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Modelling Freight Allocation and Transportation Lead-Time

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Abstract: The authors have investigated sustainable environment delivery systems and identified transportation lead-time investigation cases. This research study aimed to increase freight delivery lead-time and minimize distance in transportation. To reach the goal, the paper's authors, after analysis of the hierarchy of quantitative methods and models, proposed the framework for modeling freight allocation and transportation lead-time and delivered a study that includes discrete event simulation. During the simulation, various scenarios have been revised. Following the simulation mentioned above analysis, around 3.8 % of distance could be saved during freight delivery if lead-time for transportation were revised by choosing five days criteria for modeling freight allocation. The savings depend on the number of received orders from different geographic locations.

Keywords: delivery system; discrete event simulation; environmental sustainability; freight transportation; lead-time

1 INTRODUCTION

Due to the effect on the environment, it is important to investigate the long lead-time for freight transportation compared to the short one. It began with the topic of environmental sustainability. In the longer period, more research was provided. It broadened our understanding of sustainability, much more than reducing carbon emissions in delivery logistics. In the pick of the topic's popularity, freight logistics was named green and/or gold, suggesting an improved reduction in CO_2 emissions and costs. The simulation of the freight logistics process allows us to see delivery system behavior, which gives higher efficiency.

The study's authors investigated delivery processes and identified wasteful critical ones. As a result, sustainable solutions for freight logistics were determined by applying the discrete event simulation, which was based on the analysis of scientific literature and the application of synthesis methods used in the article.

This study suggests a framework to determine the trade-offs between short and long freight delivery lead-times. The article's authors revise studies on sustainable environment delivery systems seeking to identify contemporary trends and provide investigations on the topic.

The research has a limitation in applying economy of scale when consolidating less than truckload cargo minimizes costs. However, short lead-time allows to gain higher customer satisfaction. Nevertheless, the results are valuable for experts looking for freight transportation distance savings and systematic efficiency improvement. The research's originality is using different lead-time criteria for distance waste elimination.

2 MODELLING FREIGHT ALLOCATION AND TRANSPORTATION LEAD-TIME

The concept of environmental sustainability got greater attention in 1980. The sustainability topic was initially promoted to society, primarily following concerns about environmental problems. To minimize these concerns, most authors investigate sustainability as a tool for reducing carbon emissions. Many authors investigate this type of sustainability and publish papers on it [1-3].

The development of co-modal, intermodal, and multimodal freight delivery systems has been identified as a means of reducing high costs and pollution in freight transportation. Efforts can yield partial solutions to undesirable consequences for the freight transport sector. But more this needs to be done, particularly by reducing pollution in the road haulage sector; this is a major concern for all governments worldwide.

2010-2019 CO_2 emissions from freight transport have risen in all regions except Europe, where they have fallen by 2%, thanks to smart fuel-saving regulations and smart, sustainable urban mobility initiatives. The fastest growth rates were in developing regions and Asia. Asia had the highest emissions in absolute terms by comparing 2019 with 2010: 41 percent in Asia, 27 percent in Africa, 13 percent in Oceania, and 6 percent in North America, etc. Energy demand and CO_2 emissions also continued to rise for all types of road transport means (lorries, mini-vans), particularly fast-growing in heavy goods road transport. Making the road transport sector sustainable also requires the involvement of the private sector and society.

For the modeling freight allocation and transportation lead-time, meta-heuristic methods could be implemented to optimize various processes. Among meta-heuristic methods, genetic algorithms are widely used. In addition to genetic algorithms, meta-heuristic methods include evolutionary algorithms, differential us evolutionary algorithms, and partial optimization. Genetic algorithms are used to plan vehicles. In the works of many scientists, problems with the optimization of transport routes are solved with the help of genetic algorithms.

Many algorithms are used to create transport routes, group them, and improve them. A gigantic and long route is split into shorter routes. However, meta-heuristic methods, including genetic, evolutionary, and differential evolutionary algorithms, are not widely used by scientists to search for the best transport route. In the first table, meta-heuristic methods are already used for which route planning cases are already used and for which cases are not.

Currently, classical algorithms are applied to route planning. With the help of these algorithms, various solutions are sought. One such solution is for the route planning of vehicles of defined and indeterminate capacity. One of the prerequisites for choosing a vehicle with a defined capacity in search of the best route is that the demand is known and fixed.

Meanwhile, a classic algorithm is used with separate delivery and pick-up routes for the delivery and collection of parcels. That is, in the beginning, delivery routes are planned, after which the pick-up (collection) routes are designed accordingly, such as an algorithm called VRPMDP. The transports tool, firstly, carries out routes during which the parcels are delivered to customers, then mixed routes, during which the parcels are delivered and collected from customers served at that time. Two vehicles can come to the customer at different time intervals.

Table 1 Application of meta-heuristic methods for modeling freight allocation and transportation lead-time

Methods	Modeling	Ongoing research includes/does not include
Genetic algorithms (GA)	[4-9]	**Includes:** identifying the time intervals allotted for loading and unloading when planning routes; fuzzy demand in case of route planning; route planning with multiple loading points; route planning for timely delivery JIT for cargo. **Does not** include: transport route planning with flexible delivery time intervals; route formation solutions covering several planning periods; cases of improvement of planned routes during transportation.
Evolutionary algorithms (EA)	[10-12]	**Includes:** historical demand route planning cases and route planning with named delivery time intervals. **Does not include:** cases of increasing the load on transport; the delivery and return of small consignments when planning routes; other cases.
Differential evolutionary algorithms (DE)		**Does not include:** loading and unloading flexible and fixed time windows for loading and unloading when planning routes; the use of vehicles of different capacities; route formation solutions covering different planning periods; other cases.
Partial optimisation (PSO)	[13, 14]	**Includes:** route planning of a vehicle of a defined capacity. **Does not include:** cases of planned route improvements; routing decisions involving the transport of different product groups.

There may also be adjustments during the execution of routes. If a new customer emerges from whom to pick up the cargo, the planned route must be improved to include a new case of picking up the cargo. In addition, there may be cases of cargo delivery and pick-up cancellations when the planned routes need to be adjusted accordingly.

In conclusion, it should be mentioned that heuristics can be used to form routes for the delivery and pick-up of goods. Using heuristics, which can effectively manage various restrictions, such as the number of freight receiving and delivering points, time windows, and the various uses of vehicles, can solve route optimization problems.

Therefore, optimization solutions for planning transport routes, when these involve the use of heuristical methods, contribute to the total number of kilometers planned, reducing pollution and protecting the environment.

3 COMPARISON OF LEAD-TIMES APPROACHES

Mainly in the literature, the authors focus on shorter delivery times and lead-times. The focus on demand and supply constraints in this area is also key, but different from delivery service management, waiting for freight here means the time the customer waits before receiving the required item. Delivery time has been researched in much of the supply chain management literature since the early 1990s.

Many studies have examined strategies for defining appropriate delivery lead-times to increase efficiency [15, 16] or the achievement of the target service levels [17]. Some comments were directed at shortening decisions to shorten delivery lead-times and reduce inconvenience, and theoretical models have explored the benefits of shortening delivery times. One such concept that supports shorter lead-times is JIT [18] (Tab. 2). Some authors have shown the benefits of shortened delivery lead-times, which are sales-driven and linked with demand aspects. Others specifically felt that the customer was sensitive to delivery lead-time.

Interim choices for consumers are decisions about estimating trade-offs between costs and benefits that may occur at different times. These choices are important in psychology, economics, business, and public policy. This flow of literature generally recognizes that consumers prefer shorter freight delivery delays as time for waiting could also mean costs. Thus, consumers accept delays only if a longer waiting time means higher future value. The first models of interim selection viewed that the value of time or its discount factor was fixed and had a positive impact. But contemporary research has shown that many anomalies can violate such principles. In particular, the time discount rate decreases with increasing waiting time. In addition, consumers are more sensitive to time to get lower-value results than higher-value results, which means that consumers are more sensitive to the timing of cheap products.

Delivery lead-time is the main factor for customers making purchase decisions, and the possibility of reducing it gives retailers the ability to improve their competitiveness. The online retail company competes hard by suggesting short lead-times for freight delivery services. Companies competed hard with traditional retailers in the first years of online retailing. However, online retailers have found prompt delivery an important factor in competition. This strategy was so successful that it drastically changed consumer expectations of acceptable delivery lead-time.

However, the concept of environmental sustainability was announced earliest among other sustainability directions, but for the reduction of CO_2 emissions, different solutions were researched. In 2017 [19] presented research focusing on the combination and the sourcing decisions examining the problem of sustainable economic order quantity (S-EOQ) with the stochastic delivery timing and multimodal transport option. With S-EOQ, sequential solutions focus on order points, which can be affected by various factors, including the price per product, inventory costs, variability of delivery time, and CO_2 emissions. The authors presented an equation for the adjacent S-EOQ problem to have a wider understanding. They investigated the problem by using experiments and different scenarios to identify the inclusion of sustainability aspects in traditional models related to operations-oriented solutions, covering transport mode selection, their combinations, and supply solutions.

Table 2 Literature overview on lead-time concepts

Concepts	1950	1970	1990	2000	2010
JIT production & Quick response manufacturing (QRM) with short lead-time	[20]			[21]	[22]
Effect of lead-time on inventory		[23]	[24]		[25]
Lead-time sensitive demand				[26]	[27]
Sustainable EOQ (S-EOQ) with lead-time variability					[19]

In delivery logistics, conceptual frameworks toward sustainability are still important, and practical named problems are evident today. Both could give a better understanding of sustainability, including various delivery types but focusing on freight delivery by road. In the next section, the authors examine freight delivery lead-time aiming to produce more sustainable practices. The simulation will examine the practices and give guidelines on making freight delivery practices more sustainable.

4 THE STUDIES ON FREIGHT DELIVERY SYSTEM

Delivery is a physical process for freight transportation from a source to a destination. However, this activity does not include the modeling of freight allocation – it is the area where CO_2 emissions are generated, even if the client covers the delivery costs. The authors expand the concept of delivery by including therein decision-making approach. In case of CO_2 emissions reduction, clients shall be informed that a longer lead-time could be assigned to their orders.

In this research, the authors analyzed freight delivery services in different aspects: shorter and longer lead-time investigations before deciding on freight allocation for delivery.

Over time, researchers have been concerned about analyzing delivery systems. The approach to such systems has developed fundamentally new concepts and methods, mainly in mathematics and science. In operations research, applying such methods is premature but has great potential to analyze the freight transportation aspects. In principle, the authors investigate the system, whether resources are allocated efficiently, and whether there are appropriate conditions for optimal resource allocation to maximize output. For researching such problems, various methods were applied and defined in Tab. 3.

Table 3 The hierarchy of quantitative methods and models for investigating freight delivery lead-time

Types	Modeling technique	Solution methods	Authors investigating the topic
Mathematical programming methods	Single-objective	Bi-level linear programming (LP)	[28]
	Multi-objective	Multi-objective mixed integer linear programming (MILP)	[29]
		Fuzzy-goal programming	[30]
		Polynomial dynamic programming	[31]
		Queuing model	[32]
		Non-linear programming	[29]
Simulation methods	System dynamic (SD)		[33]
	Discrete event (DES)		[34]
Heuristic methods	Simple heuristic	Simulated annealing heuristics (SAH)	[35]
	Artificial intelligence (Al) techniques	Markov chains	[36]
		Object-oriented Petri nets	[37]
		Bayesian network modeling	[38]
		Fuzzy logic	[38]
		Artificial Neural network	[39]
		Grey system and rough sets	[40]
	Meta-heuristic	Genetic Algorithm (GA)	[41]
		Evolutionary Algorithm (EA)	[42]
		Differential evolution algorithm (DEA)	[43]
		Particle swarm optimization (PSO)	[44]
		Ant Colony Optimization	[45]
		Greedy Randomised Adaptive search procedure	[46]
Hybrid model	Hybrid simulation	SD-DES	[47]
Analytical model	Multi criteria decision making (MCDM)	Analytical hierarchy process (AHP)	[48]

To revise methods useful for problem-solving, a hierarchical view can be applied to identify the type and technique of the model and specific methods in a category. Five main categories are used, starting from the mathematical programming category, moving to model methods, revising heuristic and hybrid models, and finalizing with analytical models. Modeling methods are different in nature and relate to one or several purposes.

Many studies focus on the application of optimizing approaches. In addition, different methods have been used in the delivery system, such as multi-objective mixed integer linear programming, system dynamics, discrete events, inequality of variation, fuzzy logic, Markov chains, etc. However, also we could identify methods that are not yet explored and applied in studies.

For freight application, several route methods are used, such as first transport planner plans route and then cluster clients ("route first-cluster second"), or does this in the opposite way – first cluster clients and after plans route ("cluster first-route second"). Several researchers delivered simulation papers focusing on the topic. For decision-making aiming to reduce CO_2 emissions, it is necessary to include the aspect of lead-time as one day, it could be just one client per geographic area, and the planner could not cluster together. Further on, the authors developed a framework that could help allocate freight with lead-time modification.

5 FRAMEWORK FOR MODELLING FREIGHT ALLOCATION AND TRANSPORTATION LEAD-TIME

During the day, many orders (freights) are placed and delivered to customers as a single one into a geographic territory. In this case, the company asks customers to specify the urgency of their order delivery, which is not optimal. If possible, enterprise delivers freights with as possible lower lead-time duration.

The delivery plan of freights is the schedule where each customer announces the delivery timing information. According to the schedule, 10 minutes per order and 3 minutes per pallet are usually selected. The authors have chosen the shortest path approach to develop a delivery schedule following the optimization results. The model covers only freight movements between the customers following the vector basis.

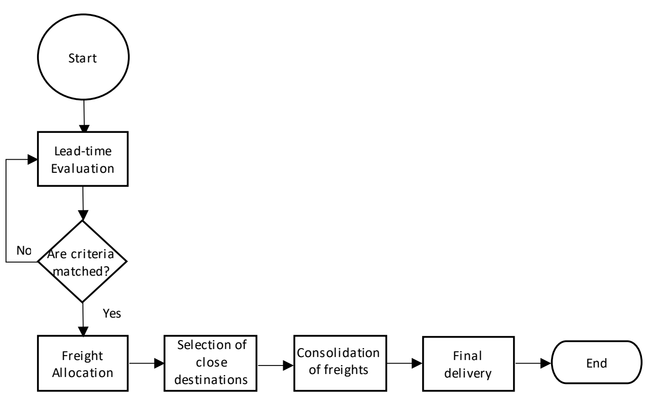

Figure 1 Adaptation of algorithm steps for freight transportation

In Fig. 1, the authors present algorithm steps. The first possibility shows the situation of lead-time evaluation. If there are orders from customers that match the same destination, their freights are allocated to the same group. But this doesn't represent the shortest distance choice. Under the next step, we must select freight that fits the closest destination criteria.

Let's assume that the customer usually places an order (n) which has its weekly volume (the number of transport units).

A freight's delivery routes are constructed each day for the next day's deliveries, but lead-time could be increased to reduce CO_2 emission for non-lead-time sensitive freights. The author suggests including steps helping to identify when freight has to be allocated to the route. The current freight allocation algorithm was modified to reach the goals.

The new framework includes several components (Fig. 1):

1) The lead-time evaluation;
2) Freight allocation with lead-time modification;
3) Selection and consolidation of freights.

The constructed strategic freights' delivery schedule is later adjusted daily (Fig. 2). According to the schema presented in Fig. 2, freight allocation is modified to reach the optimization. Each customer's delivery frequency and volume are provided and not investigated herein. In operational conflict cases, the priority status is allocated to the freights with critical needs.

Further on, the share among all freights delivered under the same truck is calculated as follows (1):

$$x_{mn} = \frac{q_{mn}}{\sum_{m=1}^{w} q_{mn}} \tag{1}$$

herein m – customer, w – all customers, q – volume in handled units, x – share of freight of m in the truck n (in percentage). The counter is the volume of a specific customer, and the denominator is the max number of pallets under the order or loading bill if it is received upfront the actual delivery. If the freight has no volume within the truck frame, its share will equal zero.

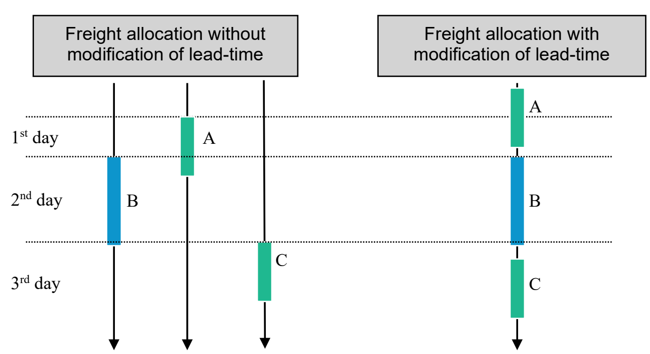

Figure 2 Schema of consolidation possibilities (A, B, C – different orders)

If all freights allocated to the truck, match its maximum capacity when all freight of the customers could be consolidated. The schema for consolidation is presented in Fig. 2.

In Fig. 2, there is the presentation of both frameworks:

1) Freight allocation without modification of lead-time (current freight allocation algorithm) (on the left);

2) Freight allocation with lead-time modification (the suggested framework) (on the right).

Let's assume that the customer places the order and which delivery time is one day. We have to add a waiting time of between 1 and 4 days to prolong lead-time. Such could be formulated by using Eq. (3).

The authors suggest a matrix for the distance parameter. Herein, the distance represents point-to-point (P2P) distances, which are vector or Euclidean based on a Steiner – Weber model.

The next step is to optimize delivery, which depends on freight (i.e., order) volume with limited unloading time.

The total freight distance S_i^n is calculated by the Eq. (2):

$$S_i^n = \sum_{j=1}^{y} d_{ij} \tag{2}$$

Herein d – the shortest distance, i – route, j – order, y – all orders in the route.

The total delivery lead-time T_t consists of 2 parts: T_o – physical delivery lead-time and T_g – waiting time (as specified in Eq. (3):

$$T_{tj} = T_{oj} + T_{gj};\ g = [1, v] \tag{3}$$

Herein T_t – total delivery lead-time, o – physical delivery lead-time in days, j – order, g – number of waiting days, v – maximum waiting limit in days.

The framework allows waiting time to be defined on an order level.

For simulation, various lead-time scenarios will be used to revise the results and benchmark them with scenarios where the waiting time equals zero.

For the case study, the three months of data are used from a 3PL company operating in the USA, which had 11 440 orders. The data source attributes are loading location, delivery location, order date, and quantity. The main relationship measured during the calculations is expressed as the duration of lead-time and the distance (Fig. 3).

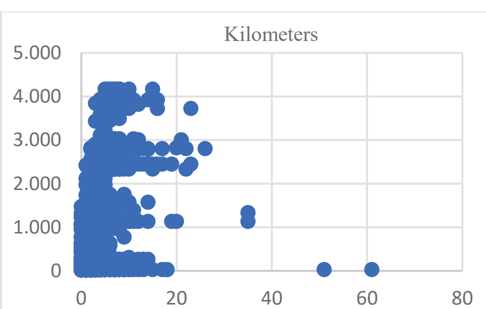

Figure 3 The simulation results: distance of truck in kilometers

As side indicators, the utilization level of trucks and warehouses and the CO_2 emission level will be determined. The scenarios of analysis will consider cargo consolidation between different periods, such as one day, two days, three days, four days, and five days. The authors estimated that 25 percent of freights are delivered as single ones.

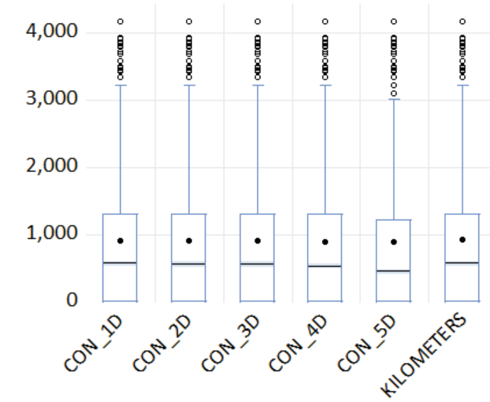

Figure 4 The simulation results: distance according to the lead-time scenarios

The authors formed a simulation model with Wolfram Matematica software, while results were processed with EViewer statistical software. Using a simulation package, various scenarios were compared to lead-time duration lasting from 1 to 5 days. In Fig. 4, the authors presented simulation results (see Fig. 4).

The benchmarking of simulation results for five days and the current scenario shows possible distance improvement. The authors figured out that the longest lead-time duration (i.e., five days) helps to save up to 3.8 % kilometers. Further, the authors suggest working out the freight delivery plan following geographical territory.

6 CONCLUSION

The theme of sustainability got special attention after 1980, focusing on environmental sustainability. However, the results of CO_2 emissions are still not as good in the road transport sector. Later, papers focusing on different lead-time approaches were investigated from 1950, when the short lead-time concept was implemented with JIT production implementation. The aspect of sustainability was not integrated into delivery studies, except in one study, which highlighted different transport modes and more sustainable ones but with longer lead-time duration.

The authors apply many qualitative methods and models for investigating delivery lead-time seeking to build a sustainable environment delivery system. However, using these methods results in resource efficiency and the implementation of freight transportation processes supporting higher efficiency.

The authors presented a case study where distance waste was eliminated and identified freight delivery possibilities during discrete event simulation. The results allow us to avoid waste and get a reduction in distance. This shows possibilities for organizing a delivery plan to have a more sustainable freight delivery system. The research results showed that to reduce distance activity, the company has to re-design the freight allocation process by adding waiting time into freight delivery. Following the scenarios-based simulation study, around 4% of the distance could be minimized by modifying lead-time to five days. These improvements could be reached if the suggested framework is applied to the delivery management system. Most actions as the revision of customers' delivery plans and their implementation, are important to reach the expected results. A deeper understanding of the features of freight delivery is important to form and apply solutions to increase efficiency in freight transportation. Such an approach focuses on distance waste elimination in the area and allows it to reach benefits through the implementation of efficient resource usage.

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