5th Asia Pacific Conference on Industrial Engineering and Operations Management
Tokyo, Japan, September 10-12, 2024
Publisher: IEOM Society International, USA DOI: 10.46254/AP05.20240107
Published: September 10, 2024

Impacts of Ergonomic Conditions on Quality and Cycle Time in Automotive Shock Absorber Assembly

Val Urman and Kuldeep Agarwal
Department of Automotive and Manufacturing Engineering Technology,
Minnesota State University Mankato,
205 Trafton Science Center E, Mankato, MN 56001
Kuldeep.agarwal@mnsu.edu

Abstract

The quality of an assembled product and cycle time are significantly influenced by a workstation's ergonomics. A study was carried out to investigate how the cycle time and assembly quality were affected by minor workstation modifications that could potentially reduce the ergonomic strain. For the investigation, a single workstation from the main assembly line—which assembled eight components and was the cause of 43% of quality defects—was chosen. In an experimental design, the standing surface surrounding the workstation, the assembly height, and the reachability of components were all changed. Many times, complaints or injuries serve as the impetus for ergonomic solutions. This study measured the effects of implementing suggested ergonomic conditions using profit-focused measures to promote proactive action. The findings show that workstation setups varied significantly in terms of cycle time and product quality. The components' reachability showed a notable reduction in cycle time. The standing surface of the workstation and the reachability of the components led to a markedly reduced assembly quality. There was no difference between the current conditions and assembly taking place at the recommended height.

Keywords
Assembly Quality, Cycle time, Standing surface, reachability, assembly height

1.Introduction
The study of ergonomics focuses on matching an employee's surroundings and job needs to improve productivity, quality, and output while reducing fatigue, overexertion, and musculoskeletal problems associated with the workplace (Edwards C. 2023). The study of ergonomics reviews the posture and movements of a person to find potentially dangerous or unfavorable conditions. This includes but is not limited to, curvature of the spine, angles of joints, rotation of limbs, forces, action frequency, noise, vibration, and lighting (Rexroth 2012). In assembly, an employee is expected to complete sequential tasks where staged parts are placed together to construct another product or component. This process could include pushing or pulling parts together, lifting objects, and accurately placing or rotating objects. This process could be repeated thousands of times throughout the tenure of an employee.

The characteristics of an assembly workstation drive the ergonomic load placed on the user. Characteristics such as the size and height of the table, the locations of the tools and parts they are using, and actions required to assemble, and drive the angles, forces, and postures the user endures. In addition to the physical characteristics, ambient conditions, like temperature and volume, impact the worker and the load placed on them. Ergonomics is important in the workplace as employees can be faced with the conditions of an environment for an entire career. Poor ergonomics can lead to an extensive list of injuries or conditions, especially in extended periods.

Reducing joint angles, improving posture, decreasing lift requirements, or any other improvement to the ergonomics of a workstation is known to make for safer working conditions. These changes reduce the risk of musculoskeletal disorders (MSDs). MSDs include disorders which impact bones, joints, muscles, tendons, and ligaments. In 2018, 38,640 musculoskeletal disorders (MSDs) were reported in the manufacturing industry in the US alone (U.S Bureau of Labor Statistics 2020). The median number of days away from work for these injuries was twelve (U.S Bureau of Labor Statistics 2020), equating to 463,680 days nationwide.

Ergonomic improvements have successfully improved assembly quality and cycle times in other studies. Cycle time is a term used in manufacturing, referring to the time to complete one unit. This number does not include anything outside of the assembly process. Quality encompasses many different factors, some of which are subjective. Quality is the difference between a product and its expectations. (Axelsson 2000) reduced quality defects from 8.9% to 5% through correction of lighting, postures, handling, and material accessibility in 17 tasks. By simply enlarging workstation tables and improving visibility of a projected image, (Yeow 2003) was able to reduce defect rates by 3%. To increase productivity, components were better organized and presented, reducing the required reach for each component, and shortening cycle time (De Looze 2010).

By nature, tasks like long reaches take more time to complete than short reaches. Parts requiring more force to install require more attention than something that simply drops into an oversized space. Speeding up assembly by shortening reaches or making installation more consistent by reducing the force required to insert also has ergonomic benefits. Instead of improving a product based on assembly times or defects, a strategy could be to review the ergonomic conditions faced by those building the product. While these and many more studies review ergonomic changes and conditions in assembly, the direct comparison of multiple is lacking. Much of the reviewed research determined the impact of various degrees of a single improvement on cycle time or quality. Maintaining the constants of working conditions is important for comparisons of ergonomic parameters. To achieve this, a study was conducted aimed to compare multiple ergonomic parameters and their impacts on assembly quality and cycle time.

1.1 Ergonomic Conditions and Assembly Cycle Time/Assembly Quality

Cycle time is the duration of one assembly process. A shorter cycle time in manufacturing is ideal as it has a direct impact on the cost of the component. Many internal factors affect the cycle time of an assembly such as: component quantity, component size, complexity, location of components in assembly cell, and assembler knowledge (Falck, 2014). It is the hypothesis of this research that ergonomics of an assembler influences the cycle time in addition to the listed factors. Other factors, such as cognitive workload, were found to increase assembly time and muscle activity (Biondi 2020). Three groups of participants: control, 0-back, and 2-back, were asked to complete a LEGO car while muscle activity was measured. 0-back had to repeat the last single digit number that was played to them during assembly. The 2-back had to repeat the third-to-last digit played (Biondi 2020). The 2-back group averaged 10 seconds, significantly greater than the control group's average of 50 seconds.

The expectation that fatigue will increase with higher production is justified as the motion requirement is increased for the same period. However, fatigue did not increase when production was increased in a simulated assembly study (Bosch T. M. 2011). Participants were asked to complete an assembly task at one of two rates, 38 or 48 seconds per assembly, for a minimum of one hour. Muscle activity was not significantly different between the shorter or longer cycle time samples (Bosch T. M. 2011). Simulation of a fastening task had increased fatigue with greater production rates and shoulder height work (Gooyers 2014). Study participants were tasked with completing 7, 14, and 21 fasteners per minute at shoulder and waist height. Samples completing 21 fasteners per minute had significantly greater muscle activity than the 7 and 14 fasteners per minute tests.

Using an array of cameras, reachability, visibility, direction, and glance scores were derived to form a quantified rank of an assembly task (Enomoto, 2013). In this case, the direction is the viewing angle from horizontal, 0-45° downwards being ideal. Glance is the requirement to look upwards. Using the images of the assembly, the assembly sequence was changed, improving the average ergonomic score from 1.99 to 2.75 and reducing assembly time. However, in a car manufacturing plant, there was not a significant correlation between postures and assembly time (Falck, 2014). With a large table, components have been observed to spread out. Increased reach times lead to longer cycle times (De Looze, 2010). As previously discussed, providing the operator with the ability to sit or stand is important for worker comfort. Height adjustable tables, material handling carts and lifts, in addition to chairs were expected to improve productivity 15-25% (De Looze 2010). Less discomfort is reported with seated postures when compared to standing or leaning. Seated postures do not allow for natural movement and can encourage a slumped position over time; a posture that can be considered hazardous (Zare 2020). Researchers have had success correcting the amount of illumination of an assembly (Yeow 2003), rearranging the order in which components are assembled to eliminate blind assembly and orient the assembly for the best view of the operation (Enomoto 2013) (Boothroyd 1984).The literature supports the claim that other ergonomic characteristics such as fatigue and posture impact assembly quality. Vehicle assembly tasks with a high ergonomic load were found to have 6.8 times more failures than tasks with low load (Falck 2014).

2. Methodology

To enlarge the body of knowledge on ergonomics in assembly, a study was conducted, aimed at directly comparing different ergonomic features of a workstation. This study is conducted through a local manufacturer and affiliated with Minnesota State University, Mankato. Data for this study requires the participation of a human operator. To ensure the participant rights were protected, approval from the MSU Institutional Review Board was required. This approval process consisted of a thorough review of the study, data collection methods, data storage, inclusion, and informed consent. Approval was given October 24th, 2022.

Setting

The study was conducted at a small aftermarket automotive suspension manufacturer located in Lakeville, Minnesota. The study was conducted on a single workstation within the primary shock assembly line. Shock Assembly, the department this line is located within, comprises 20 of the manufacturers' 160 employees. Employees are 80% male, ranging in age from 19 to 52 years old. Normal production hours are 6 am to 4 pm, Monday through Thursday.

Assembly

The entirety of shock assembly occurs in a corner section of the building. Subassemblies are processed at workstations around the perimeter of the area and stocked on the assembly line. The remaining components are picked and staged at the beginning of the assembly line. Shocks are processed linearly through seven stations, and then placed on an inline washer conveyor. Station one assembles the two components that make the shock body, followed by installing the adjuster mechanism components in station two.

2.1 Workstation Selection

The final assembly station was selected for this study out of the five manual assembly stations within the assembly line. Station qualification required a human element and more than three components assembled, ensuring minute variances in cycle time were detectable. This requirement eliminated stations one and six from consideration.
The selection criteria of qualified stations were limited to defect frequency. Assembly defects are detected and logged once the shock is completely assembled using a shock dynamometer and check sheet. Although defects are found at the end of the assembly, failure modes can be associated with specific operations and therefore traceable, a method validated by Ivarsson & Eek. Daily results are compiled and stored in a network location. Defects, resulting from errors in assembly, occurring between January 1st, 2022, and March 31st, 2023, were used to create a Pareto chart, summarizing defect frequency.

Assembly Steps

First, the shock body is secured in a vise with the piston rod pointing up. This is required as the bottom face of the body is open, and the internal components and oil can spill out. Figures 1&2, show the following assembly steps. Once fixed in the vise, a washer (A), O-ring (B), small rubber ball (C), and wiper (D) are inserted before the threaded cap is installed.

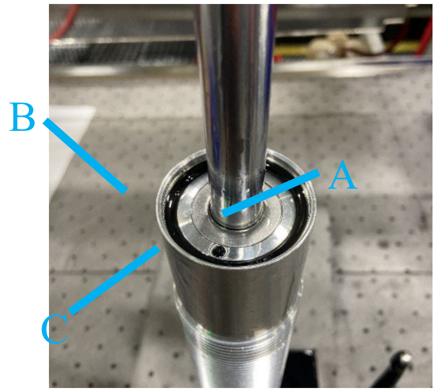

Figure 1. Assembly of the Three Internal Components

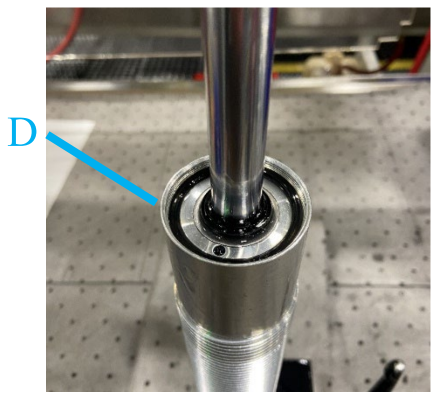

Figure 2. Wiper Installation Location

Once the cap (E) is installed and tightened, the external components; a rubber bumper (F), jam nut (G), and rod end (H), are installed on the end of the rod as shown in figure 3.

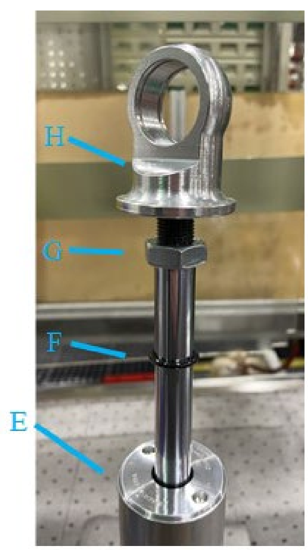

Figure 3. Assembly of Four External Components

2.3 Study Design
A factorial experiment design was used to determine the effects of multiple ergonomic accommodations in a workstation. Factorial experiments are used to screen a group of variables for statistical significance. Two predetermined values, referred to as levels, coded -1 and 1, are selected for each variable. In a full factorial design, an experiment for each combination of high and low variables is required. One complete set of experiments is referred to as a replication.

With three factors, a full factorial design would require eight experiments for each replication. The experiment followed a one-half fraction factorial design as the interactions between factors were of less interest. Three factors, assembly height, reachability, and standing surface were coded A, B, and C, respectively. Using Minitab, experiment design was generated with the predetermined factors and levels. The design included two replications of four different test conditions, totaling eight runs. The uncoded experimental plan followed in the study is in the appendix.

Table 1. Coded One-Half Fraction Factorial Design

Run Sequence	Nonrandom Order	Assembly Height	Reachability	Standing Surface	Treatment Condition
1	4	1	1	1	abc
2	6	1	-1	-1	a
3	3	-1	1	-1	b
4	2	1	-1	-1	a
5	5	-1	-1	1	c
6	8	1	1	1	abc
7	1	-1	-1	1	c
8	7	-1	1	-1	b

Each run consisted of 22 assemblies, two practice and twenty recorded. Practice assemblies were included to eliminate the concern of error resulting from repeated relocation of components or location of assembly height. The following twenty were recorded for quality defects, and assembly time. The entire study totaled 160 shocks.

2.4 Controls
Assembly height, component reachability, and standing surface were controlled. Previous research demonstrated success upon implementation of recommended conditions for each individual characteristic but lacked a comparison to other ergonomic parameters. This study was designed to determine and compare the effects of multiple ergonomic conditions on assembly quality and cycle time.The height from the floor at which the assembly operation occurs is referred to as the assembly height. An adjustable work holding fixture was designed and implemented to allow assembly height to be driven by the height of the user. The work holding fixture was constructed using 3/16-inch steel sheet, plastic clamp jaws and socket, a linear bearing carrier, aluminum rail, and an over center clamp. Plastic was used for components contacting the shock, clamp jaws and socket, to prevent damage to the product during assembly.

The vise was located 36” above the standing surface. Assembly height is raised from the vise the length of the shock body, in this case 13 inches. The low level of assembly height, coded -1, was set to 49 inches using the adjustable height fixture. The high level, coded 1, was driven by the height of the assembler, 67 inches. Using a recommended assembly height for work requiring elbow room (Ergonomics Guidebook for Manual Production Systems, 2012), assembly height was set to 41 inches. Component reachability is defined by the distance between the item being assembled and the items being installed. To control the location of the components being installed, a rack with an articulating arm was purchased and implemented. To provide a mounting point for the arm, a rigid steel tube was mounted vertically to the back of the table. Multiple mounting points were provided to allow for appropriate height of the components.
Maintaining consistent presentation, components were housed in plastic bins of various sizes, organized first to last, left to right. Bins containing small and light components were hung, using the formed hook on the back of the bin, at

the end of the articulating arm, a 17 by 18-inch louvered plate. Panel center was positioned a recommended 12 inches back and 12 inches right (16 inches diagonally) of the assembly. Components that remained on the table surface were positioned a recommended 14 inches back from the assembly (Ergonomics Guidebook for Manual Production Systems 2012). For the low level, bins were located on the table surface, against the back edge of the table. This is the standard location of components during normal production.

3. Standing Surface

During all experiments, the anti-slip grates remained as the base for the workstation. For high level standing surface experiments, a sheet of plywood, measuring 1/4 of an inch thick, was used in between the antifatigue mat and metal grate. The uneven surface on the bottom of the tile was unstable when placed directly on the perforated grate. The addition of plywood allowed the mat to perform as intended, with minimal impact on the thickness and cushion of the standing surface. Mat and plywood thickness totaled 1.25 inches. Working height was compensated using the adjustable work holding fixture the corresponding amount during these trials. For the remaining low-level experiments, the plywood and antifatigue mat was removed, leaving only the anti-slip grate.

3.1 Measures

Measuring Cycle Time with Video

Assembly quality and cycle time were measured for each experiment. Each experiment was recorded with a video camera. Prior to the study, the participant agreed to being recorded through the approved informed consent form. Experiment tasks, data and video collection and storage methods were reviewed and approved by the MNSU IRB.Video recordings were used to measure the time required for each task within the workstation. The summation of these times totals the cycle time, a primary measure of the study.

Measuring Shock Absorber Quality

The second measure of this study was the quality of the assembly. Consideration for the study required the participant to have completed the training course, WK00149, Closing a Shock. This requirement ensures all participants were qualified to complete the assembly operation without mistakes driven by a lack of understanding.

Assembly Completeness

Three methods were used to measure the completeness of the assembly. A visual inspection, comparing each shock to an engineering drawing, focusing on the external components installed during the experiment, was completed on all shocks. Complete installation of the two internal seals was verified through a second visual inspection, two days after the study, allowing visual detection of small leaks. Lastly, the inclusion of all internal components was verified during the video review. Components assembled were tallied, requiring eight upon completion of the assembly.

Shock Hysteresis

Workstation six is responsible for sealing a shock that has been completely filled by a machine. During the sealing process, air can be reintroduced to the shock through compression of the rod or incomplete installation of the seals. To maintain data integrity, a robust and proven dynamometer test method was used. Shock ends were connected to the dynamometer using clevises and pins. A pin passes through the clevis and inner diameter of a bore on the rod and body. When the clevis is tightened, the rod or body is pinched between the pin and the clevis as shown in figure 4.
One cycle of a shock on the dynamometer includes travel from the least to most compressed state, then back to the least compressed state. Figure 5 shows the four sections of this cycle: compression open, compression close, rebound open, and rebound close.

Figure 4. Clevis Connection

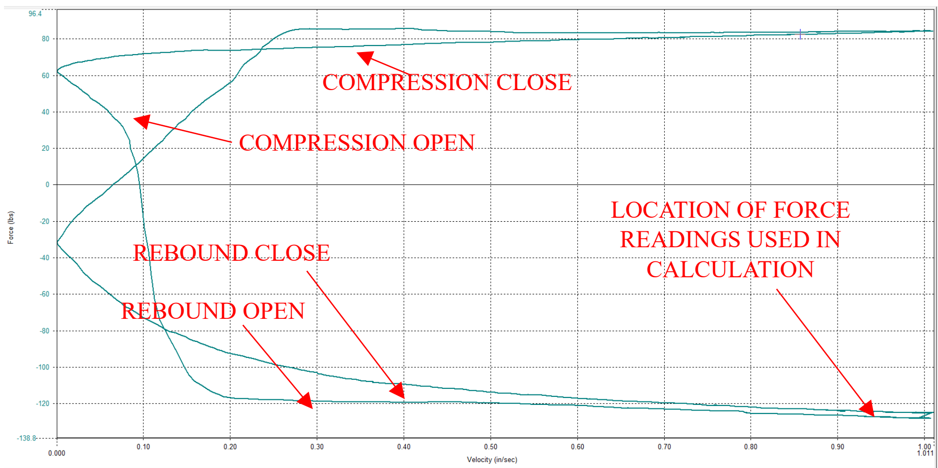

Figure 5. Shock Absorber Dynamometer Results

4. Results

Shock Absorber Hysteresis

Hysteresis was measured in each shock absorber using dynamometer test results. During the tests, five of the 160 shocks were set aside. Two from experiment four and one from experiments one, six, and eight. Two of the five were able to be tested, however, the forces produced by the shock were negligible. These five shocks were disassembled and evaluated. The findings concluded that two of the shocks had a valve installed incorrectly in station two, allowing excessive flow. Because the defects were due to prior assembly tasks, these shocks were not included in the hysteresis analysis, reducing the study population to 155. Table 2 presents the average hysteresis values and coded treatment conditions.

Table 2. Average Hysteresis Results for Each Condition

Experiment	Treatment Condition	Average Hysteresis
1	ABC	0.944
2	A	0.656
3	B	0.731
4	A	0.681
5	C	0.779
6	ABC	0.987
7	C	0.901
8	B	0.825

A factorial regression analysis was performed in Minitab. This analysis calculated the main effects of the factors and determined the significance of each, shown in table 3. A regression equation and R squared values are also developed using this analysis. The R squared value for this analysis was 87.56%.

Table 3. Hysteresis Analysis Results by Factor

	Assembly Height	Reachability	Standing Surface
P-Value	0.853	0.044	0.011
Main Effect	0.008	0.117	0.179

Reachability and Standing Surface were found to have a significant impact on the hysteresis of a shock with respective P-values of 0.044 and 0.011. Assembly height did not have a significant impact on hysteresis with a P-value of 0.853.The regression equation, equation 1, explains the degree and positive or negative effect of each factor on the response variable.

$$Hysteresis = 0.8130 + 0.0040\,A + 0.0587\,B + 0.0897\,C$$

A second factorial regression analysis was run, excluding assembly height. In this analysis, both reachability and standing surface were significant. This analysis included a lack-of-fit result as it had more replicates than the original. The lack-of-fit P-value was 0.853, demonstrating that this model could accurately fit the data.

Shock Absorber Completeness

During the video review, internal components that were installed during the assembly process were counted for each shock. It was found that all four internal components were installed in all 160 shocks. While their inclusion was verified, correct and complete installation was verified through a second visual inspection, searching for oil leaks. None of the 160 shocks considered for the eight experiments were defective after the inspections.

Cycle Time of Assembly

Upon completion of the video review and data entry into MS Excel, the average cycle time was calculated for each of the eight experiments. It was determined that the five shocks that were unable to be included in the hysteresis analysis were assembled correctly at the workstation in question and included in the cycle time analysis. No other assemblies were deemed defective or unable to be included in the cycle time analysis. All 160 assemblies were considered in the experiment averages.

Average cycle times for each experiment are presented in Table 4 with their respective treatment condition.

Table 4. Average Cycle Time Results for Each Condition

Experiment	**Treatment Condition**	**Average Cycle Time**
1	ABC	49.10
2	A	50.50
3	B	48.20
4	A	49.30
5	C	52.05
6	ABC	47.71
7	C	51.15
8	B	49.40

A factorial regression analysis was performed using the experiment averages above, associated with their respective treatment conditions in Minitab. The analysis result included an R squared value of 81.36%.

Table 5. *Cycle Time Analysis Results by Factor*

	Assembly Height	**Reachability**	**Standing Surface**
P-Value	0.152	<u>0.022</u>	0.333
Main Effect	-1.047	-2.147	-0.652

Significant analysis results were limited to component reachability with a P-value of 0.022. Assembly height and standing surface were insignificant with P-values of 0.152 and 0.333, respectively. Equation 2, the regression equation for this analysis in coded units, explains the numerical effect of each factor.

$$Cycle\ Time = 49.676 + 0.524\,A + 1.074\,B + 0.326\,C$$

Discussion

The results demonstrate that certain low and high levels of the controlled ergonomic characteristics of the workstation in question have significant effects on the hysteresis and cycle time of a shock assembly. Further analysis was completed to develop an understanding of the effects and the optimized conditions.

Assembly Cycle Time

Using the Factorial plot, the best and worst conditions could be determined. The worst combination of the three factors is: 50-inch assembly height, components located on the table surface, using the antifatigue mat. Two of these three conditions are standard practice during normal production at this manufacturer. Components staged on the table surface were much further from the assembly compared to the recommended condition, increasing the time to retrieve each component. Additionally, the raised assembly height of 50 inches would amplify this effect as components would need to be lifted higher. Lastly, the addition of the antifatigue mat without a corresponding change in the reach points would further increase the reach required.

Conditions expected to produce the shortest cycle time are: 41-inch assembly height, components located 16 inches diagonally from the assembly, and standing on steel grates. The combination of the lower assembly height and recommended position of components increases the density of the reach points. These points include tools as the distance from the table surface to the assembly height is reduced. In addition to reduced reach requirements of the workstation, assembly occurring in a more ergonomically efficient region might assist in cycle time reduction. Using the regression equation, the expected cycle time of this condition would be 47.75 seconds, 3.85 seconds shorter than the expected worst case, 51.6 seconds.

Assembly Hysteresis

The factorial plot, visualizing the effects of the three factors on hysteresis, shows a large difference in effects from reachability and standing surface, while assembly height change shows very little effect. Using this plot, the combination of workstation characteristics that is expected to result in the most hysteresis in a shock is: 41-inch assembly height, components located 16 inches diagonally from the assembly, with an antifatigue mat. Each of these conditions are recommended for their ergonomic benefits, none of which are used in normal production at the manufacturer. Considering these conditions in the regression equation, hysteresis is expected to be 0.965 pounds.
The combination expected to produce the least amount of hysteresis is: 50-inch assembly height, components located on the table surface, and standing on the steel grates, all conditions practiced during the manufacturers normal production. These two sets of conditions show that seal installation is more efficient in the conditions practiced during normal production. Hysteresis is expected to be reduced 0.304 pounds, down to 0.661 pounds, from the worst to best conditions.

5. Conclusion

This study examined the effects of simple workstation changes, potentially reducing the ergonomic load, on the cycle time and quality of the assembly. The study was conducted at an automotive shock absorber manufacturer in Lakeville Minnesota. A single workstation of the main assembly line, responsible for assembling eight components and the source of 43% of quality defects, was selected for the study. Through two replications of four different experiments, assembly height, reachability of components, and the standing surface around the workstation were controlled. Each of the three factors had two levels, the lower being the current configuration during normal production, and the higher being a condition recommended for its ergonomic qualities.

Ergonomic interventions are often motivated by complaints or injuries. To encourage proactive intervention, this study used profit focused metrics to measure the impacts of implementing recommended ergonomic conditions. The results demonstrate a significant difference between workstation configurations for both cycle time and product quality. Reachability of components demonstrated a significant improvement in cycle time. Workstation standing surface and component reachability resulted in significantly lower assembly quality. Assembly occurring at the recommended height was no different than the current conditions.

Using results from the regression equations developed during analysis, optimal conditions considering both measures were determined. Recommended conditions of a 41-inch assembly height and components 16 inches from the assembly are expected to provide the best quality and cycle time results without the use of the recommended antifatigue mat. The two recommended conditions were not practiced during normal production at this manufacturer. This demonstrates how ergonomic intervention can positively influence the quality and cycle time of assembly.

References

Axelsson, J. R., *Quality and Ergonomics: Towards successful integration (thesis).* Linköping: . Quality and Human-Systems Engineering, Department of Mechanical Engineering, Linköpings Universitet, 2000.

Aziz, R. R., Relationship between working postures and MSD in different body regions among electronics assembly workers in Malaysia. *IEEE International Conference on Industrial Engineering and Management*, (pp. 512-516), 2013.

Biondi, F. N. (2020). Overloaded and at work: Investigating the effect of cognitive workload on Assembly Task Performance. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 63*(5), 813-820,2020. doi:https://doi.org/10.1177/0018720820929928

Boothroyd, G. &. (1984). Product Design for Manual Assembly. In Design for assembly. Penton.

Bosch, T. d. (2007). Development of fatigue and discomfort in the upper trapezius muscle during light manual work. *Ergonomics, 50*(2), 161-177. doi:https://doi.org/10.1080/00140130600900282

Bosch, T. M., The effect of work pace on workload, motor variability, and fatigue during simulated light assembly work. *Ergonomics, 54*(2), 154-168,2011. doi:https://doi.org/10.1080/00140139.2010.538723

De Looze, M. P., A participatory and integrative approach to improve productivity and ergonomics in assembly. *Production Planning & Control, 14*(2), 174-181, 2010. doi:https://doi.org/10.1080/0953728031000107635

Edwards C., F. N. (2023). *StatPearls [Internet]*. Treasure Island (FL): StatPearls Publishing. Retrieved from https://www.ncbi.nlm.nih.gov/books/NBK580551/

Enomoto, A. Y. , Automatic estimation of the Ergonomics Parameters of Assembly operations. *CIRP Annals, 62*(1), 13-16, 2013. doi:https://doi.org/10.1016/j.cirp.2013.03.038

Falck, A.-C. Ö. (2014). Assembly failures and action costs in relation to complexity level and assembly ergonomics in Manual Assembly (part 2). *International Journal of Industrial Ergonomics, 44*(3), 455-459,2014. doi:https://doi.org/10.1016/j.ergon.2014.02.001

Ferguson, S. A., Musculoskeletal disorder risk as a function of vehicle rotation angle during assembly tasks. *Applied Ergonomics, 42*(5), 699-709, 2012. doi:https://doi.org/10.1016/j.apergo.2010.11.004

Gooyers, C. E. , The impact of an increase in work rate on task demands for a simulated industrial hand tool assembly task. *International Journal of Industrial Ergonomics, 42*(1), 455-459, 2014. doi:https://doi.org/10.1016/j.ergon.2011.11.005

Ivarsson, A. &. (2016). The relationship between physical workload and quality within line-based assembly. *Ergonomics, 59*(7), 913-923, 2016. doi:https://doi.org/10.1080/00140139.2015.1105303

King, P. M. (2002). A comparison of the effects of floor mats and shoe in-soles on standing fatigue. *Applied Ergonomics, 33*(5), 477-484. doi:https://doi.org/10.1016/s0003-6870(02)00027-3

Le, P. &. (2016). Evaluating the low back biomechanics of three different office workstations: Seated, standing, and perching. *Applied Ergonomics, 56*, 170-178. doi:https://doi.org/10.1016/j.apergo.2016.04.001

Rahman, I. A., The impact of work rest scheduling for prolonged standing activity. *Industrial Health, 56*(6), 492-499, 2018. doi:https://doi.org/10.2486/indhealth.2018-0043

Rexroth, B. (2012, 01 01). *Ergonomics Guidebook for Manual Production Systems - Valin. Bosch Rexroth.* . Retrieved 2023, from https://www.valin.com/documents/pdf/Bosch-Ergonomic-Guidebook.pdf .

U.S Bureau of Labor Statistics. (2020, 5 1). *Injuries, Illnesses, and Fatalities*. Retrieved 2023, from https://www.bls.gov/iif/factsheets/msds.htm: https://www.bls.gov/iif/factsheets/msds.htm

Yeow, P. H., Quality, productivity, occupational health and safety and cost effectiveness of ergonomic improvements in the test workstations of an electronic factory. *International Journal of Industrial Ergonomics, 32*(3), 147-163, 2003. doi:https://doi.org/10.1016/s0169-8141(03)00051-9

Zare, M. B.-C., Quantification of exposure to risk postures in truck assembly operators: Neck, back, arms and wrists. *International Journal of Environmental Research and Public Health, 17*, 1-15, 2020. doi:https://doi.org/10.3390/ijerph17176062

Biographies

Val Urman is a Manufacturing Engineering Masters student at Minnesota State University Mankato. He is working on his thesis at an aftermarket Automotive manufacturer.

Dr Kuldeep Agarwal is a professor in the Department of Automotive and Manufacturing Engineering Technology at Minnesota State University Mankato. His research is in the areas of Additive manufacturing, metal forming, process improvements, and robotic welding. He is the graduate coordinator and works with local industries on lean, project manufacturing, and Six Sigma methodologies.

APPENDIX A

Run Sequence	Standard Order	Factor A: Assembly Height	Factor B: Reachability	Factor C: Standing Surface	Treatment Condition
1	4	*41"*	Adjustable Panel	Antifatigue mat	Recommended height, reach, and standing surface
2	6	41"	Table Surface	Steel Grates	Recommended height
3	3	50"	Adjustable Panel	Steel Grates	Recommended reach
4	2	41"	Table Surface	Steel Grates	Recommended height
5	5	*50"*	Table Surface	Antifatigue mat	Recommended standing surface
6	8	*41"*	Adjustable Panel	Antifatigue mat	Recommended height, reach, and standing surface
7	1	*50"*	Table Surface	Antifatigue mat	Recommended standing surface
8	7	41"	Adjustable Panel	Steel Grates	Recommended reach