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Does cognitive aspects of information and material presentation matter in worker allocation in an assembly line? A case study of a recycling unit in India

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Abstract. In most manufacturing units, the contribution of human labor remains a vital element that affects overall performance and output. The research explicated in this paper is conducted in a pen recycling unit in the southern part of India which is an initiative by a non-profit organization to reduce plastic waste and highlight the need for recycling. The objectives of the study are two-fold. Firstly, to investigate the influence of cognitive aspects namely information and material presentation on worker performance in an assembly line and secondly to propose an economical worker allocation approach based on the findings of the first study considering the pen recycling unit. An experimental study was conducted with fifteen workers and was given eight different scenarios with the combinations of presenting material and information with six pen varieties for assembly. The performance of workers is identified and appropriate allocations are made to suitable workstations. Further, a subjective measurement using NASA-TLX is also done to determine the mental workload of workers. The results indicate that individual worker performance varies significantly, much more than is assumed. This variation is due to the difference in cognitive capabilities among workers when they are introduced to different product variants and work environments. It is expected that the proposed economical allocation method will be beneficial for similar micro, small and medium enterprises that contribute in achieving sustainability goals.

Keywords. Cognitive aspects; worker allocation; human performance measurement; manual assembly; sustainability.

1. Introduction

Today's manufacturing processes are transforming from mass production towards mass customization, allowing for more frequent and consistent changes in response to customer desires, the latest technology, and environmental impact. This makes the system more complicated for allocation of a specific job to a worker based on their skills or allocation of a job to a newly joined worker, especially if the production system seeks to maintain a low cost while maintaining the quality of the goods [1]. A huge demand and complexity in the assembly process increases the stress among the workers. Grosse *et al* [2] proposed a concept for incorporating human factors into order-picking operations in order to enhance productivity and the mental well-being of workers.

It is reported that the aesthetic appearance attracts the workers during the assembly task, and this is known as cognitive penetration (CP). Hence factors involved in aesthetic perception are also to be considered while assessing the cognitive workload. Expertise that is mediated by instructions and learning may shape aesthetic perception. As stated by [3], the greater the understanding based on high-level and categorical learning, the more likely cognitive penetration occurs. According to the early formulation of [4], an association between cognition and perception counts as CP as long as the relationship is internal and mental. Cognitive load theory helps to identify the mental workload of the workers assigned. Galy *et al* [5] reported the impact on cognitive load because of an additive relationship between intrinsic, extraneous, and germane load. In a workspace, if the health and protection of employees at work are crucial for productivity, the analysis of cognitive load factors and their interaction is important. Hence, workers with a high cognitive load must be provided with additional material and information presentation.

In a mixed assembly mode with different variants of the product, [6] published a comparative study of material presentation and information presentation. In this study, the

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material presentation was varied between an unstructured package and a standard package; moreover, information presentation was compared between textual and number instructions with image instructions. When using images instead of text and numbers, assembly times and performance ratings were reported to be lower. However, in this work, the different combinations of structured and unstructured material presentations with textual and image instructions are considered for experimentation. This aspect is unique to this study. With the rising complexity and automation of assembly lines, [7] identified the need for cognitive assistants, pushing human operators to apply different cognitive processes. Cognitive assistants assist human operators in analyzing, integrating, and maintaining large amounts of information. The existing literature on working memory provides important insights on how information can be displayed to operators to maximize the efficiency of cognitive assistants. The information presentation used in this study can contribute to the development of cognitive assistants and optimize efficiency.

NASA Task Load Index (NASA-TLX) is a widely used subjective measurement method for determining performance aspects by rating perceived workloads. Emotional, physical, and temporal demands, dissatisfaction, commitment, and performance are the six dimensions used to operationalize the workload. Individual worker performance is known to be influenced by the cognitive aspects of workstation design. Worker performance variability is assumed to be largely insignificant in current workstation design methods. The purpose of this study is to identify workers' varying performance when different combinations of material and information are used in a workstation. In the allocation of workers to each work station according to their skills, it will be beneficial if it can be predicted whether the worker will assemble the pen without errors in a given scenario. In this direction, a logistic regression classifier model is developed in this work.

The attempts to achieve sustainability and the management of long-term environmental problems such as climate change and biodiversity losses are important. Plastic recycling is given prime importance around the globe, being aware of the hazards caused by these pollutants. Recycling and reuse of products are different; the former is the reprocessing of a product into a new raw material from which a new product is produced, and reuse lengthens the life of an item. Compared to recycling, reusable goods have a decreased environmental impact, but manufacturers, for the most part, focus on techniques including light-weighting, recyclability and eco-labelling [8]. Actions that facilitate the reuse of products may improve sustainable behaviors [9]. In view of enhancing sustainable behaviors, the focus of this paper is to establish a manual assembly line with improved productivity for a pen recycling unit, wherein the workers are assigned the task based on their performances of the workers.

This study shows that as the complexity and requirements of assembly operations in manufacturing increase, assembly workers' workload increases, leading to errors and a decline in productivity. New worker recruits also cause hassle because it becomes complicated to identify their skills and allocate them according to their skills. Previous research has shown the complexities an assembly worker faces in the work environment, but a solution based on the work environment with a case study is absent. This is the motivation for the present study.

1.1 *Cognitive perspective on manual assembly tasks*

This research focuses on worker allocation, considering the following two factors of cognitive aspects that affect human performance:

(1) Material presentation and (2) Information presentation.

A mixed design approach of [10] is used in this study which includes time, the number of pens assembled, and the success rate in the following eight scenarios of the experiment. Two types of kits have been described in previous research by [11] as unstructured and structured kits, which can be considered as carriers of information. To examine the inconsistencies and argued consequences, in terms of cognitive aspects, as well as assembly time and assembly error, the arrangement of these kits is varied according to the pen assembly experiment. This has constituted the four levels within the material presentation factor as follows:

- Intermixed parts
- Grouped parts
- Separated parts in different boxes
- Part numbered box

It was previously investigated whether various types of instructions had an impact on the assembler in an earlier experimental study. The recommendation to use textual and numerical instructions, to present information in manual assembly, as well as photographs, to test more visual alternatives are based on previous studies by [11, 12], and [13]. As a result, the following presentation alternatives are chosen to constitute the two levels within the information presentation factor, and they are as follows:

- Instructions
- Photograph

In essence, this research identifies the combined effect of information and material presentation on the individuals for a task. The combined effects identify the performance of each worker and further helps in assigning a worker to each workstation according to their cognitive skills. This paper adds to the body of knowledge about cognitive load theory and cognitive penetration. The present study explores how the performance of workers differs according to the information (instructions and photograph) and material presentation (intermixed parts, grouped parts, separated parts in different boxes, part numbered box).

The aim of this study will be to identify the importance of information presentation with respect to the worker individually. Researchers suggest that photographs as a means of information presentation are more effective, but if it is considered through cognitive aspects, it can be observed that there needs further investigation on this criterion of information presentation. One of the hypotheses in this study states that while considering the performance between the part numbered box and separated parts in different boxes, there is a significant difference as per the analysis of results, the null hypothesis is rejected. In the case of performance between the use of the photograph and the text instructions, there is a significant difference, and the null hypothesis is rejected. Thus, this output from the hypothesis suggests that the worker performance is varied according to the material and information presentation combinations. A logistic regression model is developed with the data collected. The model is tested with a part of the data collected and the findings from the model can support the allocation of workers to the proposed assembly stations for a pen recycling unit.

The contributions of this work can be enumerated as follows:

1. Investigate the combined influence of material and information presentation on the performance of workers according to the factorial design in a pen-recycling unit.
2. Development of a novel approach for worker allocation in the pen-recycling unit considering the cognitive aspects obtained from the preliminary study.
3. Application of a classifier model to predict the performance of workers.

The paper is organized as follows: The review of literature for this research is discussed in section 2. Section 3 explains the environment and methods adopted in this work. Section 4 reports the achieved results, and section 5 explains the allocation of workers to each workstation of the pen-recycling unit. Section 6 illustrates a case study conducted in a pen recycling unit and in section 7 the conclusions are provided.

2. Review of literature

Various literature sources were reviewed within the field of manufacturing on topics related to manual assemblies such as complexity and material supply management. Further investigation was carried out in the usability and cognitive load disciplines, as these factors accounted for the research problem. Gualtieri *et al* [14] presented a case study to design a collaborative workstation to improve the physical ergonomics of the operators. Still, the cognitive aspects influencing human performance is not included. It is important to consider these factors apart from the physical ergonomics point of view to identify the importance of cognitive abilities, workload, and stress. This work also introduces the cognitive interaction of the workers with their work environment when establishing automatic or semi-automatic production units.

2.1 *Manufacturing and assembly systems*

A worker performing a task is constantly confronted with a variety of cognitive demands. The various cognitive demands in the manual assembly, include the amount of knowledge required, handling a variety of parts available, system complexity, and physical layout of workstations. When time pressure due to time constraints is low, these factors can be handled relatively easily, but when it comes to high time pressure, the mental load is increased. Product variability has a negative impact on consistency and competitiveness, as well as human factor aspects of manual assembly [15–17] and reduces the overall performance.

When product variants increase, assemblers are frequently confronted with a larger number of parts and subparts to be handled at the workstation. The theory of kitting is an interesting area when this topic is considered, which refers to the supply of pre-sorted kits of various parts to the workstation. The assembler at each workstation must identify the correct parts to be assembled on each product variant in mixed-model assembly. Continuous supply provides a continuous flow of supplies rather than materials being gathered into kits. Kitting can promote learning, and as a result, reduce learning times and increase product quality. From an ergonomics perspective, the advantage is that the assembler just needs to be concerned about the assembly process, i.e. how to assemble, rather than what parts to assemble, which can lead to higher product quality support [18].

Manufacturing and human performance were considered in previous studies by [11] and [19]. Specifically, how information and materials are presented to the assembler as well as how part variants affect them at the workstation. Unstructured and structured kits, both of which can be seen as information carriers but are organized differently, were identified in this investigation. These structured and unstructured kits were modified according to the requirements for a manual assembly of a pen to examine their inconsistencies and argued effects in terms of cognitive aspects, assembly time, and assembly error. The material presentation in this study was made up of four scenarios in order to explore the cognitive aspects. It was therefore of interest in the experimental analysis to see whether various types of instructions had an impact on the assembler. The recommendation was to use text and number instructions, to present information in manual assembly, as well as photograph instructions, to test a more visual alternative, based on previous works by [11–13]. In the present study, about eight combinations considering both information and material presentation are considered.

An ageing population of workers increases the necessity to improve ergonomics at workplace. One of the solutions as per the literature is human-robot collaboration. While the technology supporting human-robot collaboration is fast evolving, the development of supporting workstation design approaches is lagging. The present research aims to provide a generic methodology based on the cognitive aspects to design a workstation and allocate workers according to their performance. This cognitive aspect can also be considered when human-robot collaboration is implemented in the assembly line.

2.2 *Usability approach and Cognitive Load Assessment for Manufacturing (CLAM)*

One of the main objectives of this study was to look into the factors that influence human cognitive performance in manual assembly. As a result, it was interesting to go further into the factors that have been used to evaluate various aspects of manufacturing. [20, 21] developed a usability approach method to assess the complexity level of a workstation and to support assemblers in handling complexity in manufacturing. They used elements or factors gathered from a variety of other methods from the literature review. The elements or factors taken into account includes product variants, work content, layout, tools and support tools, and work instructions.

A useful framework and a modified form of usability approach for considering cognitive aspects related to manual assembly have recently been proposed. As a result, the CLAM method was developed [22, 23]. CLAM was developed with the aim of identifying and reducing possible cognitive stress among assembly workers in a manufacturing environment. It was stated that proactively identifying relevant concerns at assembly workstations can result in time and resource savings on the shop floor. Workstation designers are advised and educated on how to design in order to reduce cognitive load and on factors that are argued to have an effect on the operator's cognitive strain through the construction of a framework of factors that may cause high cognitive load. Furthermore, and may be more importantly, this framework establishes a link between cognitive load and manual assembly environments. There are eleven factors related to usability that should be evaluated in the context of manual assembly. As a result, these criteria should be considered as valuable input to the framework of factors because they relate to both usability and cognitive workload in the context of manual assembly.

In workstation design, it is important to consider presumptive usability problems and use errors. Bligård and Osvalder [24] investigated at how well two analytical methodologies, enhanced cognitive walkthrough (ECW) and predictive use error analysis (PUEA), matched the results of a usability test. The findings of the research are useful tools in the early stages of product development. In complex systems, the workload has been considered as one of the most important factors. Undertaking operations in such workstations frequently involve complex jobs and poor cognitive performance from workers, which lead to human mistakes and serious consequences. The goal of this study is to see which aspects of the CLAM approach have the greatest impact on manual pen assembly cognitive performance [25].

2.3 *Workforce planning and worker allocation systems*

According to various studies conducted earlier, the task processing time performed by a single worker is fixed. The processing time of a job, according to [26], is dependent on the quantity and characteristics of the allocated resources, including the workforce. Due to resource unavailability or production failures, these resource-dependent processing times may be deterministic, stochastic, or uncertain. Workforce planning is often combined with overall manufacturing system design, planning, and scheduling. In most cases, the physical layout and the elements of the manufacturing and transporting equipment is determined before the workforce is planned.

Hansen and Grunow [27] studied a company that produces a new product in a number of production facilities and that sells the product to different markets. The company can increase the production capacity of its facilities by assigning (further) production lines to the facilities, and in addition, it benefits from learning that occurs at the production lines as a function of the cumulative output produced. Workforce planning helps to optimize performance requirements in various manufacturing systems: minimizing cycle time, a function of product completion times (usually in the case of non-repetitive production), equipment costs, and the number of finished products per time unit. The workers following regular shifts are assigned at random orders without considering the work constraints and cognitive aspects. This study considers these factors to allocate the workers to each workstation.

2.4 *Human performance and Industry 4.0*

Wang *et al* [28] explored a semi-automated automobile engine assembly line in which a new strategy of using walking workers replaces the previous strategy of using fixed personnel in each manual assembly section. The main problem with this design is that each worker must be cross-trained in order to achieve a satisfactory level of skills in the assembly tasks to which they are assigned. This work identifies the workers who need training and specifies the kind of training such workers to require. In the present study, the individual performances of the workers are identified by making them do certain tasks in a similar work environment to that of a real-time assembly line. The study has shown great improvement in the overall system performance in terms of flexibility, efficiency, responsiveness and worker allocation based on skills. Maurizio *et al* [29] commented on the fourth industrial revolution, which has spawned a new generation of manufacturing facilities that digitalizes manufacturing and assembly processes. A human factor analyzer for work is a better concept to be implemented in large scale manufacturing units. As an alternative that is cost-effective and ergonomically suitable, the methodology used in this study helps to obtain the performance of human operators in any industrial workplace. Unlike much of the existing literature, identifying the influence of cognitive aspects in a workstation and predicting the performance of workers is not done. This work contributes to the idea of training and individual differences which affect the productivity in manufacturing units. Likewise, the workers performing the experimental study before the assigning to actual workstations of the pen recycling unit have an impact on workload and performance.

2.5 *Subjective data collection*

Cognitive Load (CL) theory identifies three types of CL, namely intrinsic, extraneous, and germane [30]. Intrinsic CL is the load caused by the task complexity of the information, extraneous CL is referred to as the load imposed by way of information presented to the users, and germane CL refers to the effort in the creation of new schema in users in the process of learning new ways to complete tasks. This research considers all three loads of cognitive load theory and uses it as subjective measurement as a whole in the eight scenarios considered. The different scenarios for assembling with a combination of information and material presentation will cause different extraneous CLs given the same level of task complexity (intrinsic CL) and similar levels of prior learning (germane CL) for workers.

As a result, this paper argues that it is important to calculate all three cognitive loads using subjective measures for each worker in order to justify their allocation based on the number of pens assembled. Several researchers reported their attempts to measure the cognitive loads, and certain methods were also mentioned. The methods for cognitive load calculation include physiological measurements [31, 32], task performance measures [33], and subjective assessment measures [34]. The validity of the quantitative measure of CL is a research challenge since CL is an assumed phenomenon. This paper considers one of the methods as per the previous literature which is the subjective assessment approach. This method helps to triangulate the CL measure data and provide reliable data for each worker.

The main findings of the literature were that there has been a recent increase in interest in the cognitive aspects of human performance in manual assembly, but that there is still a limited amount of research on this topic. The issues of usability and cognition were of key importance while studying the effect of human performance in manual assembly. Several principles and concepts collected from the research areas of usability approach, workforce planning, CLAM, subjective assessment, etc., evaluated human factors based on the assembly line context. A consolidated table with the summary of research gaps from previous studies is depicted in table 1.

3. Environment and proposed method

The experiment took place in a small-scale pen recycling unit, an initiative of a non-profit organization in the southern part of India. The unit collects six variants of pens for recycling from nearby colleges, schools and other institutions. All the pens collected were difficult to sort and prepare for reuse. The main difficulty was sorting the pens as some were damaged, some parts were damaged, and the refill of the pen also needed to be restored. Hence, from the heap of used pens collected, all the pens were disassembled, and a quality check was done, and then further it was assembled. These collected pens were reused and sold for half the price. The idea was to frame an assembly line and to set up the whole process, from separating the parts from the heap of used pens to assembling a recycled pen with a new refill. The workstations were identified as five and only could accommodate fifteen workers as the unit has a lower capital.

In view of the requirement, a factorial design was framed with eight scenarios that match the tasks to be done in each workstation of the pen-recycling unit. This technique helps to identify the best performers in each workstation and the analogy of the scenarios and workstations helps to allocate them. All six types of pens are considered in the experimental study, which involves cognitive aspects. More details about the experiment are explained in the following sub-sections.

The study is conducted in two phases, where half an hour break is provided for the workers just to relax between two phases. The first phase includes scenarios 1 to 4, and the second phase includes scenarios 5 to 8. Each worker is given a time limit of 10 minutes. Further, a quality check of the parts assembled is done after the experiment, and the number of pens assembled is noted. The information and material presentation of [11–13] have been modified for the proposed experiment, but the methodology is different.

Table 1. Research gaps identified from literature review.

Citation	Author comments	Research gap/Inputs obtained
[3]	Aesthetic differences vary the productivity when the varieties of products are more.	Cognitive penetration and Aesthetic considerations are not considered in recent studies.
[15]	A study of participant strategies in manual assembly is reported. Four groups of ten participants assembled hacksaws under varying conditions of the number of aids given to participants. Participants used many different strategies in their early learning and generally settled down to a single pattern after the early trials. The common strategy of participants was to pick and assemble the longer and heavier components, followed by small and lighter components.	Participants showed many different patterns of assembly, even for a simple product. The data indicate a need for the industrial engineer to determine the ergonomically best layout of components for assembly and demonstrate the best assembly sequence based on the performance of the operator.
[19]	Experimental study of cognitive aspects influences the worker and thus effects the productivity and output.	Application of these influence of cognitive aspects are not utilized for skill-based worker allocation.
[22]	Proposed framework is to address anddescribe cognitive load problems proactively, designing the work station and the assembly task properly, so that one avoids too high cognitive load and work environments problems in the personnel.	There are huge costs associated with neglecting cognitive and user perspectives within manufacturing, but on the other hand, there is a vast potential to improve both the workers' cognitive and physical health and an increased production outcome simultaneously.
[23]	This paper presents the development of an analytic method Cognitive Load Assessment for Manufacturing (CLAM) and a tool for assessing cognitive load in manufacturing, primarily assembly.	Many studies have explored cognitive aspects, skill allocation, workload assessment in an individual manner, but a collaborative approach including cognitive aspects in industrial production units is missing.
[35]	Cognitively straining conditions such as disruptions, interruptions, and information overload are related to impaired task performance and diminished well-being at work. The effects of a cognitive ergonomics intervention on working conditions, workflow, well-being, and productivity is considered	There is a need to expand the research of cognitive ergonomics, which poses a considerable risk to work performance and employee well-being in cognitively demanding tasks.
[36]	The companies in which skilled workforce is a primary resource is a great concern and needs to be addressed. The paper here presented concerns the theme of ergonomics in assembly lines, still little explored in literature in terms of adaptability of the assembly process to personal characteristics of workers.	1. Ergonomics studies in assembly process needs more studies on workers personal characteristics. 2. Skilled workforce is important and needs to be considered in manual assemblies.
[37]	The assembly line worker assignment and rebalancing problem (ALWARBP), which considers task times diversify in terms of workers. This study concludes with certain managerial implications which states: "It is critical to recognize that the skill levels of workers in assembly lines differ from each other and to determine which worker will work at which station to improve the performance of assembly lines".	The skill levels of workers differ from each other and it is important to recognize the skills with a methodology and validate it in the industrial environment
[38]	The focus is on skill set as a personality dimension within normal populations rather	

Table 1 continued

Citation	Author comments	Research gap/Inputs obtained
	than within clinically anxious ones, and there is a focus on individual variations in cognitive skills.	Ergonomics aspects in assembly lines were based on physical ergonomics, whereas skill-based studies on worker performance are limited.
[39]	Multimodal physiological data has certain limitations when it comes to the industrial environment also and the classifiers are not properly identified.	Many advanced multimodal approaches identify only certain physiological markers, which may prevent capturing all aspects of cognitive load.
[40]	A literature review and an analysis of the studies related to workforce reconfiguration strategies as a part of workforce planning for various production environments. The increase in mass customization and reduced product lifecycles employ manufacturing systems with a high level of reconfigurability in industrial companies to adapt to rapidly varying market conditions.	1. Lack of study on workforce reconfiguration in manufacturing units 2. Identifying real-time cross-trained worker studies are less

Participants, task design, and methodology of this study are discussed in the following subsections.

3.1 *Participants*

A total of 15 workers aged between 20 and 30 years already recruited as the workers for the pen-recycling unit, with a mean age of 21.93 years and a standard deviation of 3.23 years. Given an effect size of 0.68, generated from a prior study [6] utilizing the identical information and material presentation combinations, a sample size of 15 is estimated using G-Power for a power level of 0.96. Two significant interaction effects with a considerable impact size between material presentation and information presentation are there. This means that when information and material presentation in the factorial design were combined, certain combinations were better than others. The selection process ensured that the workers had sufficient awareness about the different parts of the pen. It is ensured that all inclusion requirements are fulfilled by the workers, such as no stress, tension, no body ailments in the last 24 hours. The workers were informed about the objectives of the experiment, tasks to be completed. A duration of ten minutes was provided for each worker to complete each task in a scenario and is monitored using a stopwatch. The number of pens assembled is noted and each pen is disassembled and checked for errors in each scenario.

The number of workers (fifteen) is considered based on the requirement of workers in each workstation of the pen recycling unit. A total of five workstations in this pen recycling unit requires three workers in each workstation, so depending upon the production demand in the pen recycling unit, the number of workers is selected. Depending on the requirements in a real-time assembly line, if the number of workers is increased in the experimental study, then the number of workers assigned to a particular workstation will be more than the number of eligible workers required. This increases the complexity in the worker allocation process, workstations lack eligible workers, and there by productivity is affected. The employer must reconsider the number of workers for the study or give appropriate training for the workers to work in an assigned workstation.

3.2 *Task Design*

The tasks done in eight scenarios of the experimental study is having an analogy to the tasks to be done at workstations. There are eight scenarios with four workers at a time in the experimental setup. The time taken and errors made are not revealed to the workers as this may influence their remaining tasks. The six varieties of pens and their parts are introduced, the different types of instructions to provide information of what they will assemble, and an exploded

Figure 1. Intermixed parts.

Figure 2. Grouped parts.

view of each pen to be assembled are displayed. The workers can select any variety of pens to assemble, but the six types of pens have to be completed before the assembly of the next set of pens. As stated in section 1, the material presentation involved the following four levels: (i) intermixed parts, (ii) grouped parts, (iii) separated parts in different boxes, and (iv) part numbered boxes. The intermixed parts contain six varieties of the pen in a single box with all the parts disassembled and put together, as shown in figure 1.

The grouped parts consist of twelve pens with two sets. In this type, the barrel, tips, refill, and other parts of all the pens are grouped according to their part family, as shown in figure 2.

The third level separated parts in different boxes has a total of thirty pens disassembled, having five sets of six varieties. In this, each part of each pen is in different boxes, and the workers have to pick and assemble them according to the information presentation. The variation in parts of different pens helps to find out the cognitive abilities of this task. A detailed top view of the setup is shown in figure 3.

The part numbered box is similar to the separated box, but the box cover includes the part numbers by which the part family can be identified so that the pen can be assembled in an easier way. As shown in figure 4, the part numbers are arranged in random order, and the workers have to identify the part numbers and then assemble them.

The information presentation included photographs and text instructions. The instructions include detailed information about the parts of each pen with which assembly of the different parts will be made easier for the worker. The instructions for part numbers with the grouping of parts for each pen is provided by grouping the parts to a family and provided with number codes. The scenarios followed the order as given in table 2, which shows the entire nature of the experiment, including the level of factors.

Figure 5 depicts an exploded view of all six varieties of the pen.

Figure 3. Separated parts in different boxes**.**

Figure 4. Part numbered box.

3.3 *Experimental Methodology*

A relevant framework, CLAM, was derived from the usability approach after being modified by several researchers. This method assesses the cognitive factors related to manual assembly. CLAM method helps to

Table 2. Factorial Experiment Design.

Scenario No.	Material Presentation	Information Presentation
1	Intermixed parts	Instructions
2	Grouped parts	Instructions
3	Intermixed parts	Photograph
4	Grouped parts	Photograph
5	Separated parts in different boxes	Instructions
6	Part numbered box	Instructions
7	Separated parts in different boxes	Photograph
8	Part numbered box	Photograph

Figure 5. Exploded view of six varieties of pen.

educate and assist manufacturing companies in reducing cognitive load on the shop floor. There are eleven CLAM factors [22] and from these five of the factors are considered, according to the experimental set-up and the workstation for the pen recycling unit. Mapping of workstations and part identification from CLAM is analogical to the material presentation. Information presentation includes quality of instructions and information cost. The need for six varieties of pen considered in this experiment is to consider the variant flora factor of CLAM. The experimental study with CLAM factors contributed to the cognitive aspects is to be taken care of in the workstations of the pen recycling unit.

Some of the highlights of the methods adopted in this study are as follows:

- Identify the various CLAM factors for the pen recycling unit
- Develop a factorial experiment design for a combination of information and material presentation, with the factors identified from CLAM. The study is conducted with fifteen workers as per the experimental design. The data collected from the study is used to allocate the workers on a pen recycling unit.
- The objective measurements are based on the errors the workers make while doing the tasks in each scenario. The number of pens assembled and the time taken to finish assembling a certain number of pens according to each scenario is noted. Task performance measurement is considered based on the relative performance of workers in different combinations of information and material presentation.
- The subjective measurements are done using the NASA-TLX assessment method. A subjective measurement of cognitive load using the different cognitive loads from the cognitive load theory is also considered. The influence of cognitive penetration and aesthetics is also a part of this study.
- A logistic regression model which classifies the workers in terms of whether they will assemble the pen without error or not is also included.

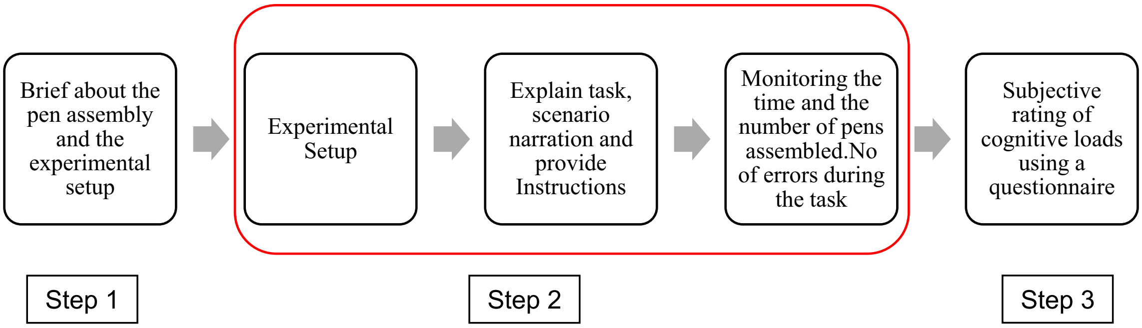

Figure 6. Experimental Methodology.

- With the data collected from the experimental study, the workforce planning for the pen recycling unit is done based on the requirements in each workstation.

The experiment involves three steps, as shown in figure 6. The workers were briefed about the experiment in the first step. In the second step, workers were given different combinations of information and material presentation. As the workers carry out the task, they are monitored and the performance of each worker is noted. At the end for subjective assessment, a questionnaire survey is conducted to measure the perceived cognitive load for the task.

The scope of the analysis comes from many different sources, which is one of the key starting points of this study, as well as other field research. An assembler, for example, gains knowledge not only from the instructions but also from the work environment and co-workers of the assembly. This study, therefore, explores how the assembly operator is influenced by multiple factors at a workstation. There are six types of pens in this sample, as shown in figure 7, with differing numbers of parts and are to be assembled in eight different materials. Two different information presentation combinations are provided.

This experiment is to analyze the performance of workers in a pen assembly task and to allocate workers based on the information presentation perspective, the number of parts assembled and the number of errors in each stage. Workers will be in an isolated room to execute the tasks with eight scenarios, as shown in figure 8.

Figure 7. Illustration of six varieties of the pen.

Figure 8. Experimental setup.

The objective measurements adopted in the present work are as follows:

- **Time** – time refers to the time required for each worker to assemble six varieties of pen and this time is fixed for all workers.
- **Error** – number of errors in an assembled pen. In this experiment, the following two types of errors were recorded: (1) picking the wrong part while assembling a unit correctly and/or (2) picking the correct part but assembling it incorrectly. The parts of the pens assembled will be checked. The errors are characterized based on either the difference in spring, refill, adding an extra part to a pen, and missing of small parts like O-rings, tips, etc.

The majority of workers stated the experiment was interesting and a fun work task. Some workers were concerned about how easy it was to make assembly errors which lead to unhappy customers. Photographs were the best choice at first, but after a while, they were no longer relevant, except for the type numbers beneath the images. Instead, the individuals put the parts together instinctively, which resulted in assembly problems as the part variants changed. The NASA-TLX method was used to perform the subjective measurement.

3.4 *Hypotheses*

The three hypotheses used for this factorial experiment (HA, HB and HC) concern the different levels of the factors: presentation of material (HA and HB), presentation of information (HC).

H0A: No significant difference between the performance when using grouped parts and the performance when using intermixed parts.
H1A: Significant difference is observed between the performance when using grouped parts and the performance when using intermixed parts.
H0B: No significant difference between the performance when using part numbered box and the performance when using separated parts in different boxes.
H1B: Significant difference is observed between the performance when using part numbered box and the performance when using separated parts in different boxes.
H0C: No significant difference between the performance when using a photograph and when using instructions.
H1C: Significant difference between performance when using a photograph and when using instructions.

Table 3. Experimental Results.

Workers	Total	Max	Min	Scenario for Max	Scenario(s) for Min	Success Rate
1	21	7	0	Scenario 6	Scenario 1 & 5	0.1346
2	26	11	0	Scenario 8	Scenario 1,2,5,7	0.1667
3	43	13	0	Scenario 6	Scenario 2	0.2756
4	36	11	0	Scenario 8	Scenario 2,5	0.2307
5	28	13	0	Scenario 8	Scenario 2	0.1795
6	47	13	0	Scenario 8	Scenario 1	0.3013
7	26	8	0	Scenario 6	Scenario 2	0.1667
8	21	10	0	Scenario 8	Scenario 1,2	0.1346
9	26	10	0	Scenario 8	Scenario 1,2,5	0.1667
10	29	14	0	Scenario 8	Scenario 1,2,4,5	0.1859
11	36	14	0	Scenario 8	Scenario 2,3,5	0.2307
12	38	19	0	Scenario 8	Scenario 1,2,3,5,7	0.2435
13	22	6	1	Scenario 6	Scenario 1,2,5	0.1410
14	13	4	0	Scenario 6	Scenario 2,5	0.0833
15	30	12	0	Scenario 6	Scenario 1,2	0.1923

Table 4. Number of pens assembled based on Instructions and Photograph.

Workers	Instructions	Photograph
1	8	13
2	10	16
3	15	28
4	12	24
5	9	19
6	10	37
7	12	14
8	5	16
9	6	20
10	10	19
11	15	21
12	15	23
13	9	13
14	6	7
15	13	17

4. Results and Analysis

The pilot study which was done in the previous work [41] is carried out with the workers of the pen recycling unit. The same experimental design is used for this study but CLAM factors (5 out of 11 factors) are considered by identifying the process in pen recycling unit .A comparison of the results obtained from Kruskal Wallis test from the pilot study and the present study is similar which verifies the validity of the pilot study and the performance of the workers based on the cognitive aspects.

The human performance measurements are important so as to get a detailed idea about the cognitive aspects. The objective and subjective measurements contribute to the results in the experimental design which we can correlate with the corresponding workstations in the study. The pen recycling unit has 5 workstations and the whole study relates these workstations with the scenarios of experimental design. There is an analogy between scenarios 1, 3, and workstation 1 and scenarios 2, 4 and workstation 2. There is an analogy between scenarios 5, 7, and workstation 4 and scenarios 6, 8 and workstation 3. All the four sections discussed below contribute to the worker allocation.

4.1 *Statistical analysis -Kruskal Wallis test*

In order to test the normality of the data, the Kolmogorov-Smirnov goodness of fit test was performed. The results revealed that the data does not follow a normal distribution, and hence to test the hypotheses, a non-parametric test of Kruskal-Wallis at 95 percent

Table 5. Scenarios based on Instructions and Photograph.

	Intermixed	Grouped	Separated parts in different boxes	Part Numbered Box
Instructions	Scenario 1	Scenario 2	Scenario 5	Scenario 6
Photograph	Scenario 3	Scenario 4	Scenario 7	Scenario 8

Table 6. Number of pens assembled based on Instructions and Photograph.

	Intermixed	Grouped	Separated parts in different boxes	Part Numbered Box
Instructions	13	4	9	129
Photograph	32	54	53	148

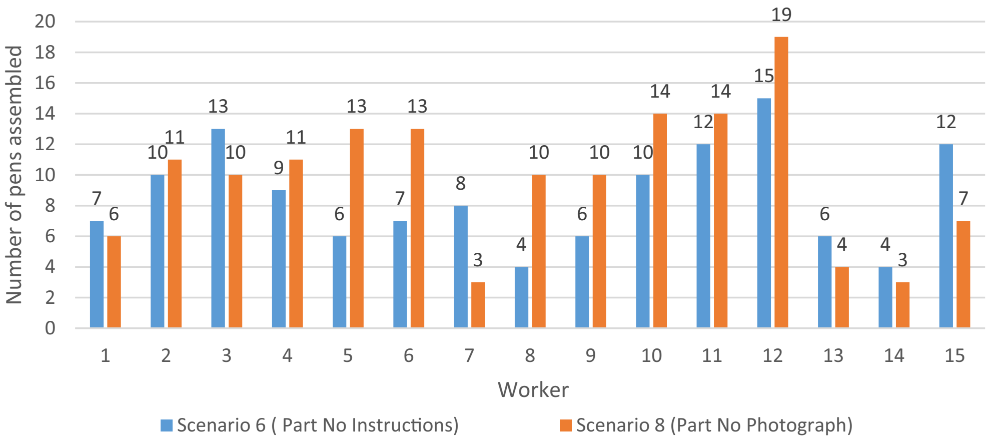

Figure 9. Number of pens assembled Vs Workers for Scenarios 6 and 8.

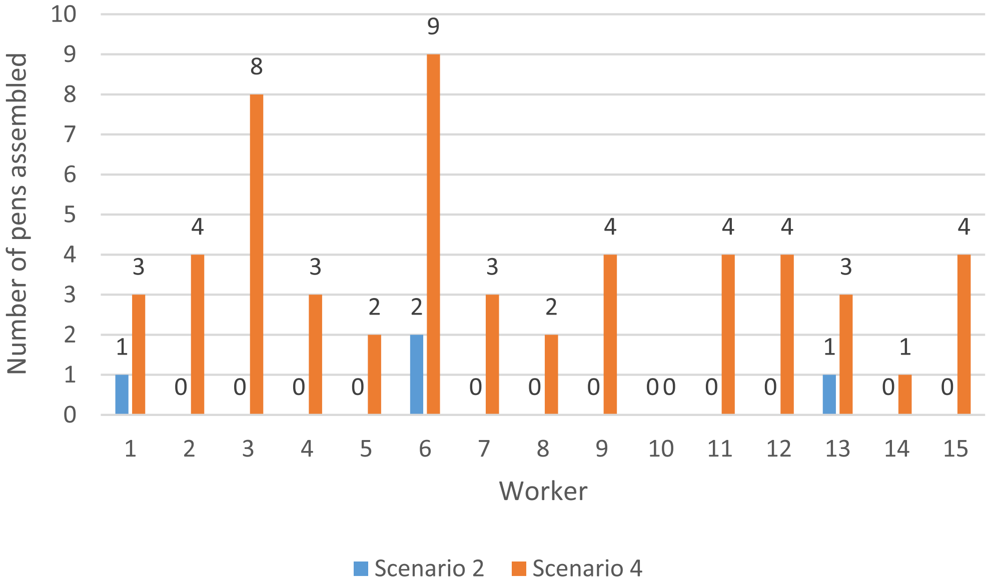

Figure 10. Number of pens assembled Vs Workers for Scenarios 2 and 4.

confidence is done using a commercially available statistical package. With the results, it was identified that some of the main effects based on the hypothesis considered are significant in the analysis of results. An exploration study of [41], leading to the hypothesis of an experimental study was conducted. One of the hypotheses states that while considering the performance between the part numbered box and separated parts in different boxes, there is a significant difference as per the analysis of results, the null hypothesis is rejected. In the case of performance between the use of the photograph and the text instructions, there is a significant difference, and the

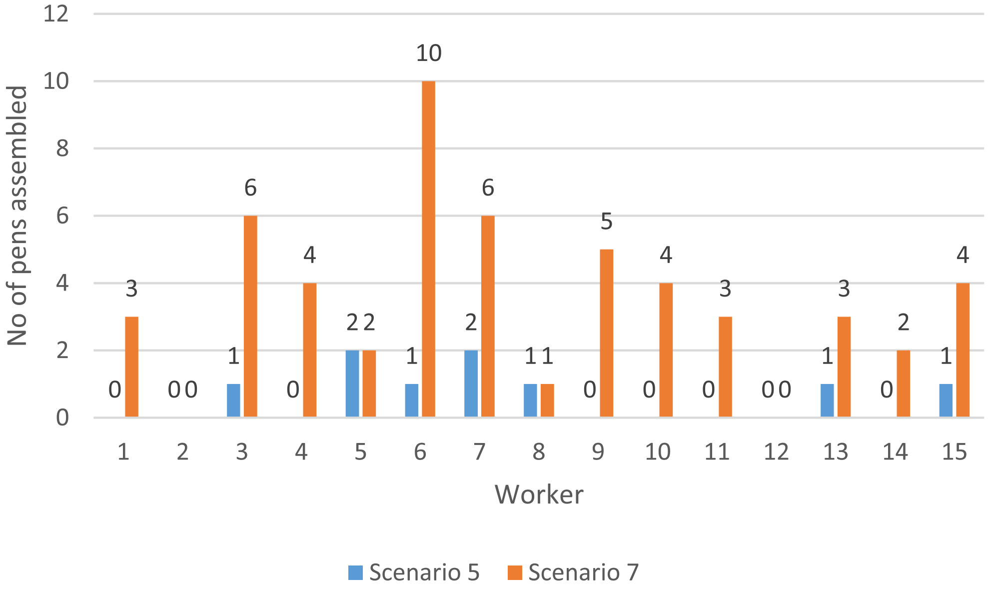

Figure 11. Number of pens assembled Vs Workers for Scenarios 5 and 7.

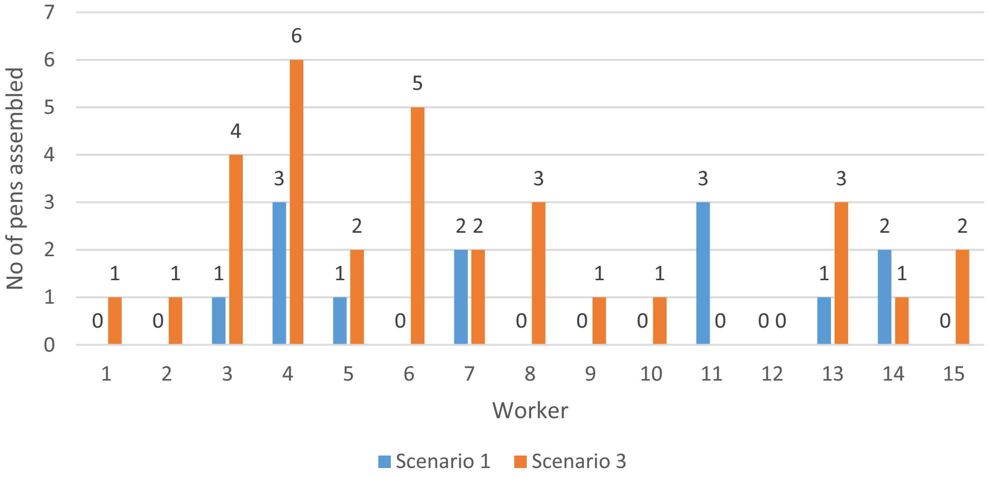

Figure 12. Number of pens assembled Vs Workers for Scenarios 1 and 3.

null hypothesis is rejected. Thus, this output from the hypothesis suggests that the worker performance is varied according to the material and information presentation combinations. The present study is an extension of the experimental study of [35] for the allocation of workers.

The results of the Kruskal-Wallis non-parametric test based on the hypothesis are as follows:

- In the material presentation, there is no significant difference in performance between grouped parts and intermixed parts ($p > 0.05$). The p-value of the Kruskal-Wallis Test is greater than 0.05, which fails to reject the null hypothesis (H0A).
- In material presentation, there is a significant difference in performance between part numbered box and separated parts in different boxes ($p < 0.05$). The p-value of the Kruskal -Wallis Test is less than 0.05 and the null hypothesis (H0B) is rejected.
- In information presentation the performance between the use of the photograph and the text instructions, there is a significant difference as per the analysis of results ($p < 0.05$) and the null hypothesis (H0C) is rejected.

The first four scenarios of material presentation are found to be similar and the worker performance does not vary

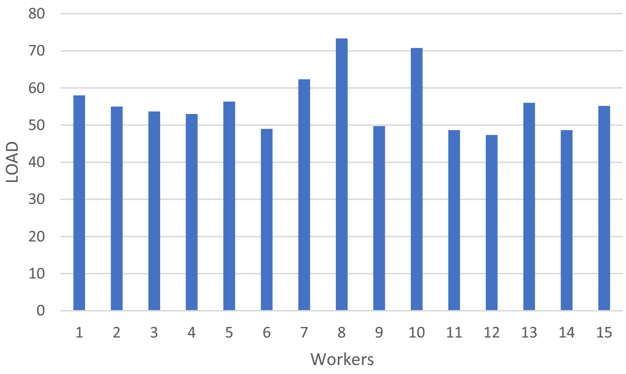

Figure 13. Intrinsic load of workers.

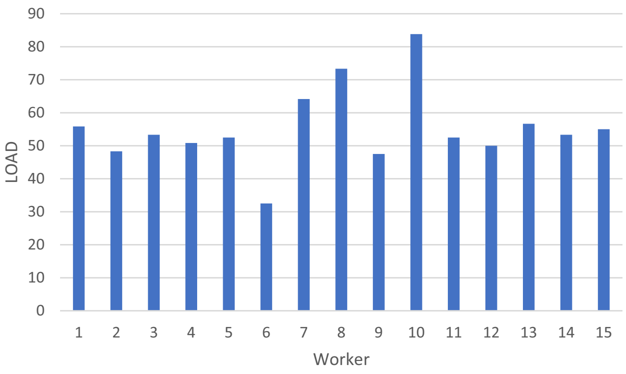

Figure 15. Germane load of workers.

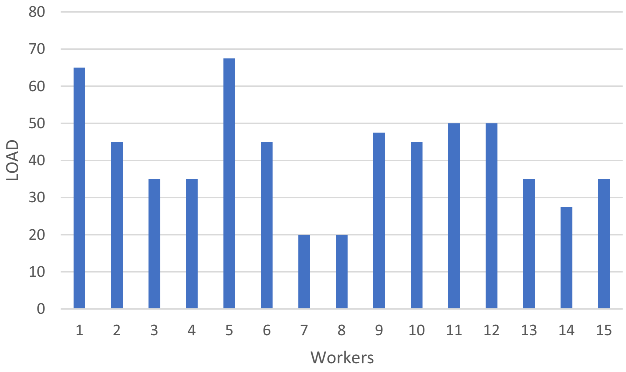

Figure 14. Extraneous load of workers.

much. In the case of the last four scenarios, when it comes to part numbered boxes and separated parts in different boxes the material presentation influences the performance, similar is the case with photographs and instructions. The combinations of information and material presentation are categorized into eight different scenarios as shown in table 2. The experiment is conducted with the workers who are to be assigned to the workstations. The results reveal that workers have assembled a maximum number of pens in scenarios 6 and 8, i.e. a scenario where the workers are provided with part numbered boxes with instructions or photograph. However, there exist variations in the minimum number of pens assembled. This variation is due to the change in their skill set and is to be applied in the allocation of the workers. A detailed analysis considering the number of pens assembled by each worker is also done to identify which combinations yielded better results individually. The success rate of the tasks is very low because the workers are not experienced in these tasks earlier. Even though the success rates are low, when considering the learning effect from the lower number of pens assembled in scenario 1 to a greater number of pens in scenario 8 provides an illustration of cognitive assessment usage. The success rates of the workers with the total number of pens assembled and the scenarios with maximum and minimum are provided in table 3.

4.2 *Human Performance Measurements*

4.2.1 *Objective measurements:* The difference in information presentation (instructions and photograph) based on the number of pens assembled is given in table 4. The total number of pens assembled using instructions is 155 and that of photograph is 287. All the workers had done a better job when information presentation is in the form of photograph in the whole experiment.

In the above comparison between instructions and photograph, it is observed that the number of pens assembled are more while presenting the information in the form of photographs. Moreover, the combination of material presentation using part numbered box and information presentation using a photograph (in scenario 8) is resulting in the best output, which means that the combination of these types of presentations in the work scenario provides better productivity. Part numbered box with Instructions (in scenario 6) has also achieved a significant output as in scenario 8; the difference of performances in other scenarios with that in scenarios 6 and 8 justifies the effect of cognitive behavior skill difference among the workers. The instructions with grouped parts (in scenario 2) showed the lowest number of assembled pens; this can be due to the difficulty in identifying the parts of individual pens. In scenario 2, the workers adopted mostly a trial and error method, by which they could not complete the assembly of pens within the stipulated time. Table 5 presents the combination of four types of material presentation and two types of information presentation in the eight scenarios considered in the present study. Table 6 gives the number of pens assembled in each scenario.

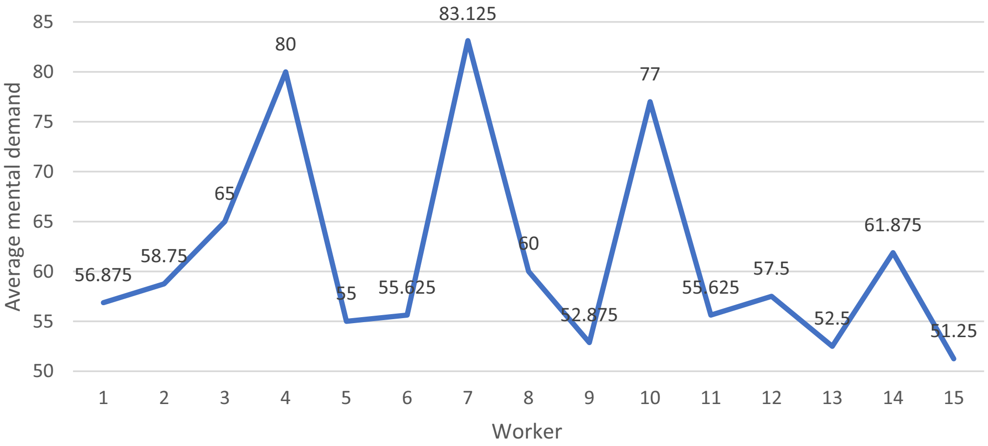

Figure 16. Average mental demand of the fifteen workers in the study.

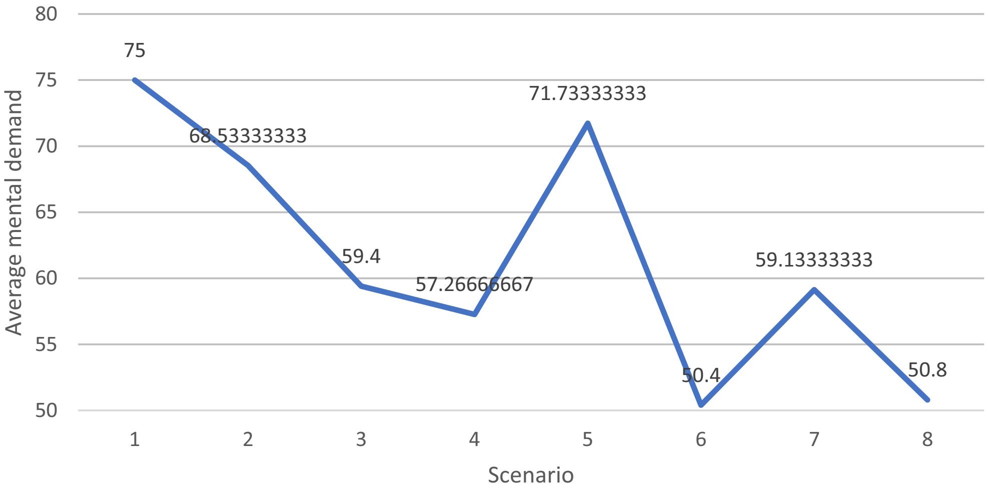

Figure 17. Average mental demand of the different scenarios in the study.

Further, a detailed analysis of each scenarios and individual performances of the workers are carried out. It is observed that in both scenarios 6 and 8, which provided the best results, the workers 1, 3, 7, 13, 14, and 15, contributed to the best performance of assembling the maximum number of pens using part numbered boxes with instructions. These results lead to the importance of individual attention to the workers for assigning them to different workstations as the final output data concluded that photographs were better than instructions. Figures 9, 10, 11 and 12 depict the number of pens assembled by workers in different scenarios.

It is observed that in scenario 2 (Grouped parts with instructions), the least number of pens are assembled. A significant difference exists between the performance of workers in scenarios 2 and 4. Therefore, it is clearly evident that the performance of workers provided with Grouped parts and photograph is better than that of workers with grouped parts and instructions. It can be noted that workers 2 and 12, could not assemble a single pen by providing both instructions and photographs. Thus, there was no output in each scenario. An equal number of pens are assembled by workers 5 and 8.

Considering scenario 5 and 7 (Separated parts in different boxes with instructions and photograph respectively), worker 5 reported equal number of pens assembled, which is to be considered during the final allotment as there can be variations in the performance if the photograph instruction method is provided. Workers 2 and 12 could not assemble any of the pens in both scenarios. All the remaining workers gave a better output in separated parts in different boxes with photograph.

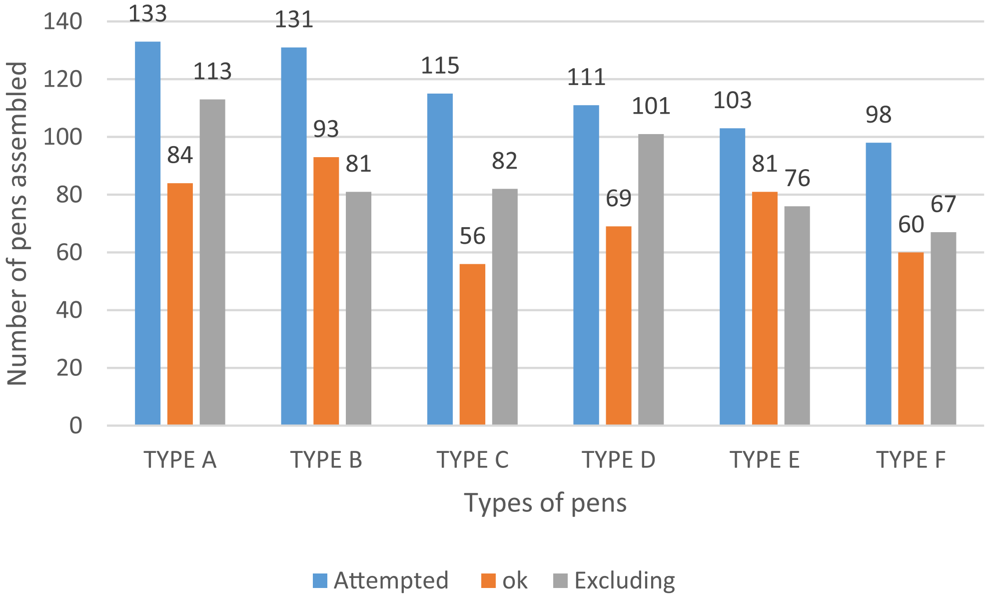

Figure 18. Pen types and total number of pens assembled.

In Scenario 1 and 3 (Intermixed parts with instructions and Photograph respectively), worker 11 and 14 had assembled very few numbers of pens, that too with instructions. Therefore, it is evident that if these workers were allotted to the scenario with photograph there are chances for their output to be zero. Worker 12 also could not assemble any pens and this can be due to the fact the there is no previous information about the task to be done, but later on learning, as the task progresses, the worker could assemble a good number of pens.

This section thus confirms that there will be differences in performances of the workers in different scenarios when considered individually and this has to be further studied and analyzed for better performance and output in industry environments. It is evident that depending on the worker, the material and information presentation has to be varied. This comparison also contributes to the allocation of the workers in each station.

4.2.2 *Subjective measurements:*

- **Subjective Measurement for Cognitive Load**

A subjective measurement of cognitive load is performed at the end of the experiment to validate the objective assessment. A questionnaire survey for rating the difficulty of the task is provided to the workers. Leppink *et al* [42] has proposed a subjective rating technique for measuring all three types of cognitive load. Adopting a similar approach, this study measured cognitive loads. It is observed that the intrinsic load is highest for worker 8 and the lowest for worker 11. The intrinsic load of workers is depicted in figure 13.

The extraneous load is less than the maximum intrinsic load. Workers 7 and 8 have the least extraneous load but they are not the ones with the highest number of pens assembled. This load mainly depends on the learning part from the initial to the final scenario. How well these workers learn can be analyzed with this result. The performance can be identified from this data as per the graph shown in figure 14.

Germane load is mostly dependent on the effort, mental demand and the frustration level. The information presentation helped to ease the tasks, whereas the material presentation made the workers to concentrate more on each scenario. The germane load is highest for worker 10 and this is the highest value among all the three loads discussed here. In this task, initially, the cognitive load is higher as they are not familiar with the assembly line. The scenarios from one to eight made them learn and at the end of the eighth task, the cognitive load had decreased. It is evident that the number of pens assembled based on a scenario by individual workers has increased. Figure 15 presents the germane load of workers.

- **NASA Task Load Index (NASA-TLX)**

NASA-TLX is the assessment method for subjective measurement in this experimental study. NASA-TLX is a workload evaluation tool used to investigate the expected workload. After finishing the task of assembling the pen in all eight scenarios, fifteen workers rated perceived workload on six different scales: mental, physical, temporal, performance, effort, and frustration; the scales were set from 0 to 100. The factors were weighted about one another to show the most significant aspects of the workload, with more importance given to mental demand. A preliminary study was conducted by [43] using the NASA-TLX assessment method to identify the mental demand.

Mental demand in NASA-TLX is considered and analyzed. Mental demand is all about the mental and perceptual activity required to assemble the pens as per the scenarios. This mental demand also identifies whether the task was easy or demanding, simple or complex. The average mental demand of the fifteen workers in the study is illustrated in figure 16. The mental demand for the two workers was very high, thus making it difficult for them to perform in all the scenarios. The remaining thirteen workers had almost similar mental demands except for worker 10. This variation in mental demand necessitates worker allocation to increase the assembly line's efficiency.

The average mental demand of the fifteen workers of eight different scenarios is depicted in figure 17. The first four scenarios are almost similar because the material presentation is similar and simple with the least mental demand. From scenario 5 the material presentation is getting complicated and the chance of assembling a pen without error is reduced. Part numbered box with instructions was the scenario in which a higher number of pens were assembled, so again the mental demand declines from scenario 5 to scenario 6. Scenario 7 was complicated as extra information with photographs was provided, which influenced the workers and thereby the increase in the mental demand. Scenario 8 has the lowest mental demand as the workers already learned about the parts and the process to assemble. Thus, a subjective measurement contributes to the experiment that the need for selection of different combinations according to the performance of each worker is to be considered.

4.3 *Cognitive penetration and aesthetics*

Burnston [3] claimed that the Openness/Intellect domain of personality and aesthetic engagement has a secure relationship. Neither of these, though, are simplistic constructs and although the relationship exists, there is still a lack of process-based evidence justifying the relationship. By analyzing the effect of the facets of Openness and Intelligence on many different aesthetic emotions, this study sought to explain the relationship. In response to the number of a certain type of pen assembled, this study looked at the variations between and within-person in arousal and the emotions of interest and selection. Figure 18 illustrates the type of pens and the number of pens assembled. Type A pen is considered to be having the highest number of pens assembled, whereas type F is the lowest. This variation is due to the fact that type A pens are easy to distinguish; their color, reflection and the similarity outside made the workers consider that type of pens to be assembled first. Many of them were successfully assembled, but the inner part of the pen such as the refill and the spring, were not similar. This data has to be decrypted from instructions and photographs which they failed to obtain. The effect of cognitive factors on sensory aspects of perception is known as cognitive penetration. Cognitive penetration typically occurs according to the evidence from neuroscience and philosophy, but to identify it in an experimental study is difficult. So, for the Type A pen for all the workers the cognitive penetration happened and that is the reason why it is not having the highest number of assembled pens. The highest number of pens assembled without error is for type B. Type B pen is also aesthetically pleasing, but their inner parts are higher in number and similar to the outside parts. Cognitive penetration can be seen in all the types of pens assembled while comparing the number of pens assembled. The size and color of the spring and the refill are the toughest parts to identify and assemble. When the worker started from the first scenario to the last, they gained the pictures and colors of the parts, which helped them to improve their learning and to improve the number of pens assembled.

4.4 *Development of predictive model – Logistic regression*

With the results of the experiment, the allocation of worker allocation is done. A logistic regression model has been developed using the data obtained. This proposed model classifies the workers in terms of whether they will assemble the pen without error or not.

From figure 19 it is evident that if a worker is given Type B pen, then there is a higher chance that the worker assembles it without error, whereas for Type C there are chances of getting assembled but cannot assure the quality of the assembled pen.

Figure 20 depicts that in Scenario 8, the workers will definitely assemble without error, and in Scenario 1, the

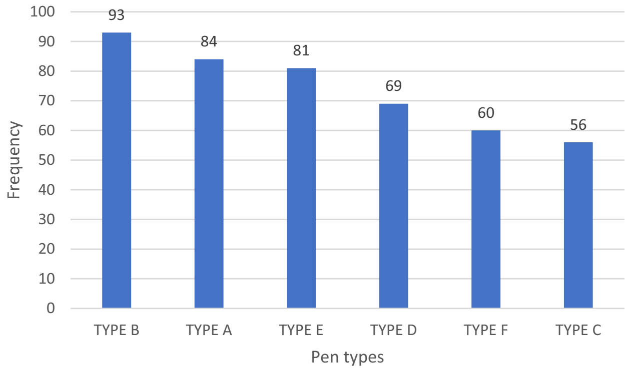

Figure 19. Frequency of pens assembled without error vs pen type.

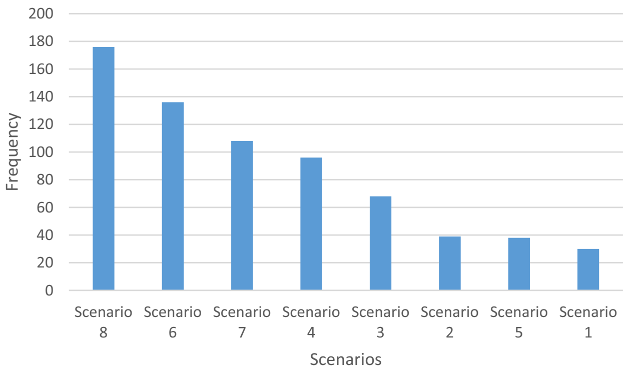

Figure 20. Frequency of pens assembled without error vs Scenario.

chances of success are very low. This suggests that some workers are good in Scenario 1 but others are not. As a whole model, the chances of assembling the pen successfully without error from Scenario 8 to Scenario 7 is high. According to the workers, the frequency is illustrated in figure 21.

In this experiment, worker 6 is the best performer and worker 14 is the slow performer. According to these results the worker allocation can be done. It is observed that the workers who had assembled Type B pens first and tried to assemble more pens in scenarios 8 and 6 (part numbered box with instructions and photograph) gave the best results.

The logistic regression model developed has an accuracy of 0.82, which can be seen in table 7. The model is more specific than sensitive. The overall model could be improved with more data and by trying other classifiers. Moreover, in the statistical analysis of binary classification, F1 score is a measure of a test's accuracy, which is 0.82 in this case. It is calculated from the precision and recall of the test, where the precision is the number of correctly identified positive results divided by the number of all positive results, including those not identified correctly, and the recall is the number of correctly identified positive results divided by the number of all samples that should have been identified as positive.

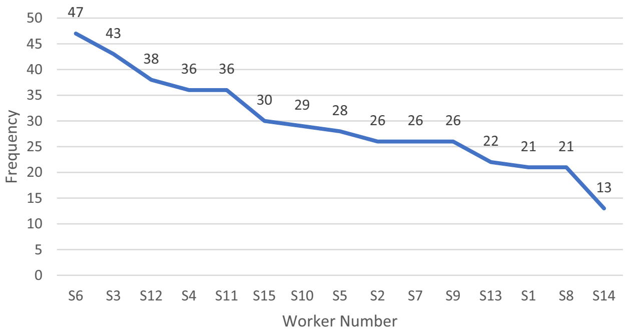

Figure 21. Workers and the frequency of pens assembled without error.

Table 7. Performance metrics of logistic regression model.

Recall score: 0.9158
Precision score: 0.7480
F1 score: 0.8235

	Precision	Recall	f1 -score	Support
0	0.91	0.74	0.81	125
1	0.75	0.92	0.82	107
Accuracy			0.82	232
Macro avg	0.83	0.83	0.82	232
Weighted avg	0.84	0.82	0.82	232

- The summary of the results suggests that:
- The -Kruskal Wallis test suggests that part numbered box is the best way to present materials to workers and photograph is the best way to present information. Even though the statistical analysis verifies this, but in an ergonomic perspective this will not be acceptable. Each worker has his own acquired skills and abilities and inbuilt skills, so based on this any of the scenarios can be good for them depending on the cognitive aspects. It is preferable to analyze all the combinations of information and material presentation individually before arriving at conclusions. So, an ergonomic workplace must check these cognitive aspects of the workers which in turn improves productivity and adds value to the unit.
- The human performance measurements are experimental study data in which we use the number of errors and number of attempts. This is actually a detailed study of the different combinations of the cognitive aspects considered. The number of pens assembled in each scenario is important as when it comes to some workstations, it is important that the initial productivity contributes to the demand as the assembly process is continuous. For example, in this study workstation 1 is complicated and once the activities in this workstation is completed, it can move to the next workstations. In order to get the best worker for this job a detailed performance measurement is required. Another benefit of human performance measurement gives the workers with poor performance and they can be allocated to workstation 5 which requires less expertise. The details about the workstations and analogy is explained in section 5.
- Cognitive penetration and aesthetics are linked to theories in cognitive science and exploring them helps to make the worker allocation effective. Even the parts color, shape, size, etc. has an influence on each individual. When it comes to actual engineering drawings of a part the worker will face difficulty in assembling it, but when the characteristics of the part are identified and can relate it to a final product the

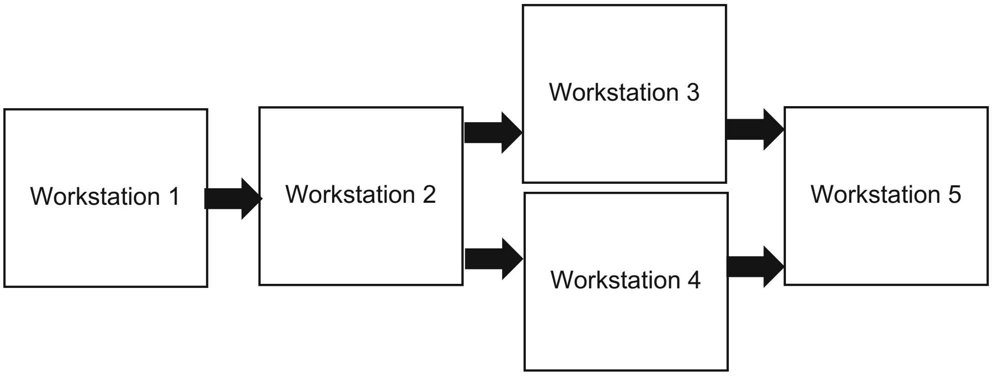

Figure 22. Workstations to which allocation is to be done based on experimental results.

worker will succeed in his job. Based on the experimental study, we must consider the person with color blindness while designing the material and information presentation.

- Development of predictive model helps the pen recycling unit to identify the right worker when a newly recruited worker joins and thereby identifying the workstation in which he fits.

5. Discussion on worker allocation

Hashemi-Petroodi *et al* [40] presented an overview of workforce reconfiguration studies and the various strategies adopted for different manufacturing conditions as a part of workforce planning. Therefore, inspired by this research, a methodology for worker allocation in a pen recycling unit, an initiative of a non-profit organization in the southern part of India, is proposed in the present work. There is an analogy between scenarios in the experimental study and workstations in the pen-recycling unit with their tasks, abilities and skills required are all similar.

The pens collected for reuse will be in a heap mixed with different varieties in the initial stage. In the initial stage, it is necessary to disassemble them to remove defective parts and restore them with a new refill.

The tasks to be done in each workstation of the pen-recycling unit is listed below.

Workstation 1: Disassemble the pens collected and use only the good quality parts.
Workstation 2: Group the similar parts and arrange them based on part numbers or similarity in appearance.
Workstation 3: Assemble the pen with a new refill with instructions or photographs.
Workstation 4: Assemble the pen with a new refill with part numbers.
Workstation 5: Arrange and pack the assembled unit.

There is an analogy between scenarios 1, 3, and workstation 1 and scenarios 2, 4 and workstation 2. In the first four scenarios, the subject does not even have an idea about the pens other than the material and information presentation given; the same situation happens when you are introduced to a heap of pens and choose the non-defective parts. There is an analogy between scenarios 5, 7, and workstation 4 and scenarios 6, 8 and workstation 3. Here, the scenarios are provided with instructions and photographs, but part numbers are the best option for some workers to assemble the pen.

The five workstations of the pen-recycling unit are depicted in figure 22. A comparative analysis of information and material presentation has been a primary objective. Based on the analysis of results, about fifteen workers need to be allotted to these work stations. The workers are allotted based on their performances in experimental study. This helps to identify the worker skills and assign them to the right work stations.

The allocation of workers is based on the number of pens assembled by all the workers in each scenario. The scenarios in which maximum and minimum number of pens assembled by the workers is depicted in table 3.

Scenario 1 and 3 in the experimental setup matches with work station 1. Therefore, for the allocation of workers to the first workstation, the following two conditions are to be met.

Condition 1: The worker considered must have maximum number of pens assembled in scenario 1 and 3.
Condition 2: The worker considered must not have minimum number of pens assembled in either scenario 1 and scenario 3.

If the first condition is not satisfied and the second condition is satisfied, then those workers can be considered as an initial allotment. Hence, workers 3, 4, 5, 7 and 14 are considered.

Scenario 2 and 4 in the experimental setup matches with work station 2. For the allocation of workers to the second workstation, the following two conditions have to be met.

Condition 1: The worker considered must have maximum number of pens assembled in scenario 2 and 4.

Condition 2: The worker considered must not have minimum number of pens assembled in either scenario 2 and scenario 4.

If the first condition is not satisfied and the second condition is satisfied, then those workers can be eliminated as an initial allotment. Hence, workers 1 and 6 can be considered.

Scenario 5 and 7 in the experimental setup matches with work station 4. For the allocation of workers to the fourth workstation, the following two conditions are to be met.

Condition 1: The worker considered must have maximum number of pens assembled in the scenario 5 and 7.

Condition 2: The worker considered must not have minimum number of pens assembled in either scenario 5 and scenario 7.

If the first condition is not satisfied and the second condition is satisfied, then those workers must be eliminated. Hence, workers 3, 5, 6, 7, 8, and 15 can be considered.

Scenario 6 and 8 in the experimental setup matches with work station 3. Hence, for the allocation of workers to the third workstation, the following two conditions must be met.

Condition 1: The worker considered must have maximum number of pens assembled in the scenario 6 and 8.

It is observed that most of the workers satisfy this condition and have maximum number of pens assembled either in scenario 6 or 8. Therefore, the maximum number of pens assembled in either scenario 6 or 8 are considered for selection of workers to workstation 3. Hence, workers 10, 11, and 12 are allocated as their respective output being 14, 14 and 19 as per table 3.

For the fifth station, the workers who are less skilled and not included in any of the four work stations can be considered. Therefore, the workers allocated will be 2, 9 and 13 to the final workstation. The data of these worker allocation is tabulated in table 8.

Each workstation requires three workers each out of the total 15 workers. First, we consider the workers who are suitable only for a single workstation. For stations 3 and 5 the exact number of workers is already allotted as per table 8. Workers 12, 11 and 10 can be assigned to station 3 and workers 2, 9 and 13 can be allotted to station 5. Station 2 can be assigned only to workers 1 and 6, though three workers are required. For station 4, workers 3, 5 ,6 ,7 ,8 ,15 can be allocated. Since worker 6 is already allocated to station 4, the only options left is 3, 5, 7, 8 and 15. Out of the five workers for station 4, workers 8 and 15 are exclusive. Workers 3, 5 and 7 are common to both stations 1 and 4 so thereby they can be reallocated according to the requirements.

In stations 4 and 1, workers 3, 5 and 7 can be allotted as they are suitable for both the workstations. But in comparison with the number of pens assembled in scenario 5 and 7 (at Station 4) with that of scenario 1 and 3 (at Station 1), as per figure 11 and 12, worker 7 can be confirmed. Worker 7 has assembled a greater number of pens and can be allocated to station 4. For station 1, already workers 4 and 14 are allocated. The workers 3 and 5 are yet to be allocated. Either worker 3 or worker 5 can be allocated to station 1 and the remaining one worker must be trained to accommodate in station 2. As worker 3 has the greater number of pens assembled compared to worker 5 in scenario 1 and 3 (see figure 11), worker 3 is preferred. Further worker 5 is remaining and needs to be trained to accommodate him/her in station 2 to satisfy the workforce. Hence training must be given only to a single worker according to the cognitive aspects. This reduces the cost of training the workers and allows for the effective allocation of workers to their respective workstations with which they can achieve maximum output without errors. The final allocation of the workers is listed in table 9.

The most critical task which can be handled by efficient workers increases the rate of recycling. The assembly unit will be operational twice in two weeks. Thus, a final allotment of the fifteen workers are effectively done based on the results from the experiment. Both instructions and photographs can be provided in station 3 and 4 for the convenience of the workers. This method of allocation can be designed based on the assembly lines, and it varies from worker to worker.

Table 8. Stations and expected workers in each station.

Work Stations	Recommended Workers
1	3,4,5,7,14
2	1,6
3	12,11,10
4	3,5,6,7,8,15
5	2,9,13

Table 9. Final allotted workers to each station.

Work Stations	Final Allotment of Workers
1	3,4,14
2	1,6,5
3	12,11,10
4	7,8,15
5	2,9,13

6. Case study: Pen recycling unit

The purpose of this case study is to enhance the performance of the workers in a pen recycling unit. A previous work with a pilot study was a success in the laboratory environment. In order to verify the methodology adapted this is applied for the pen recycling unit. The pen recycling unit as a social institution lacks funds but the amount of pens to be recycled was abundant. The school and college students nearby contributed a lot of used pens to the recycling unit. There came a situation that these pens were not able to be recycled properly and also space issues which lead to the closing of the unit. There is a huge demand among the students as they get these pens for a subsidized rate. A visit to the unit was done and identified the pen recycling unit. CLAM factors were used to adapt a scientific methodology to the study. The main issue with the recycling unit is the variety of products with different part sizes and colors which confuse the workers and leads to cognitive load. The possible solutions to this issue was listed as follows:

- Recruit highly skilled workers
- Increase the number of workers to 30
- Layout improvement, rack setup and extension of the unit
- Guidelines preparation for information and material preparation
- Worker allocation based on performance.

The first three solutions were not at all economical and we could not consider that because they can't allocate adequate fund. So, we concentrated on information presentation and material presentation improvement in the pen recycling unit. Then the pilot study which we conducted in our lab was conducted with the same setup. Then the experiment design was correlated with the workstations of the pen recycling unit and analysis was done. The person with the right skill was selected and allocated to the workstations. Then, the workers work in the allocated workstations and their performance is monitored using daily hourly monitoring. An increase in the number of pens assembled is achieved when the proposed methodology is utilized. To present the proposed approach systematically a flowchart is given in figure 23.

A further increase in the productivity can be achieved by improving cognitive abilities by providing trainings and by providing short breaks to avoid the cognitive load (was effective during the actual study).

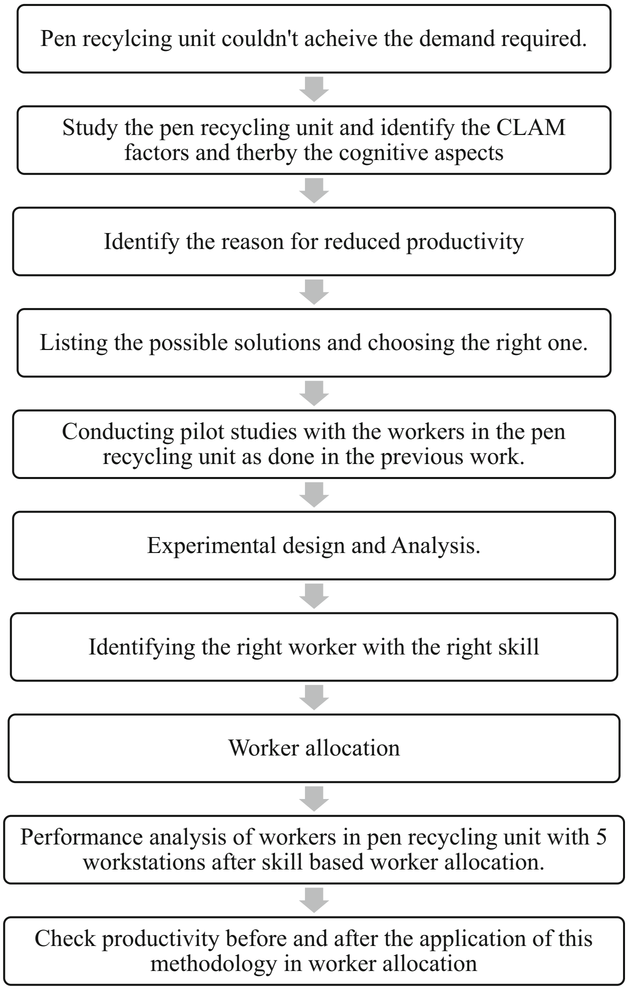

Figure 23. Flowchart of the proposed methodology in pen-recycling unit.

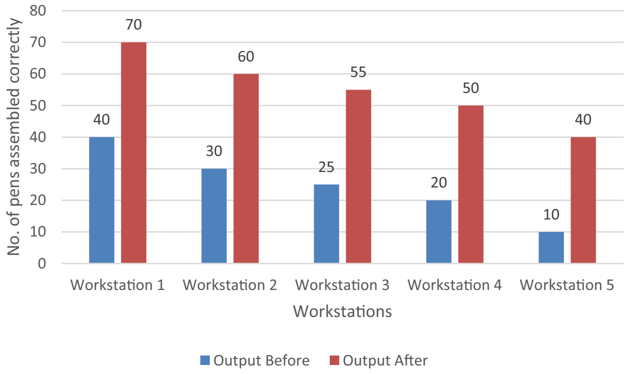

Figure 24. Variation of results before and after applying the proposed methodology.

This study can also be considered as a verification of the pilot study designed. The hypotheses considered gave similar results in the pilot study conducted with the workers and the pilot study conducted in the lab environment. The allocation of workers with this methodology adopted in paper improved the productivity. This data was cross-checked with the company officials and the before and after chart is added and depicted in figure 24.

From the data collected for eight hours, it is observed that at the end only 10 pens are assembled correctly before applying the methodology but now it has increased to 40. A four times increase can be seen. Here the skill is so important because the first workstation is critical as they have to be highly skilled to disassemble the pens collected and use only the good quality parts. So, the workers in first workstation must be able to distinguish among the parts and they are also responsible for maintaining the quality and reducing errors. The workstation follows a continuous assembling process as all the workstations must have skilled workers to achieve a good count of number of pens assembled.

7. Conclusion

The paper here presented concerns the theme of cognitive aspects to be considered in the assembly line, still little explored in literature in terms of worker performance, skills and their importance in worker allocation. The study depicts how significantly worker performance in manual assembly systems differs from what is typically accounted for by workstation designers, and how such differences might be linked to cognitive aspects. The significant differences found in workers' performance are due to the varying cognitive capabilities of the workers. The influence of cognitive aspects namely, information and material presentation on individual human performances are identified. Problems that arise from poor workstation design of manual assembly processes may entail cognitive workload, leading to less effective working and, therefore, a decrease in production efficiency. To address this issue, a real-time case study in a pen-recycling unit with a methodology is proposed. The methodology is aimed at identifying the right worker for the right workstation through a pilot study. This approach is simple and economical, and can be applied to all manual assembly workstations with a wide variety of products. The methodology reduces the complexities in identifying the objective function, formulating an objective function and the constraints when the optimization techniques are applied for real-time case studies for worker allocation (based on skill). In essence, this work can be summarized as follows:

- Cognitive aspects affecting human performance in manual assembly have to be considered to improve productivity and reduce errors.
- The cognitive aspects can be selected from CLAM factors according to the workstation to be studied.
- All possible combinations must be included in order to obtain the best results (For example, this research took all possible combinations of material and information presentation.
- Worker allocation is an important factor which decides the output in a workstation.
- Skill-based worker allocation is preferred.
- By following the methodology proposed, better results can be obtained.

The analysis of results says that the performance of each worker improved when they were allocated to the workstations based on the cognitive aspects. The results revealed that the methodology could be successfully adapted, but the pilot study needs to be varied according to the requirements of the production unit. The proposed methodology is therefore designed for industrial sectors in which assembling operations involve a wide variety of products and subparts which require manual skills. In these companies, a skilled workforce is a primary resource and, like any other, is a limited resource. A skilled workforce increases the cost, but here we suggest identifying the workers who are skilled and who can be made skilled workers through training. In future works, the method could be enhanced by implementing this methodology in workstations which utilize some tools, robots, etc.

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