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Using Simulation and UI/UX for Optimizing Warehouse Processes of Non-Profit Corporations

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Abstract: Each year, an astonishing 92% of retail garments produced end up in landfills. To address this problem, Locker Room 345 (LR345), a non-profit organization partnered with Dick's Sporting Goods, serves the Binghamton community by donating clothing, shoes, and other items to students in need. Dependent upon donated inventory and volunteers, LR345 is unable to fulfill its desired order fulfillment throughput of 50 per day. The Capstone team utilized Industrial Engineering tools such as Lean Six Sigma, Operations Research, and Discrete-Event Simulation to establish a problem statement and work breakdown structure, create a simulation and layout, and propose innovative solutions for donation delivery. These proposed solutions can enable LR345 to expand its sustainability initiatives to donate necessities to over 60 schools and organizations in Broome country, improve facility layout and reduce 75% of foot travel in the LR345 warehouse, and output 88 donations in a 2-hour work shift (282% increase).

Keywords: Discrete Event Simulation, Facility Layout, Optimization, User Interface/User Experience (UI/UX)

1. Introduction

The need for Locker Room 345 (LR345) is essential in Broome County, where almost one-third of the population lives below the poverty line. This statistic is significantly higher than the New York state average of 13% (City-Data.com, n.d.). In the United States, students with ill-fit or loose-fit clothing are at risk of lower academic achievement and dropping out of school (*CDC*, 2019). With the mission statement of "equipping students for success," LR345 aims to donate necessities to over 60 schools and organizations. Although LR345 strives to help all students in need, its capacity is limited by the inventory available at the warehouse from donations from Dick's Sporting Goods. With no set volunteer schedule, the system is stochastic. There was no inventory management system and orders were not guaranteed due to unpredictable inventory. There is no set order fulfillment process. However, with 92% of garments not recycled, LR345 is a concept that can expand to other locations in the country to benefit students and recycle garments (Dory, 2018). While over 24,000 K-12 students have access to donations in Broome county currently, an improved system can allow for more locations of the non-profit. Other corporations can adopt the concept such as H&M with more than $4.3 Billion in unsold clothes per year.

1.1. Users

Primary users include volunteers and administrators who sort, select, and package orders for over 60 schools in Broome County and other organizations. The Capstone team and Website Development team are the designers of the system. The secondary users of the system are the students and teachers who benefit from the donations provided by LR345. By leveraging the knowledge of the stakeholders, LR345 can expand to help more communities in need beyond Broome County.

1.2. Problem Statement

LR345 is facing a growing demand for donations, yet the baseline layout and order placement process were not optimal, making it difficult to meet the goal of fulfilling 50 orders per day. Until recently, donation requests had been made through PDFs sent over email resulting in inaccurate tracking of order history. Additionally, the organization's order fulfillment process led to delays and errors. To continue providing essential support to students in need, LR345 needed to improve its system, optimize its layout, and implement a more efficient order placement process.

1.3. Concept of Operations

The primary objective of this project was to significantly enhance the order fulfillment process of LR345 by increasing its efficiency by 117% (23 orders in the baseline to 50 orders per day). This was achieved by adopting a zone-batch-wave fulfillment system and reorganization of the facility layout, which reduced foot travel and streamlined operations. The scope of the warehouse includes the layout, process, and safety considerations. The sub-categories of the process are storage, counting and picking, packing, and product delivery. In addition to the warehouse, the team also focused on enhancing the website's inventory management and user interface. The website's user interface included two aspects: the customer view (teachers and students) and the administrative view (not accessible by teachers). Under the administrative view, there is a volunteer's view and a director's view. By expanding the scope of the project to encompass both the warehouse and the website, the team aimed to create a comprehensive system that could help LR345 fulfill its mission of providing essential support to students in need. This expansion of scope is shown in Figure 1.

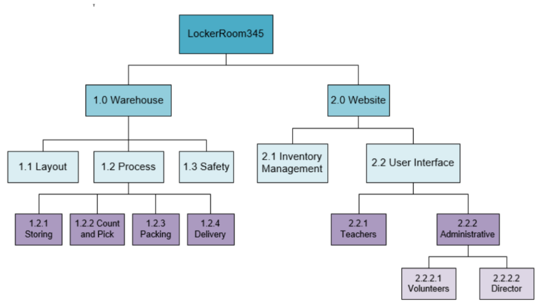

Figure 1: Work Breakdown Structure

2. UI/UX Literature Review

The design of a website comprises various elements such as visual aesthetics, information quality, flow, and user intention. Visual aesthetics involve static images, color schemes, fonts, shapes, and layouts, which significantly influence the appeal of a website. A visually appealing website is more likely to elicit positive consumer responses. This can lead to more purchase intentions as modern consumers tend to prioritize this over the product itself (Zhang, 2021). Ease of navigation is considered the most crucial factor for 79% of e-commerce users. A lengthy checkout process and difficulty in locating parts of the website are identified as the top reasons for shopping cart abandonment. Privacy policies at the bottom of each page also are essential (Vu & Proctor, 2011). Consistency in navigation controls is crucial for enhancing user experience. Website design and navigation controls were primarily researched.

Professional-looking websites that incorporate pictorial information are more likely to engage teachers and encourage them to place orders while also sharing school and student information. To achieve this, ”error-proofing” and ”user-centered interfaces” are crucial ”design considerations” that can help prolong user attention (Vu & Proctor, 2011). Product images on the website provide users with a visual representation of the items. Moreover, for products that are out of stock, the website should either indicate that they are unavailable or indicate which sizes are out of stock (Vu & Proctor, 2011). To enhance the checkout process, the website should indicate the required fields using a red asterisk. If the user attempts to submit an order without completing these fields, an error message should be displayed to prompt them to fill in the required information (Vu &

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Proctor, 2011). Whenever a product is added to the shopping cart, the number displayed next to the shopping cart icon on the top bar should be updated to reflect the total number of items in the cart (Vu & Proctor, 2011).

To ensure the usability of the website, it is essential to obtain user feedback early in the process. Users should be given the opportunity to specify what they like, dislike, and suggest improvements (Vu & Proctor, 2011). This focus on usability can benefit teachers by increasing the number of orders placed, reducing the time required for training, and improving access to information (Vu & Proctor, 2011). Usability testing is a qualitative method used to observe users' interactions with a website prototype, providing insights into any difficulties encountered and the ease of use. Additionally, it enables the collection of valuable feedback from users (Ritter & Winterbottom, 2017). When conducting usability tests, it is important to target users with varying levels of technology and online experience, social media presence, and industry experience, as well as different demographics (Ritter & Winterbottom, 2017).

3. Requirements and Verification

A total of 106 requirements were gathered and documented in a Requirements Traceability and Verification Matrix (RTVM). Each requirement was linked to a unique ID in the Work Breakdown Structure (WBS) to ensure that they were addressed in the project plan. To ensure that the requirements were met, the RTVM included verification methods such as analysis, inspection, demonstration, and testing. Analysis involved evaluating the requirements apart from the final product, while inspection involved evaluating the final product. Demonstration involved observing the use of the product, while testing involved recording events for later evaluation.

Nine requirements related to process were verified through analysis, which included the use of an Arena simulation model to detail the incoming orders, picking, packaging, and delivery. Nineteen requirements related to layout were verified through inspection, which included the use of AutoCAD drawings and spaghetti diagrams. A total of 38 requirements related to storing were verified through demonstration. Additionally, 39 requirements related to the user interface were verified through testing, including usability tests conducted on administrators and teachers involved in LR345.

4. Implementation

4.1. Layout and Process

LR345's order placement and fulfillment process was initially mapped out as follows: orders received via email, orders printed in the warehouse, two volunteers individually pick and package orders simultaneously, orders sent to the shipping station, orders either delivered to school or picked up by school representative. This process was highly inefficient, primarily in the pick-and-pack sub-process, and restrained the warehouse employees from achieving their daily order fulfillment goal of 50. When the capstone team became involved in LR345 improvements, the number of volunteers increased from two to four, so a the Zone-Batch Wave process was developed for four volunteers accordingly.

The team implemented a zone-batch-wave picking process, where volunteers simultaneously pick merchandise in their assigned zones, to optimize volunteer utilization and order fulfillment. Each volunteer was assigned a zone in the warehouse (Volunteer A to Zone A, Volunteer B to Zone B, etc.) and worked on each order one at a time together. As seen in Figure 2, foot travel is minimized and orders are able to be picked in an optimal manner. The process simulation and results can be found in Section 5, Discrete-Event Simulation Analysis.

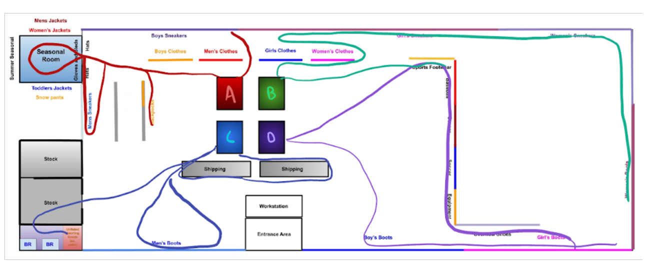

Figure 2: Spaghetti Diagram Layout

As seen in the left blueprint of Figure 3, the LR345 warehouse has a 75 ft. by 80 ft. central room with a variety of different shelving units, tables and bins holding merchandise items that are either ready to be picked or labeled as stock. It has three side rooms, with their initial purposes being to hold all winter merchandise, soccer merchandise, and clothing stock. The initial warehouse layout before the implementation of the team's changes was inefficient and disorganized, as the placement of merchandise was counter-intuitive and generated high amounts of foot travel for volunteers.

The team proposed four major warehouse layout improvements that would minimize employee foot travel and locate merchandise in an intuitive fashion. The first change physically made by the team, as noted by "1" in the right blueprint of Figure 3, was the relocation of men and boys clothing to an adjacent position to women and girls clothing. Since clothing is the most commonly ordered type of merchandise, the team deemed that it would be intuitive for volunteers to take the same walking route when picking for both males and females. With the vacant space left from the first change, the team added new shelving units, as shown by "2" in Figure 3, to compensate for the overflow of shoes that the warehouse employees had in inventory. "3" in Figure 3 depicts a new shipping station added by the team. Tables and bins labeled with receiving schools were added to this section to mitigate safety hazards resulting from packaged orders being scattered across the floor. The "4" in Figure 3 represents all changes made to stock; the winter stock room was made into a "seasonal room" and all sports equipment was moved to the soccer room to free up space in the main floor for more frequently picked items. Some shelves in the warehouse with some seasonal items are also mobile to account for different times of the year where seasonal items are ordered more often. Further research can incorporate concepts such as Association Rule Mining to include commonly bought items nearby one another in the layout.

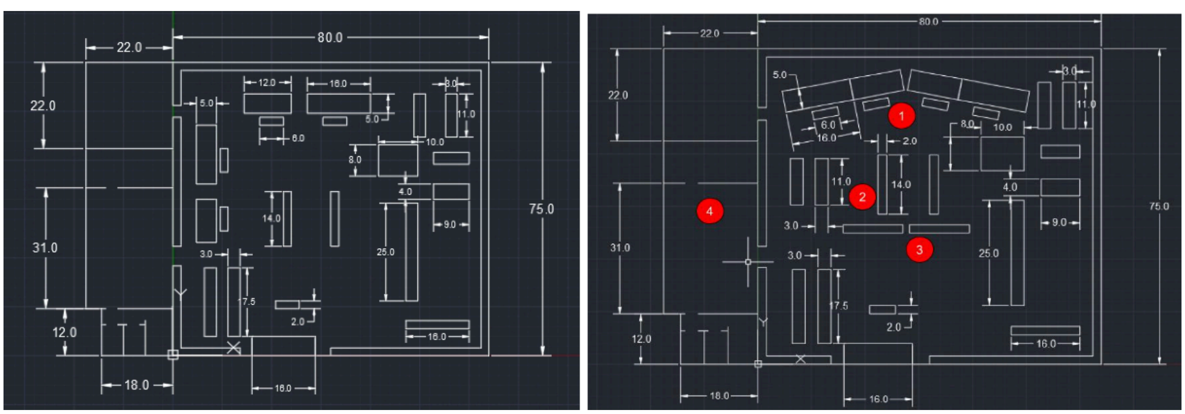

Figure 3: Initial and Improved AutoCAD Blueprints

To optimize delivery routes for LR345, the team utilized Circuit, a software that streamlined the vehicle routing problem. With Circuit, the addresses of all the 64 delivery locations could be inputted along with the number of drivers who were volunteers. The time required for each stop and the optimal route could be calculated. Available times for delivery could also be inputted for an optimization algorithm to determine the most efficient order for deliveries, taking into account expected arrival times for each driver. The software also came with a user-friendly app for drivers, which displayed their daily schedules and provided GPS directions.

This problem was classified as a Traveling Salesman Problem (TSP) and a vehicle routing problem (VRP). Both problems share similar goals, which were to minimize the total distance traveled by an entity that began at one location, visited all remaining locations, and returned to the starting point while ensuring one arc entered and one arc left any node. Typically, VRPs were applied to a fully connected network of roads, and this type of problem could be solved using the simplex method by formulating a linear programming problem.

$$
\begin{aligned}
\min z &= \sum_{i=1}^{n}\sum_{j=1}^{n} s_{i,j}x_{i,j} \\
\text{s.t.} \; & \sum_{i=1}^{n} x_{i,j} = 1 \quad \forall j \\
& \sum_{j=1}^{n} x_{i,j} = 1 \quad \forall i \\
& x_{i,j} \in 0,1 \quad \forall i,j
\end{aligned} \tag{1}
$$

To properly solve the vehicle routing problem (VRP) and calculate the shortest distance, a duality problem needed to be solved. This involved converting the original minimization problem into a negative maximization problem (i.e., min z = max -z). By making this switch, the maximization problem had ”n” constraints and ”m” variables, compared to the ”m” constraints and ”n” variables of the original minimization problem.

At the time, LR345 had over 60 donation locations within a 30-mile radius in Broome County. As the organization expanded to include additional locations, drivers, and other constraints, solving the VRP calculations could become confusing and time-consuming. Therefore, the team highly recommended the use of Circuit, which was a specialized software that could efficiently and effectively solve complex VRP problems. With Circuit, LR345 could optimize its routing plans and ensure timely and cost-effective deliveries.

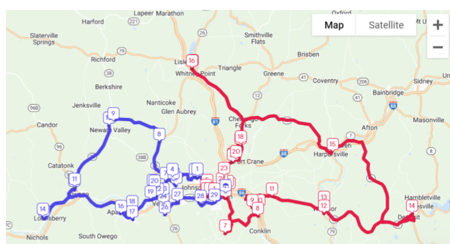

Figure 4: VRP in Circuit (Blue = Driver 1, Red = Driver 2)

5. Discrete-Event Simulation Analysis

Based on time study findings, the team developed discrete event simulation models to evaluate order throughput, volunteer utilization, and queue occupation. The first step was to create a baseline model that represented LR345’s pick-and-pack process prior to implementing process improvements. To do this, the raw data collected from time studies was fit into distributions using ExpertFit and incorporated into specific simulation model blocks. The baseline simulation includes a order reception process, both volunteer pick-and-pack processes, and a delivery process. The model utilized a variety of create, process, signal, hold, route, station, decide, and dispose blocks, as well as resource and entity assignment to processes within the system. This comprehensive model allowed the team to identify bottlenecks and inefficiencies in the pick-and-pack process, and subsequently implement changes to improve order processing times, volunteer utilization, and overall system performance.

With run parameters set to a two hour workshift, the most significant finding from the simulation was the order throughput, or ”Entities Out”. The pre-improvement order fulfillment system only outputted 23 orders, which was 46% of the target of 50. Numerous process queues across the system were active for a significant portion of the run time, indicating bottlenecks in the system. Specifically, the delivery process had an active queue 88% of the time, while the packaging process had an active queue for both volunteers approximately 60% of the time. This caused system backups, with multiple locations having occupied queues for more than 50% of the time.

In order to decrease queue times, decreasing utilization was a key objective for the team in their improved simulation, focusing on the service time and arrival rates of orders. The target was to have process queues occupied for less than 50% of the simulation run time for identified bottlenecks. By identifying and addressing the bottlenecks, the team could increase order

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throughput and improve overall system efficiency. The improved simulation model was run with the same replication length parameter of two hours, and new results were obtained. During the simulation run time, 118 orders were entered into the system through the separated order reception process. Of these, 88 orders were successfully fulfilled, resulting in an increase in order throughput to 75%. The four different volunteers worked simultaneously on each entity, which improved the efficiency of the pick-and-pack processes. The picking queues for volunteers A through D were kept under 50%.

The "Incoming Orders Queue", which represents the queue at the beginning of the system, was active less than 1% of the time, indicating that orders were received smoothly and distributed directly to the pick-and-pack processes without any backups. The "Wait for Delivery Queue", which represents the queue following the pick-and-pack processes, experienced a decrease in activity by close to half the initial value, to 43%. This decrease indicates that the delivery process was made more efficient, enabling orders to be fulfilled at a rapid pace.

However, the queue for order packaging had an 80% activity rate, which was higher than the team's target. This was due to assigning the packaging task to volunteer C, who had a high utilization rate of 98%, while the other volunteers stood idle, waiting for the next order to pass through the incoming process. To mitigate this problem in the future, idle volunteers will be assigned to the packaging process, resulting in a more even distribution of worker utilization and active queue times.

Table 1: Arena Simulation Results

Result	Baseline	Improved
Delivery Queue	88%	43%
Packaging Queue	59%	80%
Picking Queue	47%	26%
Average Volunteer Utilization	65%	49%
Output Orders	23	88

6. Conclusion

Locker Room 345 has identified several areas for improvement in order to meet their daily throughput goals. To address these issues, the team improved the organization of the warehouse, streamlined the order fulfillment process, and implemented a zone-batch wave process, which led to the exceeding of the targeted 117% increase in order fulfillment. To meet the target throughput of 50 orders per day, improvements were implemented to both the LR345 warehouse processes and multiple ends of the website. In the warehouse, shelving, inventory, and other necessary items were relocated intuitively to improve safety and efficiency. Paired with the facility changes, a zone-batch-wave picking process was established, where the team adapted to the increased number of available resources and assigned each volunteer a specific zone of the warehouse when picking. On the website end, the team used UI/UX design research to improve usability for all users, incorporating new inventory management features and improving visual appeal. With the implementation of all these changes, LR345 was able to increase their order throughput by 282% with significantly reduced queue occupation times. With Dick's having locations in 48 states, the LR345 business model has the ability to expand across the country and potentially branch out from just the retail industry.

References

Dory, K. (2018, June). *Why fast fashion needs to slow down.* `https://www.unep.org/news-and-stories/blogpost/why-fast-fashion-needs-slow-down`. (Accessed: 2023-03-21)

Ritter, M., & Winterbottom, C. (2017). *Ux for the web : Build websites for user experience and usability.* Packt Publishing.

City-Data.com. (n.d.). *Binghamton, new york (ny) poverty rate data.* `https://www.city-data.com/poverty/poverty-Binghamton-New-York.html`. (Accessed: 2023-03-21)

CDC. (2019). *Preventing bullying - centers for disease control and prevention.* Retrieved from `https://www.cdc.gov/violenceprevention/pdf/yv/bullying-factsheet508.pdf` (Accessed: 2023-03-21)

Vu, K.-P. L., & Proctor, R. W. (2011, May 19). Handbook of human factors in web design. *Taylor & Francis*.

Zhang, Y. e. a. (2021). Impact of website design features on experiential value and patronage intention toward online mass customization sites. *Journal of fashion marketing and management 25.2*, 205–223.