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Workload balancing and scheduling in picking tower systems considering different storage strategies

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Abstract: Picking tower systems are particularly suitable in the e-commerce distribution field. They permit to stock and pick a wide variety of items by maximizing storage capacity and space utilization. Such types of systems are comparable to zone picking solutions, since pickers work on one floor during the same working shift. However, differences also exist since, for example, once the picking tower system is designed, it is not possible to improve or reduce the area of each floor. Thus, a proper workload balancing is required to avoid an efficiency reduction of this system. This paper proposes a mixed integer linear programming mathematical model to assign pickers to floors and jointly schedule the picking list of each of them aiming to minimize the completion time of all orders. The model is applied to a real case study and first managerial insights are derived by investigating how the number of floors, the storage strategy and the number of pickers allowed on each floor influence the workload and the completion time. The results show that, for the considered case, the most effective configuration is the brand-based storage strategy with four picking levels.

Keywords: workload, picking tower, zone picking, order scheduling, storage strategy

1. INTRODUCTION

The order picking process, which consists of retrieving items from storage locations and bins to fulfil customer orders, represents a critical activity among warehousing operations since it strongly impacts operating costs and service levels (Van Gils et al., 2018). Generally, it is manually performed due to the higher flexibility of human pickers compared to robots and the high investment costs of automatic solutions which are not suitable for small and medium-size companies (Calzavara et al., 2017). Focusing on pickers-to-parts systems several solutions have been proposed over the years to improve picking efficiency, limit the costs and achieve the required customer service level. Further, the picking solution varies according to the customers' order profile and the type of SKUs to pick (Boysen et al., 2019). For example, e-commerce distribution centers are characterized by: 1) small orders, 2) large assortment, 3) tight delivery schedules, and 4) varying workloads (Zennaro et al., 2022). In such a context, several order picking strategies can be used. One of the most common strategies is known as zone picking, where each picker is allocated to a specific region within the picking area and he/she picks items exclusively from that designated zone. This strategy can be implemented either with a sequential strategy, where an order sequentially traverses each zone, stopping at zones where items are required, or with a parallel one, where multiple parts of the same order are picked concurrently in different zones, followed by a sorting system that consolidates the complete order downstream of the picking process (Parikh & Meller, 2008). Given the growing importance of the e-commerce market, where the level of customer service is critical for success, distribution centers have increasingly moved closer to city centers where most order destinations are located. This has led to reduced delivery times and higher service levels. However, land costs near urban centers are significantly high. For this reason, aiming to minimize the space required for picking activities, manual picking tower systems have been introduced (Figure 1). These are rack-supported tiered storage structures that are designed to maximize storage capacity in warehouses with a reduced stock superficial area. It consists of different storage and picking levels and it permits the achievement of higher picking efficiency. In fact, each level handles the picking fulfilment of a certain number of SKUs stocked in the same level. This leads to a smaller required area for picking and stocking activities, and, consequently, investment costs are considerably reduced. This type of system is an ideal solution for storage and picking in high-volume environments due to its ability to organize and manage a large variety of products in high volumes. Hence, it is particularly suitable for e-commerce. To avoid sorting activities after picking, these systems can work with a sequential zone picking strategy, where each picker is assigned to a level (zone), and the order progresses to the levels through an automated transport system. These systems are suitable for e-commerce orders (B2C), where few items per order are required. However, our experience showed that the same systems often also need to fulfill B2B orders, which require a higher number of items to be picked. This makes the item and resource allocation critical to ensure performance. Nevertheless, even if this system is widely used in practice, the literature on this field is still scarce.

As a start of our research on this topic and on this picking system, we aim to focus on an operational problem, which is the workforce and scheduling process. Then, this paper proposes a mixed integer linear programming mathematical model which assigns and balances the workload among pickers and schedules the picking order list of each picker by considering sequential picking strategy.

The remainder of the paper is structured as follows. Section 2 reports the main works in this field and defines the novelties

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of our paper compared to the previous ones. Section 3 presents the mathematical model. Section 4 briefly reports the case study and the main outcomes. Finally, Section 5 concludes the work by reporting also future research perspectives.

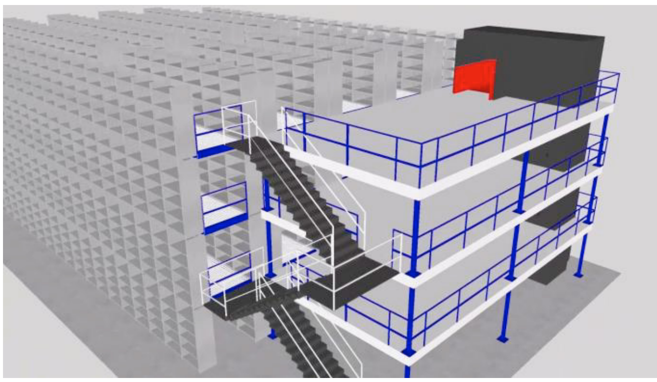

Figure 1. Picking Tower System (source:https://www.youtube.com/watch?v=E1mZTO70nK0)

2. LITERATURE REVIEW

Workload assignment is a crucial issue for all manufacturing, assembly and logistics processes (Katiraee et al., 2021). It consists of assigning tasks to workers aiming to balance the amount of work among them by avoiding working peaks and, thus, the necessity to have additional workers during the process. Further, it refers to operational decisions to a short-term period which could be set on a weekly or daily basis according to the process under analysis. Focusing on picking, the operational workload assignment problem differs from the manufacturing one for several reasons: 1) flexible resource capacity, 2) a fixed planning period and 3) fixed time windows (Vanheusden et al., 2020).

A well-known opportunity to increase order-picking performance is the division of the warehouse and, then, the assignment of pickers, into different picking zones (Bartholdi and Hackman, 2017). Each picker is assigned to a dedicated zone, and, for each order, he/she only picks the items that are in the assigned zone. Zone picking reduces travelling, as pickers traverse only a small area of the warehouse. Furthermore, pickers congestion is reduced, which results in substantial performance benefits compared to strict order picking (De Koster et al., 2012; Vanheusden et al., 2022).

Zoning and workforce scheduling are widely investigated in warehousing literature. In fact, if zoning is not appropriately designed it can cause workload imbalances (Vanheusden et al., 2020). Further, poor workforce scheduling induces workload imbalance over time (Kim et al., 2018).

In zone picking systems pickers can work by following a parallel (i.e., the same batch of orders is picked in all zones at the same time) or a sequential strategy (a set of orders is sequentially moved from one zone to the other). However, both strategies could cause workload imbalances among zones (Parikh and Meller, 2008). To overcome this issue, the size of each zone can vary over time as well as the assignment of each SKUs to each zone (Van Gils et al., 2017). However, a change in the zone size or the SKUs to zone assignment is not feasible in a short-term period and, thus, they could not lead to a reduction of workload unbalances daily. In such a way, all the advantages of zone picking could not always be achieved if additional adjustments are not taken into account. It is the case of bucket brigades strategy, which represents a dynamic picking approach. In such a scenario, the picking zones have flexible zone borders leading to a self-balanced picking system compared to the workload of each picker (Hong, Johnson, & Peters, 2016; Bartholdi and Hackman, 2017). Nevertheless, bucket brigades are not suitable for picking towers, since pickers should move from one floor to another by wasting time and, thus, efficiency.

In this context, the scheduling, and, consequently, the picking order completion time, assume a crucial role in processing each customer order according to the set delivery time. Further, scheduling is necessary due to the labor-intensive nature of the picking activity (Ardjmand et al., 2018).

Existing works on workload assignment start from a tactical level and, generally, they aim to assign the item to a zone (e.g., storage assignment problem) aiming to balance the workload among pickers (Park et al., 2022; Wang et al., 2013).Vanheusden et al. (2020) investigated workforce and scheduling problems in picking zones by following an operational viewpoint. In their model, they aimed to minimize the peaks in the number of orders to pick in a specific time slot. Further, they are considered to be among the first ones who focused on workload peaks during a single day in a warehouse. Through their approach, they first provided scheduling between picking zones, and, then, the workforce assignment. However, picking tower systems was not considered in their work. In this paper, we overcome this gap by proposing an integrated model that assigns workers to zones according to the workload in each zone and, then, defines the scheduling to process the picking orders.

3. PROBLEM STATEMENT AND MATHEMATICAL MODELIZATION

In picking tower systems each floor is considered as a zone and pickers assigned to a floor cannot move to another floor during their working shift. Each customer's order could contain one or more items which could be stocked in one or more floors. For such a type of picking, sequential picking is performed, and bins containing picked items are generally moved among picking floors and to the shipping area with conveyors. In fact, due to the orders' variability and the possibility of having items stocked on different floors, a bin could stop in a buffer area on each intermediate floor, wait until the item(s) are picked and, finally, move to the shipping area. In order to optimize the scheduling process, we evaluate the efficiency of the zone picking system considering the possible analogy with an assembly system. As in the assembly system assemblers work in workstations carrying out different tasks related to the same product, in the zone picking system different pickers are assigned to specific floors to pick different SKUs for the same order (Baker & Trietsch, 2013).

We aim to minimize the completion time, here called makespan, C_{max}, of a set of picking orders (picking lists), O, in a picking tower system by integrating the pickers to floor assignment and the workload balancing. The number of pickers on each floor is generally a constraint to avoid congestion which leads to picking time increment, thus, higher makespan or tardiness. Then, the workload balancing among

pickers is crucial since it could lead to a lower makespan, idle time and tardiness.
The main assumptions are defined as follows:

- each picker can be assigned to only one floor
- there is a maximum number of pickers that can be assigned to each floor
- in each floor, the pickers process the orders following a sequential order picking strategy
- for each order, the floor in which each item is stored (and, then, can be picked) is known in advance
- picking orders are processed by following the flow of the picking tower, starting from the higher floor to the lower one
- the release and due dates of each order are known in advance
- the completion time of each order must respect the order due date
- total picking times on the floor, including travel and picking times, are deterministic and are estimated in advance according to the number of items to pick and the chosen routing policy
- bins transportation times to move the bins from a floor to another are deterministic and are known in advance
- the buffer area containing all bins that wait to be processed on a floor is large enough to not represent a bottleneck for the system.

Table 1 reports indexes, sets, parameters, variables and decision variables of the mathematical model.

Table 1. Notations

Sets	
O	Set of orders
W	Set of pickers
Z	Set of zones
Indexes	
o, o’	Index for orders, *o,o’=1,..,O*
w	Index for pickers, *w=1,..,W*
z	Index for zones, *z=1,..,Z*
Parameters	
p_{oz}	Picking time of order *o* in zone *z*
t_{oz}	Travel time of order *o* in zone *z*
big-M	Large positive number
rd_o	Release date of order *o*
dd_o	Due date of order *o*
$wmax_z$	Maximum number of pickers in zone *z*
WT	Working Time
Variables	
S_{oz}	Starting picking time of order *o* in zone *z*
C_{oz}	Completion picking time of order *o* in zone *z*
C_{max}	Makespan
WL_{max}	Maximum workload
Decision variables	
x_{zw}	$\begin{cases} 1 = \text{picker } w \text{ is assigned to zone } z \\ 0 = \text{otherwise} \end{cases}$
y_{ozw}	$\begin{cases} 1 = \text{order } o \text{ is processed in zone } z \text{ by picker } w \\ 0 = \text{otherwise} \end{cases}$
$k_{oo'zw}$	$\begin{cases} 1 = \text{order } o \text{ is processed before order } o' \text{ in zone } z \text{ by picker } w \\ 0 = \text{otherwise} \end{cases}$

The mathematical model is defined as follows:

$$\text{O.F. Minimize } C_{max} \tag{1}$$

Subject to:

$$\sum_{z \in Z} x_{z,w} = 1 \; \forall \, w \in W \tag{2}$$

$$\sum_{w \in W} x_{z,w} \le wmax_z \; \forall \, z \in Z \tag{3}$$

$$\sum_{w \in W} y_{o,z,w} = 1 \; \forall \, o \in O, z \in Z \tag{4}$$

$$\sum_{o \in O} y_{o,z,w} \le bigM \cdot x_{z,w} \; \forall \, w \in W, z \in Z \tag{5}$$

$$C_{o,z-1} + t_{o,z-1} \le S_{o,z} \; \forall \, o \in O, z \in Z \tag{6}$$

$$rd_o + S_{o,z} + p_{o,z} \le C_{o,z-1} + bigM \cdot \left(1 - y_{o,z,w}\right) \quad \forall \, o \in O, z \in Z, w \in W \tag{7}$$

$$S_{o,z,w} + p_{o,z} \le S_{o',z,w} + bigM \cdot \left(1 - k_{o,o',z,w}\right) \quad \forall \, o, o' \in O : o \ne o', z \in Z, w \in W \tag{8}$$

$$k_{o,o',z,w} + k_{o',o,z,w} = 1 \quad \forall \, o, o' \in O : o \ne o', z \in Z, w \in W \tag{9}$$

$$\sum_{w \in W} C_{o,Z,w} + t_{o,Z} \le dd_o \; \forall \, o \in O \tag{10}$$

$$\sum_{w \in W} C_{o,Z,w} + t_{o,Z} \le C_{max} \; \forall \, o \in O \tag{11}$$

$$\sum_{o \in O} \sum_{z \in Z} p_{o,z} \cdot y_{o,z,w} \le WL_{max} \; \forall \, w \in W \tag{12}$$

$$suC_{o,z,w} \le WT \cdot x_{z,w} \quad \forall \, o \in O, \forall \, z \in Z, w \in W \tag{13}$$

$$S_{ozw}, C_{ozw}, C_{max}, WL_{max} \in \mathbb{R}^+ \tag{14}$$

$$x_{z,w}, y_{o,z,w}, k_{o,o',z,w} \in \{1; 0\} \tag{15}$$

Where O.F. minimizes the makespan of the set of orders. Constraint (2) assigns one picker to only one floor while constraint (3) guarantees the respect of the maximum number of pickers that can work on a floor. Constraint (4) assures that only one picker is assigned to an order if it requires to be processed on a single floor. Constraint (5) assigns orders to pickers on a floor only if the picker is assigned to the floor. Constraint (6) guarantees the picking sequence among the floors by considering the transportation time between floors. Constraint (7) defines the starting and the completion time of an order on a floor. Constraint (8) and (9) set the picking sequencing pickers assigned on a floor.
Constraint (10) guarantees the respect of the due date while constraint (11) defines the makespan. Constraint (12) defines the maximum workload among the pickers, while constraint (13) assures the respect of the working time duration. Finally, constraints (14) and (15) set the type of variables and decision

variables which can assume, respectively, real and positive values and Boolean values.

4. CASE STUDY AND RESULTS

4.1. Case study description

We analyze the case of a well-known yarn distribution company that, due to the significant increase in e-commerce orders, is considering the possibility to adopt a picking tower warehouse for orders fulfillment. The company needs to satisfy both e-commerce orders (B2C) and orders coming from retail stores (B2B). The company manages approximately 4,000 SKUs across 44 different brands. We have data for one month of orders, during which 1,632 orders are fulfilled, averaging 82 orders per day with peaks of 145 orders on some days. For the model application, data refer to an average representative day, with 95 orders and 2,277 rows in total.

Table 2. Configurations data

	CASE A		CASE B	
Storage strategy	Class-based		Brand-based	
Number of levels	3	4	3	4
Level SKUs	1,333	1,000	1,333	1,000
Level area $[m^2]$	2,000	1,500	2,000	1,500

To evaluate both pickers' workload and SKUs allocation, we assess two different scenarios:

A) SKUs allocated to different levels according to ABC picking classes, with the three classes properly distributed in all levels (*class-based* storage strategy, Case A)

B) SKUs allocated to different levels according to brands; specifically, since orders are predominantly single-brand, SKUs of the same brand are placed on the same floor (*brand-based* storage strategy, Case B)

Furthermore, both configurations are studied for a 3 levels solution (1,333 items, 2,000 m^2 per level) and a 4 levels one (1,000 items and 1,500 m^2 per level). Therefore, a total of four different configurations are analyzed, as presented in Table 2.

To calculate the average distance travelled for each picking order, we use the formula proposed by Manzini et al. (2007):

$$L = s \cdot p \cdot c \cdot \frac{N_{pick} \cdot S^{0,45}}{\sqrt[5]{R}} \; [m] \qquad (16)$$

where s is a constant value referred to the shape (basic with two cross aisles = 3.8), p is a constant value referred to the policy (return = 0.71) , c is a constant value referred to the class ABC values (10/40/50 and 20/70 = 0.86), N_{pick} is the number of picks, S is the picking area and R is the capacity of the picking vehicle. We consider an average speed of the pickers of 1 m/s and a pick time of 5 seconds per SKU. Table 3 summarizes the results coming from a static dimensioning considering the set of 95 orders of the representative day, in terms of picking time per level and total picking time. Looking at Table 3, it is evident that from a static dimensioning point of view the case A (i.e. applying the class-based strategy for items storage) leads to more balanced levels, in which the picking time is quite the same for each floor. On the other hand, the brand-based strategy leads to a significant imbalance in picking times across different floors, as some brands are much more popular than others. Nevertheless, considering the total picking time per configuration, the brand-based strategy with 4 levels results the faster one. Finally, Table 4 presents the orders' distribution per floor, i.e. the number of orders which cross one, two, three or four levels for each configuration. It is possible to notice that the class-based configuration has the highest percentage of orders which cross 3 levels (Case A, 3 levels 65%) or 4 levels (Case A 4 levels 62%), while the majority of orders of the configurations with the brand-based strategy crosses 2 levels (53% and 56%).

Table 3. Static dimensioning

	CASE A						
	3 Levels			**4 Levels**			
	1	**2**	**3**	**1**	**2**	**3**	**4**
Picking Time per Level [h]	7.76	7.31	8.32	5.35	5.56	5.64	5.47
Total Picking Time [h]	23.39			22.02			
	CASE B						
	3 Levels			**4 Levels**			
	1	**2**	**3**	**1**	**2**	**3**	**4**
Picking Time per Level [h]	10.49	6.59	6.19	8.70	5.47	3.34	4.14
Total Picking Time [h]	23.27			21.65			

Table 4. Orders distribution

Crossed Levels		**Case A 3 Levels**	**Case A 4 Levels**	**Case B 3 Levels**	**Case B 4 Levels**
1	n° orders	27	12	27	25
	%	28%	13%	28%	26%
2	n° orders	6	4	50	53
	%	6%	4%	53%	56%
3	n° orders	62	20	18	13
	%	65%	21%	19%	14%
4	n° orders	-	59	-	4
	%	-	62%	-	4%
Total orders		**95**	**95**	**95**	**95**

4.2. Model application and discussion

The model proposed in this paper has been applied to the case study, considering the assignment of 6 pickers, the resources which are currently carrying out the fulfilment activities. The results are presented in Table 5. For each configuration, the 6 pickers are assigned to different levels and each one works on a certain number of orders. Moreover, Table 5 reports the picking time (theoretical time to fulfill the order) and the completion time (the real time required to complete the orders due to the waiting time between floors) for each configuration and worker. Finally, Table 5 also shows the difference, expressed as a percentage, between the picking and completion time. For example, in the Case A with 3 levels, 2 pickers per floor have been assigned; picker 1 has a picking time of 4.06

hours and a completion time of 4.06 hours, meaning that he can process 32 orders without waiting. On the other hand, picker 3 is assigned to level 2 with a picking time of 3.68 hours and a completion time of 4.24 hours; this means he waits to complete his 36 orders, and, consequently, the difference between completion and picking time is equal to 13%.

Table 5. Main results

CASE A											
3 Levels						4 Levels					
Picker	Level	n° orders	Picking time [h]	Completion time[h]	Δ	Picker	Level	n° orders	Picking time [h]	Completion time[h]	Δ
1	1	32	4.06	4.06	0%	1	1	82	5.35	5.35	0%
2	1	38	3.71	3.71	0%	2	2	42	2.31	3.41	32%
3	2	36	3.68	4.24	13%	3	2	43	3.25	3.26	0%
4	2	33	3.64	4.23	14%	4	3	39	2.10	3.47	40%
5	3	40	4.20	5.01	16%	5	3	43	3.55	3.55	0%
6	3	46	4.13	5.07	19%	6	4	67	5.47	5.47	0%
Total Time [h]			**23.42**	**26.32**	**13%**	**Total Time [h]**			**22.02**	**24.51**	**11%**
C_{max} [h]			**5.07**			**C_{max} [h]**			**5.47**		
CASE B											
3 Levels						**4 Levels**					
Picker	Level	n° orders	Picking time [h]	Completion time[h]	Δ	Picker	Level	n° orders	Picking time [h]	Completion time[h]	Δ
1	1	47	5.25	5.25	0%	1	1	28	4.43	4.43	0%
2	1	40	5.25	5.25	0%	2	1	50	4.27	4.27	0%
3	2	27	3.16	5.18	39%	3	2	25	2.22	3.41	35%
4	2	36	3.44	5.17	34%	4	2	28	3.25	3.39	4%
5	3	19	3.42	5.09	33%	5	3	30	3.34	3.34	0%
6	3	12	2.78	5.00	44%	6	4	25	4.14	4.43	6%
Total Time [h]			**23.29**	**30.94**	**33%**	**Total Time [h]**			**21.66**	**23.28**	**8%**
C_{max} [h]			**5.25**			**C_{max} [h]**			**4.43**		

Considering the picking times of each picker, the case B with 3 levels presents the greatest differences compared to the completion times (picker 6 +44%). Also considering the total picking time compared to the total completion time there is an increase in time from 23.29 to 30.94 hours (+33%).

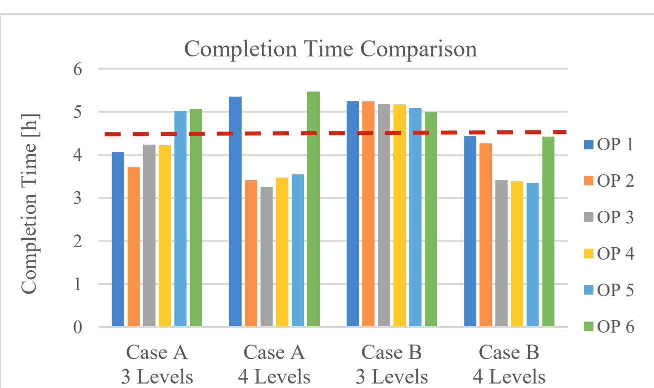

Figure 2: Completion Time[h] per worker for the four cases

By applying the model, the sequence of orders and the precedence in picking items across floors lead to a higher completion time. For each configuration, the slower picker determines the fulfillment time. The configuration which minimizes C_{max} results the brand-based storage strategy with 4 levels with 4.43 h, as shown also in Figure 2. In fact, in this strategy orders are often concentrated on a single level and do not need to stop on different floors to be completed (as shown in table 4). Moreover, with 4 levels, the available area for picking is reduced, and consequently, travel times decrease.
Considering the 3 levels configuration, instead, the strategy which minimizes C_{max} is the class-based one; this means that the picking area deeply affects picking performance, making the class-based storage more convenient.
Results also shows that the best configuration in terms of C_{max} is also the same that minimizes the difference between the picking time and the completion time (8%), meaning that the waiting time due to orders flow is minimized.

5. CONCLUSIONS

In this paper, we propose a workforce assignment and scheduling model to investigate picking tower systems from an operational point of view. Such types of systems are generally used when the storage space is lacking and they are comparable with zone picking systems. Aiming to guarantee the due date of each order and the proper service level, joint optimization of the pickers assigned to each floor and the picking order scheduling of each of them is mandatory. The model is applied to a real case study to 1) investigate how the number of floors impacts the completion time of a daily order list 2) investigate the impact of different storage assignment strategy and 3) analyze the workforce assignment and the workload balancing. The results show that, for the proposed case study, the best strategy is the brand-based one, with 4 levels. This is explained by the fact that many orders are single-brand, and this configuration reduces the need to stop to multiple floors for completion. Additionally, having 4 levels reduces the picking area, and this makes travel times decreasing. However, if the levels were fixed and we consider the configuration with 3 levels, the best solution would become the class-based storage. This is because with the class-based approach picking travel times are lower than with the brand-based strategy as the area increases, even though the order would have to stop on multiple floors.

To the best of the authors' knowledge, this work represents a pioneer study for picking tower systems which, of course, have several similarities with classical zone picking systems but also several differences, as discussed in the introduction section. Further, since this work represents a preliminary study, there are several future research directions. First, the possibility to move pickers between floors could be integrated into the model to avoid the impact of the possible imbalance between floors. Then, a parametrical analysis (e.g., by varying number of floors, area of each floor, order list features) could be conducted to investigate how pickers' assignments and scheduling change by varying one or more design factors. Finally, the model application to different real cases could provide interesting managerial insights about the pros and cons and the practical application of picking tower systems.

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