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SRM and Performance Evaluation Models for Logistics Optimization in Consumer Supply Chain

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Abstract

This paper focuses on the evaluation of transport optimization techniques in a consumer-packaged goods supply chain. In particular, it evaluates how the parameters of the optimization, such as the inbound and outbound capacity of nodes, affect the effectiveness of the distribution of goods, measured in terms both of the ability to fulfill the demand in time and of reducing the cost (and environmental impact) of logistics operations. Synthetic data regarding a realistic supply chain network have been generated and the Rulex Platform's Transport Optimizer has been applied to different scenarios where some parameters of the network have been changed. This allows supply chain experts to create a what-if analysis about how the supply chain would react if something changed in the network. Moreover, from a strategic perspective, the analysis of the behavior of the network in different situations could lead to redesigning the whole supply chain to reduce its impact while keeping the quality of service. An in-depth analysis is performed in this paper on the synthetic data and on a selected set of parameters of the network.

Keywords: Logistics Optimization, Resilient Supply Chain, Supply Chain Evaluation

1. Introduction

The Consumer-Packaged Goods (CPG) industry operates within a web of intricate logistics and supply chain challenges that demand strategic solutions. Navigating the movement of goods from production facilities to distribution centers, warehouses, and ultimately to consumers or retail outlets is a multifaceted endeavor that necessitates meticulous planning and execution. Central among these challenges is the intricate art of managing inventory levels. Given the limited shelf life of CPG products, manufacturers must orchestrate swift production and transportation processes to avert spoilage and waste. Simultaneously, striking the right balance between maintaining sufficient inventory levels and accommodating variable demand, influenced by multifarious factors, presents an ongoing challenge.

The financial dynamics of logistics and the supply chain also loom large in the CPG realm. Transporting goods across extensive distances, particularly in the context of cross-border trade involving customs and tariffs, can escalate costs substantially. For CPG companies, pricing structures and profit margins are intrinsically linked to these operational expenses. Yet, cost management doesn't stop there. Adhering to a labyrinth of regulations pertaining to transportation, packaging, and labeling adds an additional layer of intricacy to supply chain management, which can fluctuate significantly across countries and regions.

In this era of technological advancement, innovation is assuming a pivotal role in addressing the complexities that plague logistics and supply chains in the CPG sector (Bruzzone et al., 2003). Supply chain management systems offer companies an avenue to fine-tune inventory levels, reduce costs, and enhance order accuracy. Meanwhile, transportation management systems streamline cross-border goods movement and offer real-time visibility into shipment status and delivery schedules.

Beyond software integration, the industry is exploring novel transportation modalities, including air cargo and ocean freight, to expedite transit times and elevate overall efficiency. Within this realm, the concept of synchro modality emerges as a game-changer. Synchro modality entails optimizing the use of diverse transportation modes in a synchronized and efficient manner. By seamlessly transitioning between modes like road, rail, waterways, and air based on their suitability for different legs of a shipment's journey, synchro modality enhances sustainability, flexibility, and reliability in transportation systems. This optimization not only curtails transportation expenses and carbon footprints but also heightens visibility and control over the transportation process, thereby improving supply chain efficacy and customer satisfaction.

Key to this evolution is the availability and integrity of high-quality data. Synchromodal logistics hinges on seamless information sharing across organizations within the logistics sector while ensuring data consistency throughout the value chain. The data journey encompasses multiple stages, from demand forecasting and inventory allocation to managing unforeseen disruptions and optimizing transportation routes. In essence, these steps ensure efficient goods distribution to their ultimate destinations.

In summation, the complex landscape of logistics and supply chain management within the Consumer-Packaged Goods (CPG) industry offers a rich environment for technological advancements. By harnessing advanced analytics, innovative supply chain systems, and emerging technologies, businesses can finely tune their operations and expand their global footprint. This report focuses on addressing capacity constraints within shipments and carrier allocation. It delves into the intricacies of transport optimization, aiming to demystify its intricate processes and investigate its potential to reshape the logistics dynamics of the CPG sector.

2. State of the art

The history of transportation and logistics has deep historical roots, and recent times have witnessed the influence of Operations Research (OR) and computerized systems in addressing these challenges. The evolution of transportation dates to discoveries like the railroad and airplanes, while logistics, encompassing supply chain management, has aimed to efficiently provide goods where and when needed. The challenges involve managing inventory, costs, regulations, and the coordination of various transportation modes. OR's role emerged in the mid-20th century, optimizing routes, schedules, and crew coordination for transportation systems. Notably, the synchro modality, seamlessly transitioning between transportation modes, has significantly improved efficiency. The trajectory of transportation and logistics evolution can be summarized in distinct phases, including the emergence of transportation science, integration of logistics with supply chain management, and the current era marked by growing applications, data explosion, and the Internet of Things (IoT). The surge in big data and the IoT has reshaped the field, offering vast opportunities for operational researchers to harness data-driven decisions and advancements in transportation and logistics. (M. Grazia Speranza (2018), Trends in transportation and logistics)

The competitive environment encompasses the demands made by the market, including the price, characteristics, and features of the product; the location of customers; the time requirements of customers; and the variability in demand. It also refers to the relative importance of each of these attributes and the extent to which these attributes are changing or stable over time. The competitive environment might also include those economic and technological trends that shape the global marketplace and the capabilities of managers (Gregory Neal Stock, Noel Greis, John D. Kasarda, (January 1999), Logistics, Strategy, and Structure: A Conceptual Framework).

The logistics costs are included in different outlines, and the division of structural costs has different aims, both cognitive and practical. The cognitive aims should allow the determination of the following:

- The relation of the costs to the basic types of logistics processes: physical and information flows, inventory maintenance, transport, exploitation, etc.
- The structure of kinds of expenditure.
- Costs in relation to the supply and materials flow.
- Use of expenditure in specific decision-making situations.

origin of the costs and the use of this information in Activity Based Costing (Andrzej Szymonik (2016), Logistics, and Supply Chain Management)

According to Jonsson (P. Jonsson, 2008), there are two kinds of logistic costs: direct and indirect costs. Direct costs include physical handling, transportation, and storage of goods in the flow of materials together with the administration costs, whereas capacity and shortage costs are indirect costs. Jonsson also claims that direct logistics costs roughly vary between 10% and 30% of the turnover depending on the type of industry. In such a situation, it can be said that implementing optimization techniques to the transportation of goods in order to schedule when and how much to send from each origin to its respective destination over a certain time period is a possible way to make improvements over the total cost of logistics (Muztoba Ahmad Khan, 2014), Transportation Cost Optimization Using Linear Programming). In optimizing these aspects Modeling & Simulation is one of the most promising tool to innovate the SCM sector (Bruzzone et al., 2011, 2014)

3. Materials and Methods

This section provides an overview of the key factors, parameters, and decision variables, and methods in the transportation optimization problem.

3.1. Transport Optimization: Key Factors and Constraints

Transport optimization can be seen as a cost-minimization problem with linear objective functions and constraints.

The cost function accounts for shipping and transportation costs as well as other time-related values like delay, number of trucks, and external costs. Cost factors include direct transportation costs, in-transit inventory costs, and external costs.

In the proposed model, *m* items have to be sent and there are different options for each item to be delivered; each option corresponds (potentially) to a different shipping cost, a different pick-up date, a different delivery date etc… The goal of the optimization is selecting for each shipping the optimal option that allows the supply chain network to fulfill all the constraints. Let *S* be the collection of all possible choices for all the goods to be sent and *s* one element in *S* for all the shipping.

For example, consider the case of two items A and B from location X to location Y. There are two options s_{A1} and s_{A2} to send A, having different pick-up dates, costs etc… Similarly, there are three options s_{B1}, s_{B2} and s_{B3} to send B. So, in this simple case *S* includes 6 elements.

$S = \{(s_{A1}, s_{B1}), (s_{A1}, s_{B2}), (s_{A1}, s_{B3}), (s_{A2}, s_{B1}), (s_{A2}, s_{B2}), (s_{A2}, s_{B3})\}$

For example, the first element of *S* means that *A* is sent with option s_{A1} while *B* is sent with s_{B1}. A solution can be seen as a list of solutions for each shipping or, alternatively, as a list of binary vectors x_i (one for each shipping *i*) where each element is 1 if the solution is selected or 0 otherwise. This vector of 0/1 is the set of decision variables. For example, the element (s_{A1}, s_{B3}) corresponds to the binary strings $x_A = 10$ and $x_B = 001$. It is easy to demonstrate that each solution *s* can be uniquely identified by a collection $x = \{x_1,…,x_m\}$. The goal of the optimization consists then in finding the $\hat{s}$ *in S* (or, alternatively the vector $\hat{x}$) that minimizes the costs associated with fulfilling all the deliveries.

In particular, distribution centers have a limited capacity of handling inbound and outbound deliveries. Nonetheless, in some circumstances, capacity can be overcome, by paying some extra cost. We refer to this loose capacity as *soft capacity*. There is also a *hard capacity,* that represents the inbound/outbound capacity, that cannot be exceeded in any case. Let $C_{nd}^{(h,i)}$ (resp. $C_{nd}^{(h,o)}$) be the inbound (resp. outbound) hard capacity associated with node *n* on day *d* and similarly $C_{nd}^{(s,i)}$ *and* $C_{nd}^{(s,o)}$ the soft capacities.

Given a solution *x* let's denote with $I_{nd}^{(x)}$ and $O_{nd}^{(x)}$ the inbound (outbound) received (sent) items in node *n* on day *d*. It is easy to see that they are linear combinations of the decision variables.

Another constraint that logistics planners need to consider involves the quotas that should be assigned to each carrier. Usually, each carrier should take care of a percentage of the shipments. If these percentages are not respected, also considering a tolerance value, a penalty must be paid. Of course, the larger the tolerance, the higher the number of degrees of freedom for properly setting the transport problem. Moreover, each carrier has a daily capacity of shipments that can be handled every day. Let K_{cd} the capacity for carrier *c* on day *d* and $H_{cd}^{(x)}$ the actual number of shipments handled by carrier *c* on day *d*, which is a linear combination of *x*.

Moreover let ϕ_x be the cost associated with solution *x.* It is composed of different factors:

ϕ_x *= shipping cost + penalty for delay + penalty for exceeding soft capacity + penalty for violating carrier quotas*

Even if these addends have different origin, they can be seen as an overall cost related to the option *s*.

Finding the best solution corresponds then to solving this linear programming problem:

$$\min_x \phi_x$$

subject to

$$I_{nd}^{(x)} \leq C_{nd}^{(h.i)}$$

$$O_{nd}^{(x)} \leq C_{nd}^{(h.o)}$$

$$H_{cd}^{(x)} \leq K_{cd}$$

$$\sum_{k=1}^{n_i} = 1$$

$$x_{ik} \in \{0,1\}$$

The five constraints account for:

- the inbound flow in each location and on each day must not exceed the hard capacity;

- the outbound flow in each location and on each day must not exceed the hard capacity;

- the capacity for each carrier on each day must not exceed its daily capacity;

- each shipping must be performed only once (in each x_i only one element must be 1);

- the values of *x* can be only 0 or 1.

3.2. Transportation Costs Using Linear Programming: Rulex Platform's Transport Optimizer

In this paper, we want to understand how different parameters of the linear programming defined in 3.1 influence the performance of transport optimization. To this aim, the Rulex platform (www.rulex.ai), and, namely, the Transport Optimization task, has been used.

The Transport Optimization (TO) task in Rulex is a powerful tool that allows to set up the transport optimization problem by means of a graphical interface that allows the user to define the parameters related to shipments, nodes, and carriers. Each of these entities plays a crucial role in efficiently planning transportation operations and reducing logistics costs.

Parameters about shipments contain fundamental information that serves as the foundation for all transportation plans. They include details about the source and destination attributes, the number of units to be shipped, priority values, loading and unloading dates, and total shipment costs. This data is essential for answering crucial questions about what needs to be transported, where it should go, and when it should arrive.

Nodes, also known as distribution centers (DCs), are origin and destination points for shipments. The features and constraints of the nodes are very relevant to defining proper transport policies. In particular, hard capacity, soft capacity, and the cost associated with violating soft capacity must be specified.

Transportation planners organize means of transport by carrier. Each carrier has a unique ID, specific capacity, and cost for different routes and transit times, based on the number of trucks used. Additional parameters such as daily capacity, transport cost, allocation percentage, tolerance, penalty, and units sent provide valuable insights for making informed carrier decisions.

The output provided by the Transport Optimizer task is basically the vector *x* (i.e., the solution *s*) that minimizes the cost function, i.e. that reduces the costs while fulfilling all the constraints associated with nodes, shipments, and carriers. Moreover, it provides statistics about shipped, loaded, unloaded and unsent shipments.

The decision-makers combine the suggested solutions with their intuition, business sense, and experience to make final decisions. The transport optimizer then identifies the optimal transportation solution, minimizing costs while adhering to constraints and generating a long-term optimum transportation schedule.

In this paper we used the TO task to perform different experiments using the same set of data and changing the values of inbound, outbound and service capacity, to see how the output provided by TO changes.

4. Results and Discussion

In this analysis, we experimented with various decision variables to optimize transportation. We focused on manipulating the Hard Capacity, Soft Capacity for Inbound and Outbound, Tolerance in carrier quotas, and Service Daily Capacity (ranging from +25% to -25% with a 5% increment). Additionally, we considered Loading and Unloading delays to gauge the impact of transport optimization decisions on our data.

The goal of our transport optimization is to improve efficiency, reduce logistics costs, and meet customer expectations. By analyzing the number of trucks, loading, and unloading delays based on the Requested Delivery Date (RDD) as shown in Figure 1, we gained valuable insights into the effectiveness of our optimization strategies.

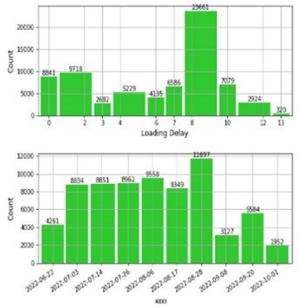

Figure 1. Bar chart of loading delay, unloading delay, and RDD with the base configuration.

4.1. Exploring Hard and Soft Capacities for Inbound and Outbound Operations

The impact of the Hard Capacity and the Soft Capacity for Inbound can vary with additional costs. Although, it should be considered that hard capacity remains fixed and cannot be easily physically exceeded (Daskin, 2019).

In this analysis, we explore the correlation between the number of trucks and average loading and unloading delays (Figure 4 and Figure 5), specifically focusing on the impact of increasing soft capacities as shown in Figure 2, or decreasing soft capacities as shown in Figure 3.

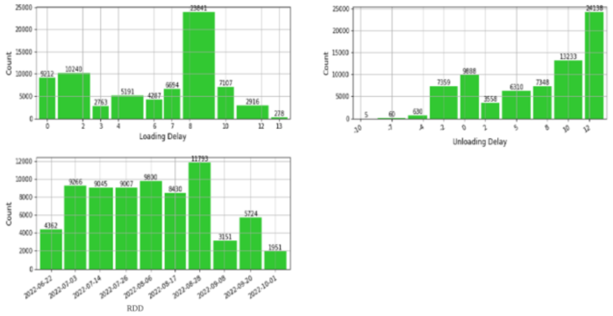

Figure 2. Bar chart of Loading delay, Unloading delay, and RDD in case of a 25% increase in its soft capacity

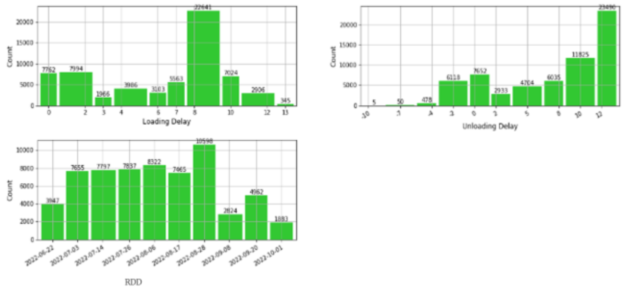

Figure 3. Bar chart of loading delay, unloading delay, and RDD in case of a 25% decrease in its soft capacity.

We examine the effects of varying the Soft Capacity (ranging from +25% to -25% with a 5% increment) on the number of trucks as shown in Figure 4, based on that average loading delay and the number of trucks as shown in Figure 5, and average unloading delay unloading as shown in Figure 6. The results demonstrate the changes in these parameters based on manipulated capacities of inbound and outbound logistics.

Increasing the number of trucks by adding to the soft capacity results in decreased delays. The relationship between the soft capacity percentage and average loading and unloading delays highlights the importance of effectively managing this parameter to optimize operations and promote sustainability.

However, when analyzing the impact of the soft capacity for outbound transportation, we find that changes in this parameter may not significantly affect the number of trucks and delays. Delays in loading and unloading operations can be influenced by various factors beyond soft capacity adjustments, necessitating a more comprehensive approach to address bottlenecks and inefficiencies.

Overall, there is a relation between average loading and unloading delays, soft capacity, and the number of trucks that play a vital role in transportation logistics. Properly managing these factors can lead to cost savings, improved efficiency, and reduced CO2 emissions, ultimately enhancing sustainability in transportation operations.

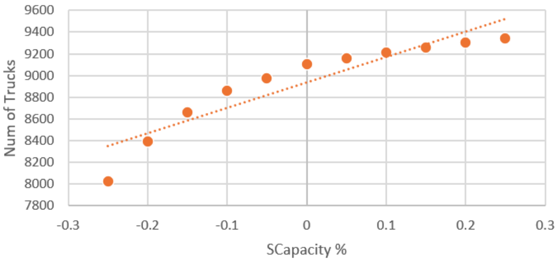

Figure 4. The relation between the number of trucks and the soft capacity

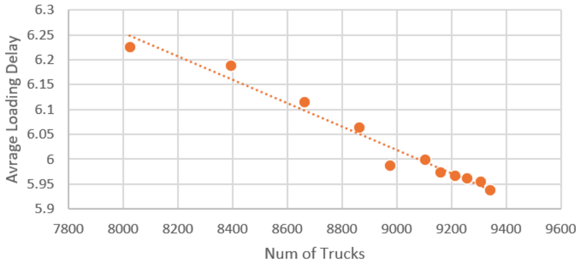

Figure 5. The relation between the average loading delay and the number of trucks

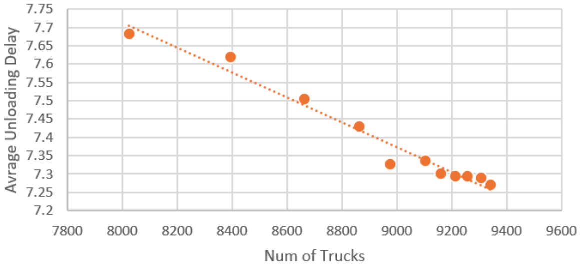

Figure 6. The relation between the average unloading delay and the number of trucks

4.2. Exploring Daily Capacity Dynamics and its Impacts in Transportation Operations

To gain a deeper understanding of transportation behavior, we manipulated the service daily capacity of carriers by both increasing as shown in Figure 7, and decreasing it as shown in Figure 8. This manipulation revealed how daily capacity impacts loading and unloading delays in transportation operations.

Generally, increasing the daily capacity means more trucks are available for transportation, leading to reduced delays. With increased resources, shipments can be handled more efficiently, resulting in quicker loading and unloading processes. Conversely, decreasing daily capacity leads to longer delays due to limited resources to handle the volume of goods.

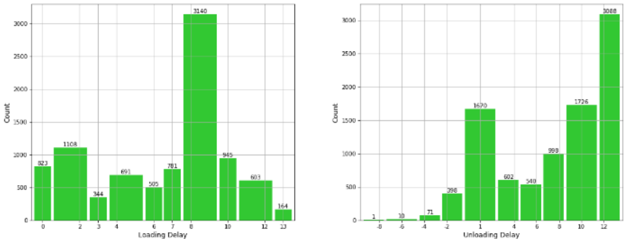

Figure 7. Bar chart of Loading and Unloading delay in case of a 25% increase in its Service's Daily Capacity.

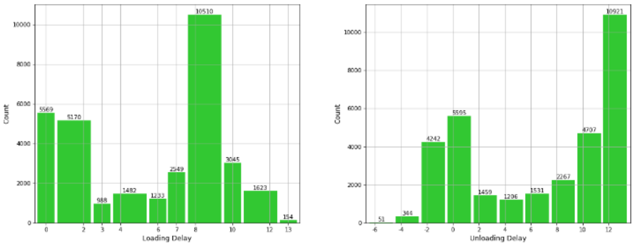

Figure 8. Bar chart of Loading and Unloading delay in case of a 25% decrease in its Service's Daily Capacity.

Finding the optimal daily capacity balance is essential to minimize delays. Factors such as demand, resource allocation, and operational efficiency play crucial roles in achieving smooth transportation operations. Additionally, the correlation between manipulation capacity percentage and the number of trucks is shown in Figure 9, and regarding that, the number of unsent goods is shown in Figure 10, and the strong correlation between the number of trucks and average loading and unloading delays, as shown in Figure 11, indicates the need for effective resource management.

However, increasing daily capacity may not always lead to reduced delays as shown in Figure 11. It can result in higher loading and unloading delays if not accompanied by proper resource adjustments and scheduling. Managing resource allocation and operational processes although by looking at Figure 11 we can see that it improves performance and reduces unsent goods.

Overall, carefully assessing the impact of daily capacity changes and optimizing resource allocation and operational processes are key to minimizing loading and unloading delays in transportation operations. Continuous monitoring and evaluation help identify areas for improvement and enhance overall efficiency.

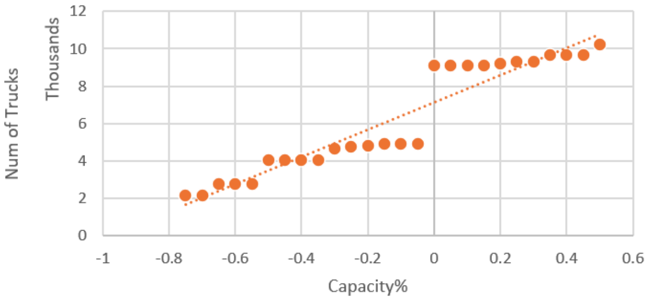

Figure 9. The relation between increasing Carrier Capacity and Number of Trucks

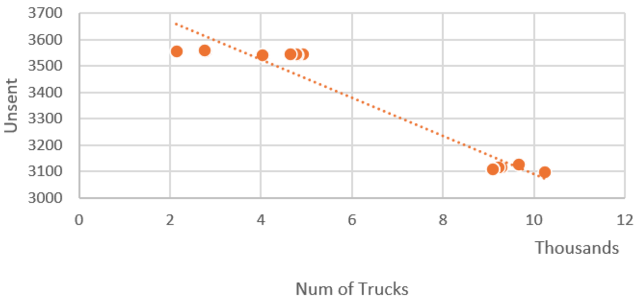

Figure 10.The relation between the number of goods which are not sent (Unsent) and the number of trucks.

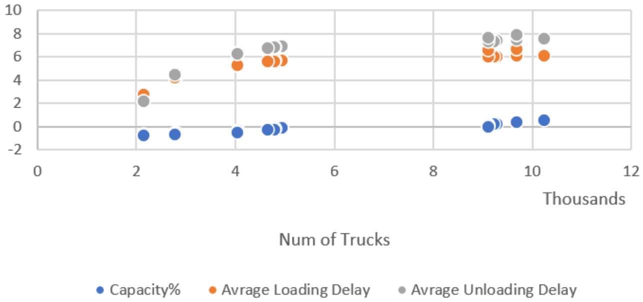

Figure 11. The relation between average Loading and Unloading Delay with the Number of Trucks and carrier capacity.

4.3. Exploring Flexibility of Carrier Tolerance in Transportation Planning

The tolerance of carriers plays a critical role in transportation planning, providing flexibility within capacity limits to handle unexpected changes without disrupting operations.

Increasing the tolerance of trucks as shown in Figure 12 reduces delays by enabling more flexible carrier allocation. Conversely, decreasing the tolerance of trucks as shown in Figure 13 may balance shipments but cause delays. The number of trucks affects resource availability, and optimizing loading and unloading processes minimizes delays, leading to cost savings and lower emissions.

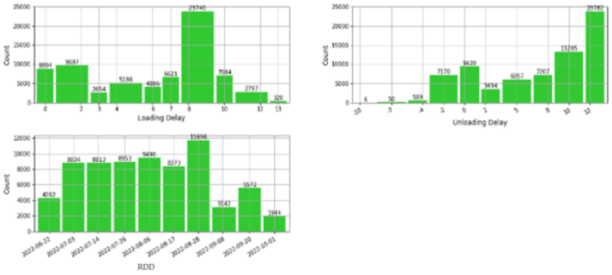

Figure 12. Bar chart of loading delay, unloading delay, and RDD in case of a 25% increase in the tolerance of trucks.

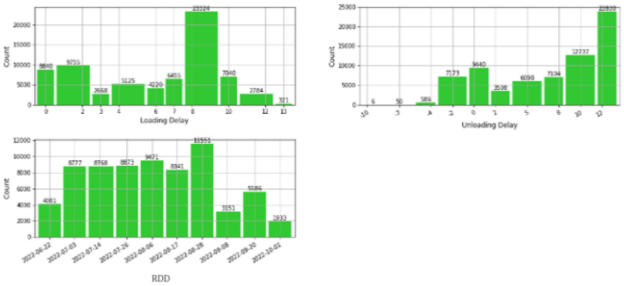

Figure 13. Bar chart of loading delay, unloading delay, and RDD in case of a 25% increase in the tolerance of trucks.

The relationship between manipulating the tolerance of trucks percentage and average Loading delay as shown in Figure 14 and unloading delay as shown in Figure 15, the tolerance of trucks, and the number of trucks as shown in Figure 16 significantly impacts costs and CO2 emissions. Efficient resource allocation and timely shipments are vital for reducing costs and environmental impact. Reduction of unsent within raising the tolerance of trucks as shown in Figure 17 is closely linked to average loading delay, further emphasizing the importance of optimizing transportation operations.

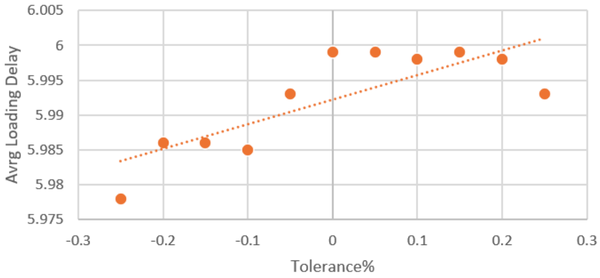

Figure 14.The relation between Average Loading delay and the manipulated percentage of the Tolerance of Trucks

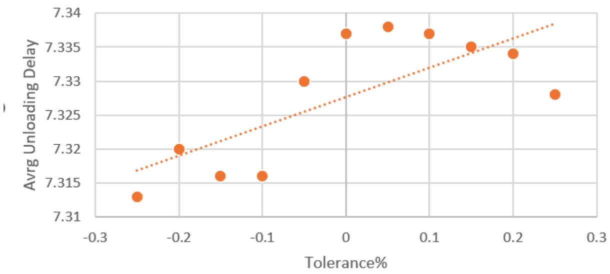

Figure 15. The relation between average unloading delay and the manipulated percentage of the tolerance of trucks**.**

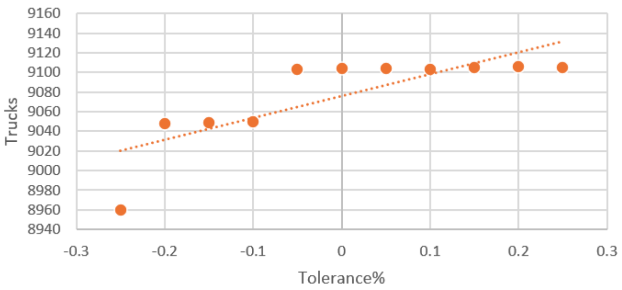

Figure 16. The relation between the number of trucks and the increase in the tolerance in carrier quotas.

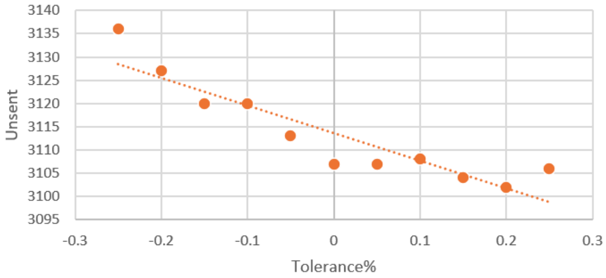

Figure 17. The relation between the number of goods that are not sent (unsent) and the manipulated percentage of the tolerance of trucks.

5. Conclusions

This analysis sheds light on the key factors that impact transportation optimization and efficiency. By experimenting with various decision variables, we have gained valuable insights into the effects of capacity adjustments on the number of trucks and loading and unloading delays. Effective management of the soft capacity and daily capacity is crucial for reducing costs, improving efficiency, and promoting sustainability in transportation operations. Additionally, optimizing resource allocation and operational processes is essential for minimizing delays and achieving smooth transportation. Tolerance also plays a significant role in providing flexibility and adaptability in handling unexpected changes. Overall, this research emphasizes the importance of data-driven decision-making and ongoing monitoring to drive improvements in transportation logistics and ensure a more sustainable and cost-effective supply chain.

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