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Design and implementation of low cost automation system in heavy vehicle brakes assembly line

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Abstract: The brake drum assembly is an essential component in the automobiles. With increasing demand for heavy-duty automobiles, like trucks and buses, there is an increasing demand for these components. With a typical assembly rate of about 400 units a day using manual assembly tools, there is enormous pressure on the operator, prohibiting the company from enhancing their production rates to meet the market demand with existing resources. Keeping in mind the volatility of the market, it is preferred to resort to low cost automation, a technology that creates some degree of automation around the existing resources, using mostly standard components available in the market with very low investment. The method reported here presents such a low cost automation solution. It has been implemented in the real production line and its effectiveness has been proved in terms of planned objectives of increased productivity and reduced operator fatigue.

Keywords: low cost automation; productivity need analysis; PNA; heavy vehicle brake assembly; operator fatigue; productivity improvement.

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1 Introduction

The current manufacturing scenario has posed several challenges in design, operation and assembly of manufacturing systems. Increased productivity and reduced operator fatigue are among the most important issues prevailing in manufacturing industries. These issues are more common in the automotive industry, especially in heavy-duty assembly lines like the brake assembly. The performance of these assembly lines still remains unpredictable, in spite of considerable research on productivity improvement.

The assembly of heavy vehicle brake is a difficult task for the operators working in the assembly line, primarily due to its heavy weight. The existing system in our study has seven operators assembling about 395 heavy vehicle brake assemblies per day using manual tools. The company wanted to enhance the capacity to meet the market demands with most of the existing resources and without increasing operator fatigue. This has led us to develop a new method of assembly process automation.

Many attempts on improving the productivity and quality based on ergonomics have been reported in the literature. Eklund (1995) conducted studies on passenger car assembly station and found that ergonomic problems caused poor workmanship, leading to low productivity. According to studies by Keyserling et al. (1993), working posture is determined by the interaction of many factors in the work place. Lim and Hoffmann (1997) found in an experiment on assembly operations that improved layout of the work place increased productivity of the workers through more economical use of hand movements. Micheletti (1998) described some advanced aspect of assembly system in FIAT plant, which helped in reducing worker fatigue and improving productivity. Lye and Boey (1994) in their research described about development of low cost automated machine for winding filament for composite compounds. Alexander (1990) and Potluri and Atkinson (2003) introduced an automated assembly system to solve similar problems mentioned above. Edmondson and Redford (2001) presented a methodology for component classification that identifies non-value adding component handling activities. Lee (1990) explained the changes needed in manufacturing methods and technologies to focus on improving productivity by assembly automation in manufacturing organisations. Khanzode and Maiti (2007) used cluster analysis and path modelling to control the melting process of a grey iron foundry by establishing relationship between process and quality variables to develop an improved quality control scheme.

Heilala and Voho (1997) have described that the productivity of a manual assembly system can be increased with better ergonomics. A manual assembly workstation can easily be modified in several ways by the operator to obtain a personal optimum ergonomic environment. Yeow and Sen (2006) studied manual insertion type of assembly and suggested some best ergonomic methods and interventions, which can be replicated to solve similar problems. Reid (2006) has presented the framework for improving the productivity of product mainly based on effective and continual implementation of process improvements in assembly operations. Kanthi et al. (2006) have reviewed and summarised manufacturing systems productivity measurement and improvement based on performance metrics in assembly. Zailani et al. (2007) attempted to examine productivity performance of different manufacturing firms using six identified quality improvement related variables. The study also investigated the moderating role of the level of automation between productivity and quality. Bertolini (2007) has done research on human reliability in industrial plants and given some indications for work improvement.

This paper presents the design, development and implementation of a low cost assembly automation system for use in a heavy vehicle brake manufacturing industry using the process improvement strategy. Keeping in mind the volatility of the market, it is preferred to resort to low cost automation (Boothroyd, 1992; Grover, 1980), a technology that creates some degree of automation around the existing resources, using mostly standard components available in the market with very low investment. Since automation is tailored around the existing machines and people, the changes are gradual, smooth and very cost effective. The hardware components are flexible, reusable and adaptable to changes in product design and market conditions. The remaining paper is organised as follows. Section 2 provides an introduction to the brake assembly automation process, Section 3 illustrates the factors considered during the development of assembly automation and Section 4 presents the results and discussions.

2 The brake assembly automation process

Figure 1 shows the various components of the heavy vehicle brake shoe assembly. The brake assembly process is carried out in nine stages. In the first stage, the brake lining pad is riveted to the metallic brake shoe. In the second stage, bearing bushes are pressed into the torque plate. Spring pins are pressed into the brake shoes in the third stage. In the fourth stage – the main assembly stage – the torque plate and brake shoes are assembled together. During this stage, two brake shoes are placed on a fixture provided to position the shoes and the torque plate is placed in between the shoes. Later, two fulcrum pins are inserted in the torque plate nest. The tension springs are assembled by connecting the two shoes and the cam rollers are placed in respective locations. The assembly is then removed from the fixture and revolved through 180°. In the fifth stage, the brake shoes are expanded and the camshaft is pressed inside the cam bore of the torque plate. Later, the brake shoes are released. In the sixth stage, it is moved for mounting bracket assembly on the torque plate. Then the assembly is moved for inspection in the seventh stage. During inspection, gauging pins are used to check some of the critical dimensions and electronic sensors are used to check any missing parts. In the eighth stage, cardboard sleeve is assembled over the camshaft to protect from any damage during handling and transportation. In the final stage, the whole assembly is packed with carton sheets, kept in a wooden box and then moved to the warehouse.

The plant was capable of producing 395 units per day when the brake assembly was carried out manually. However, due to increase in the demand for automobiles in the market, it became necessary to produce more brake assemblies. The current procedure for manufacturing the automobile brakes could not meet the increasing market demand. Increase in production rate added more stress on the assembly operators. In order to reduce the operator stress and increase productivity, it was proposed to resort to some amount of automation. Consequently, time study was carried out and the results of time study, as shown in Table 1, revealed that the existing assembly line used more cycle time during brake shoe assembly stage compared to other stages of assembly. In view of this, it was proposed to implement a low cost automation system to reduce the cycle time required for brake shoe assembly.

Figure 1 Brake shoe assembly

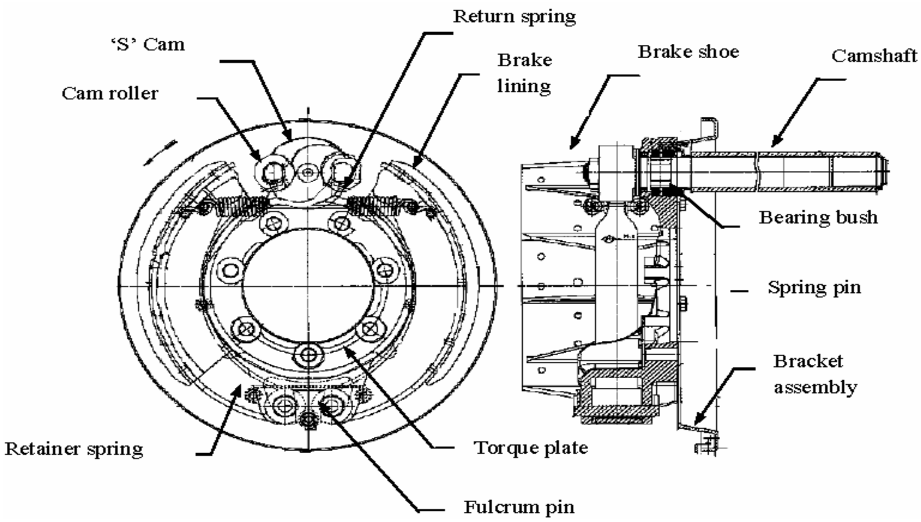


Table 1 Average cycle times of existing assembly line for heavy vehicle brakes assembly

Assembly stages		*Cycle time (seconds)*					
		Trial 1	*Trial 2*	*Trial 3*	*Trial 4*	*Trial 5*	*Average*
S1	Brake lining riveting	40	38	42	41	39	40.0
S2	Torque plate sub-assembly	36	35	35	37	36	35.8
S3	Spring pin pressing	28	30	27	29	30	28.8
S4	Brake shoe assembly	*71*	*73*	*72*	*71*	*73*	*72.0*
S5	Camshaft assembly	25	24	25	24	24	24.4
S6	Chamber bracket assembly	18	16	17	18	16	17.0
S7	Inspection	20	22	21	20	21	20.8
S8	Carton sleeve assembly	15	15	16	15	16	15.4
S9	Packing	20	21	21	20	20	20.4
Total time		*273*	*274*	*276*	*275*	*275*	*274.6*

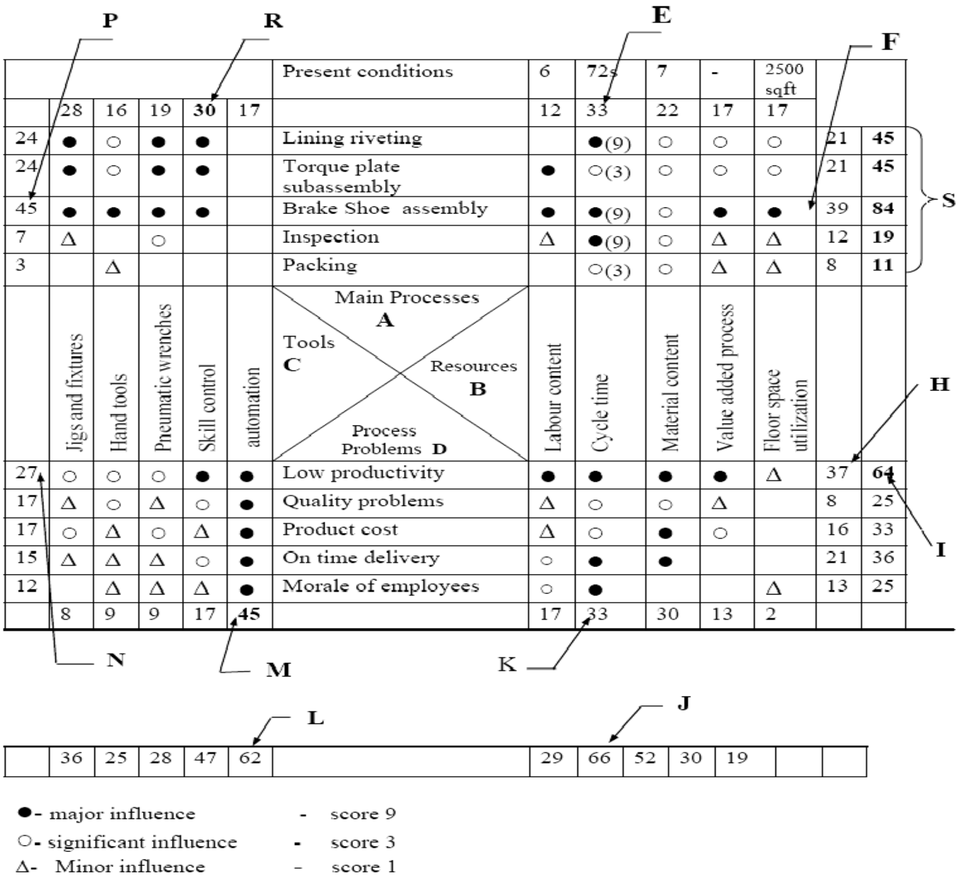
3 Methodology for assembly automation

The proposed methodology for assembly automation consists of three steps. The first step is to perform a productivity need analysis (PNA) to get an overview of the current manufacturing conditions, identify the key productivity measures for the assembly line and to form the basis for a detailed study of production efficiency. The output from the PNA (Colin and Paul, 2006) is a numerical score that identifies the vital delay at each stage. The second step is to develop a new assembly method for the process, which is a bottleneck. The final step is implementation of the proposed method for mass production.

3.1 Productivity need analysis

The PNA is similar to the quality function deployment (QFD) approach for introduction of new process. QFD is a structured process to identify potential areas for improvement (Zairi, 1993). It uses a house of quality matrix to derive relationship between key parameters. The intended purpose of the matrix was to identify where productivity interventions would be best directed to derive the greatest benefit for the company. The PNA matrix enables the strength of the correlation between manufacturing problems and tools/techniques to be quantified.

Figure 2 PNA matrix



The PNA matrix is developed considering the processes of brake shoe assembly, the resources and tools available in the industry and potential problems faced during assembly. The scores are assigned on the basis of type of relationship existing between various elements, i.e., strong relationship (nine points), medium relationship (three points), and weak relationship (one point). The PNA matrix with various relationship and their scores are presented in Figure 2.

- Process (A): The key processes within the production facility are defined and each of them had independent supervision. In this case, the key processes are brake shoe assembly or torque plate sub-assembly.
- Resources (B): These are the resources available with the company for the current level of production.
- Tools (C): The tools, such as hand tools and powered tools are identified from the assembly cell.
- Process problems (D) are the most important part of the matrix and require the most attention. For the optimum production efficiency to be obtained, it is essential that the unique problems of the company need to be identified with accuracy. The potential problems are established by conducting a workshop for employees and getting feedback from them.

The first relationship is between the process (A) and the resources (B). The second relationship is between the resources (B) and the process problems (D). The third relationship is that between the process problems (D) and the tools (C). It is observed from the matrix that a strong correlation exists between D and C, since this governs the effectiveness of the whole intervention. The fourth relationship is between the tools (C) and the main processes (A).

The matrix is completed in a clockwise manner, starting at the main processes and identifying relationships between the various elements. The scores in the matrix are assigned based on the type of relationship and added together to obtain the overall score. For instance, the score for relation between main processes and cycle time is obtained by adding 9 + 3 + 9 + 9 + 3 = 33 as shown in Figure 2.

The significance of each of the prime interactions is:

E relation between main process and resources

F process with the highest interaction with the main processes

S process having the highest interaction between both tools and resources

H process characteristic interaction with the resources and problems

I problem with highest interaction with tools and resources

J resource with the highest interaction with the process problems

K resource with the most relevance to the process and process problems

L improvement tool that has the highest reaction to processes and process problems

M tool with highest relevance to process problems

N shows the low productivity problem most aligned to the tools

P process that most interact with the tools

R shows the tools with the highest interaction with the current processes.

The relationships and the scores for processes and process problems are presented in Figure 3. The scores S (shown in Figure 2) represent the relation between processes and resources and the scores T (shown in Figure 3), which represent relation between process and process problems, are added to identify the key process to be intervened. The total scores obtained by adding S and T are presented in Table 2. The overall outcome of the PNA process suggests that first intervention should take place in the brake assembly stage since it has the highest score (117).

Figure 3 Correlation matrix of process and process problems

Processes	**Process problems**	Low productivity	Quality problems	Product cost	On time delivery	Morale of employees	T
		23	9	9	19	19	
Brake lining riveting		○	Δ	Δ	○	○	**11**
Torque plate sub-assembly		Δ	Δ	Δ	○	○	**9**
Brake shoe assembly		●	○	●	●	●	**33**
Inspection		●	○	○	○	○	**21**
Packaging		Δ	Δ	Δ	Δ	Δ	**5**

Table 2 Identification of the key process to be intervened

Process	*Scores*		
	S	*T*	*S + T*
Brake lining riveting	45	11	56
Torque plate sub-assembly	45	9	54
Brake shoe assembly	*84*	*33*	*117*
Inspection	19	21	38
Packaging	11	5	15

3.2 Proposed assembly methodology

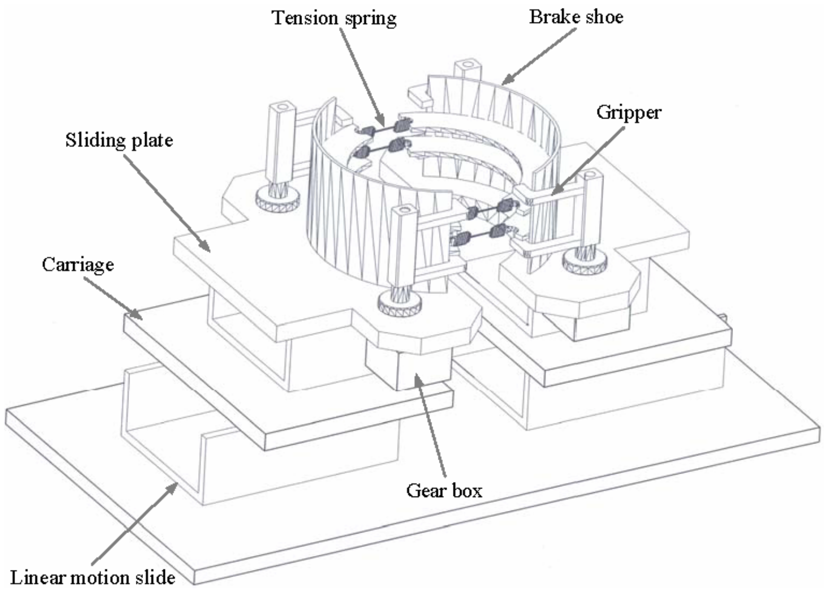
Based on the time study results, it is identified that assembly operations such as brake shoe location, expanding the retainer springs and camshaft pressing are found to be more stressful and time consuming tasks.

3.2.1 Design of brake assembly station

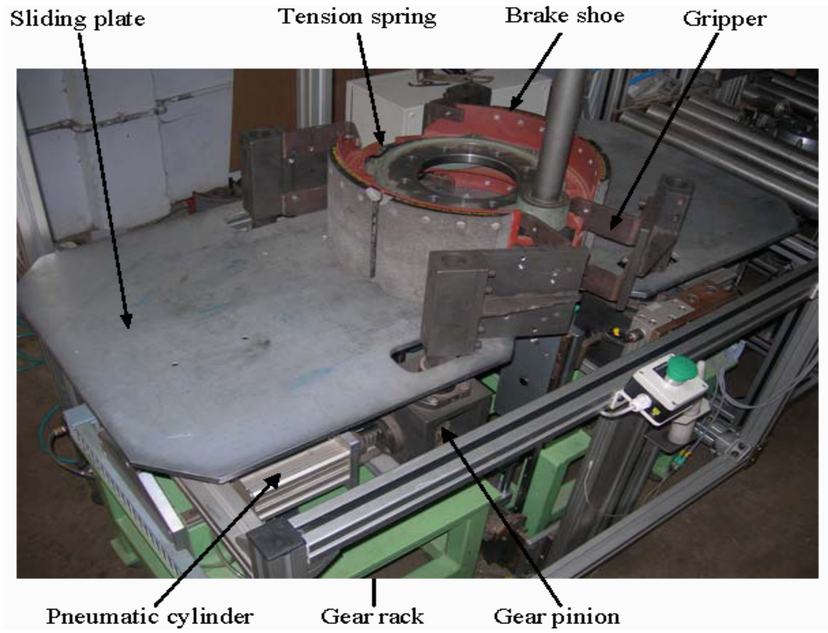
A modular brake assembly station has been designed, developed and implemented in the brake assembly line. The assembly station is designed in such a way as to facilitate easy/rapid loading and unloading of assembly components. The direct clamping pressure to support the work piece is selected appropriately so that the work piece is not distorted (Frank and John, 1962). The safety requirements for operators and parts are ensured in the design. The provision for vulnerable parts such as pneumatic couplers are designed in such a way that they can be removed and replaced quickly without disturbing the whole set-up.

3.2.2 Brake shoe clamping mechanism

Figure 4 Brake shoe assembly station (a) schematic representation of brake assembly (b) pictorial view of brake assembly station (see online version for colours)



(a)



(b)

The schematic representation of the brake assembly with various parts is shown in Figure 4(a). The assembly station consists of two assembly plates, mounted on a carriage, which travels on a linear motion slide. The brake shoe clamping mechanism consists of a pneumatic cylinder and rack and pinion. The pneumatic cylinder actuates the rack, which in turn swivels the grippers through a pinion gear (Merritt, 1962). The brake shoes kept on the assembly plate are gripped with the help of grippers.

3.2.3 Brake shoe expanding mechanism

The brake shoes are stretched out against the spring stiffness using fluid power as shown in Figure 4(b). A pneumatic cylinder employed on each side of the linear motion slide will stretch out the brake shoes against a set of three tension springs. To perform the assembly process the brake shoes need to be stretched apart by 120 mm to accommodate the torque plate, fulcrum pins, cam shaft and cam rollers.

4 Results and discussions

The key intention behind this research work is to enhance productivity of the assembly line with most of the existing resources, both man and machine, while keeping the human stress at lowest levels. As a first step, time study is carried out to find out the stage-wise time requirement during brake assembly. Table 1 show the detailed time break-up required for completing each stage in the brake assembly process for five assembly trials. As seen in the table, the average total cycle time for the entire brake assembly is 274.6 seconds, out of which the brake shoe assembly stage contributes about 72 seconds. Table 2 illustrates the results of PNA. It can be seen in the table that the break shoe assembly process has scored maximum, i.e., 117. Hence, the brake shoe assembly stage is clearly the bottleneck to be taken care of to enhance productivity. In order to handle this bottleneck, a low cost brake shoe assembly automation system has been proposed, designed, developed and successfully implemented in the brake assembly line by replacing the existing system.

The proposed assembly sequence consists of eleven processes. The main assembly consists of placing the two brake shoes on the assembly plate (P1). Three tension springs are assembled, (P2) and (P3), by connecting the two shoes and the brake assembly station is switched on to grip the brake shoes and stretch brake shoes apart against springs (P4). At this condition, the torque plate is assembled (P5) in between the shoes. The fulcrum pins (P6) and cam rollers (P7) are placed in the respective location and the camshaft is pressed (P8) and (P9) inside the cam bore of the torque plate. Now, the equipment is switched off to release (P10) the stretched brake shoes. This process makes all components in the assembly to take its respective positions. Then the assembly is moved for inspection (P11). Though the layout of the previous assembly line and existing assembly line for the assembly of heavy vehicle brakes remains same, the main brake shoe assembly stage has been automated.

Table 3 shows the detailed time break-up for the brake shoe assembly using the existing and proposed systems. It clearly indicates that the time for brake shoe assembly is brought down to 58 seconds from 72 seconds, saving 14 seconds on each assembly. Table 4 shows the results of time study conducted on the complete existing and proposed assembly lines. The table clearly indicates that the average total assembly time using the proposed system has come down to 260.6 seconds compared to 274.6 seconds using the existing system.

Table 3 Comparison of cycle time of existing and proposed brake shoe assembly stages

S. no.	*Assembly process*	*Cycle time (seconds)*	
		Existing	*Proposed*
1	Pick and position the two brake shoes (P1)	5	5
2	Pick and assemble two retainer springs (P2)	7	6
3	Pick and assemble one return spring (P3)	3	3
4	Clamp brake shoes and expand the springs (P4)	15	11
5	Pick and locate torque plate into shoes (P5)	9	7
6	Insert the fulcrum pins into the nest (P6)	6	5
7	Insert the cam rollers into the cam nest (P7)	5	3
8	Insert camshaft into the cavity (P8)	4	7
9	Locate the torque plate and press camshaft (P9)	9	3
10	Collapse assembly by releasing clamp (P10)	4	3
11	Move to inspection (P11)	5	5
Total		*72*	*58*

Table 4 Average cycle times at different stages of existing and proposed assembly lines

Assembly stages		*Cycle time (seconds)*						
		Trial 1	*Trial 2*	*Trial 3*	*Trial 4*	*Trial 5*	*Average (proposed)*	*Average (existing)*
S1	Brake lining riveting	40	38	42	41	39	40.0	40.0
S2	Torque plate sub-assembly	36	35	35	37	36	35.5	35.8
S3	Spring pin pressing	28	30	27	29	30	28.8	28.8
S4	Brake shoe assembly	*57*	*59*	*57*	*58*	*59*	*58.0*	*72.0*
S5	Camshaft assembly	25	24	25	24	24	24.4	24.4
S6	Chamber bracket assembly	18	16	17	18	16	17.0	17.0
S7	Inspection	20	22	21	20	21	20.8	20.8
S8	Carton sleeve assembly	15	15	16	15	16	15.4	15.4
S9	Packing	20	21	21	20	20	20.4	20.4
Total time		*258*	*260*	*261*	*260*	*261*	*260.6*	*274.6*

The graph in Figure 5 illustrates the variation of cycle time during different stages of brake shoe assembly, while that in Figure 6 illustrates the variation of cycle time during different stages of entire brake assembly.

Figure 5 Comparison of cycle times during brake shoe assembly (see online version for colours)

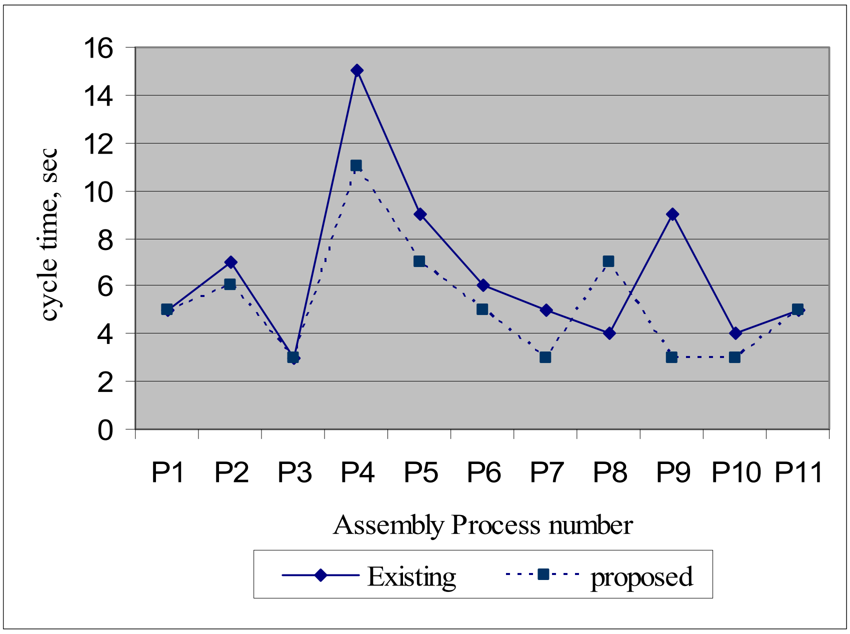
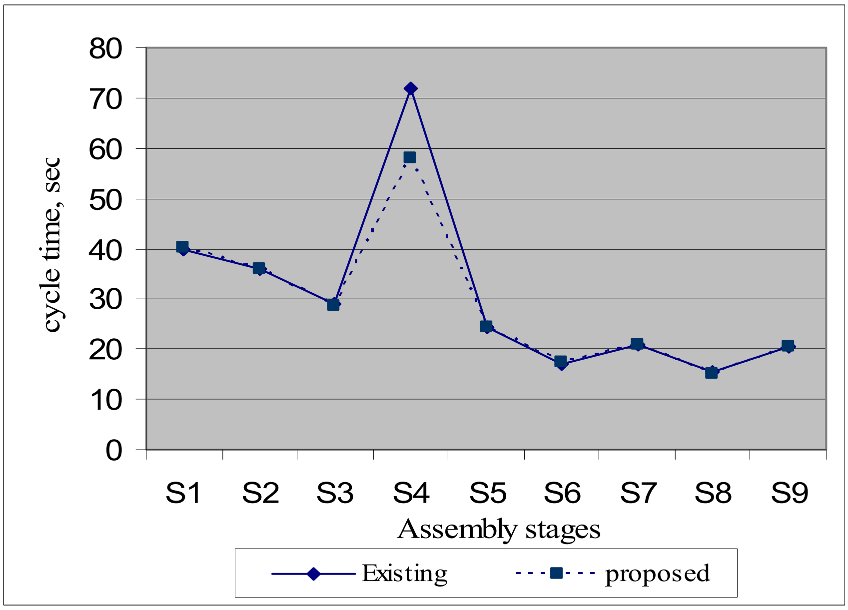


Figure 6 Comparison of overall cycle time during brake assembly (see online version for colours)



In view of the discussions presented above, it may be concluded that the proposed system offers the following advantages:

1 Increased productivity – with the proposed system, the plant output was increased to 497 units of brake assemblies per day. Thus, an overall productivity improvement of about 25.82% is achieved.

2 Cost effectiveness – the automated system is built mostly around existing resources and modest additional resources. Hence, additional investment in capacity enhancement is less. With about 25.82% increase in productivity, the returns will be high enough to break even the automation cost within short period.

3 Meets market demands – it helps in meeting the increased market demands and delivery of parts on time.

4 Reduced labour fatigue – the proposed system reduces manual handling of brake assembly, which helps in reducing the labour fatigue and drudgery of work.

5 Conclusions

The proposed system is successfully utilised in producing automobile brakes and it has increased productivity and reduced operator fatigue. The methodology for the assembly process is improved when compared with an existing assembly automation process. In this assembly system, the operator fatigue is minimised to perform the assembly operations, such as holding and stretching of brake shoes. The cycle time study shows a considerable amount of reduction in bottleneck operation such as brake shoe assembly. The cost involved for implementing the proposed assembly system is significantly low and makes it viable for industry. These novel features proposed in the present work can be extended to other assembly operations such as torque plate assembly, brake liner assembly and wheel hub assembly and other assembly stations in automobile industry.

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