# Minimizing Cross-docking in the Supply Chain for Perishable Products

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## ABSTRACT

The sustainability of the supply chain and crossdocking represent a strategic convergence where operational efficiency meets environmental and social imperatives. Crossdocking, by reducing the storage time of perishable products, provides opportunities to enhance sustainability by decreasing the environmental footprint associated with inventory management. Reduced storage can lead to a more efficient use of energy and resources, and optimizing the movement of goods can minimize transportation emissions.In this study, a linear programming model centered around door-to-storage assignment is proposed. The primary aim of this model is to optimize the cost associated with the movement of perishable products within a cross-docking facility, particularly during the unloading and transfer of perishable products from the dock area to the storage area. The approach involves allocating on of the perishable products unloaded at the entry gates to various storage zones based on factors such as their demand frequency and loading sequence. The analysis includes a numerical example that considers varying quantities of inbound vehicles, doors, perishables products, and storage zones. The findings monstrate that the overall cost can be minimized, or savings can be increased, depending on the feasibility of the research problem. Furthermore, the study confirms that adopting a direct transfer of products through crossdocking proves to be cost-effective. This is because having fewer perishable products in storage leads to a reduction in handling costs.

**Keywords:** cross-docking, supply chain, perishable products, sustainable supply chain.

## الملخص

استدامة سلسلة التوريد والتفريغ السريع تمثل تقاطعًا استراتيجيًا حيث تلتقي الكفاءة التشغيلية مع الضرورات البيئية والاجتماعية. يوفر التفريغ السريع، من خلال تقليل وقت تخزين المنتجات القابلة للتلف، فرصًا لتعزيز الاستدامة من خلال الحد من الأثر البيئي المرتبط بإدارة المخزون. يمكن أن يؤدي التقليل من الوقت اللازم للتخزين إلى استخدام أكثر فعالية للطاقة والموارد، ويمكن أن يقلل من انبعاثات النقل. في هذه الدراسة، يتم اقتراح نموذج برمجة لينية يتمحور حول تخصيص الأبواب إلى المنطقة التخزينية. الهدف الرئيسي لهذا النموذج هو تحسين التكلفة المرتبطة بحركة المنتجات القابلة للتلف داخل منشأة التفريغ السريع، خاصة أثناء تفريغ ونقل المنتجات القابلة للتلف من منطقة الرصيف إلى منطقة التخزين. يشمل النهج تخصيص أحد المنتجات القابلة للتلف التي تم تفريغها في بوابات الدخول إلى مختلف المناطق التخزينية استنادًا إلى عوامل مثل تكرار الطلب وتسلسل التحميل. تشمل التحليل مثالًا عدديًا يأخذ في اعتباره كميات متغيرة من المركبات الوافدة والأبواب والمنتجات القابلة للتلف، ومناطق التخزين. تظهر النتائج أنه يمكن تقليل التكلفة الإجمالية، أو زيادة التوفير، اعتمادًا على جدوى مشكلة البحث. وعلاوة على ذلك، تؤكد الدراسة أن اعتماد نقل المنتجات مباشرة من خلال التفريغ السريع يثبت أنه فعال من حيث التكلفة، وذلك لأن وجود أقل للمنتجات القابلة للتلف في التخزين يؤدي إلى تقليل تكاليف التعامل.

**كلمات مفتاحية**: تحويل البضائع، سلسلة التوريد، المنتجات القابلة للتلف، سلسلة توريد مستدامة

## Introduction

Cross docking, is one strategy that has highly influenced supply chain management sustainability through faster movement of goods, eliminating redundant storage, reducing distribution costs, and improving customer satisfaction (Ardakani and Fei (2020)). In crossdocks, the goods unloaded from an inbound truck are straightforwardly transferred to the shipping dock and are loaded into outbound trucks for dispatching. Thus, enabling the need for proper loading and discharging operations (Monaco and Smmarra (2020)). Cross docking consolidates smaller shipments between shippers and recipients, using the full truckload and reducing transportation costs (Stephan and Boysen (2011)).

Given the paramount objective of cross-docking to optimize throughput, minimize operational time, and reduce operational costs, the sequencing and scheduling of vehicles pose a crucial role within single cross-dock scenarios, multi-dock setups (Wisittipanich et al. (2019), Castellucci et al. (2021)), and those with multiple doors. This scheduling aspect holds immense significance within warehouse management. Among the scheduling challenges, the scheduling of trucks stands out as one of the most complex and pivotal problems, finding applications across cross-docking and broader logistics operations. This complexity has prompted numerous researchers to dedicate their time and efforts to delve into this area (Tadumadze et al. (2019)). The fundamental aim of this task is to determine the most suitable arrangement for the sequences of receiving and shipping trucks (Fathollahi-Fard et al. (2019)). (Golshahi-Roudbaneh et al. (2017)) devised a heuristic approach, harnessing a combination of five metaheuristics and a hybrid model, to ascertain the optimal sequence for shipping trucks. Dulebenets embarked on an extensive exploration of evolutionary algorithms tailored for truck scheduling within a Cross-Docking Center (CDC) (Dulebenets (2018a)). This endeavor led him to compare weak and strong mutation mechanisms (Dulebenets (2018b)) and later introduced an adaptive polyploid memetic algorithm that linked truck scheduling at the cross-docking facility with operations planning within the dock area. (Dulebenets (2019)), also formulated a mixed-integer linear programming model aimed at addressing truck scheduling challenges in cross-docks. In this model, products were either directly dispatched to the shipping dock for loading onto appropriate outbound trucks or temporarily placed within storage zones until suitable outbound trucks were assigned to respective dock doors. To tackle the objective of minimizing the overall truck service cost, a novel delayed start parallel evolutionary algorithm was conceived.

(Theophilus et al. (2019)) conducted an analysis to identify the key factors that exert influence on truck scheduling within cross-dock centers. These factors encompass attributes such as terminal layout, entryways, door-service management approach, preemption policies, employed internal transportation modes, temporary storage facility capacity, resource capacity, as well as the chosen objective and solution methodology. They conducted a comparison of outcomes based on computational runtime and the quality of the solutions attained. (Mousavi and Vahdani (2017)) formulated a robust optimization model to tackle the inherent uncertainty associated with input data in site and vehicle routing scheduling challenges within cross-docking centers. Their mixed-integer programming model was designed to determine cross-dock locations and devise vehicle routing schedules, taking into account multiple cross-dock facilities. In a separate study, (Zhang et al. (2022)) introduced a collaborative optimization approach for planning loading operations and scheduling vessel traffic in dry bulk ports. The primary objective of this research was to concurrently generate optimal traffic scheduling and loading operation plans for each vessel. They explored the navigation and departure patterns of ships in dry bulk export ports to devise the most effective plans.

Even within cold cross-dock facilities, the scheduling of trucks remains imperative due to the substantial wastage of perishable products caused by inadequate supply chain management practices (Rahal, (2024)). Given the susceptibility of perishable products to degradation during handling, coupled with the availability of temperature-controlled storage areas dedicated to such goods, (Theophilus et al. (2021)) introduced a mixed-integer mathematical formulation aimed at optimizing truck scheduling. This optimization endeavor was directed towards diminishing the overall cost associated with truck services.

Addressing the complexities of cross-dock scheduling involving perishable products, (Golshahi-Roudbaneh et al. (2021)) presented a fresh model. Their approach incorporated time windows and delivery deadlines tailored to trucks transporting perishable items. To manage the total cost resulting from the timeliness of truck shipments, they amalgamated two significant metaheuristics, the Keshtel algorithm (KA), and simulated annealing, thereby devising a novel hybrid algorithm. (Pan et al. (2021)) undertook a study focusing on truck scheduling concerning perishable products within a cross-docking context. They introduced a mixed-integer programming model to evaluate the coefficient of variation in deterioration risk for perishable items within an unstable logistics setting. (Zheng et al. (2021)) addressed crossdock truck scheduling problems pertaining to refrigerated and frozen items. Their approach involved the formulation of a mixed-integer linear programming model oriented towards minimizing operational costs. They factored in penalties associated with deviations from contracted time windows for inbound truck arrivals, delays in product delivery, inventory expenses, and transportation costs for outbound trucks.

(Das et al. (2021)) introduced a multi-objective optimization model that integrated the facility location problem, robust transportation challenge, and inventory management. This formulation aimed to optimize various objectives, including determining optimal locations for facilities, minimizing transportation costs, inventory expenses, carbon emissions, and transportation time.

The present study has integrated the concept of material handling cost by considering the count of perishable product unloaded from incoming trucks and subsequently moved to storage zones. The model has explored how the availability of material handling resources for transferring perishable products influences the material handling cost. A predetermined quantity of material handling trolleys is assigned to each entry point. Furthermore, the model has investigated the potential impact of altering the quantity of perishables products transferred to the storage area on the material handling cost.

## 1. Problem Description

In this research endeavor, our primary focus revolves around the minimization of material handling costs incurred during the unloading of perishables products from inbound trailers at designated doors. Subsequently, our attention is directed towards the seamless transfer of these perishables products from the receiving docks to predetermined storage zones. Following a consolidation operation, the offloaded products are then conveyed to the shipping dock, where they are methodically loaded onto outbound trucks for dispatch to their intended destinations. However, instances of assigned outbound trucks being unavailable at the shipping dock necessitate temporary storage of perishables products in specific zones, contingent upon demand and loading sequences. The task of transporting perishables products to their destined locations. Building upon prior studies that investigated the impact of crossdock shapes on material handling costs, with a specific focus on truck-to-door assignments, this paper crafts a model. This model revolves around the selection of inbound trucks to doors, followed by the transfer from entrances to designated storage zones.

To construct the proposed model, a set of assumptions has been formulated to establish the framework's boundaries.

**A1** : Inbound trucks, upon entering through the in-gate, are assigned to strip doors where perishable products are sequentially unloaded and transferred to receiving docks. Each inbound truck is uniquely assigned to a randomly selected door within the planning horizon. For each location, only one inbound trailer and one outbound trailer are designated.

**A2** : The cross-dock facility features multiple entryways, with all strip and stack doors operating under a fixed mode of service. Equally likely, incoming and outgoing trucks can utilize any entryway.

**A3** : The model adopts a pre-distribution approach to perishable product allocation, disregarding product interchangeability. Upon a trailer's placement at a strip door, all perishable products are unloaded without the possibility of preemption. The quantity of perishable products remains unchanged, assuming no defects, damages, or losses during the handling process.

**A4** : The study focuses on material flow from incoming trucks to the storage area. Adequate storage capacity is available in front of each dock door. The movement of perishable products from temporary storage zones to outbound trucks is not considered.

## 2. Materials and Methods

The methodology employed in this discussed model requires an approach capable of managing a multitude of variables. Dealing with an extensive number of variables using conventional optimization techniques can be quite challenging. Our research focuses on reducing material handling costs associated with the transportation and unloading of perishables products in storage areas. To address this, we utilized the IBM CPLEX optimization software, which provided an optimal solution. Also, we present a numerical example to illustrate the mathematical model.For the numerical analysis, the data set have been considered from (Yu (2002)) with some modification.

## 3. Tables

In this section, we present the notations utilized in formulating the mathematical model. This encompasses parameters (Table 1), indices (Table 2), decision variables (Table 3) and the CPLEX results in the (Table 4).

***Table 1. The parameters of the model*.**

| Parameters | Description |
|---|---|
| $nb_{pc}$ | Number of product p present in truck c |
| $nb_p^s$ | Number of product p moved to storage area s |
| $c_a^s$ | Cost of product transportation from truck c |
| $C_{max}$ | The maximal capacity of the truck |
| $Mtd_a^s$ | Cost of product unloading at door a from truck c |

*Table 2. The indices of the model.*

| Indices | Description |
|---|---|
| **X** | quantity of products transferred from supplier to customer per truck $\forall p \in X$ |
| **N** | quantity of vehicles allocated $\forall n \epsilon N$ |
| **S** | number of storage zones $\forall s \in S$ |
| **A** | quantity of operational doors within a warehouse $\forall a \in A$ |
| **C** | quantity of inbound trailers $\forall c \epsilon C$ |

*Table 3. The decisions variables of the model.*

| Variables | Description |
|---|---|
| $\boldsymbol{Y_{ca}}$ | 1 if truck c is allocated to door a<br>0 otherwise |
| $\boldsymbol{Y_{an}}$ | 1 if the vehicule A is assigned to door a<br>0 otherwise |
| $\boldsymbol{Z_{pas}}$ | 1 if the product p is transported from the door a to storage zone s<br>0 otherwise |

## 4. Mathematical Model

$$\min z = \sum_{c=1}^{C} \sum_{a=1}^{A} Mtd_a^s * \sum_{c=1}^{C} \sum_{p=1}^{P} nb_{pc} + \sum_{s=1}^{S} \sum_{p=1}^{P} \sum_{a=1}^{A} c_a^s * z_{pas} * nb_p^s \quad (1)$$

$$\sum_{a=1}^{A} y_{ca} = 1 \quad (2)$$

$$\sum_{a=1}^{A} y_{an} = 1 \tag{3}$$

$$\sum_{n=1}^{N} y_{an} \leq N \tag{4}$$

$$\sum_{s=1}^{S} \sum_{a=1}^{A} z_{pas} = 1 \tag{5}$$

(6) $\sum_{p=1}^{X} nb_{pc} * Z_{pas} \leq C_{\max}$

$$y_{ca} \geq 0 \tag{7}$$

$$y_{na} \geq 0 \tag{8}$$

$$z_{pas} \geq 0 \tag{9}$$

The mathematical model's objective is the minimization of material handling costs associated with the movement of perishables products from the dock to the storage area and the unloading of products from inbound trailers.Equation (2) illustrates that each incoming truck is exclusively assigned to a particular door, and this assignment remains constant without any subsequent changes. Equation (3) establishes a connection between handling resources and each individual door. Moreover, Equation (4) stipulates that the resources allocated to facilitate the transfer of freight at each door must not exceed the total pool of available resources. For items with predetermined departure times and destinations, Equation (5) governs the process by which delayed departure products are directed to storage areas. The formulation also accounts for the movement of products from doors to storage areas. Then, Equation (6) mean that the quantities of products should not excess the capacity of trucks.Finally, equations (8) (9) (10) are the Binary constraints.

## 5. Results and discussion

Improvise the results and discussion up to the level of indexed article. The proposed study focused on enhancing decision-making at the operational level. Whether in a conventional warehouse or a cross-dock facility, it's crucial to ensure efficient coordination between incoming trucks at the strip doors and the resources responsible for unloading and transferring perishables products to the storage area and shipping dock. This analysis takes into account the cost factors associated with both internal tasks, such as relaying goods, and external tasks, like unloading perishables products at receiving docks. In the inbound phase, variable costs are factored in based on perishables products volume, while in the outbound phase, a fixed cost is incurred for each perishable product transfer from the inbound truck to the storage area. It's worth noting that although our modeling approach is specific to the case we considered, it can be adapted to various other cross-dock scenarios and configurations, including those with more doors, trucks, and vehicles.

Table 4 provides a comprehensive overview of the outcomes for various permutations and combinations involving inbound trucks, the number of doors, the quantity of perishables products in these trucks, and storage areas. The results in Table 4 reveal that deploying four inbound trucks at a receiving door, each carrying three different types of perishables products in varying quantities, leads to variations in the handling cost. Specifically, when three perishables products are unloaded from these four trucks and transferred to a specific storage area, the handling cost amounts to 15,900 dt. Subsequently, significant reductions in cost are observed in the following two scenarios, amounting to 11,730 dt and 8,100 dt, respectively, when only two perishables products or just one perishable product are considered. This underscores the influence of the quantity of perishables products transferred on the overall material handling cost.

When the utilization of only two inbound trucks is considered, the cost amounts to 10,500 dt, representing a consistent decrease of 3,435 dt. Furthermore, deploying just one inbound truck for unloading perishables products at a specific door results in a significant reduction of around 2769 dt. It's worth noting that reducing the number of trucks from four to three also leads to a noticeable cost reduction of approximately 1830 dt in handling expenses. Hence, it is evident that the variation in the number of incoming trucks equally impacts the overall cost.

***Table 4. The CPLEX results.***

| **Instances** | **Door** | **Product** | **Truck** | **Storage** | **Objectif function (dt)** |
|---|---|---|---|---|---|
| **1** | 1 | 3 | 4 | 1 | 15900 |
| **2** | 1 | 1 | 4 | 1 | 8100 |
| **3** | 1 | 2 | 1 | 1 | 5661 |
| **4** | 1 | 3 | 2 | 1 | 10500 |
| **5** | 1 | 2 | 3 | 1 | 9753 |

| | | | | | |
|---|---|---|---|---|---|
| **6** | 1 | 1 | 3 | 1 | 6006 |
| **7** | 1 | 3 | 3 | 1 | 13935 |
| **8** | 1 | 2 | 4 | 1 | 11730 |
| **9** | 1 | 1 | 1 | 1 | 3630 |
| **10** | 1 | 2 | 2 | 1 | 7905 |
| **11** | 1 | 1 | 2 | 1 | 4686 |
| **12** | 1 | 3 | 1 | 1 | 7731 |

## 6. Conclusions

The outcomes derived from the analyzed model indicate that during the peak season of product demand, when there is a higher number of incoming vehicles scheduled for unloading in the planning horizon, the material handling cost rises significantly due to the increased volume of perishable product transfers. Consequently, it is clear that fluctuations in product quantity have a direct impact on the overall net worth. Furthermore, an increase in unloading prices substantially escalates material handling costs, emphasizing the need to explore alternative measures to manage labor and handling operations. In our proposed case study, we allocate a fixed number of vehicles for material transfer. As a result, this could lead to a shortage of products within the system, causing delays in product delivery, extended waiting times, potential lost sales, diminished customer satisfaction, or a decline in overall system efficiency.

Our suggested study possesses certain limitations that could be further investigated in future research: In this model, we have focused on the operations within a solitary cross-dock. Nevertheless, the model could be expanded to encompass multiple cross-docks, incorporating numerous receiving and shipping docks, allowing for the determination of material handling costs. Also, Exploring novel and efficient heuristics and metaheuristics to address the presented problem, along with its extensions under different assumptions or multi-objective models, would be an intriguing avenue for further investigation.

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## References


[01]. Ardakani, A.(A). and Fei, J. (2020), "A systematic literature review on uncertainties in cross-docking operations", Modern Supply Chain Research and Applications, Vol. 2 No. 1, pp. 2-22. https://doi.org/10.1108/MSCRA-04-2019-0011

[02]. CASTELLUCCI, Pedro B., COSTA, Alysson M., et TOLEDO, Franklina. Network scheduling problem with cross-docking and loading constraints. Computers & Operations Research, 2021, vol. 132, p. 105271. https://doi.org/10.1016/j.cor.2021.105271

[03]. DAS, Soumen Kumar, PERVIN, Magfura, ROY, Sankar Kumar, et al. Multi-objective solid transportation-location problem with variable carbon emission in inventory management: A hybrid approach. Annals of Operations Research, 2021, p. 1-27. https://doi.org/10.1007/s10479-020-03809-z

[04]. DULEBENETS, Maxim A. A comprehensive evaluation of weak and strong mutation mechanisms in evolutionary algorithms for truck scheduling at cross-docking terminals. IEEE Access, 2018a, vol. 6, p. 65635-65650. 10.1109/ACCESS.2018.2874439

[05]. DULEBENETS, Maxim A. A diploid evolutionary algorithm for sustainable truck scheduling at a cross-docking facility. Sustainability, 2018b, vol. 10, no 5, p. 1333. https://doi.org/10.3390/su10051333

[06]. DULEBENETS, Maxim A. A Delayed Start Parallel Evolutionary Algorithm for just-in-time truck scheduling at a cross-docking facility. International Journal of Production Economics, 2019, vol. 212, p. 236-258. https://doi.org/10.1016/j.ijpe.2019.02.017

[07]. FATHOLLAHI-FARD, Amir Mohammad, RANJBAR-BOURANI, Mehdi, CHEIKHROUHOU, Naoufel, et al. Novel modifications of social engineering optimizer to solve a truck scheduling problem in a cross-docking system. Computers & Industrial Engineering, 2019, vol. 137, p. 106103. https://doi.org/10.1016/j.cie.2019.106103

[08]. GOLSHAHI-ROUDBANEH, Amir, HAJIAGHAEI-KESHTELI, Mostafa, et PAYDAR, Mohammad Mahdi. Developing a lower bound and strong heuristics for a truck scheduling problem in a cross-docking center. Knowledge-Based Systems, 2017, vol. 129, p. 17-38. https://doi.org/10.1016/j.knosys.2017.05.006

[09]. GOLSHAHI-ROUDBANEH, A., HAJIAGHAEI-KESHTELI, M., et PAYDAR, M. M. Cross-dock scheduling considering time windows and deadline for truck departures. Scientia Iranica, 2021, vol. 28, no 1, p. 532-546. https://doi.org/10.24200/SCI.2019.52662.2824

[10]. MONACO, M. Flavia et SAMMARRA, Marcello. Managing loading and discharging operations at cross-docking terminals. Procedia Manufacturing, 2020, vol. 42, p. 475-482. https://doi.org/10.1016/j.promfg.2020.02.045

[11]. MOUSAVI, S. Meysam et VAHDANI, Behnam. A robust approach to multiple vehicle location-routing problems with time windows for optimization of cross-docking under uncertainty. Journal of Intelligent & Fuzzy Systems, 2017, vol. 32, no 1, p. 49-62. https://doi.org/10.3233/JIFS-151050

[12]. PAN, Fei, ZHOU, Wei, FAN, Tijun, et al. Deterioration rate variation risk for sustainable cross-docking service operations. International Journal of Production Economics, 2021, vol. 232, p. 107932. https://doi.org/10.1016/j.ijpe.2020.107932

[13]. Rahal, I. (2024). The Supply Chain Management for Perishables Products: A Literature Review.

[14]. STEPHAN, Konrad et BOYSEN, Nils. Cross-docking. Journal of Management Control, 2011, vol. 22, p. 129-137. https://doi.org/10.1007/s00187-011-0124-9

[15]. THEOPHILUS, Oluwatosin, DULEBENETS, Maxim A., PASHA, Junayed, et al. Truck scheduling at cross-docking terminals: a follow-up state-of-the-art review. Sustainability, 2019, vol. 11, no 19, p. 5245. https://doi.org/10.3390/su11195245

[16]. THEOPHILUS, Oluwatosin, DULEBENETS, Maxim A., PASHA, Junayed, et al. Truck scheduling optimization at a cold-chain cross-docking terminal with product perishability considerations. Computers & industrial engineering, 2021, vol. 156, p. 107240. https://doi.org/10.1016/j.cie.2021.107240

[17]. TADUMADZE, Giorgi, BOYSEN, Nils, EMDE, Simon, et al. Integrated truck and workforce scheduling to accelerate the unloading of trucks. European Journal of Operational Research, 2019, vol. 278, no 1, p. 343-362. https://doi.org/10.1016/j.ejor.2019.04.024

[18]. WISITTIPANICH, Warisa, IROHARA, Takashi, et HENGMEECHAI, Piya. Truck scheduling problems in the cross docking network. International Journal of Logistics Systems and Management, 2019, vol. 33, no 3, p. 420-439. https://doi.org/10.1504/IJLSM.2019.101164

[19]. YU, Wooyeon. Operational strategies for cross docking systems. Iowa State University, 2002. https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=b86790ff0dfc20a26aa9005dfbd5a6526beec3f3

[20]. ZHANG, Xinyu, LI, Junjie, YANG, Zaili, et al. Collaborative optimization for loading operation planning and vessel traffic scheduling in dry bulk ports. Advanced Engineering Informatics, 2022, vol. 51, p. 101489. https://doi.org/10.1016/j.aei.2021.101489

[21]. ZHENG, Feifeng, PANG, Yaxin, XU, Yinfeng, et al. Heuristic algorithms for truck scheduling of cross-docking operations in cold-chain logistics. International Journal of Production Research, 2021, vol. 59, no 21, p. 6579-6600. https://doi.org/10.1080/00207543.2020.1821118