Optimizing Warehouse Efficiency

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Introduction

Agent-Based Modeling (ABM) is an effective strategy for simulating the emergent properties of complex systems. This form of simulation models the behaviors of individual agents interacting with each other and with their world and can be used to predict the outcome of discrete events, such as the behavior of a warehouse. Many frameworks exist for creating ABMs—one such program, used here, is called AnyLogic [1].

While ABM works well for modeling individual behaviors to determine the resulting emergent group properties, it is difficult to find optimal warehouse layouts, configurations, and personnel allocation that allow the warehouse to function as efficiently as possible. Parameters must be tuned and tested to find optimal settings.

Unfortunately, the simulation time required to test all possible parameter combinations is prohibitive, making this approach impractical. In this case, it is advantageous to use a highly efficient optimization tool such as HEEDS MDO.

While most applications of HEEDS focus on design of physical parts and products, HEEDS can also be applied to many other forms of optimization. This paper discusses the success of HEEDS in the area of optimizing warehouse efficiency, using the agent-based modeling tool AnyLogic.

Wholesale Warehouse Model

The agent-based traffic model is written in AnyLogic. It utilizes the "Wholesale Warehouse" demonstration model included with AnyLogic [2]. This simulation model uses the AnyLogic Network Storage object set to predict the performance of a wholesale warehouse, including employee efficiency, zone efficiency, and storage efficiency.

The warehouse is divided into six zones and has seven employee types. The pallets are delivered to the warehouse by supply trucks. Servicing staff (unloaders) unload and transport the pallets to the reception zone where the pallets are handled, marked by registrars (acceptors), and then moved to the storage zone with forklift trucks. When the warehouse receives an order, a forklift picks a single pallet from storage and transports it to a control zone where the controlling staff matches the pallet contents with the order. Transfer employees then take the pallet from the control zone to the dispatch zone. At the dispatch zone, a retail truck pulls up and the pallet is loaded onto the truck. The pallet is then delivered to the retail store that placed the order. Figure 1 shows a depiction of the various zones and employees.

To summarize, the seven employee types and their jobs are:

- Unloaders - unload pallets from storage trucks and deliver pallets to reception zone
- Acceptors – receive and scan in goods at reception area and move pallets to placement zone
- Forklift truck operators – take pallets from placement zone and put them into storage. When an order comes in, they take the order from storage and deliver it to the control zone.
- Controllers – match orders with appropriate pallets in the control zone
- Transferers – take orders from control zone to dispatch zone
- Loaders – take pallets from dispatch zone and load on retail trucks
- Retail trucks – after pallets are loaded, deliver to store that placed order

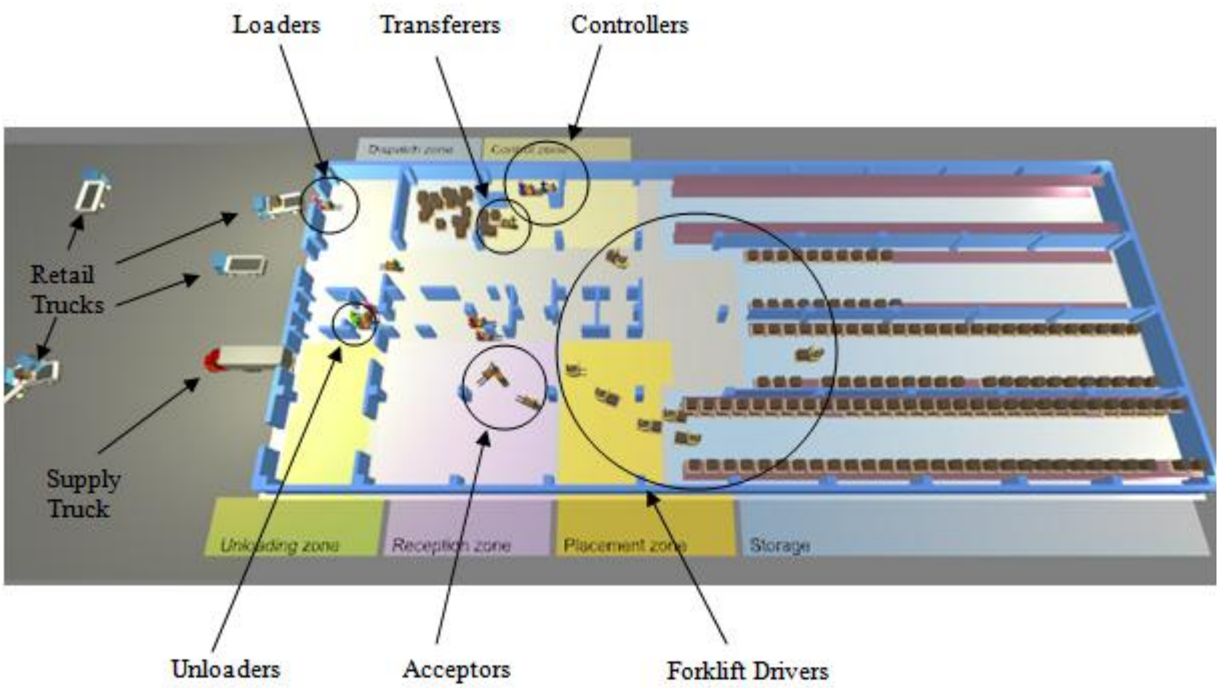

Figure 1: Wholesale Warehouse model in AnyLogic with different zones shown and with arrows indicating various warehouse employees.

When the model is executed, the warehouse is initially empty. Supply trucks begin to come in, as well as orders. The supply trucks deliver goods every 20-40 minutes and it takes 5-10 minutes to unload the trucks. Orders arrive every 8-24 minutes and the warehouse has the capacity to have 20 orders queued up at a time. The retail trucks take 3-8 minutes to deliver to the stores and return, and it takes 3-8 minutes to load the trucks. With an initially empty warehouse, it takes a few days for the storage shelves to become stocked and stabilize.

Optimization Goal

The goal for the warehouse, as defined in this paper, is to maximize warehouse efficiency. This efficiency is defined as a combination of employee efficiency, retail truck efficiency, and storage efficiency, and translates into maximizing profits. The goal is to determine the number of workers needed in each area, as well as the number of retail trucks required to maximize this overall efficiency, while not overworking employees or overloading a given zone with pallets.

Maximizing worker efficiency, storage, and retail truck efficiency are competing goals and will be handled in a multi-objective Pareto optimization using HEEDS MDO and the search method MO-SHERPA.

As mentioned previously, it takes a few days for the warehouse to fill and stabilize in its operations, due to starting with an empty warehouse. Therefore, the performance of the warehouse will be judged on the tenth day of operation. The average efficiency for that day will be used to judge a given worker configuration.

The optimization problem statement can therefore be defined as:

Objectives: Maximize *Worker Efficiency*

Maximize *Retail Truck Efficiency*

Maximize *Pallet Storage Efficiency*

Subject To: *Retail Truck Efficiency* ≤ 1.0

Unloading Worker Efficiency ≤ 1.0

Reception Zone Efficiency ≤ 1.0

Acceptor Worker Efficiency ≤ 1.0

Placement Zone Efficiency ≤ 1.0

Forklift Worker Efficiency ≤ 1.0

Pallet Storage Efficiency ≤ 1.0

Controller Worker Efficiency ≤ 1.0

Control Zone Efficiency ≤ 1.0

Transferer Worker Efficiency ≤ 1.0

Dispatch Zone Efficiency ≤ 1.0

Loader Worker Efficiency ≤ 1.0

By Varying: 1 ≤ Retail Trucks ≤ 20

1 ≤ Unloading Workers ≤ 20

1 ≤ Accepting Workers ≤ 20

1 ≤ Forklift Workers ≤ 20

1 ≤ Controller Workers ≤ 20

1 ≤ Transferer Workers ≤ 20

1 ≤ Loading Workers ≤ 20

We have specified that only integer values be used. The constraints imposed during the optimization ensure the employees are not overworked and a given zone is not overloaded with pallets. The zone efficiencies are calculated based upon the following capacities for each zone:

- Unloading Zone Capacity = 20
- Reception Zone Capacity = 20
- Placement Zone Capacity = 20
- Pallet Storage Capacity = 250
- Control Zone Capacity = 10
- Dispatch Zone Capacity = 20

Starting Design

The wholesale warehouse is initially configured with 24 employees and 5 retail trucks and drivers:

- Retail Trucks = 5
- Unloading Workers = 3
- Accepting Workers = 3
- Forklift Workers = 7
- Controller Workers = 3
- Transferer Workers = 5
- Loading Workers =3

With this configuration, the warehouse operates with an average employee efficiency of 58%, pallet storage efficiency of 79%, and retail truck efficiency of 86%. Figure 2 shows the metrics for this configuration within AnyLogic on the 10th day, while Figure 3 shows the status of the warehouse at the end of the 10th day.

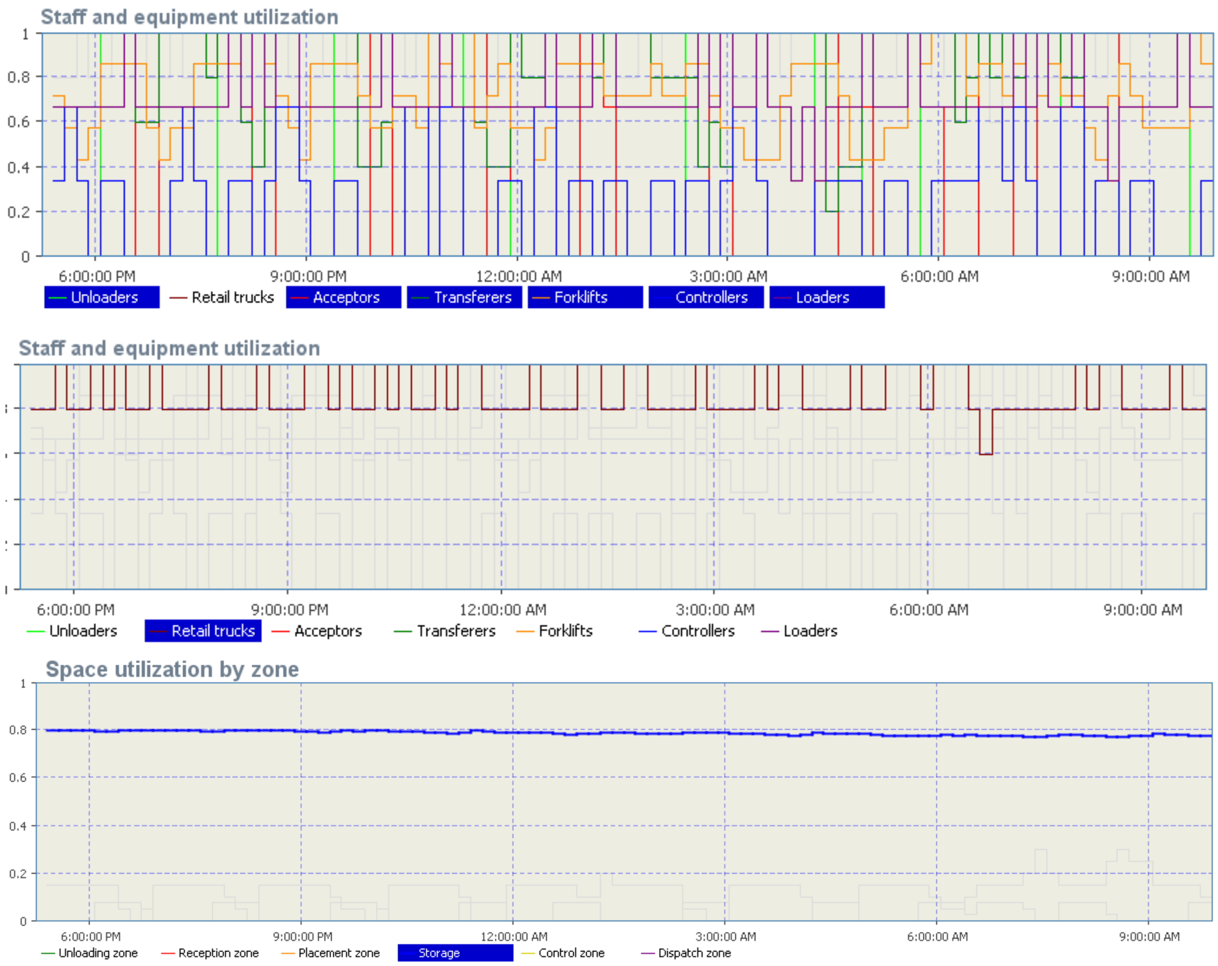

Figure 2: Wholesale Warehouse performance for the baseline design on the tenth day. Average employee efficiency: 58%; average retail truck efficiency: 86%; average pallet storage efficiency: 79%.

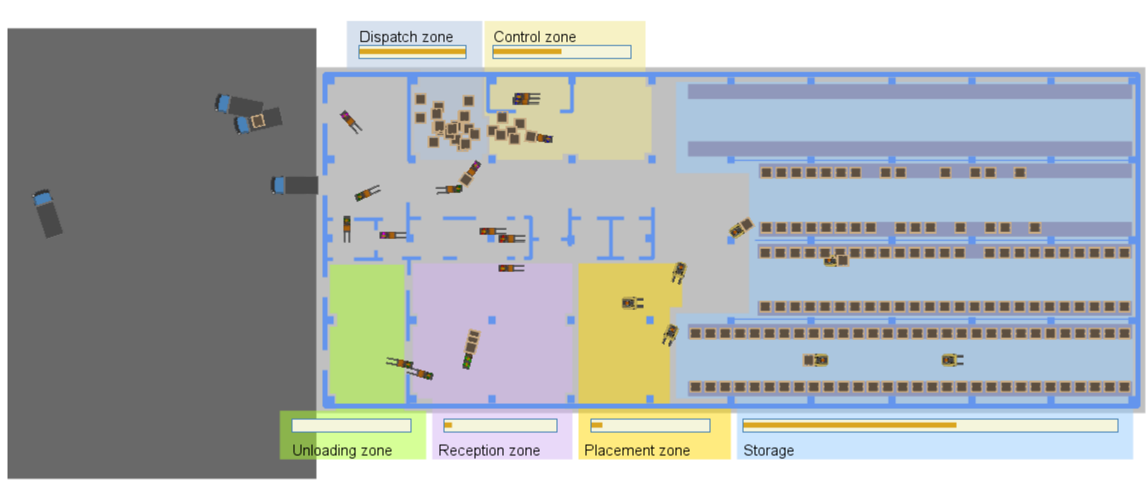

Figure 3: Wholesale Warehouse status at the end of the tenth day for the baseline design.

Optimization Results

The three objective Pareto optimization performed with HEEDS MDO found designs that drastically improved the efficiency of the warehouse. In addition, the optimization provided a set of designs that were superior in at least one of the three objectives, called rank-1 designs. This allowed the user to select the design that best met the goals of the warehouse, seeing the tradeoff between all objectives. Figure 4 shows a three-dimensional plot with the three objectives plotted, while Figure 5 shows a plot view of the Pareto fronts (figures are from HEEDS POST). The blue circular points in Figure 4 represent all feasible designs evaluated, while the larger red square points correspond with the rank-1 designs in Figure 5. The ideal design in Figure 4 would be at the front, top corner of the 3D cube, where all efficiencies are highest.

Highlighted in Figure 5 are the three designs that would be deemed optimal for a given objective. Design A is optimal in terms of retail truck efficiency; Design B is optimal in terms of employee efficiency; while Design C is optimal in terms of pallet storage efficiency. However, clearly Design A is the top performing design overall, when comparing all three designs. While Design B performs very well in terms of employee efficiency (73%), it is poor in retail truck efficiency (37%), and sub-par in pallet storage efficiency (94%). Design C performs well in terms of both pallet storage efficiency (>99%) and retail truck efficiency (100%), however, it performs poorly in terms of employee efficiency (55%). Design A, meanwhile, performs well in terms of all objectives: employee efficiency = 72%, pallet storage efficiency > 99%, and retail truck efficiency > 98%. Figure 6 shows the metrics for the Design A configuration within AnyLogic on the 10th day.

Table 1 compares the three designs highlighted in Figure 5 along with the baseline design. Design A improves employee efficiency by 13.8%, pallet storage efficiency by 20.1%, and retail truck efficiency by 12.5% over the baseline configuration. These types of efficiency improvements can correlate into large cost savings. Here, HEEDS was able to reduce the number of required warehouse employees by 6 (an accepting worker, 2 controlling workers, a loading worker, a retail truck driver, and an unloading worker) and eliminate one required retail truck.

References

1. AnyLogic 6 Professional, XJ Technologies, 2012.
2. AnyLogic 6 Professional, XJ Technologies, *Wholesale Warehouse* Example Model, 2012.

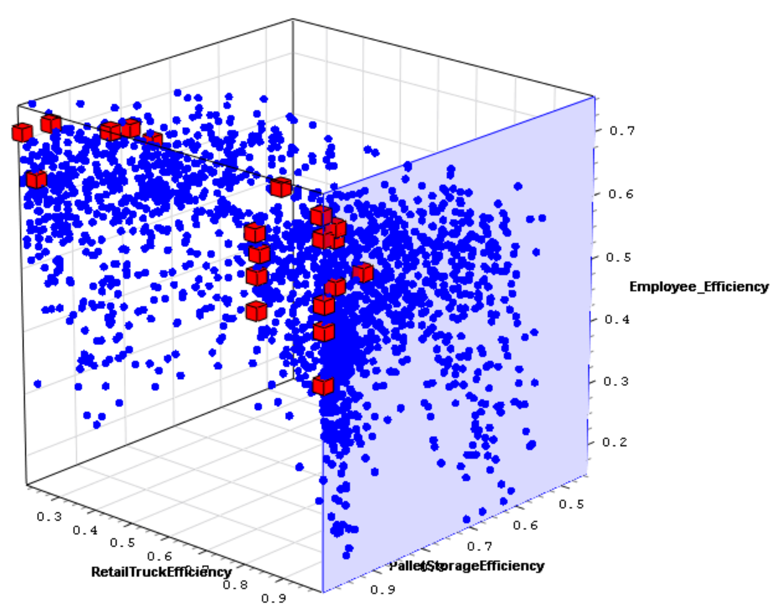

Figure 4: 3D relation plot from HEEDS POST showing the feasible designs evaluated (blue circles) and the rank-1 designs from the Pareto optimization (larger red square dots).

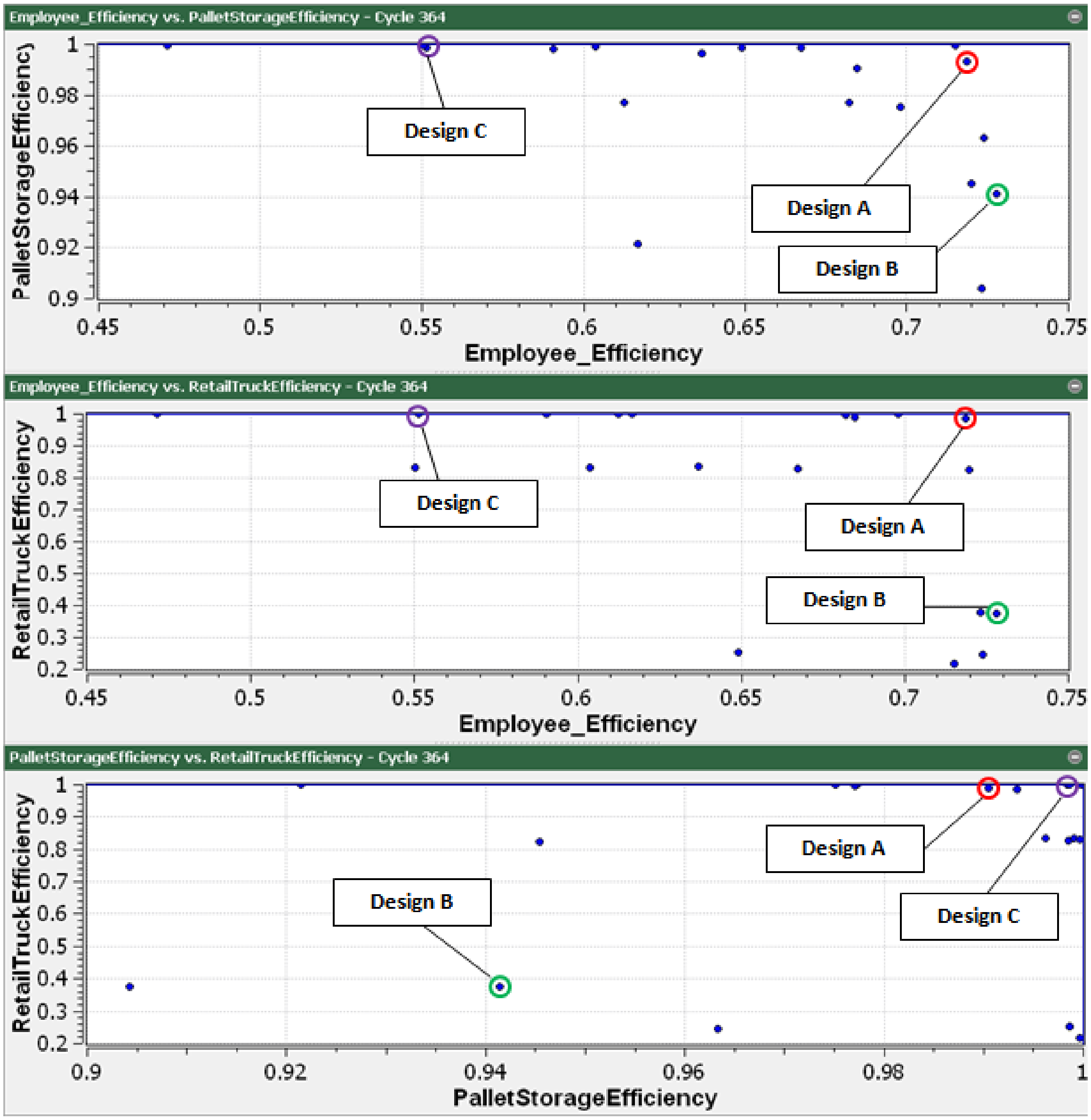

Figure 5: Rank-1 Pareto front depicted with multiple 2D plots in a plot view in HEEDS POST. Highlighted are the three designs deemed optimal. Design A is selected as having the best trade-off among the three objectives.

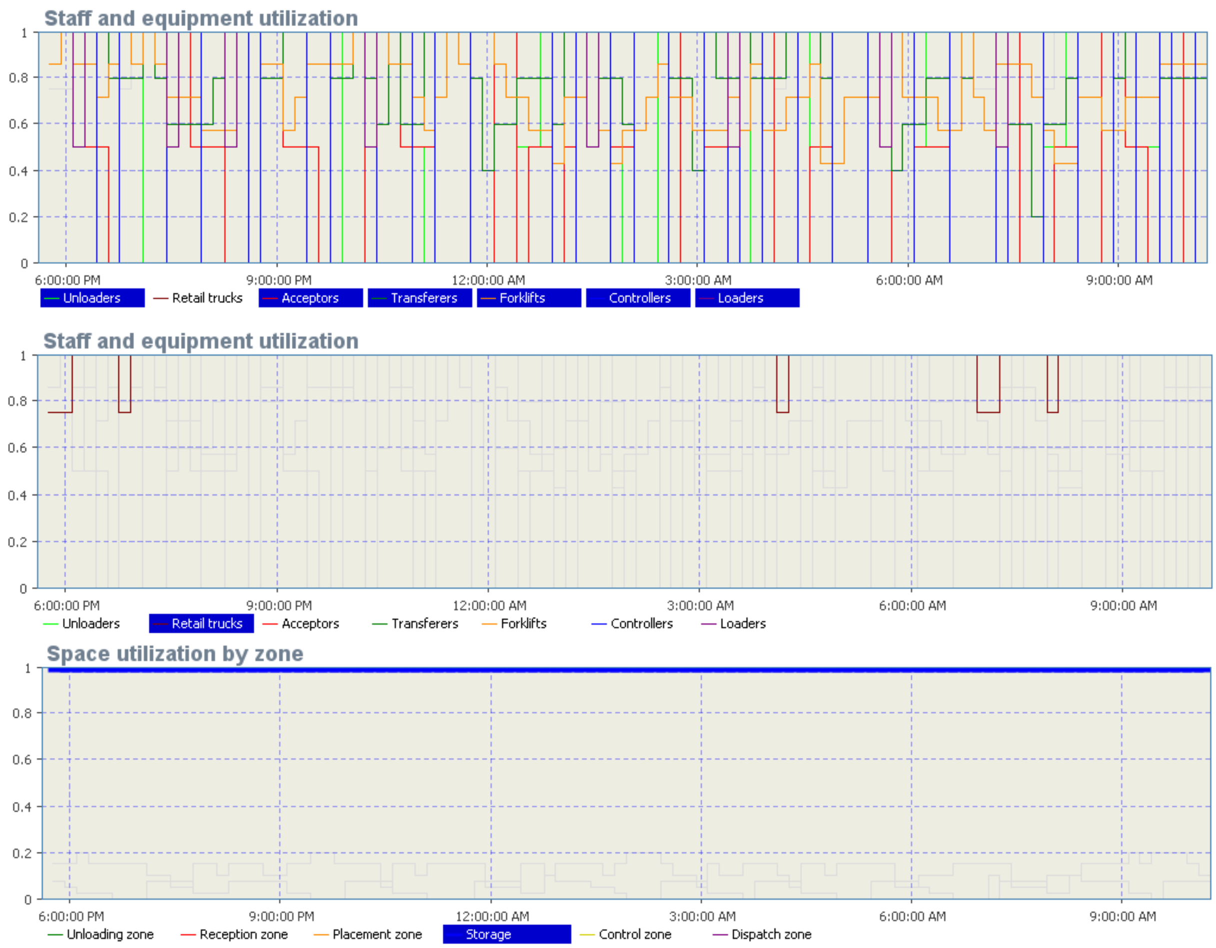

Figure 6: Wholesale Warehouse performance for the optimized design on the tenth day (Design A from Figure 5). Average employee efficiency:71.9%; average retail truck efficiency: 98.6%; average pallet storage efficiency: 99.3%.

Table 1: Summary of design characteristics for the baseline configuration, as well as the three deemed optimal designs from the Pareto front of Figure 5.

	Design			
	Baseline	**A**	**B**	**C**
Employee Efficiency	0.581	0.719	0.728	0.551
Pallet Storage Efficiency	0.792	0.993	0.941	0.999
Retail Truck Efficiency	0.861	0.986	0.376	1.000
Accepting Workers	3	2	2	2
Controlling Workers	3	1	1	1
Forklift Workers	7	7	7	14
Loading Workers	3	2	2	2
Retail Trucks	5	4	11	3
Transferer Workers	5	5	5	6
Unloading Workers	3	2	3	3