AN AHP BASED PRIORITIZATION MODEL FOR RISK EVALUATION FACTORS IN THE AUTOMOTIVE INDUSTRY

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ABSTRACT

Due to product variety and modeling structure, the automotive manufacturing process requires state-of-the art production methods that cause a high complexity level in operations which assembly operators work in a mixed-assembly environment. To maintain a competitive advantage, companies should take a different approach that considers the methodologies which ensure excellence in operations. This study aims to identify and prioritize potential risk factors that cause errors and failures by applying the Analytic Hierarchy Process to improve the production quality in a manufacturing process of mixed model assembly lines in the automobile industry. Thus, numerous risk factors under three main categories including human-focused, design and process-driven are discussed in this work. The most important contribution of this study is the application of

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this methodology to find and rank the risk factors based on their importance in a world-leading automotive company in Turkey.

Keywords: automotive; assembly line; workstation; process complexity; AHP

1. Introduction

The automotive sector has become an area that offers a wide range of options to its customers. Automotive companies should adapt customer-oriented production systems to manufacture varieties of options that the customers demand. Companies need to meet short product life cycles, increased production volumes, innovative designs and total quality under cost constraints. As a result, the companies have to deal with a high level of complexity to sustain their competitive advantage (Personne et al., 2014).

Innovative, customer-focused companies that have an ability to make continuous improvement and process development will protect their position in the future and have a competitive advantage. For this purpose, companies should focus on the following factors:

- quality and reliability of the products,
- increase in product variety,
- appropriate production time and quantity regarding customer demand,
- high customer satisfaction level.

It is an inevitable fact that these factors make the company operations more complex which can result in various errors in assembly lines. Automotive assembly lines have mixed-model characteristics in general. Mixed-model assembly lines are considered an effective method to process different products and obtain product diversity on the same line. Today, assembly lines often include both manual and automatic assembly operations. Efficiency and effectiveness of the assembly lines dramatically increase with improvement of the lines with automation which result in a reduction in error rates. Mixed-model assembly lines include at least one of the characteristics below (Urrutia et al., 2014).

- Technically complex operations,
- Excess amount of parts, components and sub-assembly,
- High level of diversity,
- A large number of workstations within the line,
- Demand with high change values in the market.

The number of operations and different types of products in mixed-model assembly lines affect the process performance, line efficiency and quality aspects (Zhu et al., 2008). A higher number of operations, components, and sub-assembly have a positive impact on the complexity level of assembly lines. On the other hand, technically complex operations increase the likelihood of human error if the operation is performed manually. Complex operations lead to an increase in uncertainty in the process. Diversity is a factor which is driven by both market needs and stable demands. Therefore, a high level of diversity makes assembly lines more complex (Zeltzer et al.,2013). Businesses, facing demand with high changes in the market, can prefer differentiation of sub-assembly processes, workstations or operations. For this reason, it also has an effect on increasing the complexity level.

In order to deal with complexity in an assembly line, it is important to find out the risk factors that cause errors and failures. The human factor is one of the main sources of error in assembly lines (Mattsson et al., 2012). Operators make mistakes for various reasons such as forgetting, choosing the wrong material or equipment, not following instructions, and misinterpreting. For example, the major reason for choosing the wrong material or tool has a high connection with human attention. This attention requires more energy, so the body tries to remove energy-consuming behavior. This is called Passive Attention Mode. Operators, especially those who work in mixed-model assembly lines, should have an active attention mode in order to perform tasks as expected. Supportive systems are necessary for operators to make right choices or operation as a guidance during passive attention mode (Mattsson et al.,2012). The information presented to the operators should include instructions about both product and process. Operators should make some decisions if there is more than one option. In this case, the operator needs to know information about which part to assemble. Other instruction is important when unique variants are involved in order to point out how to assemble instead of what to assemble. Overall, the assembly instructions should also involve a decision and support process.

To analyze human errors thoroughly, workstations should be examined from the perspective of risk factors that cause complexity and become a pending problem in the assembly lines.

This study aims to identify and to prioritize risk factors on workstations in an assembly line of an automotive company. Within the scope of the study, a real life case study is conducted in a leading Turkish automotive company. This case study utilizing an Analytic Hierarchy Process (AHP) application on assembly lines is expected to be the main contribution of this paper as, to our knowledge, there is no application of AHP on assembly lines in the automotive sector.

The paper is organized as follows. Section 2 describes the proposed decision framework, identifying risk factors, clustering them, and prioritizing the factors. Section 3 shows the findings, the priorities of the risk factors. Conclusions and further suggestions are given in Section 4.

2. Proposed decision framework

This study aims to identify the risk factors that cause errors and failures in a mixed assembly line of an automotive company. The decision framework that is proposed to achieve this aim is based on three main stages:

- Identification of the factors which cause errors on the workstations
- Development of a hierarchical model by clustering factors
- Prioritization of the factors

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2.1. Identification of factors

First, a literature review was conducted in order to identify risk factors causing errors within the scope of the study. Based on an intensive literature review, we found a preliminary list of factors that may cause errors on the workstations. The literature that provided the most benefit is Antani K.R (2014), Zeltzer L. (2013), Personne R. (2014).

Secondly, the factor list was revised at a meeting held at the automotive company of the case study with eight managers and ten specialists working at quality control and assembly departments of the firm.

Managers from quality control department are:

- production quality manager
- production quality engineering administrator
- quality method and planning administrator
- assembly/suspension process quality administrator

Managers from assembly department are:

- car assembly production administrator
- minivan assembly production administrator
- car assembly engineering administrator
- minivan assembly engineering administrator

Specialists from quality control department are:

- quality method and planning specialist
- two quality audit specialists

Specialists from assembly department are:

- assembly final approval leader
- lean team leader
- two car assembly team leaders
- two minivan assembly team leaders
- process improvement specialist

The final list of factors includes fourteen factors as given in Table 1.

Table 1
Final factor list

Alert and Error-Proof System	Assembly Design
Cognitive Load	Component Accessibility
Ergonomics	Feature Design
Material Characteristics	Sequence and Number of Task
Tooling and Fixture	Training and Experience
Utilization and Saturation	Variation in the Process
Work Environment	Workers' Reliability

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2.2. Development of a hierarchical model by clustering factors

In the second stage, we interacted with managers and specialists of the company to classify the factors based on their similarities. Although there may be some dependencies among factors, i.e., relation between Work Environment and Ergonomics, as the participants of the meeting argued that the model seems to have few dependencies, the dependencies are ignored. The resulting factors and the hierarchy constructed are as shown in Table 2.The explanations of the main factors and factors are given in the following subsections.

Table 2
Factor groups and factors

A. Design-driven factors	
	A.1 Feature Design
	A.2 Assembly Design
	A.3 Component Accessibility
	A.4 Material Characteristics
B. Process driven factors	
	B.1 Tooling and Fixture
	B.2 Sequence and Number of Task
	B.3 Variation in the Process
	B.4 Utilization and Saturation
	B.5 Alert and Error-Proof System
C. Human-focused factors	
	C.1 Ergonomics
	C.2 Training and Experience
	C.3 Cognitive Load
	C.4 Work Environment
	C.5 Workers' Reliability

Design-driven factors

Design has a great impact on the complexity of the production systems. The DFM (Design for Manufacturing) approach is a widely-used method in the design process. The DFM approach, which aims to make the production easier and more economical, is based on the principle of simplification of design. Therefore, it has great importance for the design process.

Design-driven complexity is classified into four main factors:

- Feature design
- Assembly design
- Component accessibility
- Material characteristics

Features are characteristics that define the geometric and functional specifications of a component. Geometric features represent certain geometric accuracy and surface quality. On the other hand, functional features define specified functional requirements and expected life.

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Assembly design determines how to assemble different components. The assembly process generally consists of two distinct operations: handling followed by insertion. Both operations could be done manually or automatically. For accurate assembly operations, it should be required to focus on number of parts at the assembly station and manual process time of the components and tools.

Component accessibility shows lack of direct access or difficulty in access to the assembly area or components and has impact on complexity level. The difficulty level of accessing both area and components causes both increases in errors and complexity level while operating.

Material characteristics reflect certain properties that may be required due to the function of a part and can introduce complexity in the assembly process due to other inherent properties. Material characteristics contain mechanical requirements such as strength, resistance to breakage, hardness, and ability to withstand vibrations; physical requirements such as weight, electrical conductivity, and appearance; and service requirements that show an ability to process under extreme temperature or corrosion resistance.

Process driven factors

Process driven factors are essential parameters to design, develop and implement a process that produces components that could consistently meet design specifications depending on a specified cost.

Process driven factors include:

- Tooling and fixture
- The number of tasks and assembly sequence
- Variation in the process
- Utilization and saturation
- Alert and error-proof systems

Tooling and fixtures are used to hold the workpiece securely and present the workpiece to the machining tool or to the operator in order to enable efficient processing while meeting dimensional specification and cycle time[*]. A variety of tooling and fixtures are used in operations. Their reliability is taken into consideration when performing an operation. Tooling and fixtures should be designed within the allowable ranges.

Both the number of tasks in the station and assembly sequence have an impact on the process. The number of individual tasks assigned to the workstation reflects the total number of operations within the station. An increase in the number of tasks requires more effort for an operator while performing many operations in turn. The assembly sequence may be defined or left up to the operator for the consecutive operations. If the sequence is left up to the operator, there is certainly a decision-making mechanism for the operator. However, there are supportive tools to prevent errors and to ensure the operator's performance if the sequence is predefined and specified.

[*] Cycle time is used in the meaning of the time it takes to produce successive units on an assembly line.

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Variability reflects lack of repeatability when completing a given task. Repeating the same operation several times enables operators to get experience and to decrease completion time for a given task. On the other hand, variation also represents product mix, which refers to the difference between expected and real frequency among models, versions and options.

The utilization is defined as the ratio of the total time of the tasks assigned to the station in the cycle time. Utilization allows professionals to make a performance measurement on the basis of work stations. Additionally, saturation means total preliminary times for the operator's tasks.

The systems applied to prevent and remove errors can be grouped under the heading of error and fool-proofing tools. Alert and error-proof systems are especially important for critical operations on the operational base. Usage of these tools provide prevention of errors for operators with audio-visual systems at certain areas of the work stations.

Human-focused factors

Human-focused factors include the development of tools that facilitate improved performance, safety, and user satisfaction. These factors have a direct effect on human performance.

Human-focused factors are classified as:

- Ergonomics
- Training and experience
- Cognitive load
- Work environment
- Workers' reliability

Ergonomics analyzes the interactions between the worker and the working environment. If there is a mismatch between operator and environment, the operator's ability to perform a task decreases and leads to the possiblity that it will become seriously dangerous. This situation may lead to fatigue and illness in time. From this point of view, ergonomic conditions and their impacts are extremely important for operator's health and ability to work confidently.

Training and experience level have a major role in matching operations with workers. The number of training hours in the station is a certain factor regarding learning and performing the task in a right way.

Cognitive loading can be evaluated as a total function of control, material choice, equipment choice and judgment. Operators should make the right choice from a number of alternatives in the station. The excess amount of control, choice, and judgment for the operator directly affects the error risk. In other words, as the level of cognitive load for the operator increases, the risk of errors increases.

Work environment includes environmental conditions and illusion, and has direct effects on operators in the workstation and surrounding areas. The level of lighting, noise, motion, thermal stress, and air quality constitutes work environment conditions. On the other hand, illusion can be defined as an instance of a wrong or misinterpreted perception of objects by operators.

Worker reliability reflects the power of the worker to cope with the complexity. Worker reliability ratings are formed depending on mental ability analysis, competence, and physical properties. The power of determination of worker reliability is crucial for the operation to assign it to the appropriate operator.

2.3. Prioritization of the factors

After the determination of the factors, we developed a hierarchical model at the second stage. The AHP, proposed by Saaty (1980), is an approach best suited to treat hierarchical decision-making problems and therefore, for these kind of problems, it is the most widely used method in practice and the most cited method in the literature. Besides, in this study, as the aim is just prioritizing identified criteria (factors) and there is no evaluation of alternatives, a prioritization technique such as AHP is necessary and used in the third stage of this study.

First, we utilized Super Decisions software to represent the hierarchical model as can be seen in
Figure 1 (Super Decision, 2018). Then, a pairwise comparison questionnaire survey was prepared in accordance with AHP. Accordingly, a pairwise comparison questionnaire, a part of which can be seen in
Figure 2, was sent to the managers and specialists to assess their judgments representing the relative importance of factor groups with respect to risk evaluation of assembly lines and the relative importance of factors with respect to each factor group.

In the following step, we computed geometric means of all paired comparison judgments for each question in order to reveal the aggregated group judgments. Utilizing the assess/compare module of the Super Decisions software, we arranged these group judgments in pairwise comparison matrices.

At the final step of the decision-making process, we computed the priorities of the factor groups and factors as well as inconsistencies, utilizing the computations module of the same software which did all the matrix algebra. The revealed priorities are given in the following section.

The inconsistency ratio for the pairwise comparison matrix with respect to the goal is 0.05%. The inconsistency ratios for the pairwise comparison matrices with respect to design driven, process driven, and human focused factors groups are 1.11%, 1.51%, and 0.65%, respectively.

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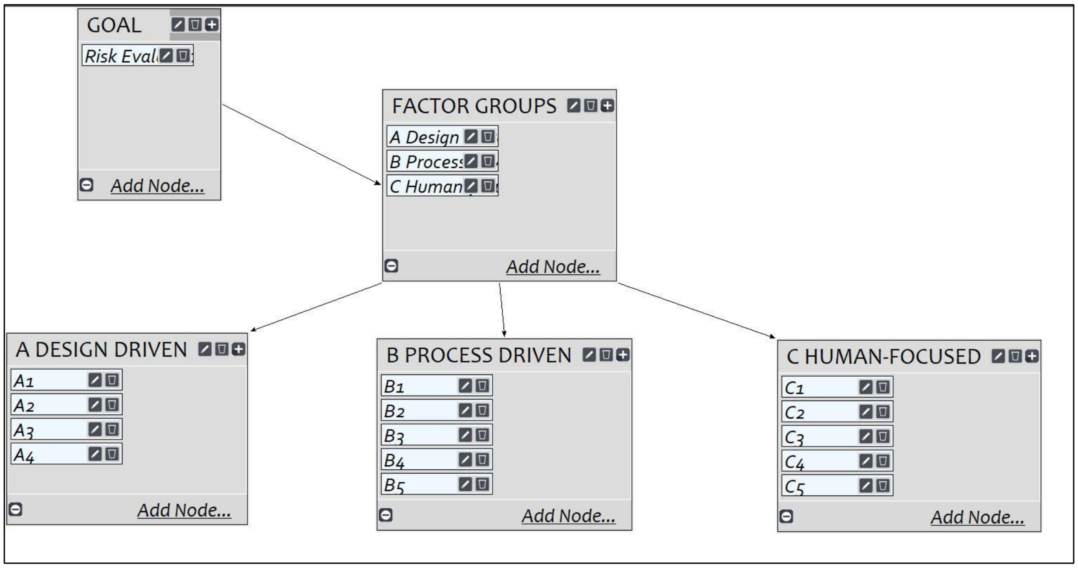

Figure 1 Hierarchical model

With respect to goal "**Risk Evaluation of Assembly Lines**" compare the following factor pairs:

1=Equal importance 3=Moderately more important 5=Strongly more important
7=Very strongly more important 9=Extremely more important

Design driven factors	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Process driven factors
Process driven factors	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Human focused factors
Human focused factors	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Design driven factors

Figure 2 Part of pairwise comparison questionnaire

3. Findings

According to the results of the survey, the priorities of the main factors are shown in Figure
Figure 3. The most important main factor found is "Process Driven Factors". It's importance is 46.41% (nearly half of the total priorities of main factors). Therefore, we can state that "Process driven Factors" are significantly more important than both human-focused and design-driven factors. The other two main factors, namely "Human-focused Factors" and "Design-driven Factors" have a very similar importance level around 27%.

The importance level of the factors in design-driven factors are found as given in
Figure 4. The results indicated that "Assembly Design" is the most important factor among design-driven factors with a priority of 40.94%. The importance of other design-driven factors is around 20% each.

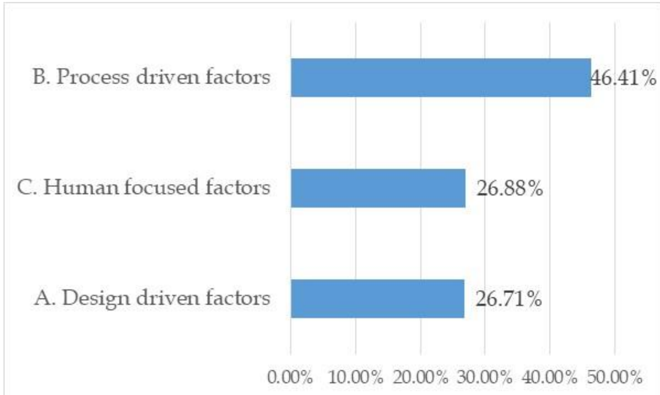

Figure 3 Priorities of factor groups

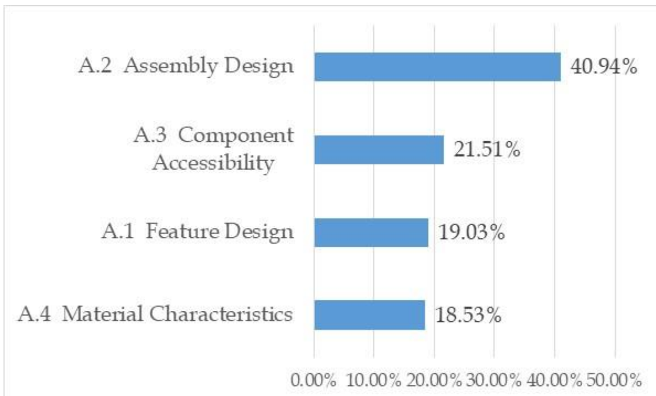

Figure 4 Priorities of design-driven factors

The results related to the process-driven factors are presented in
Figure 5. The participants assessed the importance of "Variations in the Process" as 36.15%. Other process driven factors except the "Tooling and Fixture" factor have an importance around 19%. The tooling and fixture factor is the least important with 7.2%.

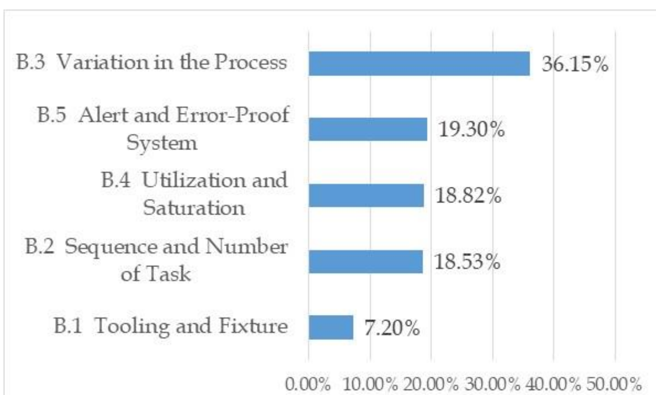

Figure 5 Priorities of process driven factors

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The importance of the human-focused factors is presented in
Figure 6. According to judgments of managers and specialists, the most important human-focused factor is found to be "Training and Experience" (33.60%), followed by "Reliability of Workers" (21.34%). "Work Environment" is not as important as other human-focused factors.

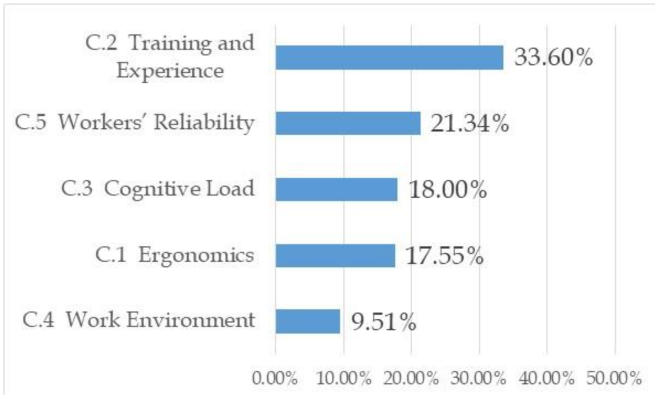

Figure 6 Priorities of human-focused factors

When the priorities are aggregated in accordance with AHP, global priorities of the factors are seen in Figure 7, and the descending order of priorities can be seen in Table 3.

Based on global priority values, the most important factor is found as "Variation in the Process" (16.78%). A group of factors follows this factor with their global importance between 8%-11%, namely, "Assembly Design", "Training and Experience", "Alert and Error-Proof System", "Utilization and Saturation", and "Sequence and Number of Task". On the other hand, the factors "Tooling and Fixture" and "Work Environment" are the least important factors for the participating managers and specialists.

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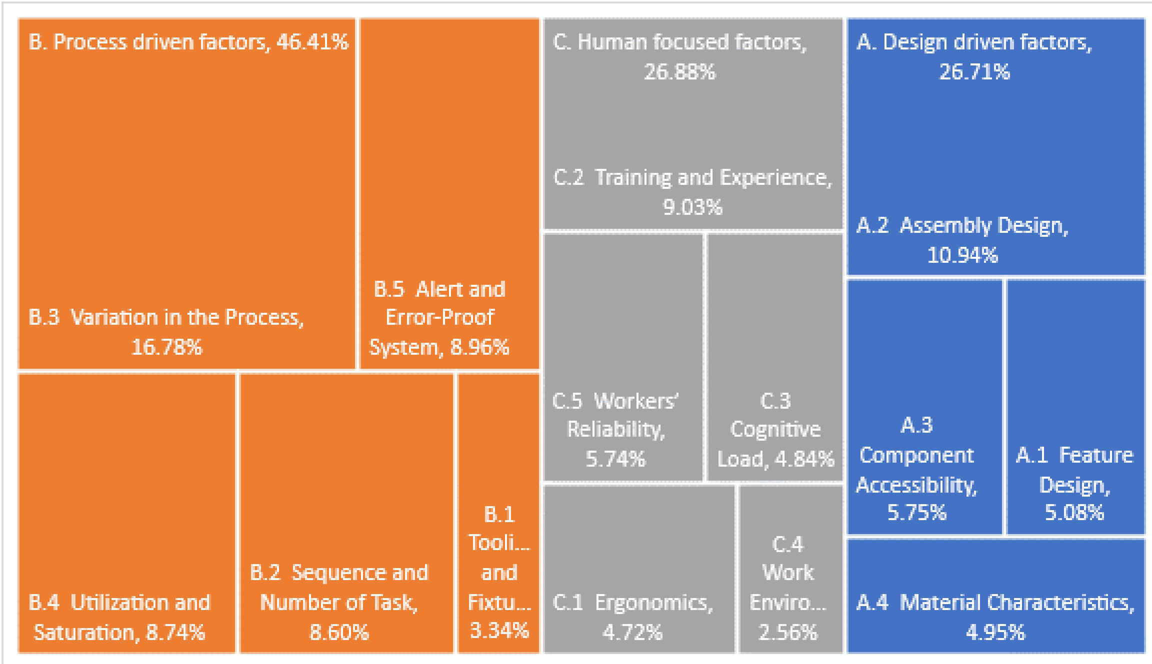

Figure 7 Global priorities of the factors

Table 3
Descending order of global priorities of the factors

Factor	Priority
B.3 Variation in the Process	16.78%
A.2 Assembly Design	10.94%
C.2 Training and Experience	9.03%
B.5 Alert and Error-Proof System	8.96%
B.4 Utilization and Saturation	8.74%
B.2 Sequence and Number of Task	8.60%
A.3 Component Accessibility	5.75%
C.5 Workers' Reliability	5.74%
A.1 Feature Design	5.08%
A.4 Material Characteristics	4.95%
C.3 Cognitive Load	4.84%
C.1 Ergonomics	4.72%
B.1 Tooling and Fixture	3.34%
C.4 Work Environment	2.56%

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4. Conclusions and further suggestions

This study aims to identify and prioritize risk factors in an assembly line of an automotive company. For this purpose, a three-stage methodology was used. Initially, the risk factors were identified based on literature review. Subsequently, a hierarchical model was developed by clustering the factors. Finally, the factors were prioritized using the AHP method.

The most important contribution of this study is the application of this methodology to find and rank the risk factors based on their importance in a world-leading automotive company in Turkey. The AHP application utilized is expected to be the first application on assembly lines in the automotive sector. We integrate literature, expert opinions, field experience and real-life data to shape the risk factors in workstations of an automotive company.

According to the results, we determined 14 risk factors under three factor groups. The priorities of these factors are quite interesting. We found variations in the process as the most important factor. In the mixed-model assembly lines, the variations are inevitable because of its nature. Actually, these lines are designed for handling variations. Therefore, the complexity of the line that causes errors and failures are due to the inherent property of the mixed-model assembly line. However, the situation is not as desperate as it seems since the variation in a line or a single station can be controlled to decrease the complexity. For instance, by planning a uniform production plan that will incur an appropriate scheduling of the models, versions, or options; the management can reduce the assembly time variations in the stations.

Assembly design is the second important factor based on global priorities. Design has enormous impacts on assembly lines because good assembly design provides cost minimization as well as process improvements. There are possible improvements in the context of the assembly design factor. For instance, changes in specific task's designs via new assembly technologies can result in better assembly outputs, when considered from the perspective of long-term consequences. The only drawback is the high investment required in the initial stage to make assembly improvements. Despite the high initial investment, it is an obvious fact that companies should give priority to assembly design to be able to compete in the market with the help of technological advances.

The training and experience factor, which is the third important factor, can be considered as the option with the least cost to achieve the goal of risk reduction. Due to changing technology, employees become under-qualified which results in a high probability of failure. This factor aims at removing potential causes of failure due to lack of knowledge. It necessitates understanding the potential risks related to humans in order to shape a specific training which allows employees not only to protect themselves but also make timely and accurate actions when necessary.

When we shared our suggestions with the managers and specialists of the company, they found them very interesting and useful. We decided to start a new study to develop a multi-criteria decision support system for the prediction and quantification of the risk of errors on the workstations in the company. In this future research, we will take the risk of errors into consideration as alternatives. Then, we will identify attributes, as sub-factors

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of the decision model on hand, to evaluate these alternatives. Before prioritizing the attributes, the dependencies among attributes will be discussed with the managers and specialists. If dependencies and feedbacks exist, the model will be a network and the Analytic Network Process (ANP) approach will be utilized.

The model developed is a general model that could be applied on any mixed model assembly line in an automobile industry, not just the particular company studied. However, the priorities may be company specific. It would be interesting to implement the model in another mixed model assembly line with different managers and specialists and compare the priorities of the factors.

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