Book Chapter

Method for Evaluating the Effect of the Design and the Environmental Conditions of the Manufacturing Cells to Improve Work Performance

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Published **March 17, 2021**

This Book Chapter is a republication of an article published by Alvaro González-Angeles, et al. at Journal of Engineering in October 2020. (Mildrend Montoya-Reyes, Alvaro González-Angeles, Margarita Gil-Samaniego-Ramos, Ismael Mendoza-Muñoz, Juan Ling-López. Method for Evaluating the Effect of the Design and the Environmental Conditions of the Manufacturing Cells to Improve Work Performance. Journal of Engineering. Volume 2020, Article ID 4235767, 8 pages. <https://doi.org/10.1155/2020/4235767>)

How to cite this book chapter: Mildrend Montoya-Reyes, Alvaro González-Angeles, Margarita Gil-Samaniego-Ramos, Ismael Mendoza-Muñoz, Juan Ling-López. Method for Evaluating the Effect of the Design and the Environmental Conditions of the Manufacturing Cells to Improve Work Performance. In: Mohamed Ali Hajjaji, editor. Prime Archives in Engineering. Hyderabad, India: Vide Leaf. 2021.

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Data Availability: The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest: The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding Statement: The authors received no financial support for the research, authorship, and/or publication of this article.

Acknowledgments: Authors are greatly grateful to the Universidad Autónoma de Baja California for facilitating access and use of their facilities and equipment to carry out this research.

Abstract

A method is proposed to improve work performance through an adequate design of the manufacturing cell along with optimal environmental conditions to contribute to the well-being of the worker. The methodology used was divided into four stages: the first corresponds to the analysis of operations; the second is the analysis of the effect of the design of the manufacturing cell; the third is the evaluation of environmental conditions such as lighting, noise and temperature to compare them with the official standard and determine if they meet the permitted levels; and the fourth is to conclude and recommend improvements to the manufacturing cell. The method was applied in a company in the automotive industry, where a change was made from a linear cell distribution to an L-shaped distribution, with a 50% reduction in workforce and an increase in the productive time of the worker of a 49%. Also, the environmental conditions of the cell comply with the requirements of official standards.

Keywords

Work Environment; Productive Time; Operations Management; Engineering Method; Standard Parameters

Introduction

Globalization has generated competition to position products in the market, therefore, consumers require innovative products with higher quality and availability, which leads companies to seek ways to optimize their processes and standard production times [1,2]. The design of the workstation, oriented to the requirements of users and tasks, allows organizations to increase their production indicators (less time, space and cost) and quality levels [3], however, the human factor remains the core of the manufacturing system, playing a constant role in the development of Industry 4.0 [4].

It is important to provide a healthy indoor environment that maximizes the comfort, well-being and work performance of workers [5]. Jan Dul, et al. [6] point out that human factors/ergonomics (HFE) have great potential to contribute to the design of all types of systems. HFE has a unique combination of three fundamental characteristics: (1) it takes a focus system (2) it is based on design and (3) it focuses on two closely related results: performance and well-being.

Research has been conducted on the working conditions of workers in workplaces due to environmental factors and developed measures to improve them [7]. Other research indicates that a harmful work environment causes occupational diseases and fatigue that reduce the quality of work [8].

One of the investigations focused on adapting working conditions to the psychophysiological characteristics of its employees. The planning and development of ergonomic actions took place in three distinctive stages: ergonomic analysis of the workplace (stage 1), ergonomic adaptations (stage 2) and Ergonomic Committee (stage 3) [9]. Recommendations for the design of the radiological workplace were provided in another

study, where factors such as backlighting and chair position are often undervalued in the design and implementation of the radiological workplace [10]. In addition, there was a study that conducted an evaluation of lighting and noise levels and the study results showed that the worker's age, lighting level and noise level contribute significantly to task performance [11].

One of the important environmental conditions to evaluate is noise, generally defined as unwanted sound and perceived as a pollutant and a stressful type of environment, acute exposure to noise directly causes a number of short-term physiological problems, responses such as increased blood pressure, increased endocrine secretion, and increased heart rate [12, 13]. For this reason, it is necessary to constantly evaluate the noise exposure of the workers to avoid affecting their health of the worker [14]. If the environmental conditions in each workplace are adequate, it improves worker satisfaction, work performance, safety and health [15].

The objective of this study was to analyze the manufacturing cell and evaluate whether its design and the environmental conditions favor the well-being of the worker and their work performance.

Materials and Methods

Method engineering and ergonomics were used as the basis for a proposal to evaluate the effect of design and environmental conditions on the performance and well-being of workers. (see Figure 1).

The analysis of operations was carried out with a study of times with a chronometer, represented through an operations diagram to identify the operations and the times in seconds that are required to produce the product. The manufacturing cell design was then evaluated to determine if it was the most suitable for the worker [16].

In the evaluation of the environmental conditions, a matrix of points is carried out on the layout of the manufacturing cell to identify the points where the readings of each factor will be

made and then make a surface graph with the data obtained, which allows observing how its name is indicated by color surfaces according to the level of each factor [17]. The next step was to evaluate whether the factors comply with official standards and finally conclude with improvements to the manufacturing cell that allows for better work performance.

Figure 1: Method of evaluating the effect of the design and the environmental conditions of the manufacturing cells to improve work performance.

Results and Discussion

The study was carried out in a company in the automotive industry, specifically in the manufacturing cell that performs two processes: lathe and grinding. Each machine is operated by a worker.

Operations Analysis

For the analysis, a process operations chart was carried out, which is shown in Figure 2. The distribution of the manufacturing cell is linear, the operators work standing up during a 12- hour shift, the production process for the first piece is 174 seconds and every 68 seconds each piece is finished, therefore the lathe operator stays busy only 23% of the time and transports the part to the grinding process; and the grinding operator stays in his area working only 35% of the time, this is in both cases because they are waiting for the machining process.

The study of times allows to identify the type of activities: a) those that add value, that is, the operations that allow the transformation of the product and must be strengthened; b) those that do not add value, but are necessary such as inspection and transportation and that it is sought to reduce their time; c) those that do not add value and are unnecessary, such as delays or dead times that are sought to be eliminated to improve the process.

Manufacturing Cell Design

Because operators' uptime is very low, it was proposed to eliminate downtime, now one operator operate both machines, achieving a 49% increase in operator uptime. In addition, it was sought to reduce transport, shortening the distance between the machines and favoring the transfer from one machine to another using an L-shaped distribution, as shown in Figure 3.

Figure 2: Process operations chart of lathe and grinding process.

Figure 3: L-shaped distribution of the manufacturing cell.

This manufacturing cell is at elbow height, it has enough legroom and anti-fatigue mats in front of each machine. The possibility of placing a chair [18] was analyzed, but it is not recommended for this process because the worker moves from one machine to another.

Assessment of environmental conditions

a) Make the matrix in layout

Each manufacturing cell is integrated by of a lathe and a grinding machine, Figure 4 shows the layout of two manufacturing cells.

Figure 4: Layout of the manufacturing cells.

Figure 5 shows how the layout was divided to form a 4 by 5-point matrix, to identify each point in the layout where noise, lighting and temperature of the area will be measured.

Figure 5: 4x5-point matrix.

b) Measure factors: light, noise and temperature

The ergonomic factors that were measured were the lighting levels, sound levels and the thermal environment. In Table 1, the measurement instrument and the measurement method for each factor are indicated. It is important to note that any other factor can be evaluated if considered necessary.

Table 1: Ergonomic factors, measurement instruments and measurement method.

Ergonomic Factor	Measurement Instrument	Measurement Method
Lighting levels	Luxmeter	The measurements of the lighting are made at the points indicated in the layout at the height of the work plane, trying not to cast shadow on the luxmeter.
Noise levels	<p>Noise level meter, allows measuring sounds between 35 and 130 decibels with frequencies between 31.5 Hz and 8 kHz and a precision of 2 decibels.</p>	The measurements of the maximum sound intensity were made at the points indicated in the layout one meter from the height of the work plane, the results were noted. Care was taken not to interfere with the body the imaginary line that connects the sound sources with the sound level meter's microphone. Also, the position of the sound level meter at the measurement points was always vertical with the pick-up microphone up. The value is read only when the indicator display stabilizes.
Thermal environment	<p>Thermometer, allows to measure the temperature in °C and the humidity percentage of the work area to determine if there is a risk of thermal stress.</p>	The temperature and humidity are taken at the points indicated in the layout at the height of the work plane.

c) Make surface graphs

The data obtained from the environmental conditions in each point of the matrix is captured in MS Excel and the surface graphs are elaborated to project them on the layout of the manufacturing cell.

Figure 6a shows the distribution of the manufacturing cells with the areas delimited by lighting levels and Figure 6b shows the area shaded by colors where it can be seen that it corresponds to the visual tasks of the work: blue corresponds to the lighting for interiors such as walkways, the highest value obtained was 104 lux; red corresponds to a simple visual requirement such as the work of the machine, the highest value obtained was 220 lux; and green corresponds to a moderate detail distinction as visual inspection, the highest value obtained was 308 lux.

Figure 6: Surface graphs of lighting levels.

Figure 7a shows the layout with the areas delineated by noise levels and Figure 7b shows the shaded area: red shows levels from 75 to 80 decibels (dB), green shows levels from 80 to 85 dB and purple shows levels of 85 to 90 dB, which corresponds to the highest noise values, which are due to noise generated by machines.

Figure 7: Surface graphs of noise levels.

Figure 8a shows the layout with areas delimited by temperature levels, and Figure 8b shows the shaded area: purple shows levels from 26 to 27 °C, and the blue shows levels of 25 to 26 °C which corresponds to the area where the workers move. In addition, the humidity was measured with results of 30% to 41%.

Figure 8: Surface graphs of temperature levels.

d) Evaluate in accordance with the official standard

In Mexico, the Official Mexican Standards are used, with respect to the health, safety and hygiene conditions that must be observed in the workplace, as established by the standards, the results obtained are compared to determine if the company complies or not. Table 2 shows the evaluation that was made to

the company and its results were that it complies with the requirements of the official standard.

Improvements to the Manufacturing Cells

The analysis of operations was carried out with which the change in the distribution of the manufacturing cell from linear to L-shaped was made, there was a reduction of labor of 50%, therefore, the operator's working time increased 49%, the distances between the machines were shortened, the space was optimized and the operator would no longer have to stand alone in front of the machine, now he has movement from one machine to the other, allowing him to move his legs more, which is of greater benefit to counteract fatigue. It was also recommended to use an anti-fatigue mat that covers the area through which the worker walks as shown in Figure 2.

When evaluating the lighting levels, noise levels and the thermal environment in the manufacturing cells, it was identified that they comply with those required by the Official Mexican Standard. However, the use of LED lamps is recommended to optimize their systems [23]. Regarding noise, it is important to note that it does not exceed 90 dB, but the exposure is greater than 8 hours, therefore, operators use earplugs. Due to the type of processes that the workplace uses, it is kept refrigerated, the standard indicates up to 26°C in hot weather and readings of up to 30°C were obtained, which is why the official standard on maximum permissible limits of Exposure to high thermal conditions, which indicates that the maximum allowable temperature in a light work regime is 30°C, therefore, the temperature does not affect work performance.

Table 2: Evaluation of compliance with official standards.

Ergonomic factor	Official standard		Results of measurement	Complies
Lighting levels	NOM-025-STPS-2008, lighting conditions in workplace, determines the minimum lighting levels that must affect the work plane, for each type of visual task or work area [19].	Minimum lighting levels Interiors: 50 lux Simple visual requirement: 200 lux Moderate detail distinction: 300 lux	Interiors: 104 lux Simple visual requirement: 220 lux Moderate detail distinction: 308 lux	☒
Noise levels	NOM-011-STPS-2001, safety and hygiene conditions in workplace where noise is generated determine the maximum permissible limits of exposure of workers to stable, unstable or impulsive noise during the exercise of their duties [20].	During a maximum permissible exposure time of 8 hours, a noise exposure level of 90 dB is allowed.	Minimum: 77 dB Maximum: 88.8 dB	☒
Thermal environment	NOM-001-STPS-2008, artificial ventilation for worker comfort or due to the requirements of activities in the workplace [21]. NOM-015-STPS-2001, maximum permissible limits of exposure to high thermal conditions [22].	Relative humidity between 20% and 60%. Air temperature of $22^{\circ}\text{C} \pm 2^{\circ}\text{C}$ for times of cold environment, and $24.5^{\circ}\text{C} \pm 1.5^{\circ}\text{C}$ for hot times. Maximum allowable temperature in a light duty regime 30°C .	Humidity: 30% to 41% Temperature: 26°C to 28°C	☒

Conclusions

The method of evaluating the effect of the design and the environmental conditions of the manufacturing cells provides clear and simple steps to determine if the worker works under optimal conditions, which affects his work performance. The analysis of operations seeks to identify operating times, dead times, sequence in operations and bottlenecks in order to optimize the process and facilitate and adapt the work to the worker, which is why the design and the environmental conditions of the cell to analyze the possible effects it may have on the health and well-being of the worker and to be able to carry out action plans to counteract them.

Official standards establish the appropriate parameters for each environmental factor to comply with health and safety regulations. However, it was observed that changes in official lighting and noise standards are required, as well as determining the possible effects on worker health. If the use of LED lighting is increasing given its benefits, such as offering different white temperatures such as warm, neutral and cold, it will be necessary to expand the parameters of lighting levels [23]. Regarding noise levels, many companies are currently opting to extend their working hours and the official standard does not indicate the maximum permissible exposure limits during 12-hour long shifts [24,25].

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