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# Adopting Business Intelligence to Enhance Cross-Dock Operations

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## Abstract

**Background:** Cross-docking optimization plays a crucial role in supply chain management by enhancing efficiency, reducing costs and streamlining operations. However, challenges arise from inaccurate data and a lack of digital tools to support decision making.

**Objective:** The objective of this study was to integrate business intelligence (BI) tools with cross-dock operation data to optimize warehouse layout and improve decision making processes.

**Methods:** A combination of Microsoft Visio and Microsoft Power BI was used to visualize and optimize warehouse layout based on historical cross-dock operation data. The methodology focused on integrating real-time data with spatial layout visualization to minimize total travel distance within the warehouse.

**Results:** The integration of BI tools led to a 10% reduction in total travel distance, enhancing operational efficiency and reducing costs. The study demonstrates that BI-based decision support tools offer significant advantages over traditional optimization methods. However, challenges remain in scalability, real-time adaptability and user adoption.

**Conclusion:** The proposed BI-driven solution improved warehouse layout optimization and facilitated data-driven decision making. Future research should explore the integration of BI with other optimization techniques and investigate its scalability in different warehouse environments.

## Index Terms

Logistics; Cross-docking; Layout; Data visualisation; Business intelligence.

## 1 INTRODUCTION

Cross-docking optimization is essential for enhancing supply chain performance by improving efficiency, reducing costs and increasing customer satisfaction. Mathematical optimization plays a significant role in decision making processes related to cross-docking operations (Mavi et al., 2020). Successful cross-docking implementation requires high performance from all supply chain members, emphasizing the need for speed, effective planning, reliability, error-proof processes and transparency (Vogt, 2010). This integrative perspective is known as a "cross-dock based supply chain", highlighting the interdependency between cross-docking and the overall supply chain (Vogt, 2010).

The layout of a cross-docking facility is crucial in determining the efficiency and effectiveness of operations within the warehouse. Research has shown that optimizing the layout of a cross-dock can lead to significant improvements in operational performance (Li et al., 2012), cost effectiveness (Bartholdi & Gue, 2004) and the flow of materials through the facility (Roodbergen et al., 2014).

The physical design of the cross-dock, including factors such as the shape of the facility, the arrangement of docks and the allocation of space, can affect labour costs and overall operational efficiency (Bartholdi & Gue, 2004). By strategically designing the layout of a cross-docking warehouse, companies can streamline material flow, reduce handling costs and enhance throughput, which can lead to significant improvements in operational efficiency and cost effectiveness.

Challenges in decision making for cross-dock operations often arise from inaccurate or incomplete data (Movassaghi, 2020). With cross-docking optimization, supported by data-driven decision making to strategically design the layout of the facility and considering factors such as space allocation, aisle arrangement and resource utilization, companies can achieve significant improvements in their cross-docking operations.

As previously stated by Andar and Kašparová (2024), business intelligence (BI) serves as a crucial tool for organizations seeking to gain a competitive advantage. However, there is a notable gap in the literature regarding the utilization of BI for cross-dock optimization.

This paper introduces a model designed for application in scenarios requiring the design or reorganization of a warehouse. The proposed dynamic layout, which adjusts according to current needs, functions as a decision support tool for both warehouse workers engaged in daily processes and management involved in designing specific cross-docking zones. This is achieved through the use of readily available BI tools.

## 2 LITERATURE REVIEW

Various studies have explored optimizing cross-dock operations through layout design and support. Motaghedi-Larijani and Aminnayeri (2018) and Luo and Noble (2012) proposed genetic algorithms to optimize lane layout in cross-dock operations. Aickelin and Adewunmi (2006) addressed the cross-dock door assignment problem, aiming to minimize material handling equipment travel distance by optimizing the arrangement of inbound and outbound doors and the assignment of destinations. Similarly, Hauser and Chung (2006) utilized genetic algorithms for layout optimization in cross-docking operations within manufacturing plants.

Ross and Jayaraman (2008) developed heuristics to minimize worker travel costs and congestion time in cross-docking terminals through layout construction. Li et al. (2012) presented a comprehensive solution for cross-docking operations planning, scheduling and coordination, covering container grouping, real-time scheduling and task assignment/sequencing. Chen et al. (2006) studied the staging of products in cross-docks to enhance throughput and analysed the impact of worker numbers on shipping and receiving throughput. Yang and Song (2022) highlighted the use of optimization algorithms, such as the Whale Optimization Algorithm (WOA), to improve the location selection process for distribution centres.

It is obvious that there are numerous opportunities for optimizing cross-docking operations, primarily through the application of operational research (OR) methods. According to Utley (2022), while operational research techniques are essential for contemporary logistics solution design, several challenges persist. Many of these methods are implemented via software tools, necessitating the development of custom software solutions by developers. For long-term utilization, organizations must ensure the maintenance and integration of these software tools within their existing digital solution portfolios. Another issue highlighted by Utley (2022) is that OR solutions often require a bespoke approach, making them difficult to transfer without extensive knowledge and skills on the part of the implementer. This challenge was further supported by Turner (2022).

Based on the authors' knowledge, there is a notable gap in the literature regarding the utilization of BI in cross-dock optimization. Despite its proven effectiveness in enhancing operational efficiency, reducing costs and improving service delivery in various other data-driven business fields, BI application in cross-docking remains underexplored.

The main advantage of BI over standard OR techniques is its seamless integration with a company's existing software systems, as highlighted by Castro et al. (2023). This ease of integration suggests that the implementation of BI tools may offer significant utilization advantages compared to traditional OR techniques.

Another advantage lies in the enhanced availability of BI tools and the experts required for their successful implementation, as noted by Ramesh (2019). Also, it has been shown by several authors (e.g., Cao et al., 2023; Chen et al., 2014; Pandian, 2019) that BI contributes to the overall transformation of logistics services through intelligent systems. Cao et al. (2023) noted that implementing intelligent logistics systems enables real-time data analysis, facilitating on-demand delivery and dynamic path optimization. This capability is crucial for reducing carbon emissions and improving sustainability in logistics operations. By harnessing BI, logistics companies can optimize their processes to meet both operational goals and environmental standards.

The adoption of BI in logistics is closely linked to implementing advanced technologies such as the internet of things (IoT) and artificial intelligence (AI). Chen et al. (2014) and Pandian (2019) have discussed how integrating these technologies allows enhanced visibility and control over logistics processes. BI systems can analyse data collected from IoT devices to provide insights into inventory levels, transportation routes and customer preferences, leading to more efficient logistics management.

However, implementing BI in logistics process optimization is not without challenges. These challenges can hinder the effectiveness of BI systems and may lead to suboptimal outcomes in logistics operations. One significant disadvantage is the complexity and costs associated with implementing BI systems. Necochea-Chamorro and Larrea-Goycochea (2023) highlighted that integrating BI tools often requires substantial investment in technology and training. This financial burden can be particularly challenging for small and medium-sized enterprises (SMEs), which may lack the necessary resources. Additionally, the complexity of BI systems can lead to difficulties in user adoption and satisfaction, as indicated by Kapo et al. (2021). If users find the systems cumbersome or unintuitive, it can result in underutilization of BI capabilities, ultimately negating the potential benefits.

Another disadvantage is the potential for information overload. As logistics operations generate vast amounts of data, BI systems can sometimes overwhelm users with excessive information, making it challenging to extract actionable insights. This phenomenon can lead to decision paralysis, where managers struggle to make informed choices due to the sheer volume of data presented. The challenge of filtering relevant information from noise is critical, as it can hinder timely decision making (Queiroz & Telles, 2018).

Moreover, the dynamic nature of logistics environments can render BI insights less effective. Logistics operations are influenced by various external factors such as market fluctuations, regulatory changes and technological advancements (Svoboda et al., 2024). Consequently, decisions based on outdated or static BI analyses can lead to missed opportunities or increased costs (Stienen et al., 2020).

To assess the feasibility of using BI as a tool for optimizing cross-dock operations, this study evaluates the implementation results within a company. The objective is to compare the feasibility of this approach and prepare a comparison with standard OR techniques. The anticipated benefits, such as improved availability and integration, are expected to be significant, particularly in mitigating financial burdens by utilizing cost-effective and readily available BI tools. Additionally, this approach addresses decision paralysis by emphasizing the visual components of BI to facilitate decision making.

## 3 RESEARCH METHODS

This study employs a combination of Microsoft Visio and cross-dock operation data combined in Microsoft Power BI to support decision making about the layout of a cross-dock warehouse. Years of cross-dock operation data from an available ERP system were used. These data include the number of handling units processed, specific sorting zones, shipment volumes, date and time of processing, place of arrival and place of delivery. A schematic representation of the presented BI tool can be seen in Figure 1. In this case, data are collected from a warehouse during typical operations at scanners and PCs. An advantage can be seen in the capability of Microsoft Power BI to connect to various other sources, thus enhancing the replicability of this solution to other companies.

The layout of the cross-dock warehouse was developed using Microsoft Visio, encompassing all relevant zones and pathways essential for cross-dock operations. The collected operational data were subsequently integrated into the layout utilizing Microsoft Power BI. Each sorting zone was linked with its corresponding operational data. To facilitate decision making, colour tones were assigned to the zones based on the number of shipments within a selected time period, providing an easily interpretable visual cue (a scale from red to blue to reflect declining number of shipments). The layout became a visual representation of selected data. A screenshot of the Microsoft Power BI tool is presented in Figure 2.

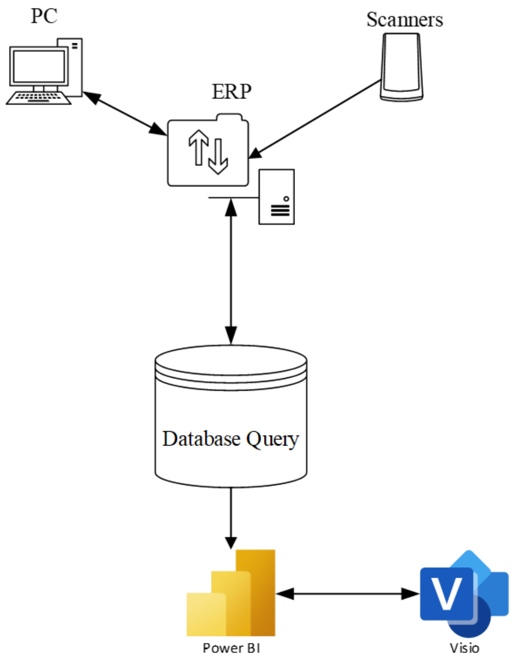


***Figure 1.*** *Schematic representation of BI tool.*

The integrated data were visualized in the Microsoft Visio layout. This visualization provides a clear picture of the operations in each sorting zone, including the number of units processed and the shipment volumes and also provides an easy-to-use interface for manually changing the layout.


***Figure 2.*** *Digital layout in MS Visio and MS Power BI.*

The total travel distance in the warehouse was minimized by considering the number of units processed per sorting zone and the distance from the inbound zone. This optimization process was guided by the principle of minimizing the product of the distance and the number of units processed.

This methodology offers a comprehensive approach to warehouse layout optimization by integrating both operational data and the physical layout of the warehouse. The resulting layout minimizes travel distance, thereby enhancing efficiency and reducing operating costs. An additional advantage is the seamless integration provided by the Microsoft Visio plugin module in Microsoft Power BI, which combines the custom visual capabilities and interactivity of Visio with the user-friendly data modelling tools of Microsoft Power BI.

This study highlights the importance of starting with a simple and cost-effective implementation of BI tools. Such an approach allows organizations to test and validate the effectiveness of BI in their specific operational context. Once initial success is achieved, these BI implementations can be scaled up to incorporate more advanced features and integrate with other optimization techniques.

## 4 RESULTS

The integration of cross-dock operation data with the Microsoft Visio layout yielded significant insights into the functioning of the warehouse. The visualization of data on the layout allowed a clear understanding of the operations in each sorting zone. It was observed that some zones had a higher number of units processed compared to others. Similarly, the shipment volumes varied across the different zones.

The BI tool provided a clear and data driven background to support empirical decision making of cross-dock managers. This was accomplished by considering the number of units processed per sorting zone and the distance from the inbound zone. The optimized layout suggested a re-routing of operations that significantly reduced the product of the distance and the number of units processed. The results indicate that the methodology employed in this study is effective in optimizing the layout of a cross-dock warehouse. The optimized layout not only improves operational efficiency but also reduces costs associated with travel within the warehouse.

Figures 3 and 4 illustrate the layout before and after optimization. Colours are assigned based on the number of processed handling units per zone, ranging from red to blue, providing an immediate visual indication of the total travel distance. The travel distance is a significant indicator of the total variable operating costs, as it consumes resources such as staff, time and warehouse technology. Table 1 shows a calculation of the total travel distance before and after the optimization. This indicates a 10% decrease in the total travel distance after the layout optimization, leading to a significant cost reduction.

***Table 1.*** *Total travel distance before and after optimization.*

| Zone | No. of handled units | Distance from inbound (m) | Total travel distance (m) | Distance from inbound after (m) | Total travel distance after (m) |
|---|---|---|---|---|---|
| **S1ECZBRQ** | 88,426 | 15.36 | 1,358,223 | 15.36 | 1,358,223 |
| **S1ECZPLZ** | 72,641 | 11 | 799,051 | 11 | 799,051 |
| **S1ECZDCB** | 57,624 | 34.08 | 1,963,826 | 16.8 | 968,083 |
| **S1ECZHKR** | 53,287 | 22.56 | 1,202,155 | 19.68 | 1,048,688 |
| **S1ECZNJC** | 51,295 | 16.8 | 861,756 | 22.56 | 1,157,215 |
| **S1ECZLIC** | 51,185 | 41.4 | 2,119,059 | 25.44 | 1,302,146 |
| **S1ECZJXD** | 41,814 | 36.96 | 1,545,445 | 31.2 | 1,304,597 |
| **S1ECZPEL** | 39,276 | 34.08 | 1,338,526 | 34.08 | 1,338,526 |
| **S1EPRG19** | 34,637 | 10.56 | 365,767 | 3.12 | 108,067 |
| **S1EPRG04** | 30,379 | 59 | 1,792,361 | 4.8 | 145,819 |
| **S1EDEDRS** | 27,060 | 24.48 | 662,429 | 24.48 | 662,429 |
| **S1EPRG10** | 25,695 | 64.43 | 1,655,529 | 6.48 | 166,504 |
| **S1EPRG21** | 25,530 | 19 | 485,070 | 11.4 | 291,042 |
| **S1EPRG13** | 25,451 | 69.12 | 1,759,173 | 10.56 | 268,763 |
| **S1EDENUE** | 23,500 | 35.28 | 829,080 | 27.2 | 639,200 |
| **S1ECZOLO** | 22,882 | 25.44 | 582,118 | 29.9 | 684,172 |

| Zone | No. of handled units | Distance from inbound (m) | Total travel distance (m) | Distance from inbound after (m) | Total travel distance after (m) |
|---|---|---|---|---|---|
| **S1ESKBTS** | 20,639 | 19.68 | 406,176 | 36.96 | 762,817 |
| **S1EITMIL** | 20,581 | 40.32 | 829,826 | 33.568 | 690,863 |
| **S1EPRG05** | 19,337 | 53.76 | 1,039,557 | 18 | 348,066 |
| **S1EPRG18** | 18,538 | 4.8 | 88,982 | 23.52 | 436,014 |
| **S1ENLEDE** | 17,129 | 32.568 | 557,857 | 36.48 | 624,866 |
| **S1EPRG14** | 16,625 | 72.72 | 1,208,970 | 28 | 465,500 |
| **S1EPLWAW** | 15,812 | 28.32 | 447,796 | 31.48 | 497,762 |
| **S1EPRG20** | 15,152 | 14.16 | 214,552 | 31.92 | 483,652 |
| **S1EPRG16** | 13,943 | 3.12 | 43,502 | 34.8 | 485,216 |
| **S1EHUBUD** | 13,592 | 44.16 | 600,223 | 34.08 | 463,215 |
| **S1EPRG02** | 13,488 | 53.76 | 725,115 | 37.6 | 507,149 |
| **S1EPRG25** | 13,436 | 15.36 | 206,377 | 47.5 | 638,210 |
| **S1EPRG09** | 12,518 | 50.6 | 633,411 | 50.6 | 633,411 |
| **S1EESBCN** | 12,080 | 31.48 | 380,278 | 37.2 | 449,376 |
| **S1EPRG17** | 11,522 | 11.4 | 131,351 | 46.32 | 533,699 |
| **S1EPRG24** | 11,426 | 37.6 | 429,618 | 53.76 | 614,262 |
| **S1EGBLON** | 10,677 | 37.2 | 397,184 | 39.6 | 422,809 |
| **S1EPRG26** | 10,602 | 26.3 | 278,833 | 49.44 | 524,163 |
| **S1EPRG22** | 10,522 | 23.52 | 247,477 | 53.76 | 565,663 |
| **S1EPRG27** | 10,491 | 31.92 | 334,873 | 56.88 | 596,728 |
| **S1EPRG15** | 10,419 | 6.48 | 67,515 | 59 | 614,721 |
| **S1EPRG12** | 10,277 | 63.12 | 648,684 | 60 | 616,620 |
| **S1EFRSXB** | 9,958 | 31.2 | 310,690 | 40 | 398,320 |
| **S1EFRLYS** | 9,849 | 29.9 | 294,485 | 40 | 393,960 |
| **S1EPRG06** | 9,555 | 49.44 | 472,399 | 62.12 | 593,557 |
| **S1EPRG08** | 9,486 | 47.5 | 450,585 | 63.43 | 601,697 |
| **S1EFRPARsxr** | 9,323 | 27.2 | 253,586 | 42.4 | 395,295 |
| **S1EPRG07** | 9,242 | 46.32 | 428,089 | 65.43 | 604,704 |
| **S1EPRG01** | 9,216 | 60 | 552,960 | 66 | 608,256 |
| **S1ENLTLB** | 8,233 | 39.6 | 326,027 | 43 | 354,019 |
| **S1EPRG23** | 7,644 | 29 | 221,676 | 69.12 | 528,353 |
| **S1EPLWRO** | 6,895 | 10.56 | 72,811 | 10.56 | 72,811 |
| **S1EPRG03** | 6,439 | 56.88 | 366,250 | 71 | 457,169 |
| **S1EPRG28** | 5,706 | 34.8 | 198,569 | 72.72 | 414,940 |
| **S1ECHBSL** | 4,818 | 36.48 | 175,761 | 45.84 | 220,857 |
| **S1EPRG11** | 3,885 | 68.64 | 266,666 | 74 | 287,490 |
| **S1ECZPRGfau** | 3,747 | 47.9 | 179,481 | 47.9 | 179,481 |
| **S1ECHZRH** | 2,536 | 36.48 | 92,513 | 45.84 | 116,250 |
| **Total** | | | **33,900,274** | | **30,444,468** |

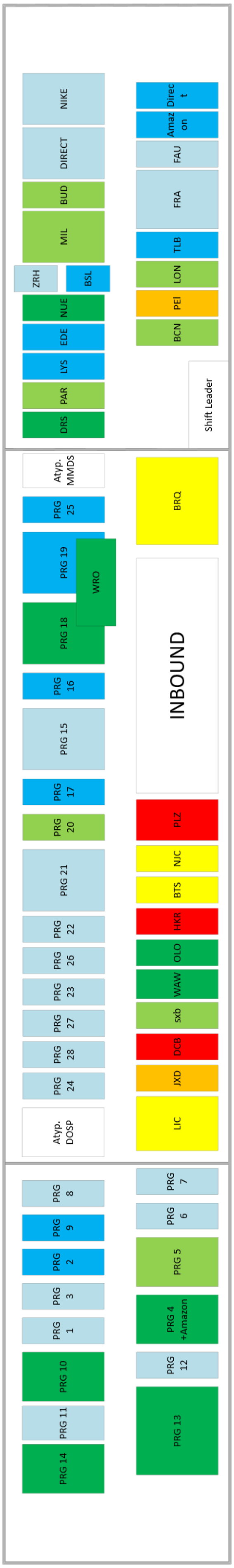


***Figure 3.*** *Original cross-dock layout.*

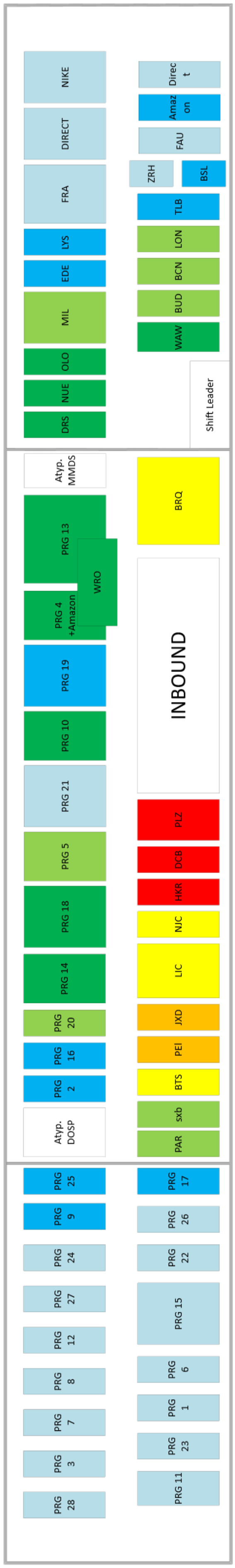


***Figure 4.*** *Cross-dock layout after optimization.*

## 5 DISCUSSION

Data visualization plays a crucial role in the analytical function of warehouse management. By integrating cross-dock operation data into the Microsoft Visio layout, we were able to transform raw, complex data into a more understandable and actionable format. This visual representation of data provides a clear picture of the operations in each sorting zone, including the number of units processed and the shipment volumes.

This combination of BI, visualisation and empirical methods was able to produce optimization results similar to those of comparable OR techniques (e.g., Motaghedi-Larijani and Aminnayeri, 2018; Luo and Noble, 2012), which supports our hypothesis that utilizing BI to enhance cross-dock operations is feasible.

The ability to visualize data in this manner allows more effective analysis. It enables managers to identify patterns, trends and correlations that might go unnoticed in text-based data. For instance, it can highlight which sorting zones are overworked or underutilized, or reveal peak times for shipments.

The insights gained from the data visualization directly affect managerial decision making. Managers can make more informed decisions about resource allocation, workflow design and operational scheduling. For example, understanding the volume of units processed in each zone can guide decisions about where to allocate additional resources or how to redesign the workflow for better efficiency.

Moreover, data visualization is integral to optimization efforts. In this study, it was instrumental in the distance optimization process. By visualizing the number of units processed per sorting zone and the distance from the inbound zone, we were able to devise a layout that minimizes travel distance. This not only improves operational efficiency but also reduces costs, demonstrating how data visualization can lead to tangible improvements in warehouse operations.

Another advantage is that the model can be utilized for various purposes, providing valuable insights such as KPI tracking, seasonality evaluation and forecasting. As demonstrated by Clausen et al. (2017), combination of visualization tools and operational research (OR) methods can lead to further advancements. Therefore, it is reasonable to test the incorporation of the presented BI model with layout optimization methods. For example, the integration of a VBA-programmed algorithm in Microsoft Visio could automate layout optimization based on distance or incorporate other aspects of cross-dock operations.

However, the empirical factors identified in this study remain crucial in cross-dock optimization. As highlighted by Utley (2022), OR techniques can sometimes provide a naïve worldview and are dependent on the selected factors included in the calculations. This perspective was shared by Strachotova and Dyntar (2021), who emphasized that there is still a place for empirical methods in logistics system optimization.

Future studies should focus on replicability on a larger scale, testing different data background systems. Additionally, the combination of BI and other OR techniques should be examined and comparisons with empirical approaches should be evaluated.

Conversely, layout changes are currently conducted at a tactical level, utilizing aggregated data over selected time periods and not accounting for seasonality and other shipment variance in specific zones. Optimization could be enhanced by the ability to adjust the layout dynamically and more frequently. Such possibilities are feasible with the integration of BI tools and the internet of things (IoT) concept, using digital layout markers in the warehouse. Implementing these tools at an operational, daily level could further enhance cross-dock optimization.

## 6 CONCLUSION

This study demonstrated the effectiveness of integrating cross-dock operation data with Microsoft Visio for optimizing warehouse layouts. The visualization of data in the layout provided a clear understanding of the operations in each sorting zone, enabling more effective analysis and informed decision making. The application of the distance optimization technique resulted in a noticeable reduction in total travel distance within the warehouse, thereby improving operational efficiency and reducing costs. This research underscores the significance of data visualization in warehouse management and its impact on managerial decision making and optimization efforts.

The methodology employed in this study, which combined Microsoft Visio and Microsoft Power BI, proved to be both cost-effective and efficient. The results indicate that the optimized layout not only enhances operational efficiency but also significantly reduces costs associated with travel within the warehouse. These findings provide valuable insights for warehouse managers and could potentially guide future decisions regarding warehouse layout design and operations management.

Despite the advancements presented in this study, there remains a notable gap in the literature regarding the utilization of BI tools for cross-dock optimization. While BI is widely recognized for its value in various data-driven business fields, its application in cross-dock operations is underexplored. Future research should focus on developing and testing more advanced BI tools and methodologies tailored specifically for cross-dock environments. Additionally, exploring the integration of BI with other OR methods could further enhance decision making processes and operational efficiency in warehouse management.

Moreover, there is a need to investigate the scalability of the proposed methodology in different warehouse settings and with varying operational data. This could include examining the impact of different types of data visualization tools and techniques on the optimization process. Another potential area of research is the exploration of dynamic layouts that can adapt in real-time to changes in warehouse operations, further enhancing efficiency and responsiveness.

Furthermore, future studies could benefit from a deeper analysis of the specific factors that influence the effectiveness of BI tools in cross-dock optimization. This includes understanding the role of data quality, user training, the IoT concept and system integration in achieving optimal results. Addressing these gaps will not only advance the field of warehouse management but also provide practical solutions for improving cross-dock operations in various industrial contexts.

## ADDITIONAL INFORMATION AND DECLARATIONS

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**Author Contributions:** J.A.: Methodology, Data curation, Formal analysis, Writing – Original draft preparation, Writing – Review & editing. J.D.: Writing – Original draft preparation, Conceptualization, Supervision.

**Statement on the Use of Artificial Intelligence Tools:** Artificial intelligence tools were utilized for language editing and proof-reading. The authors are fully responsible for the integrity and accuracy of the content presented in this manuscript.

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