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Analysis of Occupational Safety and Health of Workers by Implementing Ergonomic Based Kitting Assembly System

B.Vijaya Ramnath[a]*, C .Suresh Kumar[b], G. Riyaz Mohamed[c] K. Venkataraman[d], C. Elanchezhian[e], S.Sathish[f].

[a e]*Professor, Department of Mechanical Engineering, Sri Sai Ram Engineering College, Chennai, 600044, India.*
[b]*Research Scholar ,Dept of Mechanical Engineering, IIT Madras, Chennai-36, India.*
[c]*Senior Engineer, Rane Brake Lining Ltd. , Chennai-600058,India.*
[d]*Research Scholar, Department of Mechanical Engineering, Vels University, Chennai, 600 117 , India.*
[f] *Student, Department of Mechanical Engineering, Sri Sai Ram Engineering College, Chennai, 600044, India*

Abstract

Success of any industry depends on its quality, quantity of production and delivery time of the product to the customer. Therefore industries must develop and implement new management philosophies like lean, agile, kitting manufacturing and concurrent engineering, etc. This paper deals with a study on the impact of ergonomic based kitting assembly system on occupational safety and health of workers in an automobile industry. Kitting production is most widely used in industries that are assembly-oriented or having a high amount of repetitive human processes. Kitting assembly reduces work space requirement, operator walking distance and time, work in process inventory. For these kinds of companies, improved systems can eliminate significant levels of waste or inefficiency. So, in this paper an overall analysis was carried out to minimise the wastages and to improve the efficiency in an assembly line. Here, data collection was carried out as follows: interviews with managers and supervisors, safety specialists, safety engineer, workers, in order to know their views on both the negative and positive impacts of Kitting assembly system. Questionnaire are aimed at assessing their views on the current working conditions and also aimed at assessing their views on the differences between the conventional assembly system and the new ergonomics based kitting assembly system. The result shows that a significant increase in overall working condition of the industry which in turn led to the increase in the productivity. Also, factor analysis is carried out to group some important criteria into factors for conducting future analysis with worker to evaluate the ergonomic level of workers.

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Keywords: Conventional assembly system, Ergonomic based kitting assembly system, occupational safety, health of workers, factor analysis.

1 Introduction

Kitting assembly system is an assembly line methodology used by automotive industries in their assembly line. Kitting assembly is about doing more with less of time, inventory, space, labour, and money. Kitting assembly can be considered as shorthand for a commitment to eliminate waste, simplify assembly procedures and thus to speed up assembly process. Ergonomic based Kitting production will help an industry to work efficiently and effectively.

A South Indian automobile industry assembly line was chosen and their conventional assembly systems were studied. Questionnaires were prepared and circulated among the workers by considering their current conventional assembly method for work content and work organization factor. The top officials of the industry were taught the major concepts of

* Corresponding author. Tel.: 91-984-144-6655; fax: 044-22512229.
E-mail address: vijayaramnath.mech@sairam.edu.in

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ergonomics and the ergonomic based kitting assembly system. After 18 months from the start of this analysis, the kitting assembly was implemented in the case organization. Again, the same set of questionnaires were circulated among the employees and their working conditions after the implementation of ergonomic based kitting assembly system was collected and analysed mathematically and compared with the conventional assembly system.

2 Literature Review

Nowadays, one of the major concerns to many countries is the occupational safety and health hazards of the workers in industries. The government usually deals it by implementing legislation, safety guidelines, accident investigations and safety inspections. Gyekye et al (2007), (2005), Hafey (2009), Li et al (2003) have studied this in their previous investigations. Venkataraman (2008) proposed a new safety performance factor in order to prevent accidents in the work place and make the work place safer for the employers to work in. Generally, the safety factors were calculated based on the frequency rate and the severity rate. He consolidated that, the hours or the days lost should be included in order to improve the safety performance factor of an industry.

DiDomenico and Nussbaum (2011) investigated the effects of different physical workload parameters on mental workload and performance and thus found that Individuals were more sensitive to changes in workload, manifested through an increase in effort, as compared to physiological changes and performance decrements. Two common assessment tools (Borg CR10 Scale and NASA-TLX) were used by DiDomenico and Nussbaum (2008). They investigated the interaction between physical and mental demands and the effects of such interactions when using existing subjective workload assessment tools as such tools are appealing since they are easy to use and involve minimal interference with the task being performed.

Kitting assembly system is proposed in this paper to improve the safety and efficiency of work done. Kitting assembly system is an assembly line methodology used by automotive industries in their assembly line. It is about doing more with less of time, inventory, space, labour, and money. Kitting system in the design method of robotics, as an alternative part entry process, contributes to the reduction of overall assembly cost. Robot improves productivity, flexibility and part flow control in parts kitting operations. This was proposed by Tamaki and Nof (1991). Bozer and McGinnins (1992) developed a mathematical model which can be used to quantify the advantages in material handling, space requirement and Work In Progress (WIP) between kitting and line stocking for an assembly of stationary fitness cycle. In kitting system, the picking efficiency and accuracy can be improved by making better use of the product structure. This was proved by Johansson and Johansson (1990) who focused on design of kitting system in terms of location of the order picking activity, work organization, picking method, information systems and equipment along with key design aspects and performances from selected case studies. Kitting assembly can be considered as shorthand for a commitment to eliminate waste, simplify procedures and thus to speed up assembly process. It helps to improve the working conditions of an industry, with time saving and effective techniques. Ergonomic based Kitting production will help an industry to work efficiently and effectively. Sometimes a heuristic solution procedure is developed, which is computationally very efficient even for large-scale problems encountered in industries. Gunther et al. (1996) followed this approach and analyzed the component kitting problem faced in semi automated printed circuit board assembly. Chrismansson et.al (2002) and Medbo (2003) studied the materials kitting case study, using an alternative method for materials kitting. The material pickers' physical exposure was assessed using ambulatory equipment. It was found that the alternatively kitting system's productivity was better than the traditional one with respect to the muscular activity and work postures. It was concluded that the ideal situation is the one in which the operator picks up components from one material container. Neumann and Medbo (2010) described the modular concept which replaces the existing big box method of material supply chain with narrow bin (Kit). Borchardt et al (2012) proposed a multi-criteria decision support method to assess the degree of the implementation of ecodesign in furniture manufacturing companies. Initially, the Ecodesign constructs were extracted from the literature and questionnaire is prepared. The relative importance of the constructs for three companies are obtained by giving this questionnaire with three companies. After one year the same questionnaire is given and relative importance of the constructs is obtained. By comparing the assessed relative importance, they observe the relation of the priorities of the companies to their eco-conception.Vijaya Ramnath et al. (2010) performed multi-criteria descision making analysis for selecting optimal assembly system in an automotive assembly line using AHP and Fuzzy AHP and also used Kanban system to implement lean manufacturing and also optimize inventory using Kanban.

Lean manufacturing affects the working conditions. It is sometimes positive and sometimes negative. Lean manufacturing was first implemented by the Japanese industries to improve productivity. Many investigations have been done on impact of lean manufacturing by Landsberghis et al (1999), Saurin and Fabricio (2009), etc. Landsberghis et al. (1999) analysed the impacts of lean production and total quality management on workers health. Their study revealed that the implementation of lean production lead to intensified work pace and demands, whereas decision attitude remained low. This in turn led to increased musculoskeletal disorders to the workers. Saurin and Fabricio (2009) conducted a study on the impacts of lean production on working conditions in a harvester assembly in Brazil. They collected data based on four categories: work content, work organization, continuous improvement, and health and safety. This was then used to determine the working conditions of the workers which were found to be fairly good. Venkatraman et al. (2014) Performed Lean Production System Justification using Comparative Analysis of AHP and ANP. Conti et al (2006) made a study about the neglected work condition aspects of lean production implementation system. In this study the Karasek job stress model was used to estimate worker's stress on the shop floor. They concluded that the stress imparted on the workers was mainly due to management decisions in lean production rather than the actual implementation of lean production. Value steam methodology has been used for reducing cycle time in automotive manufacturing and assembly system [21, 22, 23].

3 The study methodology

3.1 Selection of the company for study

A case study was undertaken in mid 2010, in an Automobile industry in the southern part of India. The main reasons led to the choice of this specific company are (a) the company belongs to the automotive sector, in which Ergonomic based kitting assembly could be easily implemented (b) for past few years it has been formally adapting its production system to the ergonomic philosophy, as part of improvement activities. Periodically, audits were carried out with the workers on their requirements regarding health and working conditions, based on interviews and questionnaires. This made the study easier, since assessing the human impacts of Ergonomic based kitting assembly made use of interview and questionnaire types that were already familiar to workers and managers. Regular visits also provided opportunities to observe the assembly line work. In this work, questionnaires were supplied for CAS and EKAS to the workers and they are asked to give their feedback according to the range specified.

3.2 Introduction to assembly systems

3.2.1 Conventional Assembly system

The present method of assembly of engines in the plant is conventional Assembly system. (CAS). Here, the components for assembly are kept along the line side of the conveyor and they are replenished periodically with respect to the schedule. Here, components are distributed to the assembly station in units that is suitable for carrying and these units are refilled when they become empty. There is no procedure for refilling different components. All parts required for assembly are available at the assembly station at any time.

3.2.2 Ergonomics based Kitting assembly system (EKAS)

According to Johansson (1991), kitting means that the assembly is supplied with kits of components. Here, the parts are sorted according to the assembly objects. In manufacturing systems, the practice of delivering components and subassemblies to the shop floor in predetermined quantities that are placed together in specific container is known as kitting (Bozer and McGinnis, 1992). In kitting assembly system, worker can easily pickup the components for assembly from the kit with less effort and movement. Some of the ergonomics factors like level of pain, level of difficulty to carryout task, ease of assembly process, stress level, level of discomfort and mental strain etc are optimized in this assembly system.

3.3 Interactions and interviews with the employees

Interviews were conducted with 90 employees and the interview with each group took about 60 minutes before and after implementation of kitting assembly system. Since the initial reports provided by the employees were clear in describing their views for the given questions, there was no need for supplementary interviews. It is worth noting that the group of workers interviewed were not selected fully at random; but with the help of the supervisors we chose, the workers who were already in the company before Ergonomic based kitting assembly was implemented. This method of selection could provide more accurate results.

3.4 Development, application and analysis of questionnaires

The questionnaires were developed by considering some of the key factors which need improvement in the industry. Two types of questionnaires were developed one pertaining to the current working conditions and the other pertaining to the Ergonomic based kitting assembly system. These two questionnaires were prepared for two factors. One related to the work content and the other regarding the work organisation. Nearly 13 questions were considered for both the conventional assembly system and for the Ergonomics based kitting assembly system. These questionnaires were prepared with the intention of finding out the parameters which need to be improved for the overall efficiency of the organisation.

These questionnaires were given to the set of employees and they were asked to complete these questionnaires. They were taught the method of filling in the questionnaires. The questionnaires were filled with the values ranging from 0 to 10. A scale was set for the range of comparison. The range 10 to 7 is considered as satisfied while 6 to 4 is considered as moderately satisfied and 0 to 3 is considered as dissatisfied with the respective assembly system. Each worker was asked to fill in each feedback form with complete honesty. These filled questionnaires were not revealed to any other officials of the organisation. After collecting the feedback, calculations were performed to find out the results. Mean, standard deviation and co-efficient of variance were calculated for each data under both the factors. A software package was developed to comfort the calculation. After calculating the values, comparisons were carried out.

3.5 Feedback on the results of the questionnaires to the workers

A feedback meeting was conducted and the results of the questionnaires were discussed with the workers. The results were made clear to the workers and the necessary improvements were discussed with them. The feedback on the results were discussed with the higher officials of the organisation.

4 Results and discussions

4.1 Analysis of characteristics of population (worker)

Tables 1 and 2 represent the number of questionnaires distributed to workers, the number returned and the number of questionnaires considered valid for the Conventional Assembly System (CAS) and Ergonomic based Kitting Assembly System (EKAS).

Table 1 Data of Conventional Assembly System (CAS)

Conventional Assembly System (CAS)				
Number of questionnaires	**Returned**	**% of questionnaires returned**	**Valid**	**% of valid questionnaires**
90	64	71.1	58	90.6

Table 2 Data of Ergonomic based kitting assembly system (EKAS)

Ergonomic based kitting assembly system (EKAS)				
Number of questionnaires	**Returned**	**% of questionnaires returned**	**Valid**	**% of valid questionnaires**
90	57	63.3	50	87.7

4.2 Work content factor

Table 3 shows the results of the CAS and EKAS questionnaires. Work content factor was analysed based on Health and safety, Level of difficulty to carry out tasks, Pain and discomfort, ease of assembly, Repetitiveness, Stress, Motivation (Saurin and Fabricio; 2009) etc. These criteria were considered based on the workers perception on their job.

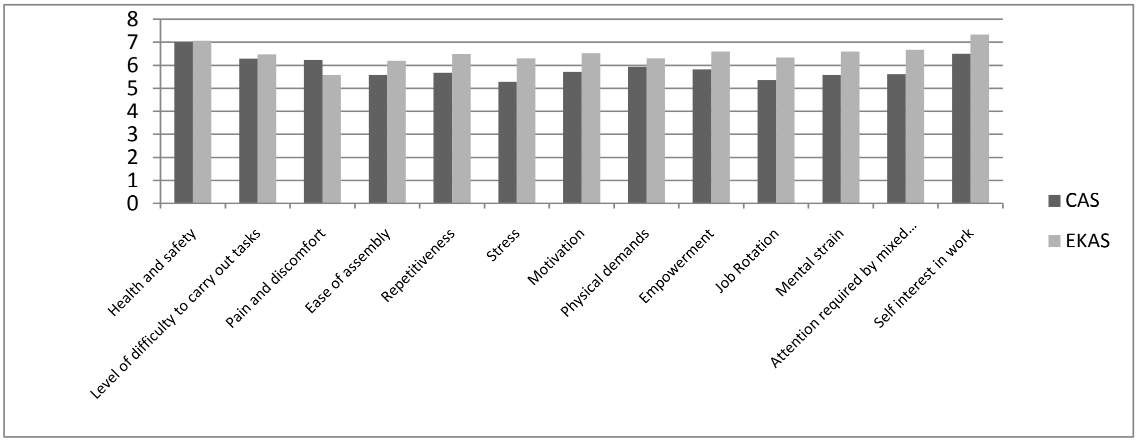
Table 3 Workers perception on working conditions (work content factor)

	Conventional Assembly System			EKAS		
Questions	**Mean**	**Standard deviation**	**Co-efficient of Variance**	**Mean**	**Standard deviation**	**Co-efficient of Variance**
Health and safety	7.000	2.037	29.095	7.070	1.838	25.984
Level of difficulty to carry out tasks	6.287	1.357	21.587	6.480	1.340	20.686
Pain and discomfort	6.222	1.913	34.344	5.571	1.625	26.118
Ease of assembly	5.571	2.820	50.632	6.185	2.602	42.070
Repetitiveness	5.678	1.656	29.175	6.481	1.602	24.719
Stress	5.285	1.997	37.788	6.296	1.957	31.090
Motivation	5.714	2.015	35.276	6.518	2.173	33.332
Physical demands	5.928	1.804	30.426	6.296	1.436	22.810
Empowerment	5.821	1.785	30.676	6.592	1.623	24.624
Job Rotation	5.357	2.112	39.423	6.333	1.641	25.907
Mental strain	5.571	1.687	30.283	6.592	1.474	22.364

Attention required by mixed production	5.607	1.323	23.946	6.666	1.109	16.640
Self interest in work	6.500	2.603	40.052	7.333	2.480	33.827

4.2.1 Comparison Method for CAS and EKAS for Work content

Figure 1 Comparison between CAS and EKAS for Work content factor



Based on the data collected from the workers, analysis was carried out on various criteria. Using mathematical tools such as mean, standard deviation and co-efficient of variance the interpretation of data was done. Comparison was made between the CAS and EKAS. The comparison between CAS and EKAS for the work content factor is shown in figure 1.

Factors like Health and safety discomfort ease of assembly and repetitiveness, motivational level shows improvement in the working environment after implementing EKAS. The physical demands and strength have increased from the conventional assembly system to the Ergonomic based kitting assembly system. This was due to the fact that the workers require some time to settle themselves with the new system.

The worker empowerment and Job rotation have shown a good increase from the conventional assembly system to the new system. This clearly states that by applying ergonomic based kitting assembly, the workers are more comfortable with their work and they feel that their job will be more liked by them. Mixed production means making different goods every day, according to the daily anticipated demand. To avoid inventory accumulation, mixed model production requires the ability to manufacture in small batches, quick changeover from one item to another, and gives best results when dispatch dates are linked to the production schedules. The mixed production value has increased from (5.607-CAS) to (6.666-EKAS), which shows that the Ergonomic based kitting assembly system has improved the attention of mixed production level. The workers self interest have shown an increase from CAS to EKAS. The survey concluded that by introducing the ergonomic based kitting assembly system, few factors such as stress, demands have increased. On the other hand it has been found that the workers are more comfortable with the EKAS system.

The obtained results of the work content factor are consistent with previous study done by Seppala and Klemola (2004). This study shows that the existing working condition of the case industry has improved after implementing EKAS.

4.3 Work organization factor

The results of CAS and EKAS questionnaires based on the work organization factor are presented in Tables 4.

Work organisation is to arrange and distribute the construction work between the gangs of workers in such a way that best use is made of the available labour, materials, tools and equipment. Work organisation factors was analysed based on factors like number of work standards, training, work pace, housekeeping standards (Saurin and Fabricio; 2009) etc.

In order to understand the work organisation, we must know:

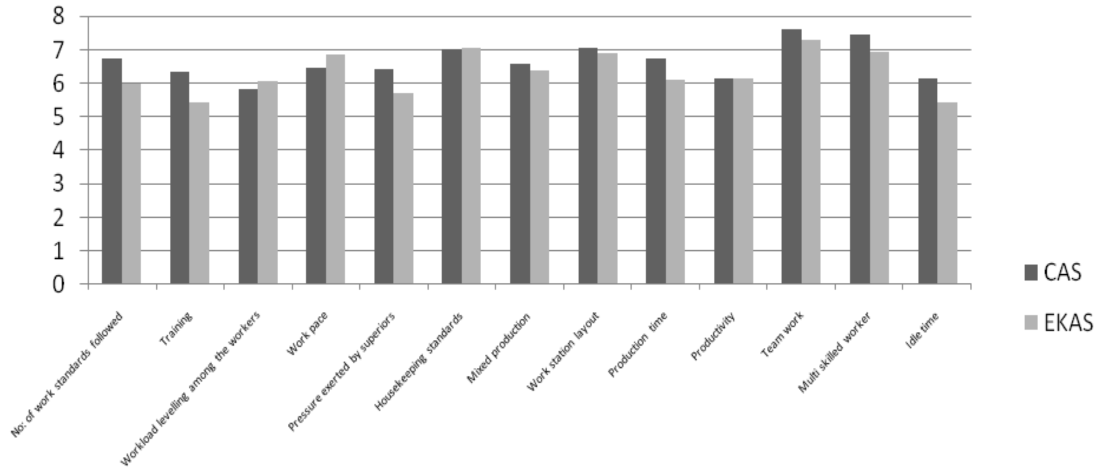
(i) The order in which the operations and activities of the work should follow each other (i.e. operation sequence);
(ii) How big the various batch should be? (i.e. batch size and balancing);
(iii) How to motivate the worker by giving incentives like task work?
(iv) How instructions should be given and received correctly to reduce the misunderstandings?

Table 4 Workers perception on working conditions (Work organization factor)

	CAS			EKAS		
Questions	**Mean**	**Standard deviation**	**Co-efficient of Variance**	**Mean**	**Standard deviation**	**Co-efficient of Variance**
Number of work standards	6.714	2.225	33.144	5.972	2.229	37.329
Training	6.321	2.073	32.804	5.432	2.363	43.505
Workload levelling among the workers	5.837	1.980	32.612	6.071	1.907	32.679
Work pace	6.464	2.442	37.771	6.837	1.878	27.471
Pressure exerted by superiors	6.428	1.619	25.199	5.702	1.955	34.299
Housekeeping standards	7.000	1.632	23.328	7.054	1.999	28.341
Mixed production	6.571	1.345	20.470	6.378	1.890	29.643
Work station layout	7.035	1.710	24.306	6.891	2.078	30.162
Productive time	6.750	1.756	26.013	6.108	1.696	27.768
Productivity	6.135	1.945	31.718	6.142	1.976	32.168
Team work	7.607	1.286	16.910	7.270	1.484	20.413
Multi skilled worker	7.428	1.793	24.144	6.945	1.562	22.495
Idle time	6.142	2.4602	40.051	5.432	1.893	34.856

4.3.1 Comparison Method for CAS and EKAS for Work organization factor

Figure 2 **Comparison between CAS and EKAS Work organization factor**



The comparison between CAS and EKAS Work organization factor is shown in figure 2. From the graph, it is clear that the number of standards to be followed in the EKAS is less than the CAS. The amount of work assigned to or expected from a worker in a specified time period is known as work load. It has been found that the level of workload has increased from (5.837-CAS) to (6.071-LIS). This means that the workers need to do some additional work in the given duration of time. The factors like training, pressure exerted by superior, workstation layout and the production time are reduced in EKAS as compared to CAS.

Also, it is seen that the house keeping standards have improved from (7.000-CAS) to (7.054-EKAS) by implementing the Ergonomic based kitting assembly system.

The production system as a whole has increased from (6.135-CAS) to (6.142-EKAS), which shows that the productivity of the industry has increased as a result of the Ergonomic based kitting assembly system. The survey concluded that by introducing EKAS, the level of work organization factors have increased.

5. Factor analysis for grouping factors

The earlier analysis shows that there was an improvement in the case industry after implementing EKAS. Hence, the case industry decided to group some important criteria from both work content and work organization factor for conducting future analysis with workers with some common factors. In order to group the criteria into factors, factor analysis is carried out at this stage.

The selected criteria are for this analysis is:

i. ease of assembly (C1)
ii. attention required by mixed production (C2)
iii. number of work standard (C3)
iv. housekeeping standard (C4)
v. health and safety of workers (C5) and
vi. Productivity of the assembly line(C6)

The management of the case industry distributed the questionnaires among ten assembly line in-charges to obtain opinion from their subordinates. They fixed the range between 0 and 10 in which 0 means low rating and 10 means high rating. The data collected from the survey is given in table 5.

The correlation coefficient matrixes, cross product matrix are calculated by incrementing the factor number in stages by 1.
STEP-1: The survey data are shown in table 5.

Table 5: Survey data

	Criteria					
Respondent	C1	C2	C3	C4	C5	C6
1	7	7	6	8	2	1
2	5	5	5	9	3	3
3	4	2	4	6	2	2
4	2	3	3	2	3	4
5	5	3	2	4	2	5
6	5	5	1	7	1	6
7	4	3	0	8	2	4
8	8	8	6	7	8	2
9	5	3	1	8	2	0
10	5	4	2	3	2	1

Step-2: The correlation coefficient between each pairs of the variables is shown in table 6.

Table 6: Correlation coefficient matrix

Criteria	C1	C2	C3	C4	C5	C6
C1	1	0.842	0.268	0.396	0.564	-0.54
C2	0.842	1	0.514	0.468	0.234	-0.204
C3	0.368	0.564	1	0.07	0.562	0.082
C4	0.596	0.568	0.04	1	0.39	0.189
C5	0.484	0.564	0.145	0.39	1	0.057
C6	-0.430	-0.104	0.087	0.287	0.056	1

Step-3: R_1 matrix is not a positive, hence variable C_6 is neglected as shown in table 7.

Table 7: Correlation coefficient matrix with reflections on the Criteria 6 [R_1'] along with column totals

Criteria	C1	C2	C3	C4	C5	C6
C1	1	0.842	0.168	0.496	0.484	0.43
C2	0.8742	1	0.424	0.568	0.474	0.204
C3	0.368	0.424	1	0.05	0.238	0.092
C4	0.596	0.568	0.05	1	0.29	0.196
C5	0.484	0.474	0.238	0.29	1	0.037
C6	0.43	0.204	0.092	0.196	0.037	1
Total [S_j]	4.43	2.700	1.923	3.94	2.523	1.959

Step-4: The first centroid factor is determined and also the sum (S_j) of each column of the matrix R_1' is shown in table 7.

Table 8: Calculations to determine loading values of factor 1 [$L_1(j)$]

j	S_j	UL_1 (j)= S_j l root (T)	L_1(j)
1	4.43	0.8356	0.8356

2	2.7	0.85876	0.85876
3	1.923	0.49633	0.49633
4	3.94	0.65439	0.65439
5	2.523	0.635	0.635
6	1.959	0.49306	-0.49306

Step-5: Increment the factor number by 1; i.e., f=1+1=2

Step-6: Next the second centroid factor is determined and the above procedure from step 2 to 5 is repeated cross product matrix, residual matrix and residual matrix with reflection on variables are calculated and furnished in table 9.

Table 9: Calculations to determine loading values on factor 2 [$L_2(j)$]

j	S_j	$UL_2(j) = S_j$ 1 root (T)	$L_2(j)$
1	0.689	0.24386	0.24386
2	0.585	0.20705	0.20705
3	1.692	0.59885	-0.59885
4	1.549	0.54824	-0.54824
5	1.268	0.44878	-0.44878
6	2.2	0.77865	-0.77865

Table 10: Calculations to determine loading values on factor 3 [$L_3(j)$]

j	S_j	$UL_3(j) = S_j$ 1 root (T)	$L_3(j)$
1	0.987	0.27081	0.26081
2	0.89	0.34789	-0.33789
3	1.796	0.65389	-0.64389
4	1.541	0.54504	-0.53504
5	1.299	0.4652	-0.4552
6	0.825	0.34118	-0.35118

The loading of all the three factors are shown in Table: 11.

Table 11: Complete three factor loading

Variable	Factor-1	Factor-2	Factor-3	Communality(h^2)
C1	$\boxed{0.735}$	0.35	0.36081	0.82572
C2	$\boxed{0.958}$	0.10705	-0.43789	0.89451
C3	0.49633	-0.49885	$\boxed{-0.543}$	1.01956
C4	$\boxed{0.754}$	-0.44824	-0.48504	1.07107
C5	$\boxed{0.535}$	-0.44878	-0.3552	0.81184
C6	-0.59306	$\boxed{-0.665}$	-0.35118	0.97273
Eigen value	1.8	1.56923	1.26959	$\Sigma h^2 = 5.59543$
Proportion of total variance	0.46	0.26	0.21	
Proportion of common variance	0.49	0.28	0.23	

Assign each variable to the factor with which it has maximum absolute loading as shown in table 12.

Table 12: Assignment of variables to factors

Factor number	Name of factor	variable	Description
1	Ergonomic factor	C1	Ease of assembly
		C2	Attention required by mixed production
		C4	Housekeeping standard
		C5	Health and safety of workers
2	Management factor	C6	Productivity of the assembly line
3	Time factor	C3	Number of work standard

From the factor analysis it is clear that the proportion of total variance of factor 1 is 0.46 factor 2 is 0.26 and factor 3 is 0.21. Since, all these factors are significant, they are retained for future analysis. So, in future while conducting a detailed study about the improvement on occupational safety, health and comfort level of workers, it is sufficient to get opinion of the workers on these three factors.

7. Conclusion

This study was based on various sources of evidence, such as interviews, questionnaires and direct observations made in an automobile industry. This paper dealt with a study on the impact of ergonomic based kitting assembly system on occupational safety and health of workers in an automobile industry's assembly line. The result of this study gives a clear picture to the workers on their improved working conditions after implementing EKAS. This analysis also increased the morale of the workers. Questionnaires were prepared based on two factors like work content and work organisation. The result shows that a significant increase in overall working condition of the industry which in turn led to the increase in the productivity. In the last stage, factor analysis is conducted to group the important criteria from work content and work organisation category in to important factors. So, in future while conducting a detailed study about the improvement on ergonomic level of workers, it is sufficient to get opinion of the workers on those three factors. On the whole, it was concluded that the Ergonomic based kitting assembly system was more convenient and productive than the conventional assembly system. Also the result of factor analysis show that the factors like ergonomic factor, management factor and time factor can be considered while conducting a detailed study about improvement in the ergonomic level of workers in future.

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