OPERATIONAL-LEVEL OPTIMIZATION OF INBOUND INTRALOGISTICS

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Abstract

This study is concerned with optimizing inbound operations at distribution centers (DCs), warehouses, and cross-docks with staging areas. The objective of the problem is to minimize the makespan required to move all unit loads from the trailers to the flow racks, and from the flow racks to their respective storage locations. It is assumed that a set of inbound trailers with known composition have been assigned and sequenced to inbound dock doors. The following three inbound logistics decisions are simultaneously considered: *i*) unloaders' assignment and scheduling, *ii*) loads-to-flow rack assignment, and *iii*) assignment and haulers' scheduling. In this study we describe the relationship between the problem of minimizing makespan and an unloader-hauler balancing problem. Three rule-based heuristics are proposed and evaluated in an instance of the problem.

1 Introduction to Inbound Intralogistics

A trend in large supply chain networks is to use storage facilities, such as distribution centers (DCs) and warehouses (WHs), as redistribution points to fulfill orders from multiple demand points. The physical space in storage facilities is typically divided into *receiving*, *storage*, *picking*, and *shipping* areas [1]. Figure 1 depicts the traditional layout of DCs. Loads arrive through the receiving side of the DC, they are moved to the storage locations via a staging area, and they are eventually picked and shipped from the another side of the DC.

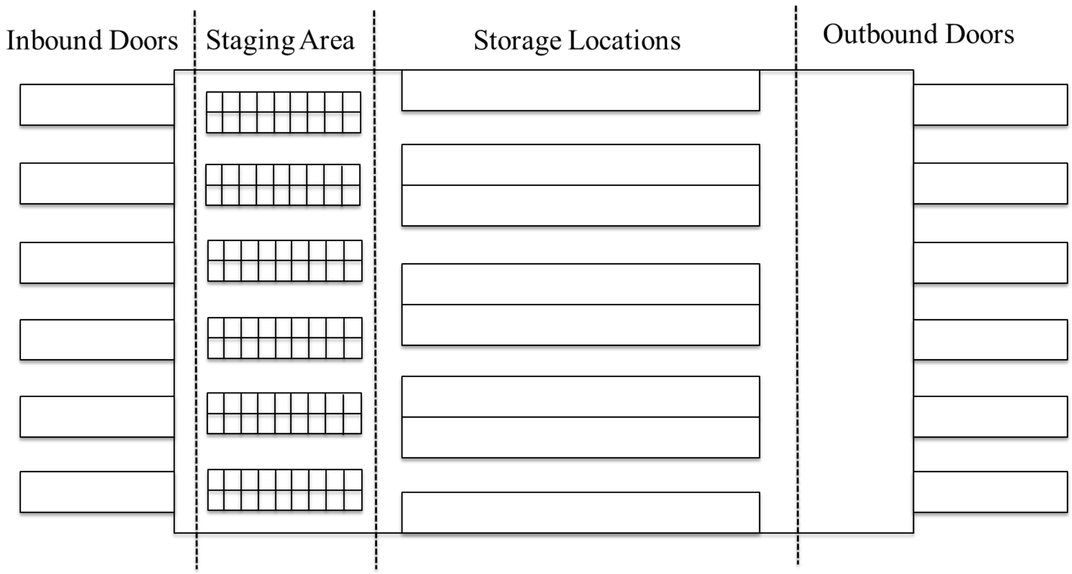

Figure1: Distribution Center Intralogistics.

The traditional receiving logistics process at DCs is as follows:

1. **Receive Inbound Trailers**: Inbound trailers typically containing unit loads (*e.g.*, pallets) are received at the gate of the facility upon arrival. At the gate, inbound trailers are assigned to a designated parking area in the storage yard until they are ready to be stripped at an inbound (dock) door.

2. **Inbound Trailers to Doors Assignment and Scheduling:** Inbound door assignment and scheduling involves determining the sequence and timing for unloading inbound trailers at each inbound door. Given the physical nature of dock doors only one trailer may be unloaded from a door at a time. Also, trailer unloading occurs without preemption. The door assignment decision needs to consider the storage locations of the truckload contents. The best door for a certain trailer would be the one that minimizes the total parts travel (*i.e.*, total travel distance between dock door and storage locations). Usually, warehouses with dedicated storage policies are arranged by type or categories of products; similar to the way they are received in the truckloads. In such scenario the door assignment decision would be simple. The door selection becomes a much harder the truck load composition is highly mixed [2] (*i.e.*, storage locations are scattered through different aisles.

3. **Unloader Scheduling:** Once the trailer-to-door assignment and scheduling are determined the unloading operations at the receiving dock begin. Material handlers known as *unloaders* use dedicated equipment (*e.g.*, counter-balanced lift trucks) to strip the inbound trailers and place loads in a staging area. The key decisions are *which unloader will unload each trailer* and *where will the loads be placed*.

4**. Pallet Staging:** Unloaded pallets are staged so they can be inspected, documented, and labeled. In practice, pallets are staged either on the floor (manual operations), in a flow rack (semi-automated), or a conveyor (automated).

5**. Haulers Scheduling for Put-away:** After staged pallets are labeled, haulers will transport the pallets to their final storage location. Hauler scheduling involves determining the sequence in which haulers will transport loads from the staging area to their storage location.

Figure 2 depicts inbound intralogistics personnel assuming a flow rack as the staging area. As described above *unloaders* move loads from inbound doors to the staging area. On the other hand, *haulers* put-away loads that were placed in the flow racks by the unloaders. Unloaders and haulers should collaborate to store the inbound loads as quickly as possible.

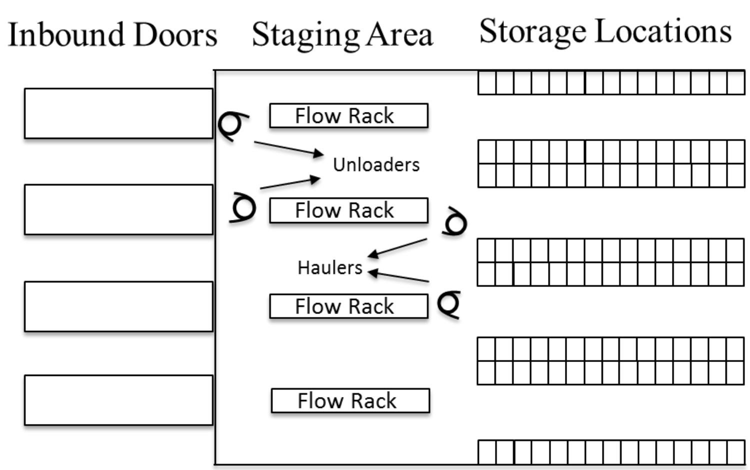

Figure 2: Distribution Center Intralogistics.

The inbound intralogistics operations in cross-docks (XDs) closely resemble those of DCs. XDs can be described as deconsolidation/consolidation facilities where loads are unloaded and immediately recombined with loads sharing the same destination [2]. In traditional XDs the inbound logistics are much simpler than the one in DCs as loads are moved directly from inbound to outbound trailers by unloaders. Vis and Roodbergen [3] and Yu and Egbelu [4] describe a special type of XDs where pallets are assigned to an intermediary short-term storage location (*i.e.*, staging area) after being unloaded in order to decouple inbound and outbound operations. The inbound logistics of these XDs with staging areas is very similar to the one in DCs, with the only difference that in XDs loads are placed in outbound trailers located at outbound doors (*a.k.a.*, stack doors) instead of storage locations. Clearly, if the outbound trailer (or destination)-to-door assignment is known and outbound trailer schedules are disregarded, the XD with stages inbound intralogistics becomes identical to the one described for DCs. Figure 3 illustrates the receiving intralogistics for cross-docks with staging areas.

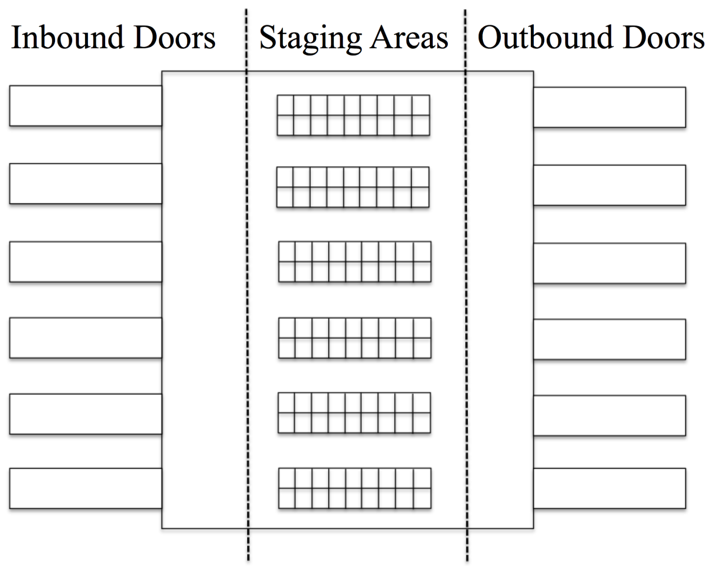

Figure 3: Receiving Intralogistics in Cross-dock with Staging Areas.

This study focuses on simultaneously solving the following *operational-level* decisions related to inbound intralogistics: *i*) unloaders' assignment and scheduling, *ii*) loads-to-flow rack assignment, and *iii*) assignment and haulers' scheduling with the objective of minimizing the makespan to store all loads. Operational-level decisions are bound by strategic and tactical-level decisions made a priori. Examples of strategic-level decisions include the design of the DC which dictates the number of dock doors, number of flow racks, the MHE used, and the travel distances. Examples of tactical-level decisions include the number of inbound trailers received, the number of unloaders and haulers, the storage location assignment, etc. Given the strategic and tactical-level decisions, we focus on assisting dock managers to make day-to-day decisions regarding assignment and scheduling of inbound logistics.

The remaining of this chapter is organized as follows. Section 2 presents a literature overview of inbound intralogistics. Section 3 reformulates the makespan minimization problem as an unloader-hauler balancing problem. Section 4 presents three new heuristics based on rules to solve the problem. Lastly, Sections 5 and 6 present the experimental results and conclusions, respectively.

2 Literature Overview

Gu *et al.* [1] published a review on warehouse operations, which explains the main research topics areas and objectives. The literature is divided into the four basic warehouse functions: *receiving*, *storage*, *order picking*, and *shipping*. According to [1], the available research on receiving and shipping operations is very limited. In fact, all references made in [1] to receiving and shipping operations are related to the trailer-to-door assignments in XDs. Buijs, et al. [5] present an exhaustive literature review and classification of cross-docks and cross-docking networks. The following are the only published work on receiving logistics found in the literature.

In the XD literature papers [2, 6-10] all focus on solving the trailer-to-door assignment problem under different assumptions to minimize either the total parts travel or the makespan. These papers do not consider staging areas in the XD, but when travel distances are assumed rectilinear the problem can be seen as having unloaders move loads from trailers to staging areas, and from the staging areas to storage locations. The difference between XDs with and without staging areas is the staging areas decouple the two movements and assign the former part to unloaders and the latter to haulers.

Vis and Roodbergen [3] developed a network formulation for XDs with staging areas. The objective of the problem is to determine the staging locations that minimize the total travel distance within the facility. The problem is formulated as a transshipment problem, where loads from factories (origins), are sent to warehouses (intermediary nodes), and then to retailers (destinations). In their problem loads are moved from inbound doors, to an intermediary staging area, and then to outbound doors. A block assignment approach is used. In this strategy blocks represent a predetermined time period in which arriving loads are assigned an available storage location until they are picked up for loading. As loads are picked, new arriving loads from the next block are considered in the optimization. Their "*row based storage assignment*" algorithm assigns cost to flows depending on the storage locations available. A minimum cost flow algorithm is used to determine the flows that go to each intermediary storage location such that the total travel distance is minimized.

Buijs and Vis [11] state that the main performance indicator for the cross-dock manager is to maximize the throughput rate, consisting of three interrelated components: *size of the workforce*, *freight volume handled*, and *makespan*. They state that freight volumes are the result of transport planning, so they cannot be influenced by the cross-dock manager. The XD manager also has little influence in the makespan as it is largely determined by the planned arrival and departure times of trailers. Hence, to maximize throughput managers should focus on maximizing the productivity of the workforce by planning the workforce capacity over time and by assigning material handlers so that operations are performed efficiently. The only inbound intralogistics publication that considers workforce restrictions as part of inbound logistics is [12]. Shakeri et al. [12] focuses on the truck scheduling problem at XDs considering the availability of resources such as doors and material handlers (unloaders) to minimize makespan. The dock door assignment is solved as part of the truck scheduling problem. A two-phase heuristic is proposed where a heuristic is used to determine a feasible sequence of trucks for the door assignment, and a rule-based heuristic is used to assign each sequenced truck to dock door. Our work is then the second publication that considers workforce productivity.

3 Problem Definition and Reformulation

As stated in Section 1, this study focuses on simultaneously solving the following operational-level decisions related to inbound intralogistics: *i*) unloaders' assignment and scheduling, *ii*) loads-to-flow rack assignment, and *iii*) assignment and haulers' scheduling with the objective of minimizing the makespan to store all loads. This study is similar to [3], but instead of working at the strategic level, we focus on the operational level by considering the workforce capacity (*i.e.*, the assignment and scheduling of unloaders and haulers) and the staging area capacity.

The most important modeling assumptions made are:

1. The trailer-to-door assignment and sequence is given. The reasoning behind this assumption is purely to simplify the problem. In practice, managers tend to assign trailers to doors either greedily (by arrival or by total parts travel), although other methodologies have been proposed in the literature (e.g., [8,10]). A heuristic to incorporate trailer-to-door assignments to our problem can be easily obtained by using any metaheuristic to change the assignment and use our proposed solution to evaluate it.
2. All trailers are readily available in the parking area so that any trailer may be assigned to any door anytime. Clearly, in reality trailers arrive sporadically depending on their truck schedule. However, in general, if the unloading schedule for a trailer is known at the destination, prioritization can be given at the origin in order to comply with the unloading schedule at the DC. Hence, minimizing makespan is a reasonable objective function.
3. There is no pre-emption for unloaders; *i.e.*, once an unloader starts a trailer, he must unload all loads before starting the next trailer.
4. Pallet inspection, documentation, and labeling are not considered (*i.e.*, assumed to be integrated into the flow racks).
5. Flow racks are used in the staging area. This means that unloaders place loads at the beginning of a flow rack, and haulers pick them up at the other end in a *First-Come-First-Served* (FCFS) manner.
6. Haulers and unloaders travel rectilinearly.
7. Travel time is a linear function of distance (*e.g.*, acceleration/deceleration are infinite)
8. All trailer contents, travel distances, number of unloaders and haulers, and storage

locations are assumed known.

3.1 Model Formulation

In this sub-section we will present a general schema for the mathematical formulation of the problem.

Minimize W = makespan

Subject to the following constraints:

1. unloader-to-trailer assignment
2. trailer completion, replacement, and availability times
3. load sequence within trailer
4. unloader scheduling
5. pallet-flow rack assignment
6. flow rack capacity
7. hauler-pallet assignment and routing

3.2 Model Reformulation

As suggested in [11], the focus of a XD manager should be on managing the internal resources as to maximize workforce productivity. We now argue that given a trailer-to-door assignment and sequence, minimizing makespan may be viewed as a resource balancing problem. Consider the logic below:

$$Min\ makespan = Min\left(Max_{loads} \left\{ [idle\ time + time]_{(trailer - flow\ rack)} + [time]_{(flow\ rack - storage)} \right\} \right)$$

Makespan may also be considered from the perspective of the hauler and the objective function becomes:

$$Min\ makespan = Min\left(Max_{(haulers)} \left\{ [idle\ time + travel\ time]_{(flow\ rack - storage)} + [travel\ time]_{(storage - flow\ rack)} \right\} \right)$$

Since travel time is assumed rectilinear and horizontal component of travel time is fixed, the objective function becomes:

$$Min\ makespan = Min(\ 〚Max〛\ \_(haulers)\ \{\ 〚idle\ time + vertical\ travel\ time〛\ \_(flow\ rack - storage) + \ 〚vertical\ travel\ time〛\ \_(storage - flow\ rack)\})$$

Since travel time is assumed to be a linear function of time we have:

$$Min\ makespan = Min(\ 〚Max〛\ \_(haulers)\ \{\ 〚idle\ time + vertical\ travel\ distance〛\ \_(flow\ rack - storage) + \ 〚vertical\ travel\ distance〛\ \_(storage - flow\ rack)\})$$

Therefore, to minimize the makespan one needs to ensure that haulers are kept busy (minimize idle time) and that loads are placed in the flow rack closest to their storage location. Unfortunately, the two components of this objective function may be contradictory. Notice that to minimize hauler idle time unloaders need to feed the flow racks as fast as possible. This is done by placing loads in the closest flow rack. Clearly, if the loads are placed by unloaders in the closest flow rack, then they may not end in the flow rack closest to the storage location (to minimize haulers' vertical travel).

4 Rule-based Heuristics

Based on the reformulation of the problem, minimizing makespan requires a work-balance between haulers and unloaders. This Section proposes three heuristics to solve the inbound intralogistics problem.

H1 Minimize Hauler Loaded Vertical Travel

In H1 unloaders select the closest trailer from his idle location to be the next trailer served. Each load will be moved by the unloader to the flow rack closest to the load's storage location. If the selected flow rack does not have capacity, the load will be placed in the closest flow rack to the storage location that is in the path between the inbound door and the storage location. We refer to this flow rack as the *logical flow rack* as it is in the minimal required vertical travel distance for the load. Haulers move loads from the flow rack to the storage location based on the *Shortest Processing Time* (SPT) from their position. The logic behind H1 is to minimize the haulers' loaded vertical travel distances.

H2 Unloader Adapts to Haulers' Workload

Similar to H1, in H2 the unloaders select the next to be the one closest to where they become idle. To determine where to locate the load, unloaders will verify if any hauler is idle. If there is an idle hauler, the load will be placed in the flow rack closest to the inbound door; otherwise it will be placed in the flow rack closest to the storage location. If the desired rack is full, the next logical rack is selected. Haulers move loads from the flow rack to the storage location based on SPT from their position. In order to properly implement this heuristic a system to capture the status of the different elements of the inbound logistics process such as the one described in [13] may be required. The logic behind H2 is to minimize the haulers' idle times and loaded vertical travel distances.

H3 Least Utilization Rack on Path

Like in the other heuristics, in this heuristic the unloader selects the next to be the one closest to where they become idle. In this heuristic the unloaders will select the flow rack with the least utilization that is located between the load and its storage location. Ties will favor the flow rack closest to the final location. Like the other heuristics, haulers' select the load based on SPT from idle location. The logic behind H3 is to minimize the haulers' unloaded vertical travel distances.

Table 1 summarizes the focus of each heuristic based on the three components that directly affect the makespan.

Table 1: Heuristic Focus with Regard to Makespan

Heuristic	Haulers Idle Time	Hauler Loaded Vertical Travel Distance	Hauler Unloaded Vertical Travel Distance
H1		✓	
H2	✓	✓	
H3			✓

5 Experimental Results

An instance of the problem was constructed to evaluate and compare the proposed heuristics. Figure 4 depicts the DC layout used in the experiment. The receiving dock has three dock doors; each door will serve one trailer. There are four flow racks, each with capacity of 5 pallets. Lastly, there are four aisles in the storage area, each side of the aisle holding 25 pallet positions (200 total storage locations).

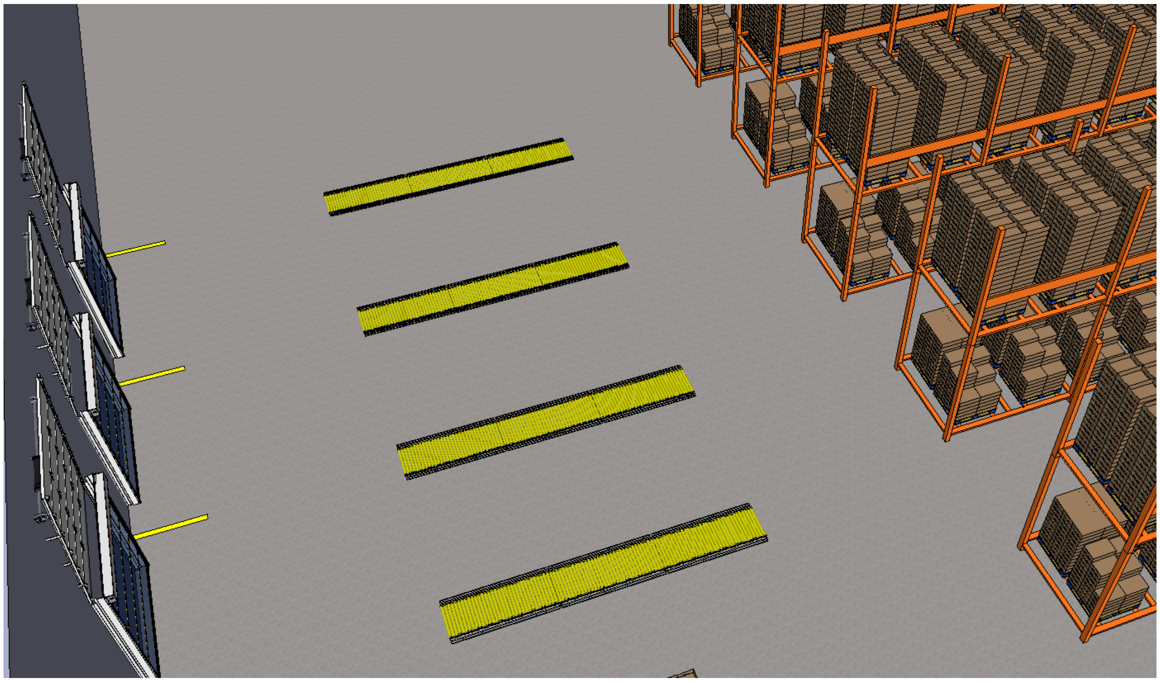

Figure 4: Layout of the DC for Experiment.

Each trailer is assumed to contain two rows of 5 pallets (10 total). The retrieval time from the dock door for each pallet position in the trailer is given in Table 2. The travel time for unloaders between the dock doors and each the flow racks is given in Table 3.

Table 2: Retrieval Time from Door to Pallet Position

Pallet Position	1	2	3	4	5	6	7	8	9	10
Load Time (secs)	2	2	3	3	4	4	5	5	6	6

Table 3: Travel Time (secs.) Between Dock Doors and Flow Racks

	FR 1	FR 2	FR 3	FR 4
Door 1	5	5	10	15
Door 2	10	5	5	10
Door 3	15	10	5	5

Pallets are assumed to take five seconds to pass through the flow racks and FCFS is honored. The distance between the flow racks and storage aisles was assumed to be 12 feet. The vertical distance between flow racks and aisles was 12 feet. The storage location of the pallets was randomly assigned to one of the 200 storage locations distributed within the four aisles. Storage locations were not repeated. The distance between storage locations was assumed to be 3 feet.

There are two unloaders and two haulers to perform all the movements. Each material handler can transport one pallet at a time. Haulers are assumed to move at a constant speed of 4 feet per second disregarding acceleration. Pick-up and deposit times were also disregarded. Unloaders started in doors 1 and 3, while both haulers started next to flow rack 1.

The scenario was programmed into Excel. Table 4 summarizes the results. The makespan in Table 4 is the time from the time the simulation started until the last pallet is stored. The low numbers for makespan has to do with the short distances in the instance. Columns 3-6 describe the pallets handled by the material handling resources. Similarly, Columns 7-10 describe the pallets handled per flow rack.

Table 4: Heuristic Results and Resource Usage

Heuristic	Makespan (min)	Pallets Per Resource				Pallets Per Flow Rack			
		Unloader 1	Unloader 2	Hauler 1	Hauler 2	FR1	FR2	FR3	FR4
H1	6.67	16	14	17	13	8	7	7	8
H2	5.08	14	16	18	12	7	7	8	8
H3	6.92	15	15	14	16	5	9	9	7

As seen in Table 4 H2 (Unloader Adapts to Haulers' Workload) performed better than H1 and H3 by 31.30% and 36.22%, respectively. The main benefit from using H2 was at the beginning of the simulation where haulers selected the closest flow rack, hence splitting the work with the unloaders.

6 Conclusions and Future Work

This study focuses on simultaneously solving the following operational-level decisions related to inbound intralogistics in DCs and XDs with staging areas: *i*) unloaders' assignment and scheduling, *ii*) loads-to-flow rack assignment, and *iii*) assignment and haulers' scheduling with the objective of minimizing the makespan to store all loads. It is argued that given a trailer-door assignment and sequence, minimizing makespan may be viewed as an unloader-hauler balancing problem. Hence, three rule-based heuristics for the problem are proposed and evaluated in a small problem instance. It is found that the heuristic that forces the unloader to adapt to the haulers' workload outperformed the heuristic that minimizes the haulers' vertical travel distance and the heuristic that distributes the work among flow racks by 31.30% and 36.22% respectively.

Future work will characterize via experimentation which rule-based heuristic performs better under each operational condition. New rule-based heuristics will also be developed and compared to the optimal solution. Once efficient heuristics are identified, they will be used as a sub-routine to solve the inbound trailer-to-door assignment and sequencing problems.

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