The Effect of Material Handling Strategies on Time and Labour Fatigue in Window Manufacturing

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Abstract –

Manual material handling in the workplace is a leading cause of musculoskeletal disorders among workers and a key driver of workers' compensation costs. As such, the primary objectives of this study are to assess the impact of manual material handling on both the time spent manually handling materials and the well-being of workers within the context of glass window manufacturing, as well as to examine potential strategies to reduce the adverse impact of manual material handling. The study focuses on the process of manually pushing carts fully loaded with 35 glass units over a 100-meter-long route at a case window-manufacturing facility. Two alternative strategies are examined: (1) reducing the weight of the carts by partially loading them, and (2) using power jacks to transfer fully loaded carts. The study analyzes the effects of these strategies on parameters such as total transfer time and the corresponding labour hours, as well as worker fatigue levels, measured on a scale ranging from 1 (low fatigue) to 5 (severe fatigue). The results reveal that the task of transferring the fully loaded carts along the route costs the company about $1,800 in labour every month, consumes more than 10% of the 8-h work shift of three workers, and causes high levels of fatigue among the workers engaged in this task. Reducing the cart load size from 35 to 25 units is found to reduce the total time needed to transfer 700 glass units by 7%, the corresponding total labour hours by 38%, and the average fatigue score (as reported by the workers) from 5.0 to 4.0. Further reducing the load size to 20 units reduces the average fatigue score to 2.3 but increases the requisite transfer time and labour hours compared to the load size of 25 units. Introducing the use of a power jack as an alternative to reducing the load size, meanwhile, reduces the total transfer time by 55%, the total labour hours by 85%, and the average fatigue score from 5.0 to 2.0 when comparing it to the current practice. Moreover, a cost analysis of the different alternatives reveals that introducing the power jack is the alternative with the lowest net present value when considering labour and purchase costs, and that the case company could realize a return on its investment within five months following the purchase of a power jack. As such, this alternative is deemed to be the most attractive among the alternatives considered in terms of time efficiency, cost efficiency, and the well-being of workers.

Keywords –

Material Handling; MMH; Time Efficiency; Cost Efficiency; Labour Fatigue; Cart System; Power Jack; Window Manufacturing.

1 Introduction

Despite the versatility and ubiquity of material handling equipment, which includes different types of conveyors, cranes, automated guided vehicles, and others [1], manual material handling (MMH) that does not involve the use of any equipment is still common in many workplaces [2]. MMH is defined as the process of "moving or handling things by lifting, lowering, pushing, pulling, carrying, holding, or restraining" [3]. It often requires workers to bend and stretch their bodies when carrying heavy loads [4]. As such, MMH is recognized as a leading cause of occupational fatigue and musculoskeletal disorders, leaving approximately three out of four Canadians whose job involves MMH with back pain resulting from workplace injuries at some point in their lives [3]. In fact, the largest portion of workers' compensation claims are associated with MMH [5]. In Canada, MMH-related back injuries contribute to roughly one-third of all lost work and an even higher percentage of total workers' compensation costs [3]. Furthermore, the impacts of MMH are not limited to physical injuries of workers and the corresponding compensation claims. In this regard, improving work design rooted in ergonomics has been shown to have many benefits, such as increased worker productivity, reduced physical demand, and reduced employee turnover [6]. Moreover, besides the ergonomic risks it poses, material handling is also generally considered a non-value-added task, from a lean perspective, as it does not directly contribute to the transformation of raw materials into a saleable commodity [7]. These non-value-added tasks can account for a significant portion of the total manufacturing time. For instance, in a recent case study undertaken in a tannery facility, non-value-added tasks were found to account for 17.42% of the manufacturing cycle time, with material handling tasks being the primary contributor [8]. Because these non-value-added tasks consume time and resources, they drive up operating costs. In fact, material handling alone has been found to be responsible for 20–50% of the operating costs in a manufacturing environment [9].

Therefore, effective material handling strategies can play a pivotal role in enhancing the overall performance of manufacturing. For instance, a case study in the automotive manufacturing sector demonstrated that implementing hand trolleys or carts for material transportation, as opposed to manual methods, led to a productivity increase of 19.6% [10]. However, as illustrated in this manuscript's case study, even a hand cart system can encounter critical issues if the load handled during each transfer trip is not properly managed (as elaborated in Section 2). Currently, there is a lack of standardized numerical guidelines regarding acceptable load limits or force exertions for hand cart operations, as stated by the Canadian Centre for Occupational Health and Safety [11]. While general recommendations suggest a load limit of 450 lb for four-wheel hand carts [11], management may be inclined to increase the load per trip with the intent of minimizing the number of trips and total transfer time, thereby boosting productivity. However, it is arguable that heavier carts might prolong transfer times and elevate worker fatigue, potentially counteracting the intended productivity gains. This hypothesis regarding cart systems has not been thoroughly explored in previous research conducted on MMH [12-15]. Therefore, this study aims to assess how varying cart loads affect total transfer time and worker fatigue levels, focusing on a glass window manufacturer where glass units are manually transferred between workstations using rolling carts. The study also evaluates the use of power jacks for cart transfer compared to manual handling and includes a cost analysis of different material handling strategies.

2 Problem Description

The case company specializes in the manufacture of double- and triple-glazed window units. The process of manufacturing a sealed glass unit entails various activities, beginning with loading the glass onto a cutting table. The glass is then cut into desired sizes, and workers load the glass pieces onto rolling carts located in Area A, as shown in Figure 1. They are then transferred to a production line, which starts at Location B (see Figure 1), where double-glazed and triple-glazed glass units are formed. The formed glass units are then loaded onto rolling carts at the end of the production line positioned at Location C, then transferred to another workstation located in Area D to begin the window framing process.

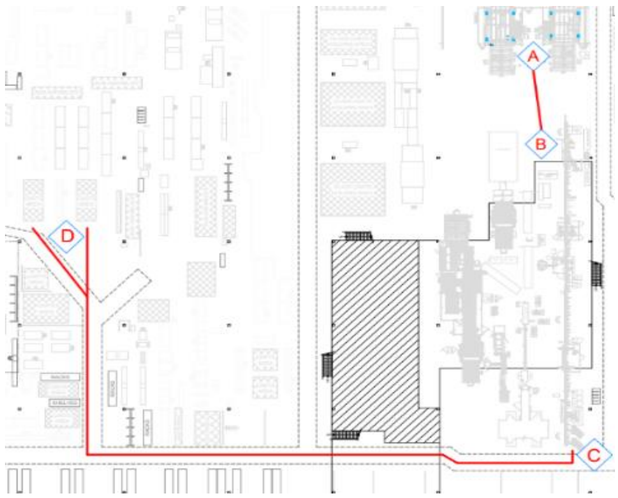

Figure 1. Material flow

The rolling carts used at the facility, shown in Figure 2, are manually transferred by workers between workstations. This manual transport of material was flagged as a notable material handling issue due to the substantial weight of the carts. This issue was highlighted through a message conveyed by the workers, as seen in Figure 3 where it required the efforts of multiple workers to handle the carts. For instance, the trip from Location C to Location D requires two to three workers to manually push fully loaded carts (35 double- and triple-glazed glass units) over a 100-meter-long route. The weight of a fully loaded cart can reach 1,102 lb, and they are manually transferred between these locations more than twenty times a day. The high physical demand associated with this task increases the risk of injury to workers and has an adverse effect on worker well-being. Moreover, this material handling practice also consumes a significant amount of labour hours, as described later in this paper.

As such, we set out to quantify the effect of the current material handling practice on transfer time and labour costs and to investigate alternative strategies that could mitigate the inefficiencies associated with the current practice. We focused in particular on the trip from Location C to Location D in the case facility, as this is material handling trip that involves the longest travel distance and the heaviest carts.

Figure 2. Rolling carts

Figure 3.Worker's note

3 Methods

This study involved four main research stages, as described in the following subsections.

3.1 Stage I: Evaluating the current practice of using fully-loaded rolling carts

The first stage consisted of identifying the different activities involved in the manufacturing process and observing the material handling system during operation. The number of glass units that need to be transferred between workstations on a daily basis and the number of workers required to transfer them were first recorded. Next, a time study was conducted to measure the transfer time required to move the fully loaded carts along the 100 m-long route. A total of 24 data points on transfer times were collected, and these were found to accurately represent the actual durations of the recorded variables. The dataset was deemed to be sufficient in size due to the low variability in the recorded data (as indicated by the low standard deviation of 0.5 min obtained). The trip duration was measured using a stopwatch which, for each trip, was started when the cart left Location C and stopped when it arrived at Location D.

To quantify the fatigue experienced by different workers while transferring the carts, the workers were asked to indicate a fatigue score for each trip on a scale ranging from 1, representing the lowest fatigue level, to 5, representing a severe fatigue level. In this stage, the workers consistently reported the highest fatigue score due to the heavy weight of the carts fully loaded with double- and triple-glazed glass units.

3.2 Stage II: Experiments with reduced cart loads

The first alternative material handling strategy examined was to reduce the number of units loaded onto the cart to reduce its weight. Although reducing the load increases the number of trips required in order to transfer the same number of units, we hypothesized that it may also reduce (1) the number of workers needed to transfer a cart, (2) the adverse effect of manual material transfer in terms of worker fatigue, and (3) trip durations to transfer the carts. To test these hypotheses, three experiments were run with the number of glass units loaded onto the 35-slot carts reduced by increments of five for each experiment (i.e., reducing the load from 35 units to 30, 25, and 20 units for the three respective experiments). To minimize interruptions to the facility operations, each experiment was restricted to only four repetitions, thereby generating four data points per experiment (i.e., per load size), which is a limitation of the present study as discussed in the Conclusions section of this manuscript. In each experiment, the trip durations, the number of trips required, and the level of fatigue reported by workers were recorded.

3.3 Stage III: Experiments with use of power jack

Following the first two stages of analysis, the use of a motorized power jack, shown in Figure 4, to transfer glass units between workstations was tested. The power jack can load up to 4,500 lb of glass and is operated by a single worker. The durations of four trips completed using the power jack were recorded, and the worker operating it was asked to report their fatigue level.

Figure 4. Power jack

3.4 Stage IV: Comparative cost analysis

Once the data had been collected for the four material handling alternatives (i.e., the three reduced cart load sizes and the use of a power jack), the costs associated with each strategy were calculated in order to gain a better understanding of the financial implications of each. First, the total labour hours spent on handling the same total quantity of glass units using each reduced cart load size was computed and multiplied by a sample hourly rate of $25/h in order to compute labour costs. Then, since the introduction of a power jack entails a purchase cost, the net present value equivalent to the labour and capital costs incurred was computed for each of the four strategies (i.e., the three reduced card load scenarios and the power jack scenario) considering a minimum attractive rate of return (MARR) of 20%. This threshold was chosen because the case company does not consider any investment that does not yield at least 20% return. This analysis was mainly intended to determine whether the decision to invest in a power jack was financially sound.

4 Results and discussion

4.1 Fully loaded carts

Data was collected on 24 randomly selected, fully loaded carts transferred from Location C to Location D, as summarized in Table 1 below. During the data collection process, four instances of transfer times (highlighted in red in Table 1) were identified as outliers due to events interrupting the transfer of the corresponding carts. Specifically, workers occasionally had to navigate slowly while pushing the cart because other workers were simultaneously pushing other materials along the same path. Consequently, they had to pause and wait until the pathway cleared. Workers also had to pause the cart transfer in some instances due to congestion of carts in the designated area, necessitating a rearrangement of the area in order to accommodate all the carts.

Most of the fully loaded carts were transferred by three workers, as they were deemed too heavy to be handled by only two workers in most cases. It took, on average, a total of 3.3 min for workers to transfer a loaded cart to Location D. Moreover, the workers consistently reported a fatigue score of 5 after transferring the carts.

Table 1. Current state results

Cart #	Transfer Time per Cart (minutes)	Cart #	Transfer Time per Cart (minutes)
1	3.5	13	3.0
2	4.4	14	3.3
3	3.3	15	3.2
4	3.1	16	3.1
5	3.2	17	4.5
6	3.2	18	3.4
7	4.5	19	3.1
8	3.4	20	5.1
9	3.4	21	3.1
10	3.5	22	3.3
11	4.2	23	3.0
12	3.0	24	4.4

Although the time spent on a given material handling trip from one location to another may be insignificant, the cumulative time spent on material handling, and the potential savings associated with strategies to reduce the trip duration, can be significant considering how many material handling trips occur in a given day. To demonstrate this, let us consider the total time and labour hours needed to transfer twenty carts, containing 35 glass units each, which is a commonly sized glass batch scheduled for production on a given day. The average total time and labour hours can be calculated by using Eq (1) below. The total time and labour hours needed to transfer twenty carts amount to 1.1 h and 3.3 h, respectively. A total transfer time of about one hour per day is equivalent to more than 10% of an 8-h work shift spent by each of the three workers on manually transferring heavy carts—a significant amount of non-value-added work.

$$\begin{aligned} &Estimate\ of\ total\ transfer\ time\ per\ day \\ &= average\ transfer\ time\ per\ cart \\ &\times\ carts\ per\ day = 3.3\ \frac{minutes}{cart} \times\ 20\ carts \\ &= 66\ minutes \\ &= 1.1\ hours\ \times\ (\sim 3\ workers\ per\ trip) \\ &\approx 3.3\ labour\ hours \end{aligned} \tag{1}$$

4.2 Partially loaded carts

To evaluate the effect of the load size on the number of carts required in order to transfer a given batch of glass from Location C to Location D, a batch size of 700 glass units was considered. The total number of carts necessary to transfer this batch was then computed satisfying Eq. (2). The total transfer time and labour hours were also computed, satisfying Eq. (1). It was found that, for a load size of 30 units, the number of required carts would total 23.3 based on Eq. (2). In this case, 23 carts would be loaded with 30 units each and one cart would be loaded with the remaining ten units. The total transfer time corresponding to the 23 carts was calculated satisfying Eq. (1) using the average transfer time per cart loaded with 30 units. As for the time needed to transfer the remaining cart containing ten units, since the relevant data was missing, it was assumed to be equal to the minimum time recorded for pushing a cart containing 20 units during the present time study, which was measured at 1.7 min as shown in Table 2. As such, the total time needed to transfer the 24 carts was computed by adding 1.7 min to the transfer time computed using Eq. (1). The results are summarized in Table 2.

$$\begin{aligned} &Number\ of\ required\ carts \\ &\qquad = \frac{700\ glass\ units/day}{Load\ size\ (units/cart)} \end{aligned} \tag{2}$$

As the presented results show, decreasing the cart load size reduced the number of required workers from about three workers for the carts with 35 glass units to two for carts with 30, 25, and 20 glass units. The average transfer time also decreased, with the lowest total transfer time of 61.6 min and total labour hours of 2.1 h recorded for carts with 25 glass units. Reducing the load size from 35 units per cart to 25 units per cart reduced the total transfer time by about 7% (i.e., increased daily productivity by about 7%) and the total labour hours by about 38%. Further reducing the load size to 20 units per cart, on the other hand, increased the total transfer time and total labour hours, as the increase in the number of required trips outweighed the reduction in transfer time per cart. These results are reasonable, considering that walking freely (without pushing a cart) from Location C to Location D at the factory takes about 1.5 min, meaning that further reducing the load size will not have a significant effect on the transfer time, as it approaches the average walking time needed to travel between the two locations.

Table 2. Results from reducing cart weights

# Glass units per cart	**35**	**30**	**25**	**20**
Transfer time per cart (min)	-	2.8	2.3	1.8
		2.7	2.3	1.7
		2.9	2.2	2.2
		2.8	2.1	2.1
Average transfer time per cart (min)	3.3	2.8	2.2	2
# Needed workers	3	2	2	2
Average fatigue score	5	5	4	2.3
# Trips per day	20	24	28	35
Total transfer time per day (min)	66	66.1	61.6	70
Labour hours per day	3.3	2.2	2.1	2.3

The average fatigue score dropped from 5.0 for carts loaded with 35 and 30 units to 4.0 for carts loaded with 25 units, and further dropped to 2.3 for carts loaded with 20 units. The fatigue score remained high when the load size was reduced to 30 units because there were two workers transferring the carts rather than the original three. Hence, while this initial reduction in load size was beneficial in reducing the total labour hours, there was no discernible benefits in terms of alleviating worker fatigue. Decreasing the load size by another five units, though, did result in a reduction the average fatigue score to 4.0. While further reducing the load size to 20 units adversely affected transfer time and labour hours, it significantly reduced the average fatigue score. In this regard, a reduction in load size that may adversely affect productivity may nevertheless be considered preferable as a means of further mitigating the adverse effects that manually transferring heavy carts has on the health of workers.

4.3 Power jack

Following experimentation with the different partial load sizes, the use of a power jack to transfer fully loaded carts, each containing 35 glass units, from Location C to Location D, was introduced. Although the purpose of this strategy was to reduce manual input in material handling, it was more feasible to remove the cart from the power jack and manually maneuver it to place it at its intended position, as the drop-off area is often congested with other carts. Despite this limitation, the data presented in Table 3 shows the promising results obtained for this material handling strategy. On average, using a power jack reduced the transfer time for each cart by about half. The effect on the total labour hours was also significant, since only a single worker is needed to operate the power jack. The total labour hours decreased by about 85%, from 3.3 h in the case of manually handled carts to 0.5 h in the case of carts transferred using the power jack. The average fatigue score also significantly decreased from 5.0 to 2.0, but it did not drop to 1 since the worker must manually maneuver the cart at the drop-off location (as noted above). Overall, the use of a power jack was found to be the most attractive material handling strategy in terms of time efficiency and the well-being of workers. Further analysis was conducted in order to better understand the financial implications of investing in this equipment, as described in the following section.

Table 3. Power jack results

Cart handling strategy	**Manual**	**Power Jack**			
# Glass units per cart	35	35			
Transfer time per cart (min)	-	1.3	1.5	1.4	1.7
Average transfer time per cart (min)	3.3	1.5			
# Needed workers	3	1			
Average fatigue score	5	2			
# Trips per day	20				
Total transfer time per day (min)	66	30			
Labour hours per day	3.3	0.5			

4.4 Cost analysis

The labour costs associated with each material handling strategy and the respective net present value equivalent to twelve months of labour costs were computed. The results obtained for a MARR of 20% are presented in Table 4. Notably, the expenditures on transferring carts from Location C to Location D alone amount to $1,815 each month. It is also remarkable that a mere adjustment in the load size of these carts could lead to monthly labour cost savings of over $800 for the company. The power jack strategy was found to have the lowest net present value among the tested strategies, with a recorded value of $10,177, resulting in cost savings of 48% when compared to current practice. The strategy of using a cart load size of 25 units was also found to be financially attractive, where a 36% reduction in costs could be realized without investing in new equipment. Still, despite requiring initial capital investment, the power jack strategy stands out as the preferable choice due to its significant time and cost savings coupled with the reduction in the level of fatigue experienced by workers.

Table 4.Cost results

Cart handling strategy	**Ma-nual**	**Manual**			**Power Jack**
# glass units per cart	35	30	25	20	35
Capital investment	-	0	0	0	$7,210
Monthly labour costs	$1,815	$1,210	$1,155	$1,265	$275
Net present value	$19,584	$13,056	$12,462	$13,649	$10,177
Cost savings	-	33%	36%	30%	48%

To better judge the financial benefits of the different strategies, though, the capital investment cost of the power jack needed to be taken into consideration. Using the power jack results in monthly labour cost savings of $1,540. Considering the initial purchase price of $7,210, the number of periods (N) needed to recover the cost of the power jack can be calculated using Eq. (3) as follows.

$$PV = C + \frac{1-((1+\mathrm{r})^{-\mathrm{N}})}{\mathrm{r}} \times \mathrm{S}$$
$$0 = -7{,}210 + \frac{1-((1+0.0167)^{-\mathrm{N}})}{0.0167} \times 1{,}540 \quad (3)$$

where:

- PV is the present value, set to 0 in order to determine the breakeven point at which the case company would recover the purchase cost of the power jack;
- C is the initial capital investment, which is the purchase price of the power jack;
- r is the monthly discount rate; and

- S is the monthly savings in labour costs realized using the power jack.

Based on Eq. (3), it would take the case company approximately five months to recoup the initial investment of $7,210. Beyond the breakeven point, the company would begin realizing monthly savings of $1,540 relative to the base scenario cost of $1,815 (i.e., manually pushing fully loaded carts from Location C to Location D).

5 Conclusions

This study examined the influence of MMH on time and worker fatigue in glass manufacturing. Various strategies of transferring glass between workstations were investigated to evaluate the influence MMH has on these factors. These strategies included reducing the number of glass units per cart and utilizing a power jack.

The current practice involved workers dedicating a considerable amount of time to transferring carts, resulting in fatigue and increased labour costs. Among the alternatives examined, three demonstrated promising results: using a cart with 25 glass units instead of 35, using a cart with 20 glass units, and using a power jack. Among the three reduced load size scenarios considered, the 25-unit option proved to be the most economical, while the 20-glass option led to the least fatigue for workers. As for the power jack, it significantly reduced both the time spent on transferring carts and worker fatigue. However, the decision to adopt this solution ultimately hinges on the company's willingness to introduce new equipment and the anticipated return on investing in it. In this regard, the cost analysis results show that the case company would recoup the purchase costs within five months, while also saving costs, improving productivity, and improving the well-being of workers in the long term.

Perhaps the most notable limitation of the present study was the limited size of the dataset used to evaluate the alternative material handling strategies. To address this limitation, average transfer time per cart was used to estimate the total transfer time corresponding to a batch of glass units. In future research, alternative strategies could be tested over the course of days in order to obtain more accurate transfer times and labour cost data. For prolonged data acquisition periods, automated technologies like radio frequency identification (RFID) may prove more efficient compared to manual data collection methods. Further exploration could encompass additional analysis factors such as (1) occupational safety, (2) ergonomics of worker movement, and (3) training needs for adopting new technology in material handling processes. Finally, given the labour costs expended on material handling, future research could examine the prospect of implementing fully automated material handling systems such as automated guided vehicles to eliminate the reliance on human labour.

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