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The Black Hole of Transport Logistics Efficiency: A Multi-Method Study on Yard Management

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ABSTRACT

Yard management is crucial for warehouse efficiency, as it accelerates and aligns incoming and outgoing material flows at these sites. This is especially relevant in modern logistics and supply chain management because recent market trends demand increasing product assortments, which must be produced, processed, and delivered in ever shorter times. While efficiency improvements within warehouses have received considerable interest in operations management research, prior studies have generally failed to establish how to design and evaluate processes at warehouse sites. Research on decision prioritisation regarding critical sub-processes in yard management could offer interesting new insights, helping to increase overall warehouse efficiency through the prioritisation of critical optimisation sub-processes. Accordingly, this paper examines the prioritisation and evaluation of critical yard sub-processes for efficient yard management at warehouse sites. A multi-method research approach is applied, combining analytic hierarchy process (AHP) interviews with a detailed literature review and quantitative empirical data analysis to allow for triangulation of the results to develop theoretical contributions and practical implications. Five critical yard sub-processes are identified and prioritised: management of the shunting system, registration at the gateway, allocation of trucks to gates/parking spaces, removal of a transport unit from the gate, and exit control.

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1. INTRODUCTION

Increasing customer demands and the valorisation of industrial land require logistic firms to improve their operational performance in order to remain competitive in the post-COVID-19 era. For example, logistics service providers (LSPs) are facing an increase in road transportation volumes. The freight volume of road transport in the UK increased from 139,536 ton kilometres to 165,499 ton kilometres (+19%) from 2009 to 2019 [1]. In Germany, the average transportation volume per day at a reference warehouse amounted about 350 to 500 full truckloads (FTL) in 2009 [2]. About ten years later, the transportation volume of a comparable hub exceeded 750 FTL per day [3]. The proportion of road transport demand in relation to supply was 60% in Europe in February 2021. One year later, this proportion increased to 73% [4]. Another indicator of the growth in the logistics sector is the market for warehouse space and logistics areas. In Germany, 4.78 million square metres of warehouse space and logistics areas were built over the first half of 2022, which represents the highest amount of warehouse space and logistics areas that were built within a half-year in the country's history [5].
Besides increasing transportation volumes, warehouse sites must also deal with limited industrial land, which is still not sufficient to cover all the transport volume demands despite the increase of the offer of warehouse space [13]. Further, the lack of continuity in data exchange between LSPs and other supply chain actors hampers the efficient management of scarce resources, representing another ongoing challenge for LSPs [6]. The abovementioned challenges underline the importance of integrated and optimised management of interface processes, such as yard management, to ensure synchronisation between adjacent supply chain processes [7]. Synchronising transportation

and warehousing activities through effective yard management could improve efficiency in the transportation process.

Yard management links transportation with intralogistics at warehouse sites. The purpose of yard management is to ensure regular capacity utilisation of the warehouse [8] and represents the bottleneck of transportation operations at one specific location [9]. Therefore, process consistency and maximum transparency must be ensured to prevent a warehouse performance decrease. Poor yard management can lead to long waiting times for trucks at checkpoints and gates, incorrect allocation of trucks to the depot gates, and delays in loading and unloading activities.

To optimise yard management processes, individual characteristics of movable and immovable objects must be considered. The types and numbers of movable objects depend on the organisation of the logistics network. Shunters, swap bodies, tractor vehicles, and semi-trailers are examples of such movable objects [14]. Further, the layout and size of the yard as well as the purpose and details of the production process determine the yard management [15]. The organisation of the logistics network must consider the characteristics of the transported goods (e.g. stackability) and the frequency of transport [16]. To illustrate the specific focus on yard management at warehouse sites, Figure 1 displays a layout of a yard at a warehouse site [42]. This example includes a rectangular warehouse and different participants, including shunting vehicles, swap bodies, semitrailers, and transporters. In addition to different vehicle types, the characteristics of the transported goods (e.g. refrigerated, hazardous materials) are illustrated. Petrol and charging stations could also be part of the yards at warehouse sites and require safety precautions. The same applies for construction works. Within the illustrated yard a one-way street regulation appears as a traffic regulation.

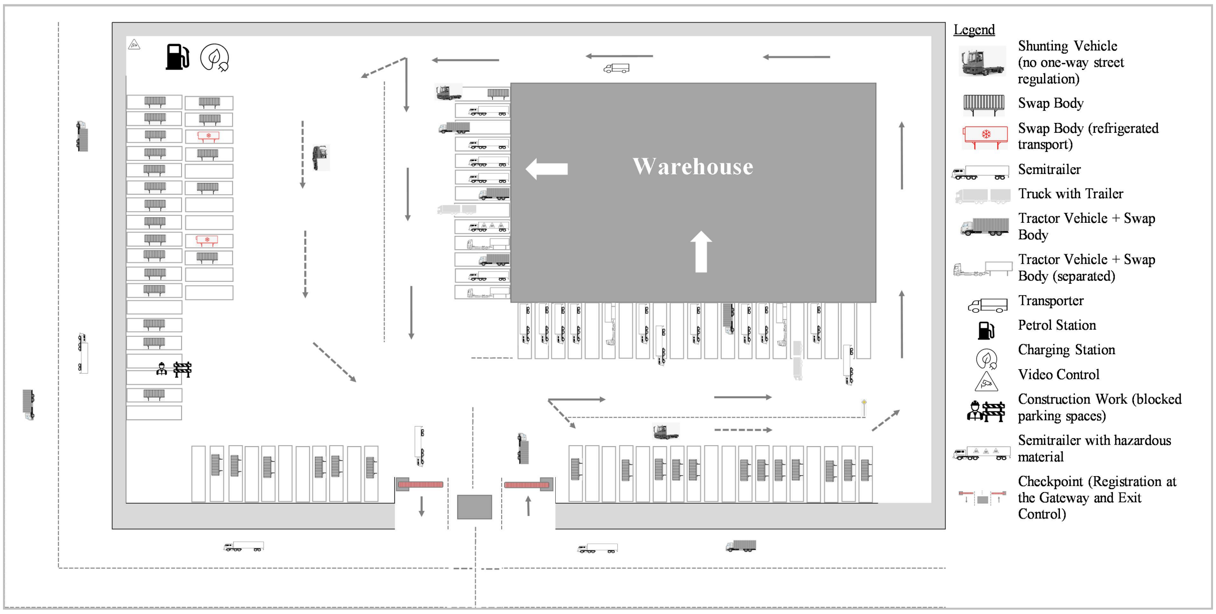

Fig. 1. Example illustration of a yard at a warehouse site

This example illustration shows the typically high level of complexity involved. Key developments, challenges, and opportunities associated with yard management have evaluated previously [6]. The deficiency of drivers and skilled professionals is a central factor that influences yard management [17]. Moreover, yard management faces challenges related to demographic change, especially in relation to physical and operational activities [6]. Therefore, sub-processes within the yard must be prioritised while optimising yard management. The prioritisation of sub-processes provides an order for optimisation based on their significance to the whole yard process, thus improving warehouse efficiency.

Research has focussed on the optimisation of port container terminal yards [43, 44]. Nevertheless, port container terminal yards are not comparable to yards at warehouse sites, especially due to the size restriction. The layout, operations, and stakeholders of port container terminal yards within port operations are also not transferrable to trucking yards at warehouse sites. Yard management in port operations (e.g. with container terminals) has been a focus of existing research due to size and visibility, whereas yard management at warehouse sites has received less attention [45]. Moreover the opportunity to increase the efficiency of logistics processes in warehouse sites through yard management optimisation has received little attention from researchers or practitioners. Instead, companies are prioritising the improvement of other processes and areas, such as transportation and intralogistics, for example, through investments in new trucks, innovation fleet management systems, or new warehouse management systems. For this reason, yard management is also known as the 'black hole' of the supply chain [7, 12, 13].

However, the literature on warehouse efficiency has generally failed to consider that warehouse sites are responsible for more than receiving and picking products based on customer orders. Given that a majority of transports volume are now pre-loaded on swap bodies and containers, the link between intralogistics and transportation at warehouse sites is highly relevant. The lack of research attention on this issue is problematic, as homegrown theories in operations management propose cross-functional material flow perspectives [65]. Therefore, a complete theoretical and practical accounting of warehouse efficiency must include yard management, linking transportation with intralogistics at warehouse sites.

This paper provides detailed insights on the yard sub-processes that are critical for efficient yard management, identifying priority sub-processes. The paper aims to answer the following overarching research questions: What sub-processes within yard management are classified as critical? How is yard management, and therefore warehouse efficiency, influenced by these critical sub-processes and their corresponding criteria? Therefore, the specific contribution of this paper is the application of a multi-method design to triangulate the results. The methods applied include a structured literature review, a quantitative empirical data analysis, and an analytical hierarchy process (AHP). (A) The literature review examines the field of yard management to provide an initial overview of the research and to identify critical yard sub-processes. (B) The quantitative empirical data analysis seeks to add the operational transportation practices view to the overview of yard management. Additionally, this method aims to develop and evaluate criteria for yard management. (C) The prioritisation of the identified critical yard processes based on estimations by practitioners as well as the development and prioritisation of further evaluation criteria are targeted by the AHP. (D) The results of the three methods are then combined to answer the overarching research questions (triangulation). In addition, triangulation enables combining theoretical research with empirical data. The combination of the three described methods through triangulation represents a new approach in the research on field yard management at warehouse sites. Here, an exploratory interview method resulting in initial, explanatory approaches is conducted, which makes a combination of exploratory, explanatory, and structured methods necessary for triangulation.

This paper is structured as follows: The detailed literature review is presented in Section 2, and the methodological approach of the AHP is outlined in Section 3, along with the five identified critical yard processes, the prioritisation of these processes, ant the evaluation criteria. The quantitative data analysis is discussed in Section 4. The triangulation of the results is presented in Section 5. The results are discussed in Section 6, followed by the conclusion of the paper in Section 7.

2. LITERATURE REVIEW

To highlight the positioning and contribution of the study, we review the relevant literature on yard management at warehouse sites while explicitly considering critical yard sub-process. Existing studies and contributions were selected, evaluated, and summarised [24]. A systematic review was utilised since it is a transparent, scientific, and reproducible methodological approach that strives to diminish bias [25]. In this paper, the systematic review process was adapted to the field of management and organisation studies [24].

2.1. Review Methodology

The systematic review process carried out in this paper was based on the five steps suggested by Denyer and Tranfield [24], that will be presented and discussed in Sections 2.1 and 2.2. Section 2.3 concentrates on the identification of the critical sub-processes, while Section 2.4 considers the research gaps. The literature review started with the *question formulation*. The quality of research questions is fundamental to the quality of the results of a review and improves its applicability [26]. Hence, this first step of the literature review sought to lead to the formulation of a specific, unbiased, extensive, and significant question [24]. Consequently, the following question was designed for the literature review within this paper: How does the scientific literature consider yard management at warehouse sites in terms of identifying critical yard sub-processes?

The purpose of the second step was to *locate the studies*. First, it was necessary to identify all potentially relevant keywords and literature search strings using Boolean connectors (AND, OR). Several sources were used for searching the literature (databases, literature search engines, recommendations from experts, etc.) [24]. The keywords and Boolean connectors used in this paper are presented in Figure 2.

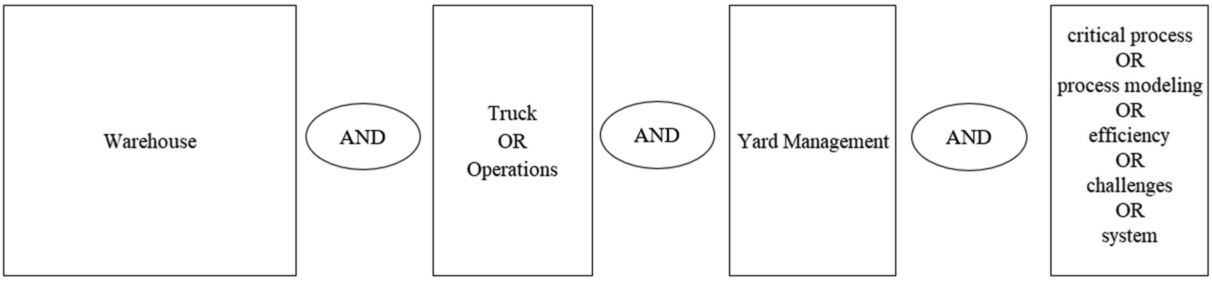

Fig. 2. Search strings for the literature review

Several literature search engines (Science Direct, EBSCOhost, Google Scholar) and electronic journal databases (Transportation Research Part D + E, Transportation Science) were used to search for publications. To ensure an encompassing review, all types of studies were examined, including academic papers, conference papers, articles in non-peer reviewed journals, discussion papers, and other grey literature [24], resulting in 33 publications. Although, the number of search engines and electronic databases was high, the number of considered publications was low, which reflects the research gap within yard management at warehouse sites.

The third step, *study selection and evaluation*, focussed on the relevance of the searched literature to the research questions. The assessment of relevance was based on explicit criteria for the inclusion or exclusion of sources. The criteria also addressed the principle of transparency within the review process [24]. In the first exclusion round, two criteria were applied. Publications that were listed more than once (duplicate) (1) and that were not academic papers (3) were excluded. The year of publication was not an exclusion criterion because the literature review also targeted the research development of yard management over the years. After the first exclusion round, 29 publications were selected for full-text screening in the following step. In this step, the publications were examined to determine whether they were missing the consideration of yard management at warehouse sites, resulting in 28 publications, which form the basis for the literature analysis and synthesis (the publications are listed at the end of the reference).

2.2. Descriptive Analysis and Synthesis

The last two steps of the systematic review were the *analysis and synthesis* and *reporting and using the results*. The emphasis of the analysis was to examine the constituent parts of the sources and outline the relation of the individual sources. Meanwhile, the aim of the synthesis was to highlight associations between the identified parts of the studies. The analysis and synthesis were thus connected processes within the systematic review. This paper distinguishes between descriptive and thematic analysis and synthesis. The examination of general descriptive characteristics was the focus of the descriptive analysis and synthesis, while the classification of the contents of the selected sources was based on the thematic analysis and synthesis [24].

The number of publications on yard management at warehouse sites peaked in 2020. However, the overall publication numbers as well as the number of publications per year are significantly low compared to other structured reviews [23]. For example, in 2020 four publications were released on this research topic, representing the highest number of publications per year. Overall, an increasing interest in this topic can be seen. Of all the publications, 68% were released in the second half of the considered period (2011–2022). Within the first half of the considered period (1999–2010), the peaks in the number of publications per year are mostly followed by decreases. This indicates a lack of strategic and continuous considerations of yard management, consistent with the notion of yard management as a 'black hole' of supply chain research. A detailed distribution of the number of publications per year is presented in Figure 3.

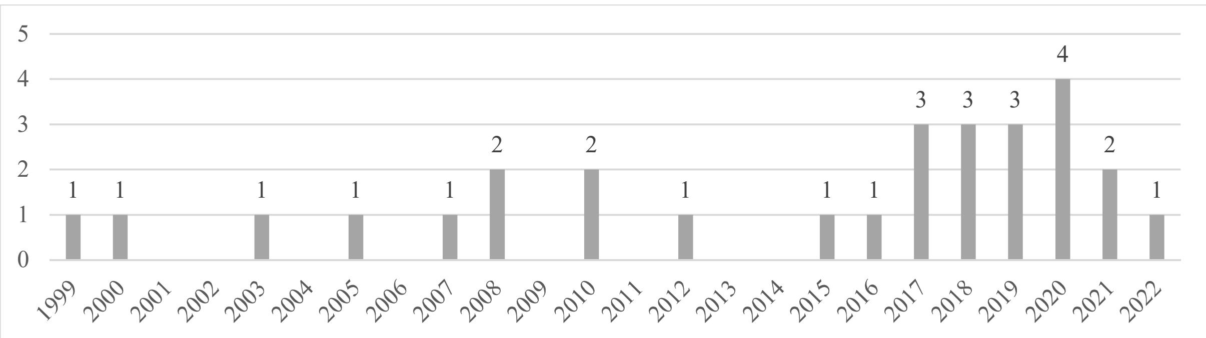

Fig. 3. Number of publications per year

Besides the number of publications per year, the publications can also be divided into the number of publications in comparison to the geographical location of the 1st author's research location. Special emphasis should be placed on the high number of publications from the USA and Germany. Five publications are published in both countries, accounting for 37% of the total publications. The second-highest number regarding the author's research location were published in Iran and Thailand (3 publications), followed by China (2 publications). Overall, 14 different research locations are found. The high number of publications in the author's research location is associated with the high number of top logistics companies in the different countries. For example, the headquarters of three of the 10 top logistics companies based on revenue are in the USA, while two of the top ten logistics companies are based in Germany [55]. Figure 4 shows a representation of the different countries, with the intensity of the colours indicating the relative number of studies.

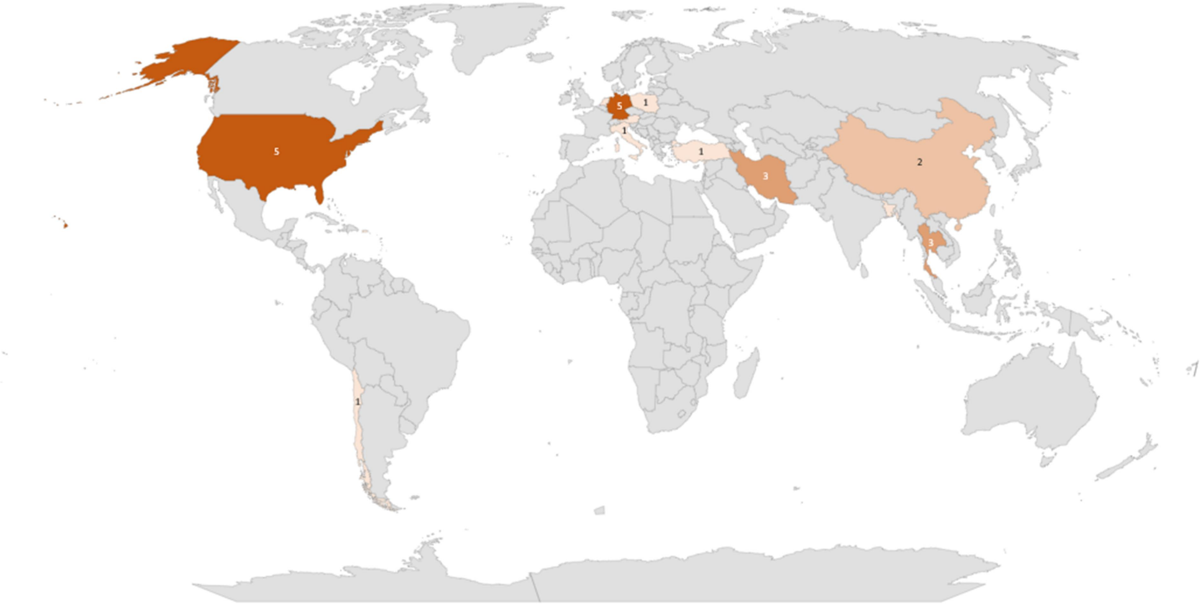

Fig. 4. Number of publications in comparison to the geographical location of the 1st author's location

2.3. Thematic Analysis and Synthesis

The thematic analysis was divided into two parts. The first part included the number of studies and the methodological approaches used. The considerations and first implications of critical yard sub-processes were evaluated in the second part.

The different methodological approaches used in the reviewed publications painted a broad picture. The predominant approach was the use of mathematical models in general (8 listings). Heuristic solutions as well as mixed integer programming were used in four publications. The use of case studies (3 listings) and simulations (2 listings) was significantly lower than the detailed use of mathematical models (20 listings, e.g., mixed integer programming). The other approaches, such as DMAIC (define, measure, analyse, improve, control) or decision support tools, were used in only a few studies. Figure 5 shows the distribution of the individual approaches. It must be noted that mixed-methods research was not utilised in any of the publications.

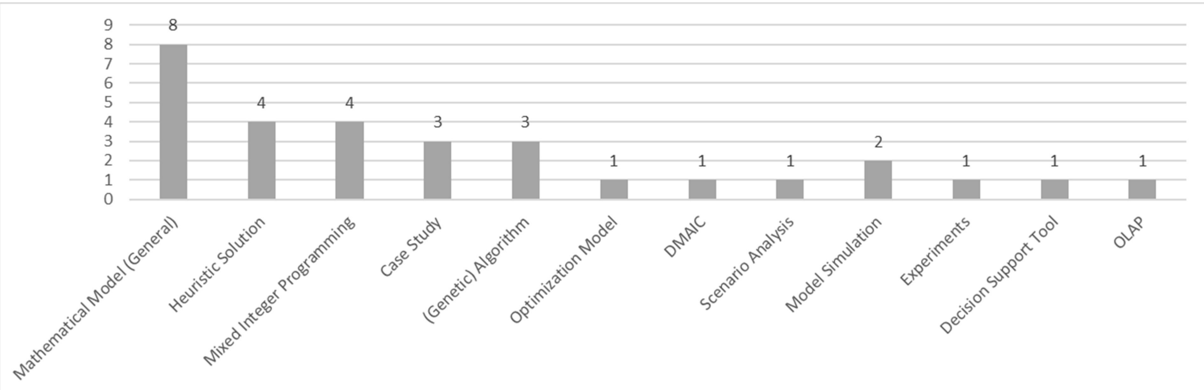

Fig. 5. Number of listings per methodological approach

In the second part of the thematic analysis and synthesis, the papers were analysed regarding the identification of critical yard sub-processes. Specifically, the focus of the studies was figured out by comparing the number of considerations of each yard sub-process. The sub-process *Assignment of trucks to parking spaces/gates/slots* (17 considerations) had the highest number of considerations, followed by the sub-process *Scheduling of trucks* (11 considerations). The sub-processes *Material flows within the yard* and *Registration at the gateway* were evaluated in four papers. The Interface between the warehouse and the yard regarding waiting times at the loading and unloading ramps was mentioned in three papers. Two papers considered the sub-process *Exit control*. Other sub-processes, such as *Decision of yard manager* and *Truck-door operations*, were assigned minor importance due to having the lowest number of considerations. Figure 6 summarises the number of considerations of all the yard sub-processes.

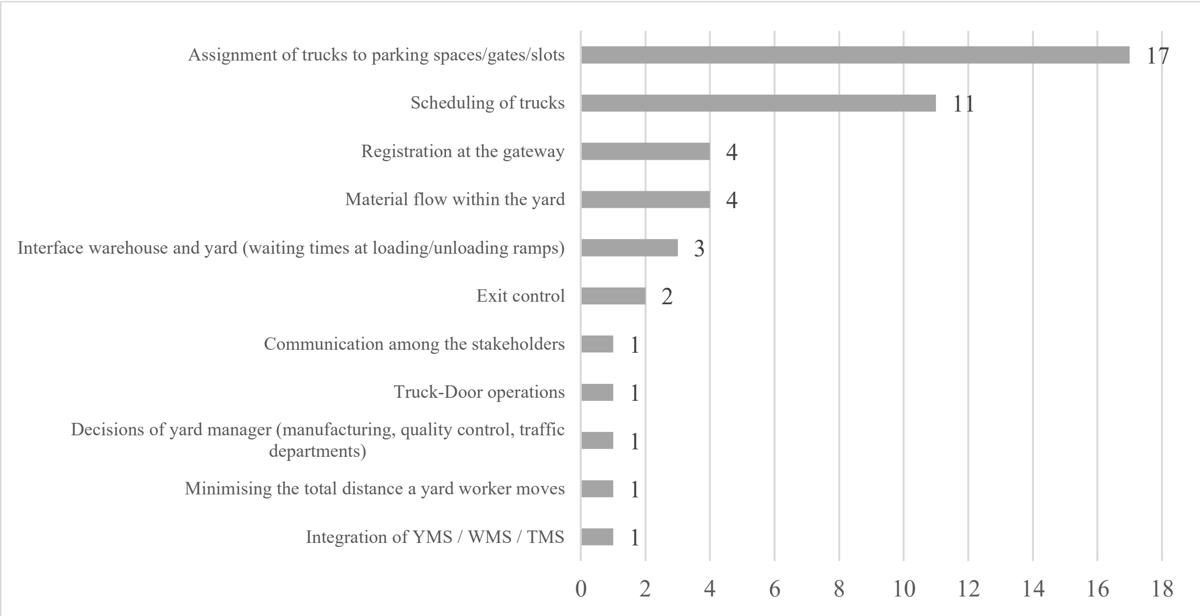

Fig. 6. Number of considerations of yard sub-processes

Based on the 11 critical yard sub-processes derived from our literature analysis and synthesis, five major targets for warehouse efficiency improvements were identified: (1) *Allocation of trucks to gates/parking spaces*; (2) *Management of the shunting system*, which can be facilitated by the mentioned sub-process material flows within the yard and truck scheduling; (3) *Registration at the gateway* and (4) *Removal of a transport unit from the gate*, which can be considered as critical parts of the interface between the warehouse and the yard; and (5) *Exit control*, which is also a critical yard sub-process.

Despite the low number of publications, the various irregular peaks in the number of publications per year underline the lack of constant strategic considerations of yard management in research as well as in business practice. Overall, the literature review illustrates why yard management is considered the 'black hole' of the supply chain.

Because the existing publications provided a limited understanding of yard management, the following Section includes an application of the AHP method. The use of AHP is related to the prioritisation of critical yard management factors evaluated in the literature review. Combined with the literature review, and a following quantitative analysis triangulation is implemented based on the multi-method research approach used in the current paper. Triangulation, based on multi-method research, is also missing in the studies examined in the literature review.

3. ANALYTICAL HIERARCHY PROCESS ANALYSIS

3.1. Methodological Approach

The prioritisation and evaluation of the critical yard sub-processes identified in the literature review presented here was based on the AHP. A multi-criteria decision analysis (MCDA) tool was used to rank the critical sub-processes and the criteria. This prioritisation and evaluation of critical yard sub-processes aimed to answer the overarching research question: How is yard management in warehouse sites influenced by critical yard sub-processes and their specific criteria?

The AHP method was developed by Thomas Saaty in the 1970s. In contrast to other multicriteria methods, AHP involves a complicated mathematical process [31]. The focus of AHP is on structuring a problem and its solution. Moreover, this method emphasises a relative assessment of decision alternatives based on pairwise comparison [32]. AHP has a wide range of possible applications—from structured scientific solutions to the Israeli–Palestinian conflict to the selection of suitable hub locations [33, 34]. At the beginning of this analysis, the problem was defined. Next, the main criteria and sub-criteria for evaluating the critical yard sub-processes were selected. In addition, the hierarchy was designed. Experts were then asked for their assessments regarding the pairwise comparison of the criteria as well as the sub-processes in this paper [34]. The estimations were obtained through a questionnaire based on a template [35], which was also used for calculating the rankings. For the assessments, each criterion/sub-process was compared to other criteria/sub-processes of an equal hierarchical level. In this way, a scale of measurement was established. In this paper, a common scale (1–9 points) was used [36], and the priorities were determined using the eigen vector method [37]. Prior to implementing the results, the consistency of the pairwise comparison must be verified [34]. To perform a consistency check, a consistency ratio (CR) was calculated, with a value around or below 10% considered insignificant [38].

The ability to structure complex problems is one of the advantages of the AHP method. Moreover, quantitative and qualitative criteria can both be included in the decision-making process. Further, AHP has a wide range of applications [32, 39, 40]. By using AHP, objectives for individual priorities can be quantified, facilitating transparency [39]. Criticism of AHP includes the personal subjectivity of the experts within the pairwise comparison. To counteract this subjectivity in this study, a consistency check was applied [41]. In addition, there may be issues with the selected scale, as it is sometimes complicated and difficult to differentiate between the levels of the scale. Moreover, a different scale could lead to a rank reversal [41]. In sum, due to its wide range of applications, AHP was considered suitable for prioritising critical yard sub-processes and their evaluation criteria. In addition, the application of AHP in this paper made it possible to include different experts and helped to ensure transparency in the calculations.

3.2. AHP Prioritisation

Prior to the prioritisation of critical yard sub-processes and their evaluation criteria, the critical yard sub-processes and their criteria must be identified. Five critical yard sub-processes were identified in the literature review: registration at the gateway, allocation of trucks to gates/parking spaces, exit control, removal of a transport unit from the gate, and management of the shunting system.

After identifying these five critical yard sub-processes, evaluation criteria were developed based on an argumentative analysis of yard management and its internal and external factors. Six criteria and 24 sub-criteria were identified. To clarify the selection of the sub-criteria, their key arguments and references are presented in Table 1.

Table 1. Key arguments for the sub-criteria

Sub-criteria	Key argument	Reference
Customer satisfaction	Corporate loyalty	Smyrlis 2008 [57]
On-time delivery	Crucial competitive advantage	Vahrenkamp 2012 [19]
Flexibility (relating to other customer requirements)	Customer satisfaction	Scholz et al. 2019 [6]
Transparency of costs	Prerequisite for optimisation	Jenne and Noche2016 [58]
Theft protection	High costs caused by theft	BAG 2016 [59]
(Avoidance of) idle times	Costs	Bichler 2017 [60]
Work ergonomics	Physically demanding operating activities	Scholz et al. 2019 [6]
(Avoidance of) work accidents	Occupational safety, health	DGUV 2017 [61]
Control of vehicle data	Prevention of vehicle breakdown	BG Verkehr 2012 [62]
Data availability	Prerequisite for follow-up processes	Terreri 2007 [47]
Data protection	Legal regulation, reputation	Bousonville 2017 [63]
Forecast quality	Basis for the operational planning	Tunstall and Muynck 2019 [64]
Visualisation	Crucial for the management in the yard	Scholz et al. 2019 [6]
Tracking of (moveable) objects	Crucial for the management in the yard	Scholz et al. 2019 [6]
Plausibility check	Avoidance of inefficient follow-up processes	Doherty 2007 [18]
Communication	Process stability, avoidance of work accidents	Neumann and Szewczyk 2008 [15]
Productivity	Costs	Bichler 2017 [60]
Processing time	Costs, on-time delivery	Posluschny 2007 [19]
(Avoidance of) idle and short downtimes	Costs, productivity	Brombacher 2013 [20]
(Avoidance of) search processes	Processing time	Brombacher 2013 [20]
(Avoidance of) backlogs	Limited capacities, customer satisfaction	Kruse and Wittberg 2008 [21]
Energy efficiency	Costs, environmentally friendly	Wehking 2020 [22]
Vehicles empowered by renewable energies	Environmentally friendly	Wehking 2020 [22]
Process stability	Sustainable process	Scholz et al. 2019 [6]

The first level of hierarchy of AHP is the research issue here (prioritisation of critical yard sub-processes and evaluation criteria). The criteria and their sub-criteria represent the second and third levels of the hierarchy. The fourth level includes the alternatives to the research issue, which in this context are symbolised by the critical yard sub-processes. The prioritisation of individual levels was based on the estimations of six experts. The experts are employed by a large German brick-and-mortar grocery retailing company, which also provided the data for the quantitative data analysis. To ensure the internal validity of the results, the focus was on different experts and not on a high number of companies. The different roles of the six experts are presented in Table 2.

Table 2. Role of the AHP experts

Expert	Role
1	Head of Department Incoming
2	Transportation Manager
3	Operations Manager
4	Team Lead Yard Management
5	Transportation Manager
6	Transportation Manager

Prior to the precise analysis of the prioritisations, the CR was determined. Each level other than the second had a CR below the 10% level, which was considered insignificant. However, the second level had a CR of 25.0%, indicating significant inconsistency. For the third and fourth levels, the highest CR was 7.0% (prioritisation of the sub-criteria regarding information transparency). The CR of the sub-criteria of criterion efficiency (third level) had the lowest CR (1.3%). Overall, the inconsistencies of the prioritisations were negligible, except for the second level. Due to the small deviation, the results were considered significant. Figure 7 shows the prioritisation of the individual levels (local), including the CR, presented in the form of a hierarchy.

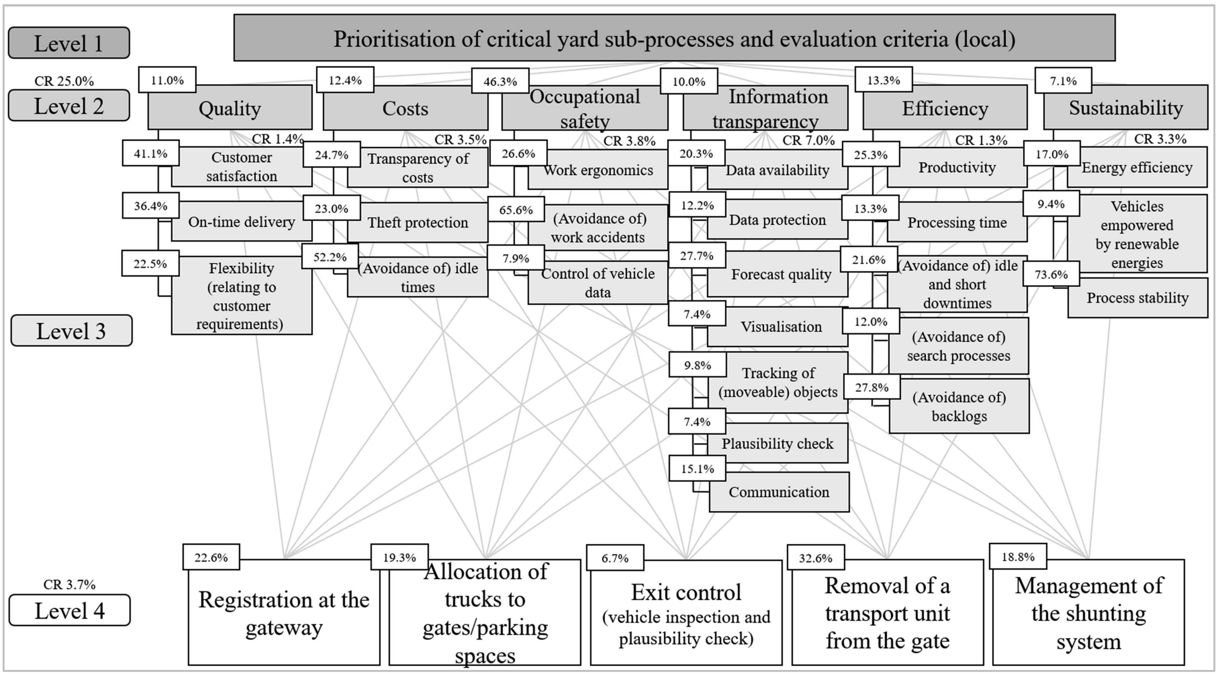

Fig. 7. Prioritisation of the critical yard sub-processes and evaluation criteria (local)

According to Figure 7, the removal of a transport unit from the gate was considered particularly crucial (32.6%), followed by registration at the gateway (22.6%). With a value of 19.3%, the allocation of trucks to gates/parking spaces was considered less critical than registration at the gateway. The management of the shunting system (18.8%) as well as the exit control (6.7%) had the least significance for the entire yard process and its follow-up processes.

The occupational safety criterion was the most significant (46.3%). The efficiency (13.3%) and costs (12.4%) criteria received significantly less priority than occupational safety (46.3%), followed by quality (11.0%). Information transparency (10.0%) and sustainability (7.1%) were also given minor importance. The ranking of the sub-criteria within an individual criterion was not the focus here. Rather, the emphasis was on comparing all the sub-criteria. In preparation for this comparison, the global prioritisation of the sub-criteria had to be calculated. This was done by multiplying the local third level prioritisations by those of the second level [31]. This categorisation was based on the principles of ABC analysis. Therefore, the sub-criteria were classified according to the following boundaries: 70%, 20%, and 10% (classical boundaries in an ABC analysis). Table 4 shows that the first eight sub-criteria sum to a total prioritisation of 70.3%. Hence, they were the most important criteria, corresponding to the A criteria. The seven following sub-criteria account for 19.4% of the total prioritisation, and thus they were considered B criteria. The last nine sub-criteria had the least importance (10.4%) and were classified as C criteria. In particular, the high prioritisation of the sub-criterion (avoidance of) work accidents should be noted (30.4%). The following sub-criterion, work ergonomics, was given far less priority (12.3%). The difference in prioritisation between the other sub-criteria was quite low, with a maximum of 5.8%. Plausibility checks and renewable energy were the least important considerations in the evaluation of yard processes.

Table 3. Prioritisation of the sub-criteria (global)

Sub-criteria	Prioritisation
(Avoidance of) work accidents	30,37%
Work ergonomics	12,32%
(Avoidance of) idle times	6,47%
Process stability	5,23%
Customer satisfaction	4,52%
On-time delivery	4,00%
(Avoidance of) backlogs	3,70%
Control of vehicle data	3,66%
Cumulative sum	70,27%
Productivity	3,36%
Transparency of costs	3,06%
(Avoidance of) idle and short downtimes	2,87%
Theft protection	2,85%
Forecast quality	2,77%
Flexibility (relating to customer requirements)	2,48%
Data availability	2,03%
Cumulative sum	19,43%
Processing time	1,77%
(Avoidance of) search processes	1,60%
Communication	1,51%
Data protection	1,22%
Energy efficiency	1,11%
Tracking of (moveable) objects	0,98%
Visualisation	0,74%
Plausibility check	0,74%
Renewable energies	0,67%
Cumulative sum	10,33%

In conclusion, five critical sub-process, six criteria, and 24 sub-criteria were identified and prioritised. Certainly, the method used had some problems regarding the subjectivity of the pairwise comparison. However, the CR values at the individual level were almost all below 10% (except for the second level), indicating a low risk of inconsistency.

4. QUANTITATIVE ANALYSIS

Drawing on the literature review from Section 2 and the AHP from Section 3, we shift to a quantitative data-driven analysis as a third element of our triangulation approach in this Section. For this purpose, we obtained a unique large-scale dataset in cooperation with a large German brick-and-mortar grocery retailing company. The focus is on the yards of four different warehouses. The data were requested by the researchers using a prepared template, ensuring standardisation within the data collection process. Additionally, the individual components of the template were explained during an appointment with those responsible for the four different warehouses. The data were used to gain a first overview of the individual requirements of the yards and their activities. The raw data consisted of general organisations and circumstances, the number of transports per day, and the average duration of a transportation process. The data were collected for a one-month period for Warehouses A and C and, for a one-week period for Warehouses B and D. The data included numbers of transports per day and average durations of transportation processes. An evaluation and presentation of the collected data follows.

First, the general organisations and circumstances of the individual yards are presented. Almost all of the warehouses operate six days per week with two shifts per day. Warehouse C is an exception: It operates seven days per week in three shifts per day. The number of employees is 470 (+ 250 third-party service providers) in Warehouse B, approximately 600 in Warehouse A, and more than 500 in Warehouse C. Most employees in Warehouse D are involved in yard management. It has 17 employees (1 team manager, 12 drivers, and 14 un-/loader). The warehouses do not differ in terms of the shape of the warehouse (square shape). It should be noted that Warehouse D consists of two separate warehouses. However, the yards vary in size, with the smallest being 28,000 qm² (Warehouse B) and the largest 200,000 qm² (Warehouse D). The number of gates is related to the yard size. The characteristics of the transported goods are also recorded in the dataset. The yard process of Warehouse B is focussed on refrigerated transport, whereas in Warehouse D, most goods have a uniform size and do not require refrigerated transport. The transported goods of Warehouse A are partly perishable. The transported goods of Warehouse C are also categorised as perishable, temperature sensitive, and stackable. The data are summarised in Table 4.

Table 4. General organisations/conditions of the considered warehouses

Warehouse	Number of Employees	Yard size [qm²]	Shape of the warehouse	Number of gates	Characteristics of the transported goods
Warehouse A	approx. 600	90,000	square shape	148	partly perishable goods
Warehouse B	approx. 470 + 250 third-party service providers	28,000	square shape	109	refrigerated transport, fragile, food
Warehouse C	> 500	135,000	square shape	146	perishable + temperature- sensitive goods, stackable
Warehouse D	yard management (1 team manager, 12 drivers, 14 un-/loader)	200,000	square shape (two separate warehouses)	211	no refrigerated transport, predominant uniform size

Next, the individual yards are compared in terms of the number of transports per day and the average duration of the transportation process. The point when a unit starts moving is classified as the beginning of the transportation process. The transportation process is separated into the outgoing, incoming, and internal transports. Outgoing transports are those that lead to the removal of units from the yard, whereas incoming transports involve units entering the yard. For example, shunting processes within the yard are defined as internal transports. Here, the data are characterised based on the yard size. It was hypothesised that *A huge yard leads to a greater number of transports per day and a longer average duration of transportation process*. Figure 7 shows to the number of transports per day.

The number of outgoing transports is higher than the number of incoming and internal transports, with the notable exception of Warehouse D, which has 535 internal and 180 incoming transports per day. Warehouse D consists of two separate warehouses, which is one reason for the high number of internal transports per day. The average number of outgoing transports per day is 228, while there are 1533 incoming and 190 internal transports per day. The yard size is related to the total number of transports per day for all warehouses except Warehouse B. For example, the total number of transports in Warehouse B is 380 per day, whereas Warehouse A has at least 318, despite having a yard size that is more than three times larger. The results are presented in Figure 8.

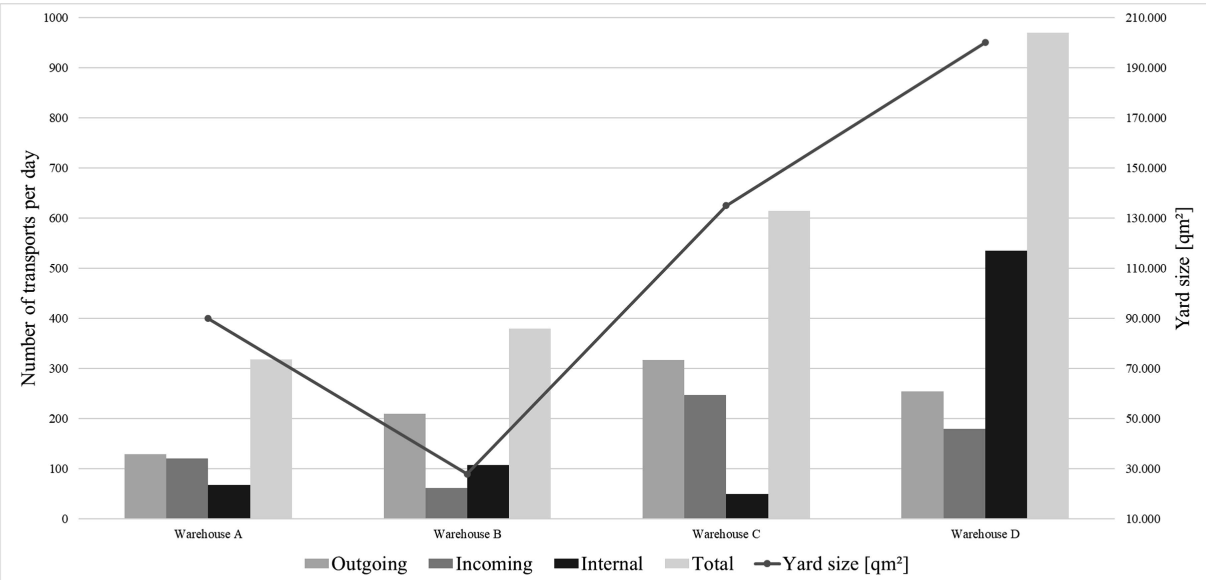

Fig. 8. Number of transports per day

Next, the average duration of a transportation process (min) is compared. The data are not complete, indicating that the companies prioritise areas other than yard management. The shortest transportation duration is 00:48 minutes (internal transportation in Warehouse A), whereas the longest is 07:00 minutes (outgoing transportation in Warehouse C). The average transportation duration in Warehouse B does not distinguish between the individual processes (05:30 minutes) and includes a circuit as well as one-way street regulation. In Warehouses C and D, the average duration of the outgoing transportation process is longer than the average duration of the incoming and internal transportation processes.

Specifically, the average duration is 06:17 minutes for an outgoing transport, 03:50 minutes for an incoming transport, and 03:50 minutes for an internal transport. There is no clear association between yard size and the average duration of the outgoing transportation process. On one hand, in Warehouses A, B, and C, yard size is associated with the average duration of the outgoing transportation process. On the other hand, the average duration of the outgoing transportation process in Warehouse D is shorter than the average duration of the outgoing transportation processes in the warehouses with the second and third largest yard sizes, although the yard size in Warehouse D is the largest. Segmentation in large yards could explain this result. The comparison of the average duration of the transportation processes is shown in Figure 9.

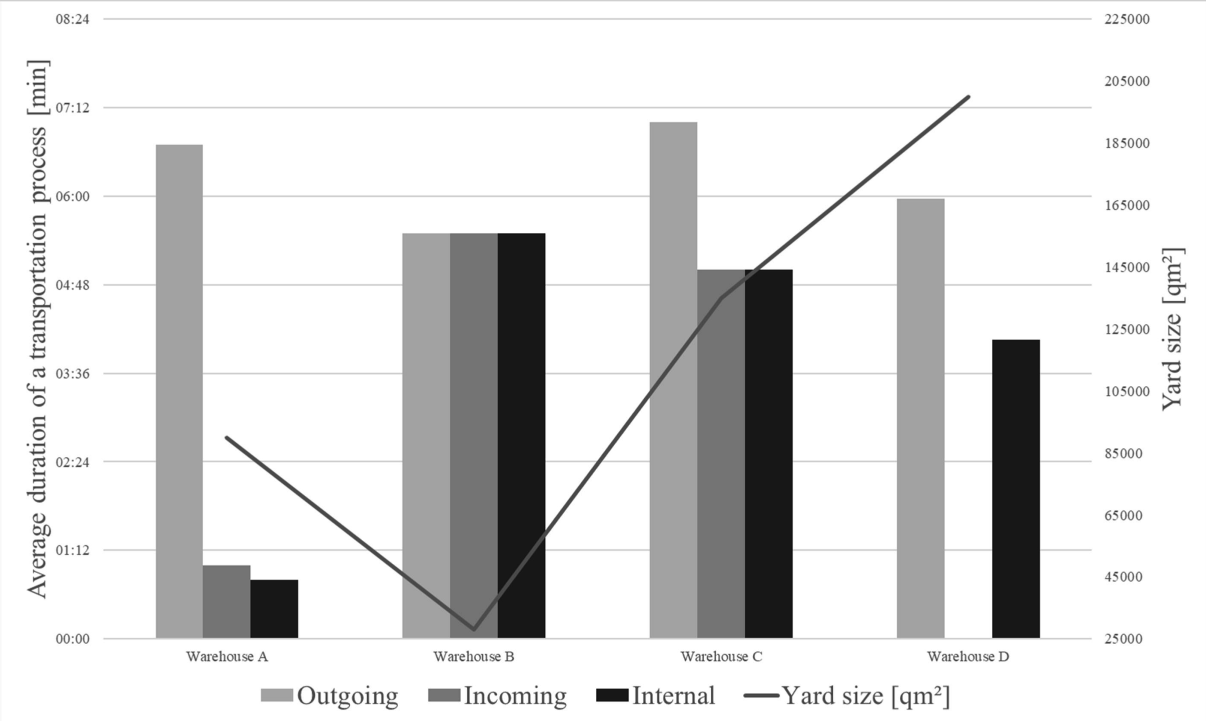

Fig. 9. Average duration of a transportation process [min]

Different warehouses have unique circumstances that affect yard management. The perishability of goods does not have a significant impact on the average transportation duration. For example, the average outgoing process time in Warehouse B is at least 28 seconds shorter than that in Warehouse D. Yard size does not determine the quantitative factors of yard management, as the largest yard has shorter transportation processes than two smaller yards. Moreover, the number of employees does not indicate interconnections between different yards. Yard management depends on circumstances related to the individual location, and yard management in a huge yard may be prioritised and optimised more than in smaller yards.

Moreover, the lack of data reflects the company's negligible considerations related to yard management. It must be noted that the data are based on the warehouses of one company. This could lead to smaller differences in the data than might occur for other companies because the strategic transportation approach applies as equal. Hence, data on different companies and logistics networks should be examined in future research. Additionally, the data collection periods varied between the different locations, and a uniform data collection period could increase the validity of the data.

Overall, the quantitative analysis of the empirical data reflects the individual circumstances of different yards and the companies' considerations related to yard management. Further, the empirical analysis provides an overview of current yard management practices and provides initial approaches for the evaluation of criteria for yard management.

5. TRIANGULATION DISCOURSE

The critical yard sub-processes were identified in the literature review. Criteria for yard evaluation were considered in the quantitative data analysis of four different warehouses. The prioritisation of the identified critical sub-processes as well as their evaluation criteria were examined following the AHP. Triangulation was then performed based on the individual results.

The triangulation method involves using multiple methods to gather data on the same research issue [51]. The aim of triangulation is to obtain comprehensive insights on a phenomenon through these various sources [49]. Further, triangulation can be considered a qualitative research strategy for examining validity through the convergence of the different sources or methods [50]. In this paper, between-method triangulation was applied, including a combination of qualitative (literature review), quantitative (quantitative data analysis), and semi-qualitative methods (AHP). In combining the results of the different methods, it is important to avoid giving precedence to one method [52]. Three basic principles must be considered in methodological triangulation: completeness, contingency, and confirmation. Completeness refers to the choice of methods, contingency refers to the strategy selected, and confirmation refers to the conclusions [53]. In this study, the triangulation proceeded as presented by the following listing:

1) The literature review resulted in the identification of five critical yard sub-processes.
2) The prioritisation of the five critical yard sub-processes in terms of their significance to the yard process was determined based on the AHP.
3) The prioritisations (local) of the evaluation criteria of the second AHP level were multiplied by the prioritisations (local) of the criteria of the fourth AHP level (critical sub-processes). The resultant products (global prioritisations) indicated the significance of the evaluation criteria for the critical sub-processes.

   To further elucidate the formation of the percentage values concerning the significance of the evaluation criteria with respect to the critical sub-processes, we provide an example: the local prioritisation of the evaluation criterion *quality* corresponds to 11.0% (second level of the AHP model, see Figure 7). The local prioritisation of the critical sub-*process registration at the gateway* amounts to 22.6% (fourth level of the AHP model, see Figure 7). Multiplying these two local priorities the weighting of the evaluation criteria in relation to the critical sub-process, specifically the assessment of the evaluation criterion quality with respect to the critical sub-process registration at the gateway, resulting in a prioritisation of 2.5%. By multiplying two local priorities, one obtains a global priority. Another example is as follows: the local prioritisation of the evaluation criterion *sustainability* is 7.1%. The critical sub-process *management of the shunting system* is locally prioritised at 18.8%. By multiplying these local two priorities, a global prioritisation is obtained, representing the significance of the *sustainability* evaluation criterion in relation to the critical sub-process *management of the shunting system* (1.3%).

   The newly formed global prioritisations are thus based on the prioritisations derived from the AHP. In contrast to the AHP, the newly established prioritisations in triangulation support the consistent and comprehensive evaluation of the critical sub-processes since the reveal new prioritisations that are not discernible solely based on AHP.
4) The evaluation criteria *number of transports per day* and *average duration of a transportation process* were considered in the quantitative data analysis regarding the incoming, outgoing, and internal yard processes. The three triangulation processes focussed on the five critical yard sub-processes identified in the literature review. Subsequently, the criteria were evaluated based on a comparison of the averages of the data of the four warehouses. The comparison results in a categorisation into three classes: strong, moderate and weak/no influence.
5) Moreover, the organisational data of the four warehouses that were considered in the quantitative data analysis (*yard size, shape of the warehouse, number of employees, number of gates,* and *characteristics of the transported goods*) were added as evaluation criteria for the research question. The evaluation of these five identified criteria was based on argumentation. This detailed argumentation is carried out after the presentation of the triangulation results in Table 5.

Figure 10 illustrates the combination of the methods used for triangulation.

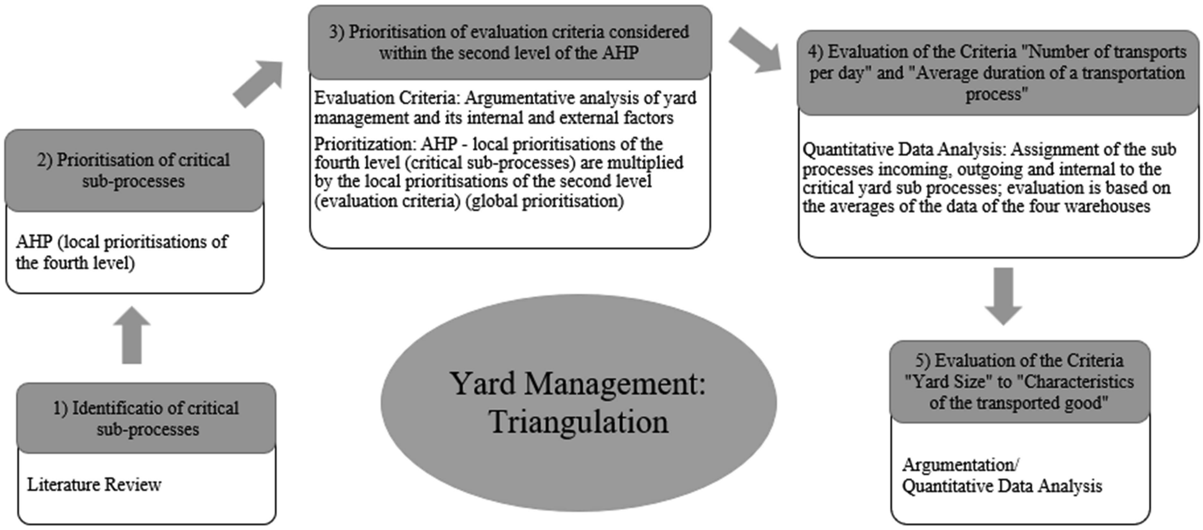

Fig. 10. Triangulation process

The triangulation results have internal validity because the AHP experts are all employed by the same German brick-and-mortar grocery retailing company from which the quantitative data were obtained. The research environment is identical for all analysed data. The triangulation results are presented in Table 5.

Table 5. Triangulation results

	Critical sub processes	*Incoming* Registration at the gateway	*Incoming* Allocation of trucks to gates/parking spaces	*Outgoing* Exit control (vehicle inspection and plausibility check)	*Outgoing* Removal of a transport unit from the gate	*Internal* Management of the shunting system
	Prioritization	22,6%	19,3%	6,7%	32,6%	18,8%
11,0%	Quality	2,5%	2,1%	0,7%	3,6%	2,1%
12,4%	Costs	2,8%	2,4%	0,8%	4,0%	2,3%
46,3%	Occupational safety	10,5%	8,9%	3,1%	15,1%	8,7%
10,0%	Information transparency	2,3%	1,9%	0,7%	3,3%	1,9%
13,3%	Efficiency	3,0%	2,6%	0,9%	4,3%	2,5%
7,1%	Sustainability	1,6%	1,4%	0,5%	2,3%	1,3%
	Number of transports per day	○	○	●	●	◐
	Average duration of a transportation process	◐	◐	●	●	◐
	Yard size	◐	●	◐	○	●
	Shape of the warehouse	○	●	○	○	●
	Number of employees	○	○	○	◐	◐
	Number of gates	◐	●	◐	●	●
	Characteristics of the transported good	●	●	●	●	●

Legend
● strong influence
◐ moderate influence
○ weak/no influence

Whereas the significance of most criteria was based on quantifiable data, the significance of the yard size, shape of the warehouse, number of employees, number of gates, and characteristics of the transported goods was based on the following argumentation. Aside from the specifications based on prioritisations, the specifications were divided into those with a strong influence, those with a moderate influence, and those with a weak/no influence.

The removal of transport units from the gate is independent of the yard size because changes to the yard size do not lead to changes in this sub-process. The removal process is itself independent of the yard size, whereas the allocation of trucks to gates or parking spaces as well as the management of the shunting system sub-processes are strongly influenced by the yard size. A larger yard has more gates and parking spaces, which leads to more allocation processes. Furthermore, a shunting system is most needed in large yards. The exit control and registration at the gateway are influenced indirectly by the yard size. For instance, larger yards may have a high number of incoming and outgoing transportation processes, resulting in a higher workload related to exit control and registration at the gateway.

While the yard size has an indirect influence on registration at the gateway and exit control, the shape of the warehouse has no influence on these sub-processes because these processes do not change whereas the shape of the warehouse does. The same applies for the removal of a transport unit from the gate sub-process. In addition, this sub-process is independent of changes within the shape of the warehouse. The sub-process allocation of transport units to gates or parking spaces is directly influenced by the shape of the warehouse because a change in the shape of the warehouse can change the number and location of gates and parking spaces. In addition, the shunting process is strongly influenced by changes in the shape of the warehouse. Here, the transportation distance for shunters varied noticeably between square-shaped and U-shaped warehouses.

Similar to the shape of the warehouse, the exit control and registration at the gateway sub-processes are not influenced by the number of employees. The same applies for the sub-process allocation of trucks to gates or parking spaces. A weak influence can be affect the productivity of the employees. Higher productivity can lead to smoother warehouse processing, which in turn affects the workload related to exit control, registration, and allocation of truck units. The removal of a transport unit from the gate sub-process is indirectly affected by the number of employees. Moreover, removal of a transport unit from the gate is accompanied by a safety risk [56]. To prevent this process from failing, employees need to know the safety instructions. Therefore, a higher number of employees implies more safety instructions. The success of shunting operations depends on correct information, for example, regarding the content of the cargo that can be provided by the employees, which is therefore indirectly affected by the number of employees.

Related to the yard size, the number of gates indirectly influences the exit control and registration at the gateway sub-processes due to the effect these sub-processes have on the workload. A higher number of gates can lead to an accurate and immediate allocation of trucks to gates, and thus the number of gates has a strong influence on this sub-process. The same applies for shunting operations. Further, the removal of a transport unit from the gate has a strong influence, as a higher number of gates can result in a higher number of safety risks related to the removal of a transport unit from the gate.

The characteristics of the transported goods have a strong influence on the whole yard process. For example, temperature-sensitive goods need to be prioritised and handled with care in each of the five identified critical yard sub-processes. Moreover, high-volume goods also require special handling due to yard size restrictions. In addition, special characteristics of the transported goods may require different vehicle types, as illustrated in Figure 1, which also influences the individual sub-processes within the yard.

Through the utilisation of triangulation, the critical sub-processes of yard management can be comprehensively assessed and prioritised, a capability achievable only through the comprehensive integration of individual methodologies.

The triangulation table (Table 5) implicates the following recommendations for practitioners and researchers. Based on the triangulation, a consideration ranking of critical yard sub-processes for practice and research is developed in addition to their most influential evaluation criteria. To be more precise, examples for these implications are presented. The most critical sub-process in transportation is removing the transport unit from the gate, which strongly influences the number of transports per day and the average transportation process duration. Occupational safety and the characteristics of the transported goods must be considered during this sub-process. Registering at the gateway is less critical, but it is still important for occupational safety and transported goods. Allocating trucks to gates or parking spaces is less critical than registration, while yard size and the number of gates are significant factors. Shunting system management is more critical than exit control, and occupational safety is a key criterion. Exit control is the least critical sub-process, although occupational safety and transported goods must still be considered.

In sum, the triangulation results show how critical sub-processes within yard management are assessed and thus prioritised in terms of protection and optimisation measures, considering the specification of the individual evaluation criteria. This has implications for research as well as transportation management practices. While the individual methods (literature review, quantitative data analysis, and AHP) resulted in new findings relevant for yard management, the triangulation itself is the most relevant contribution of this research, which takes a first explorative step to addressing the research gap within yard management ("black hole"). Moreover, the combination of methods used for triangulation answers the overarching research question of how yard management in warehouse sites is influenced by critical yard sub-processes and their specific criteria.

6. DISCUSSION

The triangulation results have the following implications for transportation management at warehouse sites. The research gaps, as well as the lack of companies' consideration of yard management, lead to a risk of failure of the identified critical yard sub-processes. Moreover, individual circumstances determine the design and critical sub-processes related to yard evaluation criteria. Therefore, it is recommended that transportation management should focus on identifying critical sub-processes, which should then be supported by a pairwise comparison by experts who are classified as important stakeholders. Based on the results of the AHP, transportation management should concentrate on these critical sub-processes in the order of priority with consideration to the evaluation criteria. Additionally, these methods and their results should be validated in an expert group session with yard managers in logistics practice.

The importance of this topic warrants further theoretical research. For example, further specification of the AHP criteria as well as the different manifestations of the criteria within the individual sub-processes should be a focus in future studies. Moreover, the development of an integrated concept for optimising critical yard sub-processes is needed. Due to the interdependencies between yard management and intralogistics and transport logistics, the methodological extension of using, for example, an analytical network process (ANP) should be considered [55].

Regarding the local requirements of individual warehouses considered in the quantitative data analysis and the developed criteria and their individual prioritisations, further research could focus on traffic regulations (speed restrictions, traffic guidance, etc.). For example, studies could examine whether one-way street regulation is a suitable strategy for supporting transport logistics in yards (Figure 1). Also, shunting vehicles (internal vehicles) are not bound by this regulation. Such a traffic regulation could affect the consideration of the average duration of transportation process. Therefore, this traffic regulation must be well designed. Decision alternatives include no one-way street regulation, a one-way street regulation applicable for all participants in the yard, or a one-way street regulation applicable for individual participants in the yard. The addition of various speed limits is also conceivable. A multitude of decision criteria must be integrated into the decision-making process. In considering criteria like the costs, duration, time required for transportation, as well as yard safety and transparency, the prospects and risk factors involved should be weighted carefully. The presentation of the complex problem description within a morphological box represents an initial approach. Based on our results, a simulation study on this research question is also missing and is thus recommended.

Besides the practical implications, theoretical contributions, and suggestions for further research, the new research approach of combining three methods to allow the triangulation of results should be noted. The combination of theoretical research and empirical data may help to reduce the research gap in yard management at warehouse sites, with the overarching aim of increasing warehouse efficiency.

7. CONCLUSION

The research question in this paper was related to the influence of critical yard sub-processes and their specific criteria on yard management at warehouse sites and, therefore, on warehouse efficiency. To answer this question, the results of three different methods were combined, including a literature review, which resulted in the identification of five critical yard sub-processes, a quantitative data analysis, which provided evaluation criteria for the sub-processes, as well as an AHP, which prioritised the critical sub-criteria, provided further evaluation criteria, and prioritised them. The combination of these methods resulted in triangulation of the results. Through this triangulation, the five critical sub-processes were combined with the evaluation of the identified criteria. Therefore, the influence of the specific criteria on the critical sub-processes within yards was described, and based on the prioritisations/determined significance, a ranking of optimisation measures was developed to improve warehouse efficiency. Given that we found a relatively low number of publications dealing with yard management and its impacts on warehouse efficiency, we emphasise the need for an explorative approach and propose further research avenues for quantitative investigation.

The limitations of the AHP are based on the considerably low number of criteria. In addition, the assessments within the pairwise comparisons cannot be considered anonymous because the experts sent in their completed questionnaire under their names. This could have led to assessments based on expectations. Nevertheless, the estimations by six experts who are employed by one company support the internal validity of the results and allow comparison of the AHP results to the quantitative data because both were based on the same company. Even so, there are certain important limitations. First, the internal validity is limited by the low number of experts. Moreover, the assignment of sub-criteria to criteria was not completely unambiguous. This may have resulted in correlations between the sub-/criteria. Combining the results through triangulation is an uncommon, although we believe justified, approach. Indeed, the triangulation results answered the overarching research question of this paper and offered new insights. Although the AHP and the quantitative data focussed on internal validity, the results can be generalised. The identification of critical yard sub-processes was based on a literature review and is therefore transferable to different companies (logistics service providers, manufacturers, retailers). While the AHP and quantitative data were based on one company, that company is a large, common company and is representative of others in the industry. Nevertheless, the AHP and quantitative data analysis could be performed with more than one company to verify the results.

Conflict of Interest. The authors declare that they have no conflicts of interest.

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