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Design improvements by using the design for assembly (dfa) method in elevator production

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Design Improvements by Using the Design for Assembly (DFA) Method in Elevator Production

Highlights

- *With the redesigned assembly process, the number of parts was reduced by 43.88%.*
- *50.58% improvement was made in design efficiency with new designs.*
- *It sets an example for small and medium-sized businesses that aim to grow.*
- *The benefits to be gained by redesigning assembly processes are shown.*

Graphical Abstract

In this study, it was studied in an elevator manufacturing company and the design efficiency values of the products and the improvements in production times were examined by applying the Design for Assembly (DfA) principles. This application aims to guide the growth of target enterprises with the DfA applications and contribute to the literature with an exemplary application.

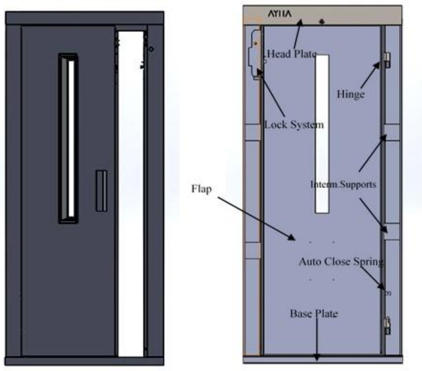

Figure. Semi-Automatic Door CAD Drawing Display

Aim

The purpose of this research is to show the benefits to be obtained by redesigning production processes for small and medium-sized enterprises, which aim to grow but cannot progress due to traditional production understanding.

Design & Methodology

In this study, the production of semi-automatic door frames from elevator parts was investigated. First of all, a time study was applied to analyze the current process and the design efficiency value was calculated in the B&D DfA method. Then, three assembly processes were determined as the front plate, intermediate supports and head plate as the priority improvements. Finally, design improvements were made in these process steps and the design efficiency value of the door frame was calculated. The obtained design efficiency values were compared and the results were discussed.

Originality

The most important problem faced by small and medium-sized enterprises that want to grow is a product design and production organization. In this study, a way to solve the problems of these enterprises is shown.

Findings

According to the number of parts in the process groups; It has been revealed that there is 95% improvement in the front sheet, 100% improvement in intermediate supports and 64% improvement in head sheet preparation. In addition, according to the time spent in the transaction groups; Improvement (efficiency) was achieved by 79.8% in front sheet, 49.1% in spiraling, 100% in intermediate supports, 74% in head sheet preparation and 16.4% in handling operations.

Conclusion

In the improvement designs made within research scope, the TE value increased from 8.5% to 12.8%. Trial production of the improved design proposals presented in the research was validated.

Declaration of Ethical Standards

The author(s) of this article declares that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Design Improvements by Using the Design for Assembly (DFA) Method in Elevator Production

Araştırma Makalesi / Research Article

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ABSTRACT

The purpose of this research is to show the benefits to be obtained by redesigning production processes for small and medium-sized enterprises, which aim to grow but cannot develop due to runaway production. In this study, an exemplary approach is presented using the principles of Design for Assembly (DFA) in an enterprise aiming to grow in the elevator industry. Within the scope of the research, the doorframe assembly process of the semi-automatic elevator door, which is the most produced in the elevator industry, was examined. According to this; Design improvement studies were carried out in the assembly processes of the side profiles, head plate, forehead plate, floor plate and their subparts used in the production of the case. In the design improvement, the B&D design efficiency measurement principles were used. As a result of the improvements; The semi-automatic door frame, which is 98 pieces in its current design, has been reduced to 55 pieces with the new design. With the reduction in the number of parts and design changes, the total assembly time was reduced by 33.8% in assembly time. As a result of the improvements, the Design Efficiency has been increased from 8.5% to 12.8%.

Keywords: Design for assembly; boothroyd - dewhurst method; elevator production.

1. INTRODUCTION

In today's world where product complexity is increasing, the importance of modern production methods is more prominent to increase production efficiency and produce high-quality products. To maintain their competitive power in current industry conditions, producers are required to apply production methods that can provide the highest quality within the life cycle with the minimum production cost they can achieve [1-2].

DFA is a method that solves the inefficiencies encountered in production by making design improvements. The DFA method predicts design improvements based on the concurrent engineering product development method. The main purpose of DFA is to quantify the problems of the design affecting production and to verify the increase in design efficiency as a result of design improvements [3].

Until the 1970s, no study was conducted to measure designs with numerical methods. The first study on this subject was developed by Hitachi company as Assembly Evaluation Method (AEM). This method was developed based on the "One Piece One Move" approach. In 1977, the Boothroyd - Dewhurst (B&D) Method was developed at the University of Massachusetts by G. Boothroyd and P. Dewhurst. Incentives have been given by the American Science Foundation to support businesses across the country to use the DFA method in the industry [3,4].

When the studies about DFA were searched in the literature, most sources were found with the keyword "DFMA (Design for Manufacturing and Assembly)". When the studies on DFMA in the elevator industry are examined; It was made by Imrak & Salman (2010) on the assembly of cabin doors, and by Imrak & Kocaman (2012) using the B&D Method in the production of double cabin elevators and Cabello Ulloa et al. (2018) for the assembly of elevator parts with the Lucas Hull method is seen as applications in the elevator industry [5-7]. Apart from these three application examples, there has been no application in the elevator industry in recent years.

When the studies on DFMA in other sectors are examined; Favi et al. (2016); They have applied the B&D DFA Method in the production of CNC machine tool holders [8]. Suresh et al. (2016), in a study they conducted in the automotive sector, provided design improvement by examining together Design for Assembly (DFA) and Design for Environment (DFE) approaches on a pulley system assembly in vehicles [9]. Gao et al. (2018) revealed the effect of the DFMA method on the development of the construction industry in Singapore [10]. Remirez et al. (2019), in the study on solar panels, developed a new design approach for long-lasting and large-size (Ll-Ls) products by combining them with DFA methods [11]. Ezpeleta et al. (2019) stated that DFA methods support designers in the design phase and this situation has a positive effect on production efficiency [12]. Gao et al. (2019) made an application that could set an example for applying the DFMA method in the construction industry [13]. Naga Malleswari et al. (2020) attempts to shorten the total installation time by using the B&D DFA Method in an enterprise that produces an electrical plug [14].

When the results were examined in the literature, it was determined that an average of 38% increase in productivity was achieved and the B&D Method was

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used more as a method of measuring design efficiency [14].

This study will contribute to the literature by presenting an application example of DFA, which is a method that can be used to improve product development times, which are seen to be limited in number and whose importance is increasing due to today's technological development speed. In addition, in sectors with complex products such as elevator production, the benefits of redesigning production processes for enterprises that aim to grow have been revealed.

2. METHOD

In the application where design improvement will be made with DFA principles, the B&D Method, which is seen to be used more than other methods in the literature, was used. The basis of the B&D Method is to determine the design efficiency of each station of the current production separately and accordingly, to reveal a new design called "improved design" in stations with low design efficiency value. For this purpose, the three basic principles of the B&D Method were examined on workstations with high design efficiency. These principles are [3]:

- Part/Process Destroy: Does the inspected part move with other parts?
- Part/Process Assembly: Is the inspected part made of a different material or insulated from the other parts prior to assembly?
- Part Repairable: Some essential parts must be seperated from all other parts already assembled. Otherwise, assembly or disassembly of other parts will be impossible.

The method tree of the research is given in Fig.1. Accordingly, the production processes of the examined design were firstly analyzed with the work and time study method, and then design improvement ideas were discussed with B&D principles.

Before starting the research, a Concurrent Engineering (CE) Team consisting of researchers, managers and engineers was formed in order to analyze the production correctly. Existing design and field analyzes were carried out by the team.

The elevator is a multi-part industrial product. According to the examinations of the CE Team; within the scope of the study, the frame design of the semi-automatic door from the elevator parts was determined for the application. A semi-automatic door elevator was preferred because it is the most productive model of the company. Side profiles, head plate, front plate, baseplate, and their lower parts and joining processes are discussed (Fig. 2).

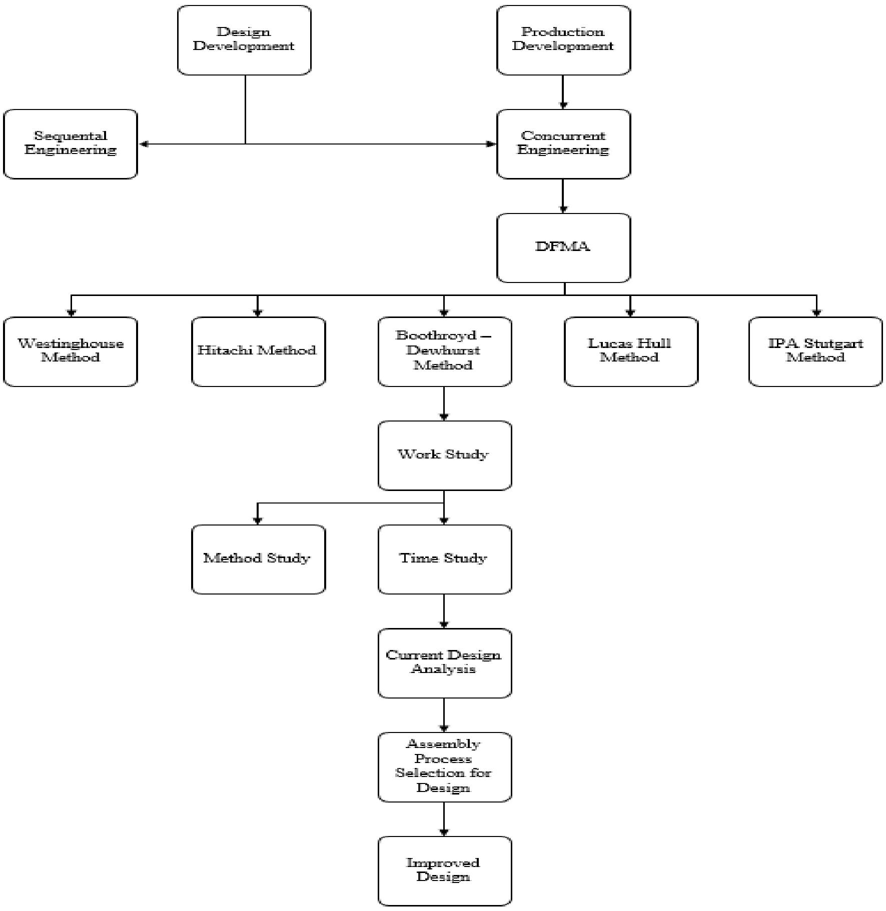


Figure 1. Method Tree

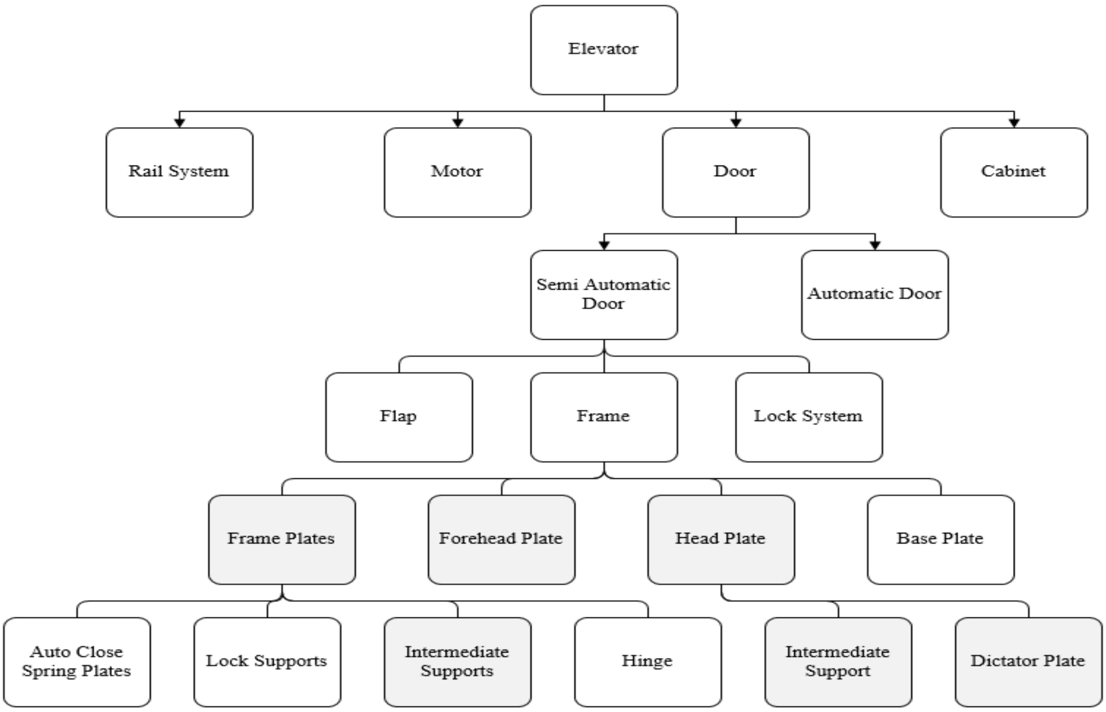
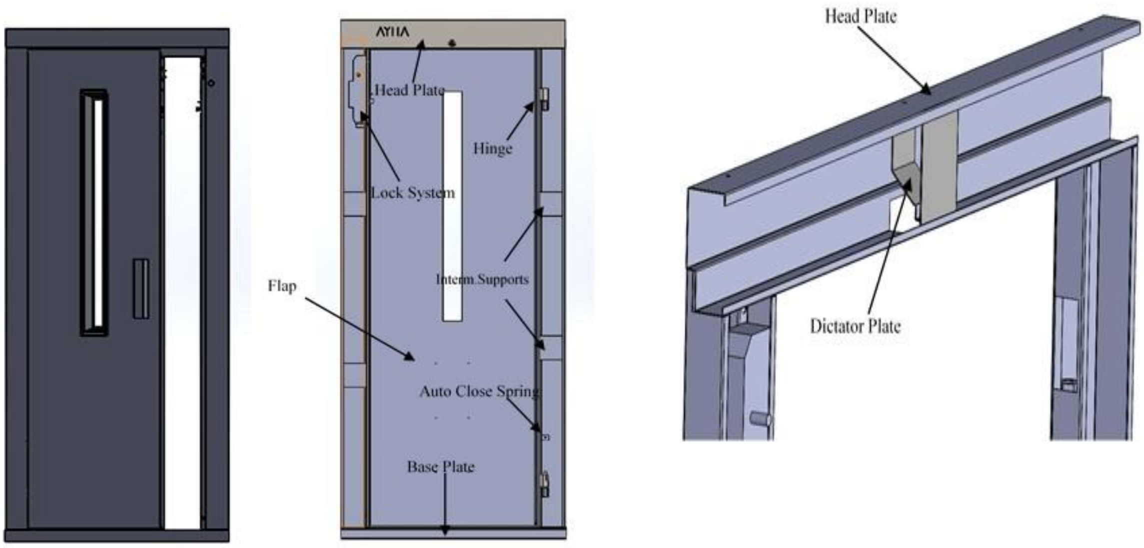


Figure 2. Product Tree

The parts of the semi-automatic door frame, whose design, manufacture and assembly method are examined, are shown in Fig. 3a. When using semi-automatic elevator doors in buildings, if the elevator cabin is not on the floor, the lock system that prevents the door from opening is called the dictator. The dictator plate, which supports the dictator to move freely on the head plate, is mounted by welding (Fig. 3b).

In order to collect data, approximately 130 hours of fieldwork were carried out for 26 weeks, with an average of three hours of observation at the production site and an average of two hours of office work, starting on September 25, 2019.



(a) (b)

Figure 3. (a) Semi-Automatic Door CAD Drawing Display, (b) Dictator Plate Display

A time study of the main semi-automatic door frame assembly processes was carried out in the enterprise. Observation sizes were calculated following the formula below with 95% confidence in the time study. According to the sample sizes obtained by Eg.(1), a time study was performed at the workstations and average labor times were determined.

$$N = \left[\frac{40\sqrt{n\sum x^2 - (\sum x)^2}}{\sum x}\right]^2 \quad (1)$$

N: Sample Size, n: Pilot Sample Size, x: Total Time

After firstly 5 pilot observations were made for each station, the required sample size was determined with 95% confidence by the above formula. A time study was conducted until the required number of observations was reached in work steps where 5 pilot observations were insufficient. The required sample size was provided by adding to the data obtained in the pilot time study. In order to measure the effectiveness of DFA studies, after the preliminary analysis of the first design, the duration and theoretical minimum numbers of all parts are determined and the Design Efficiency (DE) is calculated according to the B&D method.

$$\mathrm{DE} = \frac{a \times (Xmin)}{(t)} \quad (2)$$

In Eq. (2), Xmin is theoretically the minimum number of parts that should be in the design and cannot be eliminated, t is the total assembly time and the parameter a refers to the theoretical minimum assembly time of a part. The average theoretical assembly value in studies using the B&D method is 3 s [3, 6, 17].

3. RESULT AND DISCUSSION

3.1. Measuring Current Design Effectiveness

According to the B&D Method, it is necessary to measure the design effectiveness of the current situation before design improvement. For this, first of all, a time study was carried out at the workstations, and measurements were made according to the number of observations revealed with the formula specified in Eq.1. Average values of assembly times are given in Table 1. The minimum amount of pieces that can be applied in production has been determined as the theoretical minimum number of pieces with concurrent engineering studies and field observations.

In Table 1, the number of welds is considered a fastener because welding is preferred instead of other fasteners. It has a structure that occupies volume, weighs, and can be seen physically on the design.

Table 1. Current Design Number of Parts and Average Assembly Times

Process Group	Process Name	Current Piece Number	Teorical Minimum Piece Number	Assembly Time (s)
Preparation	Frame Sheet (hinge side)	1	1	38.8
Hinge	Hinge Welding (4 hinge pieces + 4 big welds)	8	8	66.9
Auto Close Spring	Auto Close Spring Welding (1 piece + 6 small welds)	7	1	25.1
Mid. Brackets	Mid. Brackets Welding (2 support brackets + 6 small welds)	8	0	33.2
Spiraling	Spiraling	-	-	20.3
Carrying	Carrying	-	-	10.4
Preparation	Frame Sheet (lock side)	1	1	39.0
Mid. Brackets	Mid. Brackets Welding (2 support brackets + 6 small welds)	8	0	35.0
Lock Support	Lock Support Welding (4 pieces + 4 small welds)	8	0	55.8
Spiraling	Spiraling	-	-	22.8
Carrying	Carrying	-	-	9.7
Head Plate Prep.	Head Plate Preparation	1	1	10.5
Head Plate Prep.	Dictator plate welding (8 welds)	10	0	54.8
Carrying	Carrying	-	-	8.6
Assembling	Head Plate Preparation	1	1	42.5
Assembling	Head Plate Welding (6 big welds)	12	4	51.8
Assembling	Base Plate Preparation	1	1	17.1
Assembling	Base Plate Welding (6 big welds)	12	4	69.3
Forehead Plate	Forehead Plate Preparation	-	-	31.9
Forehead Plate	Forehead Plate Welding (20 small welds)	21	0	92.1
Spiraling	Spiraling	-	-	80.8
Carrying	Carrying	-	-	30.9
	TOTAL	98	24	847.3

When the product was examined, it was seen that the total number of parts was 98 and the theoretical minimum number of parts was 24. The total production time is 847.3 hours. Accordingly, the design efficiency of the current state of the semi-automatic door frame design was calculated using Eq.(2). According to these data, B&D design efficiency:

$$\mathrm{DE} = \frac{3 \text{ x } 24}{847{,}3} = 0{,}085$$

As shown in Table 1, it is striking that the spiraling process, which has no added value on the product, and its durations are high. Spiraling is a process that is performed to eliminate the weld marks on the visible surfaces after welding due to aesthetic concerns and slows down the assembly of the product due to sensitive work. Among the joining processes, the assembly of the front plate is the labor with the highest time. With the preparation process, 124 s. takes time. When the current design's design efficiency (DE) was measured, 0.085 points were obtained. It will be compared to this score after design improvements.

3.2. Analysis

When the labor times are examined, the workmanship based on parts and main operations are grouped, combined, and listed. This ranking was made according to the priorities of detailed analysis and improvement studies (Table 2). Accordingly, priority was given to the "Assembly, Forehead Plate, Spiraling" processes, which are the process groups that take the most time, for improvement design.

Table 2. Labor Priorities According to Process Groups

Process Groups	Piece Number	Process Time (s)	Percentage
Assembly	25	180.7	21.3%
Forehead Plate	21	124	14.6%
Spiraling	0	123.9	14.6%
Preparation	2	77.8	9.2%
Mid. Brackets	16	68.2	8.0%
Hinge	8	66.9	7.9%
Head Plate Prep.	11	65.3	7.7%
Carrying	0	59.6	7.0%
Lock Support	8	55.8	6.6%
Auto Close Spring	7	25.1	3.0%
TOTAL	98	847.3	100%

In order to reveal the current situation, the following determinations were made as a result of the analysis of the time study data and video records of the process steps by the CE Team:

- As can be seen in the time studies, a total of 123.9 s spiraling process is performed to produce the frame. The spiraling process corresponds to 14.6% of the total time. One of the important findings is that eliminating or reducing the spiraling process should be considered in the improved design.
- As a result of the current situation studies, it was decided to determine the forehead plate assembly with 124 s of welding work as the priority improvement point. The forehead plate assembly has a share of 21.4% of the total assembly work (an improvement on the frontal plate has been evaluated together since it will affect the spiraling processes). It also consists of 21 pieces in total, including welds.
- The other finding is intermediate supports in the head plate and frame sheets (Fig. 3). It has been determined that these intermediate supports do not carry any load and are not exposed to a load horizontally. In addition, the welding of these intermediate supports is made by hand support from the bottom up (not suitable for gravity) and is more difficult than similar operations.
- When using semi-automatic elevator doors in buildings, if the elevator cabin is not on the floor, the lock system that prevents the door from opening is called the dictator (Fig. 4). The dictator sheet, which supports the dictator to move freely on the head sheet, is fixed by welding. The necessity of this part needs to be investigated.

According to these determinations, it was decided to improve the assemblies of the front sheet, intermediate supports and head sheet, which are the processes that take the most time in the production of semi-automatic elevator doors.

3.3. Improvements

The obtained priority parts were evaluated with the existing design and findings and the suggestions for improvement were examined. Subsequently, improvement designs were made in accordance with DFA principles. Three assembly processes to be improved were evaluated separately and the appropriate ones from part/process destroy, part/process assembly and part repairable principles were used in the design.

3.3.1. Improvement 1 (Forehead Plate)

The forehead plate is assembled with approximately 20 small welds (variable according to the operator operating). This part, which has the highest workmanship share in the frame assembly station, was designed as a tight fit under the "elimination principle" of the B&D Principles. Accordingly, a sliding design has been developed as shown in Fig. 4. In the pilot productions, it was observed that the sliding forehead plate would save labor, consumables, and parts, and it was decided to apply the new design.

(a) (b)

Figure 4. The Forehead Plate (a) New and Previous Design, (b) Sliding Assembly

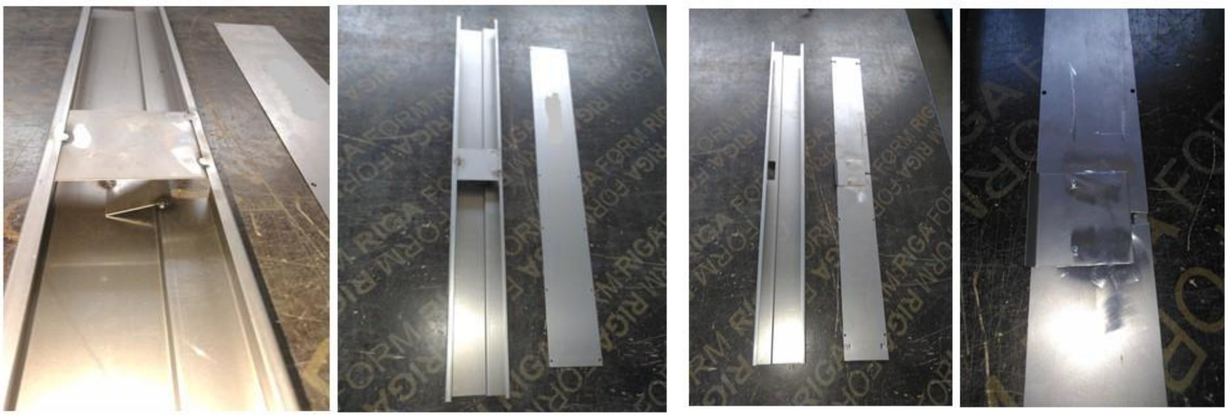
Figure 5. New and Previous Design of Side Plates

3.3.2. Improvement 2 (Intermediate Supports)

It has been determined by the investigations that the intermediate supports available in the right and left side profiles are traditionally used in the sector, they do not provide support for the part or increase the strength of the part under use conditions, because intermediate supports provide support to the part against horizontal force. The exposed loads in all conditions of assembly, transportation and use were examined in CE meetings. Because of the supports are not exposed to a horizontal load and the thickness of the side plates provides sufficient strength, it was decided to be removed from the design (Fig. 5). In accordance with the "elimination principle" of the B&D Method, 16 welding processes were eliminated by removing intermediate supports in the new design.

3.3.3. Improvement 3 (Head Plate)

When the preparatory processes on the head plate were examined, it was decided that the support plate could be removed. However, it has been taken into account that the dictator system can deform quickly if the support plate is removed. Under the "repairability principle" of the B&D Method, it was decided that it would be easier to assemble the dictator plate by riveting it to the forehead plate (Fig.6).



(a) (b)

Figure 6. Head Plate Design: (a) Previous, (b) New

The changes made to the design were implemented and pilot productions were made in the field. Operation times were observed in these pilot productions and improvements were verified with video records. As a result of the improvements made, significant amounts of savings have been achieved in operation times.

Improvement 1 (Forehead sheet): The initial state of the forehead sheet assembly took 180.8 s with the spiraling work. It has been observed that this period has decreased to approximately 25 s with the pilot production and video record. The number of pieces has been reduced from 21 pieces (with the welds) to 1 piece.

Improvement 2 (Interm. supports): By eliminating the intermediate supports existing in the previous design, 68.2 s of labor was saved. Including the welds, 21 pieces in total were eliminated.

Improvement 3 (Head sheet): In the previous design with the carrying process 73.9 s of workmanship, was reduced to approximately 17 s by the dictator support riveted to the forehead plate in the new design. With this design change, 56.9 s of saving was achieved. Also, the design which was 11 pieces together with welds was reduced to 4 pieces.

In the new design, the number of parts has been reduced to 55. The theoretical minimum number of pieces was observed to be 24. The total assembly time was 561.2 seconds. According to these data, B&D design effectiveness was calculated as follows:

$$\mathrm{DE} = \frac{3 \text{ x } 24}{561.2} = 0.128$$

In the design improvements made within the scope of the research; the DE value increased from 8.5% to 12.8%. The DE value obtained in this study is similar to the studies of Adam & Shukor (2018), which is one of the applications made using the B&D design efficiency measurement method in the literature.

Table 3. Improvement Rates by Process Group

Process Groups	Previous Design Piece Number	New Design Piece Number	Reduce of Piece Number	Previous Process Time (s)	New Process Time (s)	Productivity Increase
Assembly	25	25	0%	180.7	180.7	0%
Forehead Plate	21	1	95%	124	25	79.8%
Spiraling	0	0	0%	123.9	63.1	49.1%
Preparation	2	2	0%	77.8	77.8	0%
Mid. Brackets	16	0	100%	68.2	0	100%
Hinge	8	8	0%	66.9	66.9	0%
Head Plate Prep.	11	4	64%	65.3	17	74%
Lock Sup.	8	8	0%	55.8	55.8	0%
Carrying	0	0	0%	59.6	49.8	16.4%
Auto Close Spring	7	7	0%	25.1	25.1	0%
TOTAL	98	55	43.88%	847.3	561.2	33.77%

As seen in Table 3, the discussed improvement suggestions were confirmed by observing again on the trial production. Based on the process group, it has been demonstrated that 95% improvement was achieved in the forehead plate, 100% in intermediate supports, and 64% in head plate preparation. Also, examining the time improvements in the process groups, improvement (efficiency) was achieved at 79.8% in the forehead plate, 49.1% in the spiraling, 100% in the intermediate supports, 74% in the head plate preparation, and 16.4% in the carrying operations.

4. CONCLUSION

The purpose of this research is to show the benefits to be obtained by redesigning production processes for small and medium-sized enterprises, which aim to grow but cannot progress due to traditional production understanding. For this reason, in this research, an exemplary model was created in the elevator industry, which has many assembly processes and has a high international competitive power.

When other studies in the literature applied in the elevator industry are examined, Imrak & Salman (2010), in their study on the assembly of cabin doors in the elevator industry, used the principles of the B&D Method to save approximately 20% - 30% in assembly costs and 10% - 15% in production costs. Imrak & Kocaman (2012), achieved an improvement of 52% in the number of parts, 49% in assembly time, and 207% in design efficiency by applying the B&D method in the production of double-cabin elevators. Cabello Ulloa *et al.* (2018) achieved a 7.9% increase in design efficiency in their study [5-7]. When evaluated together with the results obtained from these studies, a result that increases production efficiency was obtained with 43.88% improvement in the number of parts, 33.77% in assembly time, and 50.58% in the design efficiency in this study.

Today, companies in the elevator industry prefer to continue with the traditional production approach instead of giving importance to R&D studies and developing innovative approaches in their production. Elevator manufacturers have to renew themselves in today's world, where technology is indispensable in our lives. Therefore, the financial burdens of the steps to be taken can be overcome by collaborating. The examination of the study from this point of view also reveals its contribution to the production sectors. Finally, during this research process, it has been seen that researchers who will work in the field of machine assembly and production can contribute to the industry in industrial production problems such as simplifying complex production and simplifying assembly processes.

Project time management can be made more disciplined by using CRM and PERT project management methods together with DFMA and Concurrent Engineering projects [15]. In future studies, continuous improvement can be achieved with digital human modeling [18] for the production processes of the designs, developed with the DFMA method.

DECLARATION OF ETHICAL STANDARDS

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

AUTHORS' CONTRIBUTIONS

Mesut AYDINLI: Performed the research, analyse the results and wrote the manuscript.

Kadir ÖZKAYA: Performed the research, analyse the results and reviewed the manuscript.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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