy MAX VOLUME solely focuses on the maximal terminal transhipment volume. In cases where beneficial solutions had the same maximal terminal transhipment volume, the solution with the lowest number of wagons and trucks (i.e., decision variables) was selected to save resources. In some cases, contingency planners have to deal with terminals which do not provide space for a stockyard. Thus, the second strategy NO STOCKYARD was developed, which selects a solution where no stockyard is needed (i.e., if there are no solutions with no stockyard availability, the one with the lowest stockyard was chosen). From those solutions with the lowest stockyard, the one with the highest transhipment volume was chosen. The resulting solutions performed well according to their main KPIs, but also showed limitations regarding others. Thus, the MAX VOLUME strategy requires high transport resources. This also holds true in some cases for the NO STOCKYARD strategy, which provided comparatively low transhipment volume. Consequently, a third strategy BEST FIT was developed. In order to save both truck and train resources and to simultaneously keep transhipment volume on a high level, solutions with an up to 10% lower maximal transhipment volume were considered. Among all feasible solutions the one with the lowest number of wagons and trucks was selected, and if these were equal the solution with the lowest required stockyard was chosen.

2.2. Business Cases for Evaluating Managerial Impact

In order to evaluate the practicability of simulation results provided as tables as a basis for operational transport planning, three different business cases are formulated: (1) Restricted wagon availability, (2) restricted truck availability, and (3) defined delivery quotas. The first business case discusses the handling of restricted wagon availability. The terminal size limits the number of wagons for simultaneous transhipment and rail carriers define the maximal number of train pick-ups a day. However, after natural calamities or capacity planning errors (e.g., misjudgment of demand), as well as during harvesting periods of other train shipped goods such as beets, the number of available wagons can further decrease and fluctuate on a weekly basis. The transport templates should be used to find the appropriate number of trucks for a given number of train pick-ups, wagons, delivery time, and transport tonnage to guarantee an efficient (i.e., high volume and utilization, low resources and queuing times) wood transport.

The second business case provides a guideline for planning under restricted truck availability. In mountainous regions which have steep and widely ramified forest roads and lack GPS reception, planning should focus on a high utilization of the limited number of local forest truck drivers (= bottleneck), which are able to navigate through the forest road network. Here, the transport templates can be used to find an efficient number of wagons for a given number of train pick-ups, trucks, delivery time, and transport tonnage.

The third business case covers the common issue of defined delivery quotas. Wood based industry factories such as sawmills or pulp and paper mills, depend on a stable wood supply to guarantee smooth-running production. Furthermore, harvesting teams are dependent on constantly available transport to maintain enough space for harvested wood and its extraction (e.g., especially for cable logging to narrow mountain roads). Consequently, fixed delivery quotas are arranged to enable a smooth flow of wood. The transport templates permit the selection of an appropriate terminal, as well as transport configurations and provide KPIs in order to compare the effects of potential exemption clauses for higher transport tonnages after natural calamities.

3. Results

The managerial practice for operational wood transport planning follows a rolling weekly planning horizon. Thus, all results were aggregated to a weekly level and rounded to the nearest ten to provide a clear overview for short-term contingency planning. This approach allows contingency planners to react dynamically to changing conditions and restrictions after natural calamities or other disturbances. The numbers of available trucks and wagons are the main decision variables for contingency planners and thus, define the structure of the resulting templates (Appendices A and B; Tables 4–11; Figures 3 and 4).

Table 4. Best performing simulation results for strategy MAX VOLUME (maximal terminal transhipment volume) for one train pick-up.

Wagons	Number of Trucks			Terminal Transhipment Volume (m^3)			Required Terminal Stockyard (m^3)			Average Queuing Time (min)			Maximal Queuing Time (min)		
	D1	D2	D3	D1	D2	D3	D1	D2	D3	D1	D2	D3	D1	D2	D3
1	3	5	4	240	250	240	950	1070	320	20	10	70	120	120	120
2	3	2	4	490	470	470	710	0	130	10	0	60	110	70	110
3	3	5	6	730	710	730	360	530	170	10	10	60	70	70	120
4	9	4	9	980	940	980	2610	0	290	20	0	70	130	70	140
5	4	8	12	1220	1220	1180	0	770	430	20	10	80	90	80	150
6	12	12	12	1470	1470	1410	3000	1500	180	30	20	70	140	110	140
7	7	8	13	1710	1650	1640	830	160	0	10	10	70	80	80	140

Table 5. Best performing simulation results for strategy NO STOCKYARD (no or low required terminal stockyard) for one train pick-up.

Wagons	Number of Trucks			Terminal Transhipment Volume (m^3)			Required Terminal Stockyard (m^3)			Average Queuing Time (min)			Maximal Queuing Time (min)		
	D1	D2	D3	D1	D2	D3	D1	D2	D3	D1	D2	D3	D1	D2	D3
1	1	1	2	230	230	230	120	0	80	10	0	50	60	70	110
2	2	2	3	450	470	440	240	0	0	10	0	40	80	70	110
3	2	3	5	710	680	660	0	0	0	10	0	50	70	70	110
4	3	4	7	940	940	930	0	0	0	10	0	60	80	70	120
5	4	5	9	1220	1170	1170	0	0	0	20	10	60	90	100	130
6	4	6	11	1350	1350	1400	0	0	0	20	20	70	120	90	150
7	5	7	13	1630	1640	1640	0	0	0	20	30	70	130	110	140

Table 6. Best performing simulation results for strategy BEST FIT (at least 90% terminal transhipment volume) for one train pick-up.

Wagons	Number of Trucks			Terminal Transhipment Volume (m^3)			Required Terminal Stockyard (m^3)			Average Queuing Time (min)			Maximal Queuing Time (min)		
	D1	D2	D3	D1	D2	D3	D1	D2	D3	D1	D2	D3	D1	D2	D3
1	1	1	2	230	230	230	120	0	80	10	0	50	60	70	110
2	2	2	3	450	470	440	240	0	0	10	0	40	80	70	110
3	2	3	5	710	680	660	0	0	0	10	0	50	70	70	110
4	3	4	7	940	940	930	0	0	0	10	0	60	80	70	120
5	4	5	8	1220	1170	1100	0	0	0	20	10	50	90	100	120
6	4	6	10	1350	1350	1320	0	0	0	20	20	60	120	90	140
7	5	7	11	1630	1640	1490	0	0	0	20	30	60	130	110	140

Table 7. Strategy comparison for one train pick-up (in %).

Delivery Time	MAX VOLUME	NO STOCKYARD			BEST FIT		
		Short	Medium	Long	Short	Medium	Long
Number of trucks	100	−49	−36	−17	−49	−36	−23
Transhipment volume	100	−5	−3	−3	−5	−3	−7
Required stockyard	100	−96	−100	−95	−96	−100	−95
Average queuing times	100	−17	0	−17	−17	0	−23
Maximal queuing times	100	−15	−3	−5	−15	−3	−8

Table 8. Best performing simulation results for strategy MAX VOLUME (maximal terminal transhipment volume) for two train pick-ups.

Wagons	Number of Trucks			Terminal Transhipment Volume (m^3)			Required Terminal Stockyard (m^3)			Average Queuing Time (min)			Maximal Queuing Time (min)		
	D1	D2	D3	D1	D2	D3	D1	D2	D3	D1	D2	D3	D1	D2	D3
1	2	2	4	490	470	470	360	0	160	20	10	30	70	120	120
2	4	4	6	940	980	940	710	0	10	20	20	30	120	110	80
3	10	6	9	1420	1410	1470	2500	0	10	30	20	30	130	110	90
4	11	8	12	1880	1880	1880	2410	0	0	30	20	30	120	120	160
5	11	10	15	2390	2350	2360	1750	0	0	40	20	40	140	120	170
6	13	12	18	2830	2820	2820	1910	0	0	30	20	50	150	130	180
7	12	15	21	3300	3430	3300	1100	130	0	30	30	60	130	190	250

Table 9. Best performing simulation results for strategy NO STOCKYARD (no or low required terminal stockyard) for two train pick-ups.

Wagons	Number of Trucks			Terminal Transhipment Volume (m^3)			Required Terminal Stockyard (m^3)			Average Queuing Time (min)			Maximal Queuing Time (min)		
	D1	D2	D3	D1	D2	D3	D1	D2	D3	D1	D2	D3	D1	D2	D3
1	1	2	2	240	470	360	120	0	0	0	10	20	50	120	70
2	3	4	5	930	980	820	190	0	0	20	20	20	100	110	80
3	2	6	8	830	1410	1300	0	0	0	10	20	30	80	110	90
4	3	8	12	1170	1880	1880	0	0	0	20	20	30	110	120	160
5	5	10	15	1710	2350	2360	0	0	0	10	20	40	90	120	170
6	7	12	18	2460	2820	2820	0	0	0	20	20	50	110	130	180
7	8	14	21	2820	3300	3300	0	0	0	20	20	60	100	120	250

Table 10. Best simulation results for strategy BEST FIT (at least 90% terminal transhipment volume) for two train pick-ups.

Wagons	Number of Trucks			Terminal Transhipment Volume (m^3)			Required Terminal Stockyard (m^3)			Average Queuing Time (min)			Maximal Queuing Time (min)		
	D1	D2	D3	D1	D2	D3	D1	D2	D3	D1	D2	D3	D1	D2	D3
1	2	2	3	490	470	460	360	0	20	20	10	20	70	120	80
2	3	4	6	930	980	940	190	0	10	20	20	30	100	110	80
3	4	6	9	1310	1410	1470	100	0	10	10	20	30	100	110	90
4	6	8	11	1770	1880	1760	430	0	0	20	20	30	110	120	160
5	8	9	14	2180	2120	2240	690	0	0	20	20	40	110	130	170
6	9	11	16	2650	2590	2590	500	0	0	20	20	40	120	120	180
7	10	14	18	2990	3300	3060	380	0	0	20	20	50	120	120	190

Table 11. Strategy comparison for two train pick-ups (in %).

Delivery Time	MAX VOLUME	NO STOCKYARD			BEST FIT		
		Short	**Medium**	**Long**	**Short**	**Medium**	**Long**
Number of trucks	100	−54	−2	−5	−33	−5	−9
Transhipment volume	100	−23	−1	−3	−7	−4	−5
Required stockyard	100	−97	−100	−100	−75	−100	−78
Average queuing times	100	−50	−7	−7	−35	−7	−11
Maximal queuing times	100	−26	−8	−5	−15	−8	−10

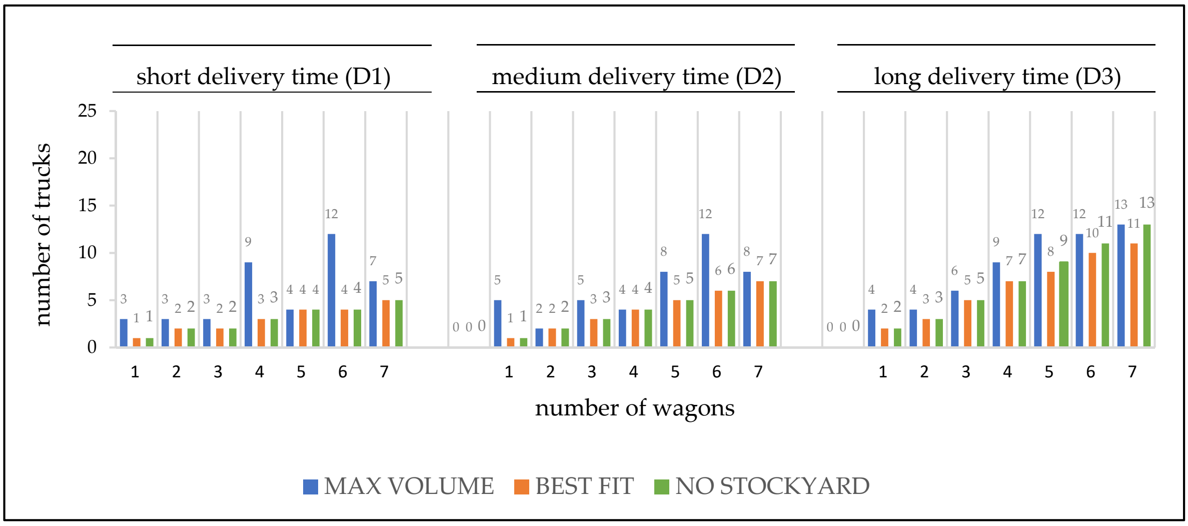

Figure 3. Best performing truck to wagon ratios for one train pick-up and low tonnages regarding three strategies.

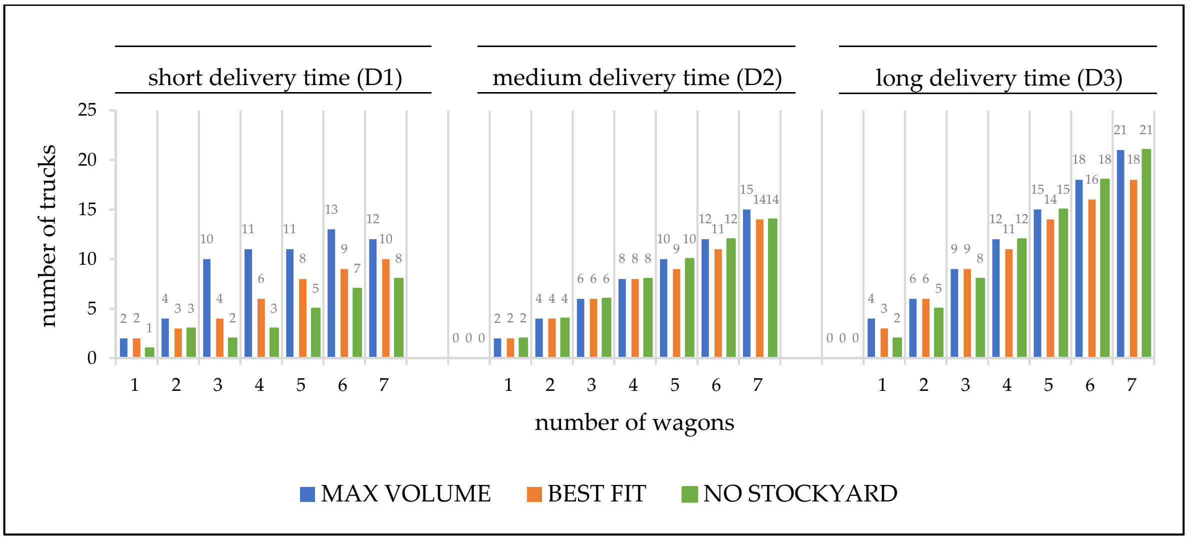

Figure 4. Best performing truck to truck ratios for two train pick-ups and low tonnages regarding three strategies.

For the one train pick-up scenario the BEST FIT strategy provided the lowest number of trucks per wagon, closely followed by the NO STOCKYARD strategy, which performed worse for long delivery times whenever it goes beyond four wagons (Figure 3). Moreover, the BEST FIT strategy reduced the number of trucks compared to the MAX VOLUME strategy and transhipped similar amounts of wood (Table 7). Additionally, both the BEST FIT strategy and the NO STOCKYARD strategy reduced the required stockyard compared to the MAX VOLUME strategy. The BEST FIT strategy also outperformed MAX VOLUME, as well as the NO STOCKYARD strategy with regard to queuing times.

Two train pick-ups show a more diverse picture, because the lowest number of trucks per wagon switches between the BEST FIT strategy with 12 times lowest value and the NO STOCKYARD strategy with 15 times lowest value (Figure 4). If the MAX VOLUME strategy is used as a benchmark, on the one hand, the number of trucks is lower for the BEST FIT strategy and the NO STOCKYARD strategy (Table 11). On the other hand, the transhipment volume is slightly lower for the BEST FIT strategy, but drops sharply for short delivery times for the NO STOCKYARD strategy. Regarding the required terminal stockyard the NO STOCKYARD strategy outperforms BEST FIT strategy. For queuing times, the BEST FIT strategy outperforms for long delivery time, and the NO STOCKYARD strategy for short ones.

A framework for beneficial wagon to truck ratios is provided in Figure 3 for one train pick-up and Figure 4 for two train pick-ups. High quality solutions can be compared and selected according to the main contingency planning objective and strategy. Thereby, the framework is complemented by the transport configuration tables (Tables 4–6 and 8–10), as well as transport templates (Appendices A and B) where KPIs can be compared in detail. For instance, it can be observed that the MAX VOLUME strategy builds up higher stockyards and thus, also more trucks and wagons are needed. Simultaneously those figures and tables are also useful, if contingency planners have other customizable decision variables such as delivery time or to deal with transport capacity limitation such as fewer truck or wagon availability. For example, Figure 4 shows, that if there are only 10 trucks available to supply a terminal with seven wagons and two train pick-ups, only supplying forests with short delivery time to the terminal would enable full utilization of the terminal capacity. Moreover, decision support can be provided regarding terminal selection, if different terminals are available.

In business cases where higher transport tonnages are possible due to legislative changes or exemption clauses invoked by the authorities, the relevant KPIs can be looked up in the complete transport templates (Appendices A and B). Furthermore, the Appendix shows the potential for truck trip reduction. On average, the number of truck trips can be reduced by 6% for one train pick-up (short delivery time 9%/medium 8%/long 2%) and 10% for two train pick-ups (8%/11%/9%), when tonnages change from low to moderate. If tonnages change from low to high, the number of truck trips can be reduced by 10% for one train pick-up (14%/14%/7%) and 17% for two train pick-ups (14%/19%/16%). The distribution of the number of reduced truck trips per week is shown for one train pick-up in Figure 5 and two train pick-ups in Figure 6. In addition to tonnages and delivery times, the number of trucks in the system (i.e., higher for two train pick-ups), the number of wagons (i.e., from one up to seven), the average queuing times for one train pick-up (minutes: 20/12/74) and two train pick-ups (25/14/35) influence the number of reduced truck trips per week.

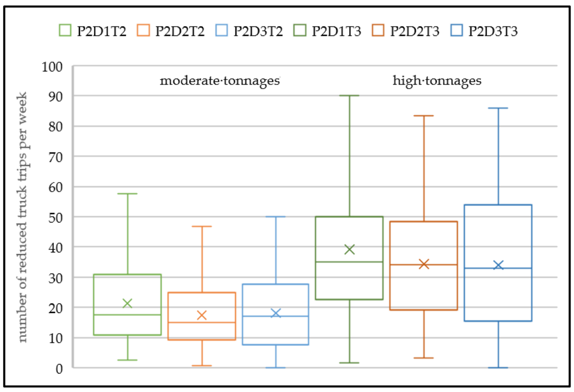

Figure 5. Reduced truck trips for one train pick-up. P = train wagons pick-ups: P1 = one a day, P2 = two a day. T = tonnage of forest trucks equipped with crane: T1 = low, T2 = moderate, T3 = high. D = delivery time to train terminal: D1 = short, D2 = medium, D3 = long.

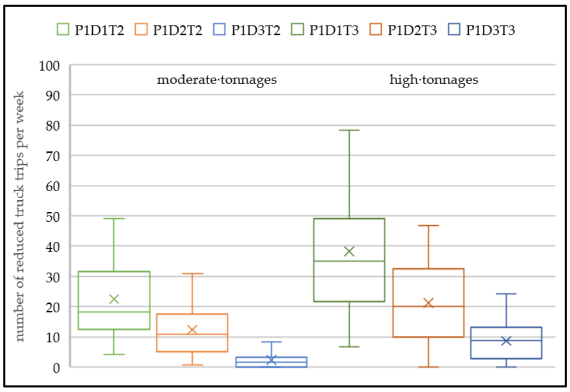

Figure 6. Reduced truck trips for two train pick-ups. P = train wagons pick-ups: P1 = one a day, P2 = two a day. T = tonnage of forest trucks equipped with crane: T1 = low, T2 = moderate, T3 = high. D = delivery time to train terminal: D1 = short, D2 = medium, D3 = long.

3.1. Contingency Planning Under Restricted Wagon Availability

The practical applicability of the simulation model for short-term transport and especially contingency planning is demonstrated by selected realistic business cases. For the first business case, contingency planning under restricted wagon availability, the transport templates can be used to find the appropriate number of trucks for a given number of train pick-ups (e.g., two), wagons (e.g., five), delivery time (e.g., medium), and transport tonnage (e.g., low). If there is no stockyard available, the corresponding transport template (Appendix Table A5) shows for 10 trucks a maximal weekly transhipment volume of 2350 m^3 and an average queuing time of 20 min, as well as a maximal queuing time of 120 min. If there are only five trucks available, a switch to only one train pick-up a day (Appendix Table A2) with a maximal transhipment volume of 1170 m^3 is the better option. For terminals with stockyards a controlled inventory accumulation at the train terminal (e.g., to prevent bark beetle infestation in the forest) can be achieved with one additional (11 trucks 250 m^3) or two additional (12 trucks 490 m^3) trucks per week. If truck carriers would not accept an average queuing time of 20 min (i.e., truck carrier paid per transhipped m^3 tries to use negotiation power due to limited transport options after natural calamities), the number of trucks could be reduced from 10 to 8 to lower the average queuing time to 10 min (resulting in a transhipment volume of 1890 m^3).

3.2. Contingency Planning Under Restricted Truck Availability

The second business case considers contingency planning under restricted truck availability, where transport templates can be used to find an efficient number of wagons for a given number of train pick-ups (e.g., two), trucks (e.g., five), delivery time (e.g., short), and transport tonnage (e.g., low). Without a stockyard available, five wagons can provide a transhipment volume of 1710 m^3, an average of 10 min, and maximal queuing time of 90 min (Appendix Table A4). If more wagons (e.g., seven) are available, one train pick-up (Appendix Table A1) may be an alternative (providing 1630 m^3, 20 min average, and 130 min maximal queuing time). In order to guarantee supply security from terminal to industry (e.g., restrictions in forest road usability due to snow, rain, or maintenance) buffer inventory at terminals with stockyards can be a strategic advantage. To build up inventory at a terminal supplied by five trucks, the number of wagons can be reduced to one, allowing a weekly stockyard accumulation of 1670 m^3 (Appendix Table A1) for one train pick-up and 1430 m^3 (Appendix Table A4) for two train pick-ups, respectively. If the queuing time for five trucks and wagons at the terminal needs to be reduced (e.g., because of negotiations or complaints), one train pick-up would lower the average queuing time to 10 min and the maximal queuing time to 80 min (transhipment volume 1130 m^3, required stockyard 600 m^3).

3.3. Contingency Planning Under Defined Delivery Quotas

The common issue of defined delivery quotas is showcased by the third business case. If a transport quota of 3300 m^3 per week is designated, it can be achieved by a terminal with two train pick-ups per working day providing seven wagons each. For short delivery time 12 trucks (Appendix Table A4), for medium14 trucks (Appendix Table A5), and for long 21 trucks are needed (Appendix Table A6). If it is possible to increase the transport tonnage from low to moderate, the quota could be fulfilled with 11 trucks for short, 13 trucks for medium, and 19 trucks for long distances. In case of an increase from low to high, for short delivery time 8 trucks, for medium 12 trucks, and for long 17 trucks would be sufficient. In order to classify the truck savings through multimodal transport, one scenario setting for a similar unimodal supply chain was calculated (i.e., drive time forest MIN = 35 min/MODE = 40 min/MAX = 45 min, drive time industry 145/150/155, unloading and queuing time industry 85/90/95; resulting in one trip per truck per day to achieve an equivalent truck utilization for comparable results). To achieve a unimodal transport quota of 3300 m^3 per week for low, moderate, and high tonnages the number of required trucks would be 28, 25, and 22 trucks, respectively.

4. Discussion

Comprehensive transport templates structured by main decision variables were proven to provide contingency planners with decision support for various conditions and objectives. Recommended transport configurations can be further refined by negotiations, legal adjustments, or process optimization that were not evaluated in the simulation model. Refinements by negotions may include modifying industry delivery quota to enable a higher utilization, providing additional transport capacity to fulfill required delivery quota, switching supply to an alternative forest region or adding additional train pick-ups. Legal adjustment could include the targeted use of over-time working to fill all wagons or exemption clauses regarding both worktime or tonnages to prevent bark beetle infestations. Further process optimization could be achieved by shorter process times, business process reengineering, learning curve or staggered shifts.

The results were obtained for rail terminal configurations that are typical for Austria's mountainous regions. Due to limited space there is usually only a single, short loading track for transhipping wood to few wagons. Therefore, developed measures and strategies cannot be generalized for conditions where rail terminal have more than one loading track and provide space for a whole block train as is common in other countries. Another important restriction is the one-way truck driving route within the rail terminal, which provides no possibility for passing, since this causes trucks to queue up. In order to support a detailed planning for similar rail terminal configurations, main input parameters of the simulation model such as legal payload for trucks and wagons need to be adapted. If these restrictions apply, the general findings can be transferred to provide support for basic contingency planning in other regions of the world.

For the purpose of discussing the findings in a broader scientific context, it is vital to mention that there are also DES studies, which concentrate on specific parts of the wood supply chain such as harvesting [22] and log yard logistics at industry sites [23,24]. These studies consider in greater detail modules for harvesting and industry site management. However, the simulation model of this study concentrates on the logistics of the wood supply chain and thus connects the initial harvesting and final industry consumption of those studies [22–24]. Furthermore, impacts of climate change and risks were simulated on a higher abstraction level with other methods for upstream processes such as primal tree planting, forest stand growths, and forest management, but the studies did not focus on supply chain management and wood logistic [25–28]. Others simulated wood supply chains and pointed out the resulting outcomes of risks such as raw material availability and quality [19], quality loss during storage [29], and oversupply [13,14], but did not focus on concrete contingency strategies and plans to give operative decision support to manage those risks. In the past, many studies observed biomass supply chains and concentrated on logistics for in-wood operations [30,31] and there are also contributions for moisture content reduction during in-wood storage for wood biomass feedstock [32], but they did not focus on discrete event simulation nor on multimodal timber transport.

In order to enable short-term contingency planning for multimodal wood supply chains, the terminal and queuing processes need to be modeled in detail. In a recent review [33], the simulation model of Kogler and Rauch 2019 [15] was described as "perhaps the most detailed railroad terminal study to date for the wood supply chain" (i.e., presumable Acuna et al. [33] accidentally interchanged the references of [10] and [15] in their paper). For this study, that model was further developed to cover identified sensible factors, as well as various scenario designs, KPIs, and strategies to provide robust results for a variety of small scale train terminals with different delivery times, train pick-ups, and tonnages. This was supported by comprehensive business process mapping and reengineering, which was also heavily used for other detailed DES studies in the wood supply chain [34,35].

The results indicate in line with Korpinen et al. [36] that higher truck transport tonnages provide potential to reduce truck trips and thus, transport costs and emissions. However, for political discourse further factors such as potential shifts from rail to road, traffic intensity, social compatibility, technical reliability, and unified competition regulations in the European Union have to be taken into consideration. In accordance with Eliasson et al. [37] emphasis was put on observing the impacts of transport distance, number of trucks in the system, and stockyards. Contrary to Eliasson et al. [37] staggered truck shifts were not implemented in this study, rather, truck shifts were coordinated with train schedules to guarantee high utilization. A potential for improvement could be the modeling of wood value loss during long lead times and the implementation of different delivery strategies [29]. Next to advantages such as buffer capacity and saved emission, terminals also show disadvantages such as higher costs, which were accordingly discussed for the wood assortment chips [38]. Managerial options such as staggered shifts, or targeted use of over-time working were not considered in this study but provide promising opportunities for further research. Another future approach is to focus on the modeling and management of log quality deterioration and the resulting wood value loss, caused by challenging transport (e.g., long lead times), as well as storage (e.g., weather, temperature) conditions.

5. Conclusions

The management of wood supply chains is a complex task facing many challenges such as decreasing forest truck transport capacity, lack of digitalization, and increasing risks of natural calamities due to climate change. The transhipment of wood from trucks to trains at terminals offers important strategy options and operational advantages including additional transport capacity, shorter truck queuing times at industrial sites, and reduced CO_2 emissions. Moreover, fewer bottlenecks caused by the limited availability of forest trucks equipped with cranes occur, since trucks are deployed on indispensible short-distance wood transport from forest landings to terminals rather than long trips to industry.

Simulation provides powerful methods to cover dynamic and interdependent changes and analyze bottlenecks and queuing times to support advanced short-term contingency planning. Consequently, this study introduced a toolbox consisting of a discrete event simulation model set up for analyses on an operational level, strategies to cope with challenging business cases, as well as transport templates and tables including critical parameters, decision variables, and KPIs to facilitate contingency planning.

Identified critical factors such as the number of wagons and trucks in the system, terminal transhipment volume, required terminal stockyard, average and maximal queuing times at the terminal, truck and train utilization, as well as worktime coordination provide useful decision support for a variety of objectives. The multiobjective transport planning strategy BEST FIT provides robust solutions which save truck and train resources, as well as keep the transhipment volume on a high and the stockyard and queuing time on a low level.

Furthermore, different planning conditions such as the number of train pick-ups, the delivery time from forest to industry (i.e., resulting in different number of truck trips per day), as well as the truck transport tonnage (i.e., varies between regions or due to exemption clauses) influence contingency plans. Thus, the transport templates presented provide a sound overview of beneficial (i.e., high truck and wagon utilization) solutions to compare alternatives and support developing customized plans. The results supported contingency planning in common business cases such as restricted wagon or truck availability, defined delivery quota, terminal selection, inventory accumulation, and queuing time reduction.

The simulation model provided a variety of supply chain configurations outcomes of decisions before real, costly, and wide-ranging changes have to be made. Consequently, simulation results provided a well performing configuration which can be fine-tuned in real life business and contingency cases. For example, the permission granted for higher truck transport tonnages (e.g., after natural calamities) was evaluated as a potential means to reduce truck trips.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Terminal transport template for one train pick-up, short delivery time, and all tonnages (P1D1 T1/2/3).

Wagons	Trucks	Terminal Transhipment Volume [1]			Required TERMINAL Stockyard [1]			Average Queuing Time [2]			Maximal Queuing Time [2]			Half loaded Train Wagons [3]			Reduced Truck Trips [3]	
		T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T2	T3
1	1	230	270	290	120	130	140	10	0	0	60	0	60	0	0	0	4	7
1	2	230	260	290	590	660	660	10	10	20	110	120	120	0	0	0	8	11
1	3	240	260	280	950	1060	1110	20	20	20	120	130	130	0	0	0	11	17
1	4	240	260	280	1310	1470	1560	20	20	30	130	140	130	0	0	0	15	24
1	5	240	260	290	1670	1870	2010	30	30	30	140	140	140	0	0	0	18	33
2	2	450	530	590	240	270	250	10	0	0	80	60	60	0	0	0	9	13
2	3	490	530	570	710	760	750	10	10	10	110	120	110	0	0	0	8	10
2	4	470	530	590	1190	1310	1290	10	10	20	110	120	130	0	0	0	15	18
2	5	470	530	590	1550	1710	1740	20	20	20	120	130	130	0	0	0	18	26
3	2	710	790	880	0	0	0	10	10	20	70	70	70	0	0	0	7	14
3	3	730	790	880	360	400	360	10	0	0	70	60	60	0	0	0	8	13
3	4	700	770	880	830	850	890	10	10	10	110	120	70	0	0	0	8	20
3	5	700	760	880	1300	1390	1380	10	10	20	110	120	120	0	0	0	13	22
3	6	730	790	880	1780	1940	1900	10	20	20	110	120	130	0	0	0	18	23
3	7	710	790	910	2140	2340	2360	20	20	20	120	130	130	0	0	0	23	35
3	8	700	790	880	2480	2740	2760	20	20	30	130	140	140	0	0	0	29	38
3	9	710	820	880	2780	3070	3210	30	30	30	130	140	130	0	0	0	33	50
3	10	700	820	880	3210	3500	3620	20	30	30	130	140	140	0	0	0	34	49
4	3	940	1060	1170	0	0	0	10	20	20	80	110	90	0	0	0	10	19
4	4	940	1060	1170	480	530	440	10	0	10	80	60	90	0	0	0	14	16
4	5	940	1020	1180	940	940	1000	10	10	10	110	110	70	0	0	0	7	25
4	6	940	1020	1180	1410	1430	1490	10	10	10	120	120	100	0	0	0	8	27
4	7	940	1060	1180	1900	2000	2000	10	20	20	120	120	120	0	0	0	18	28
4	8	940	1060	1170	2300	2480	2490	20	20	20	130	130	130	0	0	0	25	35
4	9	980	1060	1130	2610	2830	2920	20	20	20	130	140	130	0	0	0	25	38
4	10	940	1020	1180	2870	3160	3270	30	30	30	150	140	140	0	0	0	31	53
4	11	940	1090	1170	3350	3630	3730	20	20	30	130	150	150	0	0	0	36	51

Table A1. *Cont.*

Wagons	Trucks	Terminal Transhipment Volume [1]			Required TERMINAL Stockyard [1]			Average Queuing Time [2]			Maximal Queuing Time [2]			Half loaded Train Wagons [3]			Reduced Truck Trips [3]	
		T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T2	T3
5	4	1220	1320	1470	0	0	0	20	20	20	90	90	110	0	0	0	8	21
5	5	1130	1330	1470	600	660	540	10	0	10	80	60	70	0	0	0	22	23
5	6	1170	1370	1470	1060	1070	1090	10	10	10	120	70	70	0	0	0	18	28
5	7	1170	1320	1470	1540	1510	1630	10	10	10	110	110	80	0	0	0	10	33
5	8	1180	1320	1420	1880	2020	2070	20	20	20	120	120	120	0	0	0	23	36
5	9	1170	1320	1470	2320	2480	2550	20	20	20	120	130	130	0	0	0	26	44
5	10	1170	1320	1470	2670	2920	2960	30	30	30	130	140	140	0	0	0	33	49
5	11	1170	1320	1510	2920	3210	3300	30	30	30	140	130	150	0	0	0	37	60
5	12	1120	1320	1420	3340	3680	3850	30	30	30	130	150	140	0	0	0	45	68
6	4	1350	1620	1740	0	0	0	20	20	20	120	140	120	0	0	0	23	33
6	5	1410	1580	1700	20	0	0	20	20	30	160	130	130	0	0	0	13	23
6	6	1410	1580	1770	720	770	620	10	0	10	70	60	70	0	0	0	18	22
6	7	1410	1580	1830	1170	1200	1190	10	10	10	120	70	70	0	0	0	17	37
6	8	1410	1580	1760	1560	1590	1690	20	10	10	130	100	110	0	0	0	17	40
6	9	1410	1580	1820	1940	1990	2090	20	20	20	140	140	90	0	0	0	18	47
6	10	1350	1590	1690	2310	2450	2450	30	20	30	130	140	140	0	0	0	32	40
6	11	1410	1580	1760	2650	2890	2820	30	30	30	140	150	140	0	0	0	34	43
6	12	1470	1590	1750	3000	3300	3320	30	30	40	140	140	150	0	0	0	35	50
6	13	1410	1520	1700	3340	3730	3990	30	30	30	140	130	140	0	0	0	42	78
6	14	1350	1580	1760	3580	3890	4320	40	30	30	190	140	140	0	0	0	45	96
7	5	1630	1850	2120	0	0	0	20	20	30	130	160	150	0	0	0	18	41
7	6	1640	1850	2050	50	0	0	20	40	30	120	140	130	0	0	0	13	30
7	7	1710	1850	1990	830	890	680	10	0	10	80	60	110	0	0	0	17	11
7	8	1640	1910	2060	1230	1300	1270	10	10	10	130	100	110	0	0	0	28	38
7	9	1640	1910	2050	1680	1640	1740	20	10	10	130	120	130	0	0	0	19	39
7	10	1570	1850	2050	2060	2050	2200	20	20	20	140	130	130	0	0	0	23	52
7	11	1570	1850	2060	2430	2470	2560	20	20	20	150	140	140	0	0	0	27	52
7	12	1640	1850	2060	2760	2910	2900	30	30	30	140	140	140	0	0	0	30	47
7	13	1650	1850	1990	3080	3340	3400	30	30	30	140	140	150	0	0	0	38	55
7	14	1640	1850	2060	3400	3750	4160	30	30	20	150	140	130	0	0	0	47	98
7	15	1640	1850	2130	3510	3890	4320	40	40	30	200	140	140	0	0	0	49	108
7	16	1650	1850	2050	3640	4020	4460	50	50	40	210	150	140	0	0	0	48	102

[1] Average per week in solid cubic meters (rounded to the nearest ten). [2] In minutes (rounded to the nearest ten). [3] Average quantity per week.

Table A2. Terminal transport template for one train pick-up, medium delivery time, and all tonnages (P1D2 T1/2/3).

Wagons	Trucks	Terminal Transhipment Volume [1]			Required Terminal Stockyard [1]			Average Queuing Time [2]			Maximal Queuing Time [2]			Half Loaded Train Wagons [3]			Reduced Truck Trips [3]	
		T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T2	T3
1	1	230	260	290	0	0	0	0	0	0	70	70	70	0	0	0	3	5
1	2	240	260	290	280	270	300	10	10	10	70	70	70	0	0	0	1	6
1	3	240	260	300	540	540	600	10	10	10	80	130	80	0	0	0	2	10
1	4	230	260	290	800	820	890	10	10	10	80	150	130	0	0	0	4	13
1	5	250	260	280	1070	1100	1190	10	10	10	120	80	130	0	0	0	3	13
2	1	240	260	300	0	0	0	0	0	0	70	0	70	0	0	0	2	5
2	2	470	530	570	0	0	0	0	0	0	70	70	70	0	0	0	5	8
2	3	470	530	590	270	270	240	10	10	10	70	70	70	0	0	0	5	8
2	4	470	530	590	530	540	600	10	10	10	70	70	70	0	0	0	6	16
2	5	450	530	590	770	810	890	10	10	10	70	80	80	0	0	0	10	22
3	1	250	260	300	0	0	0	0	0	0	70	70	70	0	0	0	1	4
3	2	480	530	590	0	0	0	10	10	10	70	70	70	0	0	0	4	9
3	3	680	790	880	0	0	0	0	0	0	70	70	80	0	0	0	9	17
3	4	710	790	910	240	230	140	10	0	0	70	70	70	0	0	0	6	8
3	5	710	790	880	530	530	550	10	10	10	70	70	80	0	0	0	7	16
3	6	700	790	880	770	810	890	10	10	10	80	80	80	0	0	0	11	25

Table A2. *Cont.*

Wagons	Trucks	Terminal Transhipment Volume [1]			Required Terminal Stockyard [1]			Average Queuing Time [2]			Maximal Queuing Time [2]			Half Loaded Train Wagons [3]			Reduced Truck Trips [3]	
		T1	**T2**	**T3**	**T1**	**T2**	**T3**	**T1**	**T2**	**T3**	**T1**	**T2**	**T3**	**T1**	**T2**	**T3**	**T2**	**T3**
3	7	710	790	880	1020	1080	1190	10	10	10	80	80	90	0	0	0	12	28
3	8	700	790	880	1270	1350	1490	10	10	10	80	150	150	0	0	0	14	33
3	9	700	790	880	1540	1630	1790	10	10	10	90	80	90	0	0	0	15	36
3	10	680	820	880	1830	1900	2090	10	20	20	90	140	150	0	0	0	18	38
4	2	500	530	590	0	0	0	0	0	0	70	70	70	10	10	10	3	8
4	3	750	760	910	0	0	0	10	10	10	80	80	80	0	0	0	1	13
4	4	940	1060	1210	0	0	0	0	0	0	70	70	80	0	0	0	10	23
4	5	940	1020	1180	220	210	20	10	0	0	80	70	70	0	0	0	6	3
4	6	940	1060	1170	510	510	440	10	0	10	70	80	80	0	0	0	10	13
4	7	940	1060	1170	780	800	850	10	10	10	80	90	80	0	0	0	12	25
4	8	940	1060	1170	1020	1070	1180	10	10	10	80	80	150	0	0	0	14	33
4	9	940	1060	1170	1280	1350	1470	10	10	10	140	150	150	0	0	0	16	35
4	10	940	1060	1140	1520	1630	1770	10	20	10	110	90	160	0	0	0	19	38
4	11	940	1060	1170	1770	1890	2070	20	20	20	140	140	160	0	0	0	20	44
5	3	740	800	880	0	0	0	10	0	0	80	70	70	10	10	10	5	12
5	4	950	1060	1170	0	0	0	10	10	10	80	80	80	0	0	0	9	18
5	5	1170	1270	1470	0	0	0	10	10	10	100	80	90	0	0	0	8	25
5	6	1180	1320	1470	190	130	0	0	0	0	70	80	100	0	0	0	7	8
5	7	1170	1270	1470	500	490	310	10	0	10	70	80	80	0	0	0	8	9
5	8	1220	1270	1460	770	780	730	10	10	10	80	100	90	0	0	0	5	17
5	9	1170	1320	1470	1020	1070	1090	10	10	10	80	140	90	0	0	0	17	31
5	10	1120	1320	1480	1270	1340	1410	10	10	10	100	100	100	0	0	0	23	42
5	11	1180	1320	1420	1510	1620	1660	20	20	20	110	140	100	0	0	0	21	33
5	12	1170	1320	1520	1760	1890	1970	20	20	20	100	140	160	0	0	0	23	47
6	4	950	1060	1170	0	0	0	10	0	0	80	80	80	10	10	10	9	18
6	5	1180	1330	1420	0	0	0	20	20	20	90	90	90	0	0	0	13	20
6	6	1350	1650	1760	0	0	0	20	20	20	90	90	90	0	0	0	25	34
6	7	1410	1640	1770	160	60	0	0	0	10	70	80	100	0	0	0	11	17
6	8	1410	1530	1760	500	430	150	10	10	10	100	90	90	0	0	0	4	0
6	9	1410	1580	1820	770	760	530	10	10	10	80	100	90	0	0	0	13	14
6	10	1350	1590	1750	1020	1050	900	10	10	10	120	100	100	0	0	0	23	23
6	11	1350	1580	1770	1250	1320	1250	20	10	20	110	110	110	0	0	0	25	35
6	12	1470	1520	1760	1500	1600	1540	20	20	20	110	170	180	0	0	0	13	28
6	13	1410	1590	1760	1750	1870	1810	20	20	20	160	160	180	0	0	0	25	34
6	14	1410	1590	1760	1980	2130	2080	30	20	30	160	170	170	0	0	0	28	38
7	5	1190	1320	1470	0	0	0	10	10	10	90	80	80	10	10	10	11	23
7	6	1420	1580	1760	0	0	0	20	20	10	90	90	90	0	0	0	13	28
7	7	1640	1850	2060	0	0	0	30	30	30	110	110	90	0	0	0	18	35
7	8	1650	1850	2040	160	20	0	10	10	10	80	120	100	0	0	0	5	19
7	9	1640	1850	2050	480	380	20	10	10	10	100	100	100	0	0	0	9	0
7	10	1640	1910	1980	770	710	430	10	10	10	100	100	150	0	0	0	18	0
7	11	1650	1850	2060	1020	1010	760	10	10	10	110	100	170	0	0	0	16	13
7	12	1570	1850	2120	1260	1300	1100	20	10	20	110	120	100	0	0	0	27	33
7	13	1640	1780	2060	1490	1570	1430	20	20	20	170	170	170	0	0	0	18	30
7	14	1570	1850	1980	1740	1830	1690	20	20	30	160	170	190	0	0	0	31	30
7	15	1640	1850	2050	1970	2080	1960	30	30	30	170	180	180	0	0	0	27	33
7	16	1640	1850	2120	2200	2350	2220	30	30	40	180	170	190	0	0	0	30	42

[1] Average per week in solid cubic meters (rounded to the nearest ten). [2] In minutes (rounded to the nearest ten). [3] Average quantity per week.

Table A3. Terminal transport template for one train pick-up, long delivery time, and all tonnages (P1D3 T1/2/3).

Wagons	Trucks	Terminal Transhipment Volume [1]			Required Terminal Stockyard [1]			Average Queuing Time [2]			Maximal Queuing Time [2]			Half Loaded Train Wagons [3]			Reduced Truck Trips [3]	
		T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T2	T3
1	2	230	260	300	80	30	10	50	60	70	110	110	110	0	0	0	0	0
1	3	230	260	290	190	160	150	70	80	80	120	130	130	0	0	0	0	2
1	4	240	260	290	320	310	300	70	80	90	120	130	130	0	0	0	1	3
1	5	230	260	290	440	430	450	80	90	90	120	130	130	0	0	0	2	6
2	3	440	430	450	0	0	0	40	50	60	110	110	110	0	0	0	0	1
2	4	470	530	590	130	50	0	60	70	70	110	120	120	0	0	0	0	0
2	5	470	530	590	260	170	160	60	80	80	120	130	130	0	0	0	0	2
3	5	660	700	740	0	0	0	50	60	70	110	120	120	0	0	0	3	7
3	6	730	790	880	170	50	10	60	70	70	120	120	120	0	0	0	0	0
3	7	700	760	880	290	180	150	70	80	80	130	130	130	0	0	0	0	3
3	8	700	790	850	400	310	300	70	80	90	130	130	140	0	0	0	0	4
3	9	730	790	880	510	440	450	80	90	90	130	140	140	0	0	0	0	8
3	10	710	790	880	630	580	600	80	90	90	140	140	150	0	0	0	3	12
4	5	730	740	740	0	0	0	40	50	60	110	110	110	0	10	10	1	1
4	6	850	860	890	0	0	0	50	60	60	110	120	120	0	0	0	1	3
4	7	930	960	1040	0	0	0	60	70	70	120	130	130	0	0	0	3	9
4	8	940	1060	1170	180	60	10	60	70	80	120	130	130	0	0	0	0	5
4	9	980	1060	1170	290	190	150	70	80	80	140	150	150	0	0	0	0	4
4	10	980	1020	1210	420	320	300	70	80	90	140	150	150	0	0	0	0	9
4	11	940	1060	1130	540	440	450	80	90	90	150	150	150	0	0	0	2	8
5	6	910	830	910	0	0	0	40	50	50	110	110	110	10	10	10	0	0
5	7	980	1000	990	0	0	0	50	60	60	120	120	120	0	10	10	2	1
5	8	1100	1140	1180	0	0	0	50	70	70	120	130	130	0	0	0	3	7
5	9	1170	1230	1320	0	0	0	60	70	80	130	140	140	0	0	0	5	13
5	10	1170	1270	1470	180	40	10	70	80	80	140	140	140	0	0	0	0	11
5	11	1170	1370	1470	330	180	150	70	80	90	140	150	150	0	0	0	4	10
5	12	1180	1310	1470	430	320	300	80	90	90	150	150	160	0	0	0	2	13
6	9	1210	1230	1320	0	0	0	60	70	70	140	140	140	0	10	10	2	9
6	10	1320	1360	1470	0	0	0	60	70	80	140	140	150	0	0	0	3	13
6	11	1400	1490	1620	0	0	0	70	80	80	150	140	140	0	0	0	8	18
6	12	1410	1580	1760	180	40	0	70	80	90	140	140	140	0	0	0	3	14
6	13	1410	1580	1760	330	170	150	80	90	90	150	150	150	0	0	0	1	14
6	14	1410	1640	1770	420	320	300	80	90	100	190	200	200	0	0	0	11	20
7	10	1340	1370	1470	0	0	0	60	70	70	140	140	140	10	10	10	3	11
7	11	1490	1450	1620	0	0	0	60	70	80	140	140	150	0	10	10	0	11
7	12	1560	1620	1760	0	0	0	70	80	80	140	140	140	0	0	0	5	17
7	13	1640	1760	1910	0	0	0	70	80	80	140	150	150	0	0	0	10	23
7	14	1640	1850	2050	220	50	10	80	80	90	150	150	150	0	0	0	3	17
7	15	1640	1850	1990	300	180	150	80	90	100	210	210	220	0	0	0	8	17
7	16	1640	1850	2060	430	320	300	90	100	100	220	220	230	0	0	0	8	24

[1] Average per week in solid cubic meters (rounded to the nearest ten). [2] In minutes (rounded to the nearest ten). [3] Average quantity per week.

Appendix B

Table A4. Terminal transport template for two train pick-ups, short delivery time, and all tonnages (P2D1 T1/2/3).

Wagons	Trucks	Terminal Transhipment Volume [1]			Required Terminal Stockyard [1]			Average Queuing Time [2]			Maximal Queuing Time [2]			Half Loaded Train Wagons [3]			Reduced Truck Trips [3]	
		T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T2	T3
1	1	240	270	380	120	120	0	0	0	10	50	60	70	0	0	0	3	2
1	2	490	530	590	360	390	370	20	10	20	70	120	120	0	0	0	6	9
1	3	470	530	590	710	800	810	30	30	30	120	140	130	0	0	0	13	18
1	4	450	530	590	1070	1200	1260	40	40	40	130	130	140	0	0	0	18	28
1	5	450	530	590	1430	1600	1710	50	40	40	130	140	130	0	0	0	21	35

Table A4. *Cont.*

Wagons	Trucks	Terminal Transhipment Volume [1]			Required Terminal Stockyard [1]			Average Queuing Time [2]			Maximal Queuing Time [2]			Half Loaded Train Wagons [3]			Reduced Truck Trips [3]	
		T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T2	T3
2	2	460	820	910	230	0	0	10	10	10	60	70	70	0	0	0	11	18
2	3	930	880	960	190	320	310	20	20	20	100	100	100	0	0	0	7	13
2	4	940	1060	1170	710	780	700	20	10	20	120	120	120	0	0	0	16	18
2	5	900	1060	1170	1070	1170	1140	30	20	30	120	130	130	0	0	0	22	28
3	2	830	860	890	0	0	0	10	20	30	80	120	120	0	0	0	3	5
3	3	810	1090	1310	230	20	0	10	10	10	70	70	70	0	10	10	6	23
3	4	1310	1260	1470	100	260	150	10	20	20	100	100	100	0	10	10	9	18
3	5	1330	1240	1470	610	790	660	20	20	20	110	120	120	0	10	10	8	16
3	6	1360	1530	1750	1070	1140	1000	20	10	30	120	120	130	0	0	0	20	27
3	7	1410	1580	1700	1430	1520	1470	20	20	30	120	130	130	0	0	0	22	28
3	8	1410	1590	1820	1770	1920	1880	30	30	30	130	130	130	0	0	0	28	43
3	9	1410	1530	1760	2070	2280	2320	30	30	40	130	130	140	0	0	0	28	50
3	10	1420	1590	1770	2500	2700	2720	30	30	40	130	140	130	0	0	0	31	48
4	3	1170	1230	1350	0	0	0	20	20	20	110	80	110	10	10	10	5	15
4	4	1030	1470	1760	420	20	0	10	10	10	70	70	80	0	10	10	3	26
4	5	1600	1620	1860	110	230	120	10	10	10	100	100	100	10	10	10	12	23
4	6	1770	1650	1820	430	760	650	20	20	20	110	110	110	0	10	10	18	23
4	7	1830	1690	1940	930	1110	1050	20	20	20	110	120	120	0	10	10	3	19
4	8	1810	2070	2310	1390	1450	1320	20	20	30	130	120	130	0	0	0	27	36
4	9	1830	2070	2340	1660	1790	1730	30	30	30	130	140	140	0	0	0	31	48
4	10	1820	2080	2430	1930	2100	2110	40	30	30	150	150	140	0	0	0	36	66
4	11	1880	2120	2350	2410	2570	2550	30	30	30	120	150	140	0	0	0	33	51
5	4	1530	1680	1790	0	0	0	10	20	20	80	80	100	10	10	10	13	22
5	5	1710	1930	2270	0	0	0	10	10	20	90	70	90	10	10	10	18	47
5	6	1970	2100	2260	30	20	10	10	20	10	100	100	100	10	10	10	10	23
5	7	2130	2080	2320	320	540	510	20	20	20	110	120	110	0	10	10	14	32
5	8	2180	2160	2400	690	870	870	20	20	20	110	120	120	0	10	10	13	33
5	9	2270	2520	2690	1160	1120	1130	30	20	30	120	120	120	0	0	0	18	33
5	10	2260	2560	2910	1540	1640	1470	30	30	30	130	130	150	0	0	0	33	48
5	11	2390	2700	2940	1750	1910	1810	40	30	40	140	140	150	0	0	0	39	51
5	12	2360	2640	2940	2160	2340	2370	30	30	30	130	140	130	0	0	0	38	66
6	4	1620	1750	1770	0	0	0	20	20	30	100	130	110	10	10	10	11	13
6	5	1850	2060	2220	0	0	0	20	20	20	130	170	130	10	10	10	18	31
6	6	2090	2400	2640	0	0	0	10	10	20	80	70	100	10	10	10	26	46
6	7	2460	2550	2920	0	0	0	20	20	20	110	100	150	10	10	10	8	38
6	8	2530	2620	2800	170	270	240	20	20	20	120	120	130	10	10	10	16	28
6	9	2650	2870	3090	500	450	540	20	20	20	120	130	130	0	10	10	14	40
6	10	2740	2980	3510	870	770	730	30	30	30	130	130	130	0	0	0	12	53
6	11	2640	3080	3440	1270	1240	1070	30	30	40	130	130	130	0	0	0	34	50
6	12	2780	3160	3400	1590	1720	1540	40	30	30	130	130	140	0	0	0	43	48
6	13	2830	3180	3540	1910	2110	2210	30	30	30	150	130	130	0	0	0	46	84
6	14	2820	3300	3530	2010	2150	2380	50	40	40	190	140	140	0	0	0	52	90
7	5	1980	2090	2220	0	0	0	20	20	30	120	120	130	10	10	10	9	20
7	6	1960	2220	2580	0	0	0	20	20	30	180	180	160	20	20	10	22	52
7	7	2420	2810	3060	0	0	0	10	10	20	70	160	160	10	10	10	33	53
7	8	2820	3120	3250	0	0	0	20	20	20	100	100	140	10	10	10	25	36
7	9	2820	3140	3510	130	80	10	20	20	20	110	110	130	10	10	10	23	48
7	10	2990	3160	3690	380	340	260	20	20	20	120	130	110	10	10	10	11	48
7	11	3130	3400	3840	690	650	600	30	30	30	120	120	130	0	10	0	19	52
7	12	3300	3510	3780	1100	1030	990	30	30	30	130	130	130	0	0	0	12	31
7	13	3200	3740	4010	1450	1460	1390	30	30	40	150	140	140	0	0	0	46	63
7	14	3300	3700	4250	1710	1880	2080	40	30	30	150	140	130	0	0	0	48	110
7	15	3300	3700	4110	1690	1880	2080	60	50	40	190	150	160	0	0	0	49	100
7	16	3280	3840	4110	1750	1880	2090	70	60	60	210	160	160	0	0	0	58	98

[1] Average per week in solid cubic meters (rounded to the nearest ten). [2] In minutes (rounded to the nearest ten). [3] Average quantity per week.

Table A5. Terminal transport template for two train pick-ups, medium delivery time, and all tonnages (P2D2 T1/2/3).

Wagons	**Trucks**	**Terminal Transhipment Volume** [1]			**Required Terminal Stockyard** [1]			**Average Queuing Time** [2]			**Maximal Queuing Time** [2]			**Half Loaded Train Wagons** [3]			**Reduced Truck Trips** [3]	
		T1	**T2**	**T3**	**T1**	**T2**	**T3**	**T1**	**T2**	**T3**	**T1**	**T2**	**T3**	**T1**	**T2**	**T3**	**T2**	**T3**
1	1	250	260	290	0	0	0	0	0	0	10	10	0	0	0	0	1	3
1	2	470	530	590	0	0	0	10	10	20	120	110	110	0	0	0	5	10
1	3	470	530	570	240	270	300	20	20	20	130	110	120	0	0	0	8	13
1	4	470	530	590	480	540	590	20	30	30	120	120	110	0	0	0	10	19
1	5	470	530	590	720	800	890	30	30	30	120	120	110	0	0	0	12	24
2	1	250	280	290	0	0	0	0	0	0	10	0	0	0	0	0	3	3
2	2	490	530	570	0	0	0	0	0	0	20	20	20	0	0	0	3	7
2	3	710	760	880	0	0	0	10	10	10	110	110	110	0	0	0	4	14
2	4	980	1060	1210	0	0	0	20	20	20	110	110	110	0	0	0	7	19
2	5	940	1060	1170	240	270	300	20	20	20	80	120	130	0	0	0	13	24
3	1	240	270	290	0	0	0	0	0	0	10	10	0	0	0	0	3	4
3	2	470	550	590	0	0	0	0	0	0	20	20	20	0	0	0	7	10
3	3	710	790	880	0	0	0	0	0	0	20	20	20	0	0	0	7	14
3	4	940	1060	1140	0	0	0	10	10	10	110	110	100	10	10	10	10	17
3	5	1180	1320	1470	0	0	0	10	10	10	110	110	110	0	0	0	12	24
3	6	1410	1590	1760	0	0	0	20	20	20	110	110	110	0	0	0	15	29
3	7	1410	1530	1770	250	270	300	20	20	20	120	120	120	0	0	0	12	34
3	8	1410	1590	1760	480	540	600	20	20	20	120	120	110	0	0	0	20	39
3	9	1410	1590	1770	720	800	890	20	30	30	120	130	130	0	0	0	22	44
3	10	1350	1590	1820	960	1070	1190	30	30	30	120	130	120	0	0	0	29	58
4	2	470	530	590	0	0	0	0	0	0	20	20	10	0	0	0	5	10
4	3	680	800	890	0	0	0	0	0	0	20	20	20	10	0	0	10	18
4	4	900	1060	1180	0	0	0	0	0	0	20	20	20	0	0	0	13	23
4	5	1170	1330	1470	0	0	0	10	10	10	110	110	110	10	10	10	13	25
4	6	1420	1590	1830	0	0	0	10	10	10	120	110	110	10	10	10	14	34
4	7	1640	1860	2060	0	0	0	20	20	20	110	120	100	0	0	0	18	35
4	8	1880	2120	2350	0	0	0	20	20	20	120	120	110	0	0	0	20	39
4	9	1800	2110	2270	240	270	300	20	20	20	130	130	130	0	0	0	28	44
4	10	1880	2190	2270	480	540	600	20	20	30	130	130	140	0	0	0	31	43
4	11	1880	2110	2280	720	800	890	30	30	30	130	130	130	0	0	0	26	48
5	3	740	790	910	0	0	0	0	0	0	20	20	20	10	0	0	4	14
5	4	950	1020	1180	0	0	0	0	0	0	20	20	20	10	0	0	6	19
5	5	1170	1370	1470	0	0	0	0	0	0	20	20	20	0	0	0	17	25
5	6	1420	1590	1710	0	0	0	10	10	10	110	110	100	20	20	20	14	24
5	7	1650	1860	2060	0	0	0	10	10	10	120	110	110	10	10	10	18	34
5	8	1890	2120	2350	0	0	0	10	20	20	120	120	120	10	10	10	19	38
5	9	2120	2380	2560	0	0	0	20	20	20	130	120	120	0	0	0	22	37
5	10	2350	2650	2850	0	0	0	20	20	20	120	120	120	0	0	0	25	42
5	11	2350	2650	2940	250	270	300	20	20	20	130	130	130	0	0	0	27	53
5	12	2350	2550	2940	490	540	600	20	30	30	130	130	130	0	0	0	21	58
6	4	950	1060	1180	0	0	0	0	0	0	20	20	20	10	0	0	9	19
6	5	1230	1320	1470	0	0	0	0	0	0	20	20	20	20	0	0	8	20
6	6	1420	1590	1770	0	0	0	0	0	0	20	20	20	0	0	0	14	29
6	7	1650	1850	2070	0	0	0	10	10	10	110	100	100	20	20	20	17	35
6	8	1960	2120	2350	0	0	0	10	10	10	110	120	110	20	20	20	13	33
6	9	2040	2390	2650	0	0	0	10	10	20	120	120	110	10	10	10	29	51
6	10	2360	2650	2940	0	0	0	20	20	20	130	120	120	10	10	10	24	48
6	11	2590	3020	3220	0	0	0	20	20	20	120	120	120	0	0	0	36	53
6	12	2820	3180	3650	0	0	0	20	20	20	130	120	130	0	0	0	30	69
6	13	2820	3300	3520	250	270	300	20	20	30	140	130	120	0	0	0	42	63
6	14	2820	3170	3520	370	400	450	30	30	30	190	190	190	0	0	0	32	65
7	5	1190	1320	1470	0	0	0	0	0	0	40	20	20	10	0	0	11	23
7	6	1480	1590	1770	0	0	0	0	0	0	20	20	20	20	0	0	9	24
7	7	1650	1930	2060	0	0	0	0	0	0	20	20	20	0	0	0	23	34
7	8	1890	2120	2350	0	0	0	10	10	10	100	100	100	30	30	30	19	38
7	9	2110	2380	2560	0	0	0	10	10	10	110	100	110	20	20	20	23	38
7	10	2260	2650	2940	0	0	0	10	10	20	110	110	100	20	20	20	33	57
7	11	2600	2910	3240	0	0	0	20	20	20	110	110	100	10	10	10	26	53

Table A5. *Cont.*

Wagons	Trucks	Terminal Transhipment Volume [1]			Required Terminal Stockyard [1]			Average Queuing Time [2]			Maximal Queuing Time [2]			Half Loaded Train Wagons [3]			Reduced Truck Trips [3]	
		T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T2	T3
7	12	2820	3170	3530	0	0	0	20	20	20	110	110	110	10	10	10	29	59
7	13	3060	3310	3830	0	0	0	20	20	20	120	110	110	0	0	0	21	64
7	14	3300	3840	4130	0	0	0	20	20	20	120	110	110	0	0	0	45	69
7	15	3430	3560	4110	130	140	150	30	30	30	190	190	190	0	0	0	12	58
7	16	3150	3700	4110	260	270	300	40	40	40	200	200	210	0	0	0	47	83

[1] Average per week in solid cubic meters (rounded to the nearest ten). [2] In minutes (rounded to the nearest ten). [3] Average quantity per week.

Table A6. Terminal transport template for two train pick-ups, long delivery time, and all tonnages (P2D3 T1/2/3).

Wagons	Trucks	Terminal Transhipment Volume [1]			Required Terminal Stockyard [1]			Average Queuing Time [2]			Maximal Queuing Time [2]			Half Loaded Train Wagons [3]			Reduced Truck Trips [3]	
		T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T2	T3
1	1	230	230	230	0	0	0	0	0	10	60	60	60	0	0	0	0	0
1	2	360	370	410	0	0	0	20	20	20	70	70	70	0	0	0	1	4
1	3	460	480	530	20	50	50	20	20	20	80	90	90	0	0	0	4	8
1	4	470	510	540	160	170	240	30	30	30	120	110	120	0	0	0	4	13
1	5	470	490	550	280	350	380	30	30	40	120	120	130	0	0	0	8	15
2	1	230	220	230	0	0	0	0	0	10	60	60	60	0	0	0	0	0
2	2	470	430	450	0	0	0	0	10	10	60	60	60	0	0	0	0	0
2	3	580	640	630	0	0	0	10	20	10	70	70	70	0	0	0	5	4
2	4	710	780	820	0	0	0	20	20	20	80	80	80	0	0	0	6	9
2	5	820	920	1000	0	0	0	20	20	30	80	80	90	0	0	0	8	15
2	6	940	1030	1160	10	30	20	30	30	30	80	80	90	0	0	0	9	19
2	7	930	990	1160	140	170	170	30	30	30	80	110	110	0	0	0	8	22
3	6	1010	1210	1210	0	0	0	20	20	20	80	80	110	10	10	10	17	17
3	7	1180	1350	1390	0	0	0	20	30	20	80	90	80	0	0	10	14	18
3	8	1300	1450	1590	0	0	0	30	30	30	90	120	110	0	0	0	13	24
3	9	1470	1580	1760	10	10	0	30	30	30	90	90	90	0	0	0	9	23
3	10	1410	1560	1760	130	170	150	30	30	30	110	120	120	0	0	0	16	31
4	9	1510	1620	1810	0	0	0	30	30	30	160	160	100	10	10	10	9	25
4	10	1650	1830	2000	0	0	0	30	30	30	160	160	110	0	10	10	15	29
4	11	1760	1980	2180	0	0	0	30	30	30	160	160	100	0	0	0	18	35
4	12	1880	2190	2430	0	0	0	30	30	30	160	160	160	0	0	0	26	46
4	13	1880	2040	2360	120	140	150	40	40	40	170	160	160	0	0	0	15	43
5	12	2000	2230	2390	0	0	0	30	30	30	180	170	120	10	10	10	19	33
5	13	2030	2370	2590	0	0	0	40	30	30	170	170	160	0	10	10	28	47
5	14	2240	2520	2690	0	0	0	40	30	30	170	160	170	0	0	0	23	38
5	15	2360	2650	2940	0	0	0	40	40	40	170	170	160	0	0	0	24	48
5	16	2360	2550	2930	120	140	150	50	40	40	180	180	170	0	0	0	18	50
6	15	2480	2760	2880	0	0	0	40	30	30	240	170	160	10	10	10	23	33
6	16	2590	2810	3270	0	0	0	40	30	30	180	180	180	0	10	10	18	57
6	17	2710	3050	3360	0	0	0	50	40	30	260	180	170	0	0	0	28	54
6	18	2820	3050	3510	0	0	0	50	40	40	180	180	180	0	0	0	19	58
6	19	2700	3290	3410	120	130	90	60	50	50	230	180	230	0	0	0	50	57
7	18	3060	3290	3570	0	0	0	50	40	40	190	190	180	10	10	10	19	43
7	19	3050	3420	3740	0	0	0	50	40	40	250	190	190	0	10	10	31	58
7	20	3170	3580	3930	0	0	0	50	40	40	190	190	190	0	0	0	34	63
7	21	3300	3830	4040	0	0	0	60	50	50	250	180	220	0	0	0	44	62
7	22	3290	3690	4050	120	100	0	60	60	60	270	250	220	0	0	0	32	53
7	23	3300	3690	4050	240	260	150	70	70	60	260	220	220	0	0	0	34	55
7	24	3290	3700	4080	360	410	370	70	70	70	250	260	240	0	0	0	38	67
7	25	3290	3690	4200	480	540	600	80	80	70	250	250	220	0	0	0	38	86

[1] Average per week in solid cubic meters (rounded to the nearest ten). [2] In minutes (rounded to the nearest ten). [3] Average quantity per week.

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