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PRODUCTION & MANUFACTURING | RESEARCH ARTICLE

Analyzing the enhancement of production efficiency using FMEA through simulation-based optimization technique: A case study in apparel manufacturing

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Abstract: In service and production area, problems such as severity of competition and increasing customers' expectations, put the producers' under a commitment to eliminate product defects and make up for any kind of shortage and deviations in its performance. In order to reach the mentioned aim, failure mode and effects analysis (FMEA) technique can be typically utilized for prevention, identification, control and elimination of possible errors. In this paper, FMEA approach is adopted to design and implement a system of quality control in the apparel production lines, to identify and rank the possible difficulties, and then finally, to issue the right commands to the quality control stations. For this purpose, the data are gathered from a medium-sized apparel factory and implemented by FMEA and then, improvability of production efficiency is analyzed using simulation-based optimization technique. The results of the simulation show significant decrease in product defects, rework, and total production cost.

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PUBLIC INTEREST STATEMENT

In order to meet customers' expectations and to solve some of the most significant production and service problems, this study delivers practical solution by means of statistical optimization methods. The results show significant decrease in product defects, rework, total production cost, and finally caused better customer servicing. Design and process failure mode and effects analysis (FMEA) is the selected methodology which has been applied to analyze the practical collected data. Design FMEA explores the possibility of product malfunctions, reduced product life, and safety and regulatory concerns. Process FMEA discovers failure that impacts product quality, reduced reliability of the process, customer dissatisfaction, and safety or environmental hazards.

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1. Introduction

In the age of ever-growing global competition, production efficiency is one of the most important issues in factory management. Factories no longer can afford to incur delays, failures and cancellations. One of the most important problems in the production process is defect creation in labour stations and as a result, occurring delays in the production program. Hence, there has been an increase in using scientific approaches to recognize failure sources and prevent failures and defects from occurring in the production process. In the other words, the first step to control and eliminate such operational problems is to start up a production system and quality control system in a standard way based on scientific and experimental findings (Case, Nor, & Teoh, 2010; Sheng-Hsien & Shin-Yann, 1996). Those problems may occur due to inefficient management of production resources. Thus, management of resources, including human resources have become a fundamental issue in improving production control process; nonetheless, common tools and techniques of human resource management are not prevalent in apparel production lines (Dadashian, Monfared, & Nasrabadi, 2009; Liang-Hsuan & Wen-Chang, 2007; Stamatis, 2003). Therefore it is of great importance to design and utilize a system, capable of elaborate monitoring of operators work schedule and examining each station with regard to its properties each industry, dependent upon its own requirements is able to take advantage of these techniques. These techniques have their merits and demerits (Dadashian et al., 2009; Yuen, Fung, Wong, Hau, & Chan, 2008). Consequently, using these techniques will also play an important part in optimizing production processes. Failure modes and effects analysis (FMEA) is one of the most effective tools to systematically identify activities that can decrease or remove the chance of possible error occurrence managing implementation and documentation of these activities, and also is a technique to identify, define and, eliminate possible or definite failures, errors, and existing problems in the system, design, service and process, prior to end-use (Lipol & Haq, 2011). FMEA is one of the first steps of a system reliability study that involves reviewing as many components, assemblies, and subsystems as possible to identify failure modes, and their causes and effects. Also, all of factors such as equipment, environment, materials, and human are to be taken into account. To collect accurate and thorough data on the project, techniques such as interviews with informed and proficient people in workshops and organization were used (Bahrami, Bazzaz, & Sajjadi, 2012). After that, a list of errors, their causes and plausible mechanisms was supplied and the causes must be known. In order to assess risks more accurately, adequate attention should be paid to documents, requirements, operational standards, the workplace and the conditions of working. Commonly satisfactory level of possibility changes for each organization depends upon the financial and economic resources, technological constraints, human resource factors and management of making decisions (Ahire & Relkar, 2012). In this study the FMEA was implemented and accompanied by quality control of apparel production lines, to decrease the defective products and enhance the productivity. As a consequence, using Arena simulation software, enhancement programs and defensive actions can be taken prior to starting the project, through utilizing FMEA to avoid wasting resources and decreasing cost.

2. Theory

In1950s, procedures for conducting FMEA were described in US Armed Forces Military Procedures document, which was almost the elementary definition of that. In 1970s, NASA was the first organization which proposed FMEA as a means for their apparent reliability requirements.

Ever since, it has widely served as a powerful approach for systematic analysis of products and processes in different industries. In that decade the mentioned system was utilized in nuclear establishments and also in the automotive industry, including Ford Motor Company and Peugeot-Citroen Company (Bahrami et al., 2012).

In the subsequent decades use of this system was broadened to the point where, nowadays, this technique is applicable for more of the organizations. FMEA is straightforward to use and powerful engineering quality approach that assists to identify activities which can diminish or eliminate the chance of possible error during the design or process (Bahrami et al., 2012; Carbone & Tippett, 2004; McDermott, Mikulak, & Beauregard, 2009). Moreover, this method can decrease disastrous errors causing damage to the industries.

At first glance, it might seem that by this method, such problems will be solved temporarily. But the main philosophy is to change system behavior in same experiences when the company encounters operational problems. Entire accomplishment of this method strongly depends on its structural executing members. Institutionalization the executing of this method in a company, in long-term, will improve the whole system behavior by production optimization and controlling system improvement.

There have been some applications of FMEA on spinning and weaving industries; but this powerful technique has not been extensively used in apparel industries (De Toni & Meneghetti, 2000; Özyazgan & Engin, 2013; Walser, 2006). Therefore, this research aims at examining the applicability of FMEA on apparel production.

3. FMEA system explanation

In the mentioned system, each factor is examined to recognize possible failures. Therefore, three measures including the probability of failure occurrence (O), the severity or impact of the failure (S), and the capability of detection of failure occurrence (D) which will be clarified below, are taken into account. The multiplication of these measures leads to identification of the risk priority number (RPN) (Snooke & Price, 2012; Varzakas, 2011).

3.1. Probability of failure occurrence (O)

This factor determines the possibility of occurrence of a potential cause or mechanism of failure. In other words, the probability of occurrence specifies that a potential error happens with a specified frequency.

The probability of occurrence is evaluated on the basis of a range of 1–10. Now it is essential to examine the cause of a failure mode and its probability of occurrence. All the possible causes for a failure mode should be identified and documented. Examples of causes can be human faults, manufacturing errors, and so on. Therefore, only through the elimination or reduction of the causes or mechanisms of each failure, it would still be possible to reduce the number of different failures, possible values of which are shown in Table 1.

Table 1. Occurrence scale		
Range	**Possible failure rate**	**Probability of failure**
1	<1 in 1,500,000	Nearly impossible
2	1 in 150,000	Remote
3	1 in 15,000	Low
4	1 in 2.000	Relatively low
5	1 in 400	Moderate
6	1 in 80	Moderately high
7	1 in 20	High
8	1 in 8	Repeated failure
9	1 in 3	Very high
10	>1 in 2	Extremely high

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3.2. Severity of failure (S)
Severity is the intensity of the effect of failure on the product or end-user's experience thereof. Severity of failures is expressed on a scale from 1 to 10, ranging from "none" to "dangerously high" shown in Table 2.

3.3. Detectability of failure (D)
This factor shows the probability of detection of a fault by the operator or end-user.

It should be clarified how the failure mode or cause can be detected by an operator under normal circumstances or if it can be detected by the maintenance team by some inspection or other types of actions, which is shown in Table 3.

Also, potential risk scores should be evaluated after ranking and making sure that the rating is still unchanged.

3.4. RPN evaluation
After achieving Severity (S), Occurrence (O) and Detect (D), these values should be multiplied, to calculate the RPN number. Indeed, Equation (1) shows the RPN number calculation:

$$RPN = (S) \times (O) \times (D) \tag{1}$$

Table 2. Severity scale

Range	Probability of failure	Effect of failure
1	None	Be unnoticed and not affect the performance
2	Very minor	Failure may have minor effects on the customer's process or product
3	Minor	Cause a minor nuisance but can be overcome with no performance loss
4	Very low	Cause minor performance loss
5	Low	Failure creates enough of a performance loss to cause the customer to complain
6	Moderate	Failure results in a subsystem or partial malfunction of the product
7	High	Failure causes a high degree of customer dissatisfaction
8	Very high	Failure renders the unit inoperable or unfit for use
9	Extremely high	Failure involves hazardous outcomes
10	Dangerously high	Failure could injure the customer or an employee

Table 3. Detection certainty scale

Range	Probability of failure	Detection approach
1	Almost certain	The defect is obvious or there is 100% automatic Inspection with regular calibration
2	Very high	All units are automatically inspected
3	High	100% inspection surrounding out of control conditions
4	Moderately high	Statistical Process Control is used with an immediate reaction to out of control conditions
5	Moderate	Some Statistical Process Control is used in process and product is final inspected off line
6	Low	Manual inspection with mistake proofing modifications
7	Very low	All units are manually inspected
8	Remote	Product is accepted based on no defectives in a sample
9	Very remote	Occasional units are checked for defects
10	Almost impossible	The product is not inspected or the defect caused by failure is not detectable

RPN value lies in a range of 1 and 1,000 and failures will be ranked with regard to their numbers. Failures of high risk priority are preferred to be examined more carefully, and operators should concentrate on errors owning a higher RPN value. RPN is a measure for separating tolerable and intolerable risks in the mentioned system.

In fact, the higher RPN value of a specific failure, the more unacceptable the failure (Almannai, Greenough, & Kay, 2008; Bahrami et al., 2012; Chiozza & Ponzetti, 2009; McDermott et al., 2009).

In general, regardless of the RPN value, special attention should be paid to suitability of present design control actions. For prevention of errors, precautionary or corrective actions should be taken by removal, decrease or control of their causes. After ranking errors and determining RPN, some solutions may be found to decrease or eliminate specified errors. It is worth mentioning that for the above RPN values the related team should take the appropriate action to decrease them. For example, for RPN values greater than 120, 30% per hour, RPN between 120 and 60, 12% per hour and for RPN less than 60, 7% in each work shift should be controlled.

It must be considered that the mentioned percentage of applied quality control may be varied by some independent parameters; such as production plan, type of product and etc.

Corrective actions including removal of the basic cause of risk, reduction of the error severity, heightening job satisfaction and increase in the likelihood of identification in the process should be taken (Geum, Shin, & Park, 2011; Ravi Sankar & Prabhu, 2001; Seung & Kosuke, 2003; Zhou & Stalhane, 2004).

These corrective actions should be followed by appropriate follow-up measures as mentioned above. Approaches like examination of the processes, plans and designs are used to improve the process and enhance efficiency.

It should be noted that if the administrative team has successfully completed all the last steps, the main job of this team will commence.

In other words, if the mentioned team cannot take appropriate actions to remove or decrease these cases, no good results will be obtained, and also lots of financial expenses will be imposed (Mariajayaprakash & Senthilvelan, 2013; McDermott et al., 2009).

With regard to the above statements, the precise mechanism of the FMEA method can be demonstrated as Figure 1.

For performing this approach, required data should be gathered by qualified engineers who are familiar with the production process and by experts who are the most knowledgeable about the process and product (McDermott et al., 2009; Sheng-Hsien & Shin-Yann, 1996).

The merit of this working manner is that all of the stations would be unaware about each action defined. There has been a significant lack of research regarding utilization of the FMEA system in apparel production lines.

The chief aim of this paper is to implement the FMEA system on the quality control of apparel production and evaluate the efficiency of the aimed system.

Figure 1. FMEA implementing cycle.
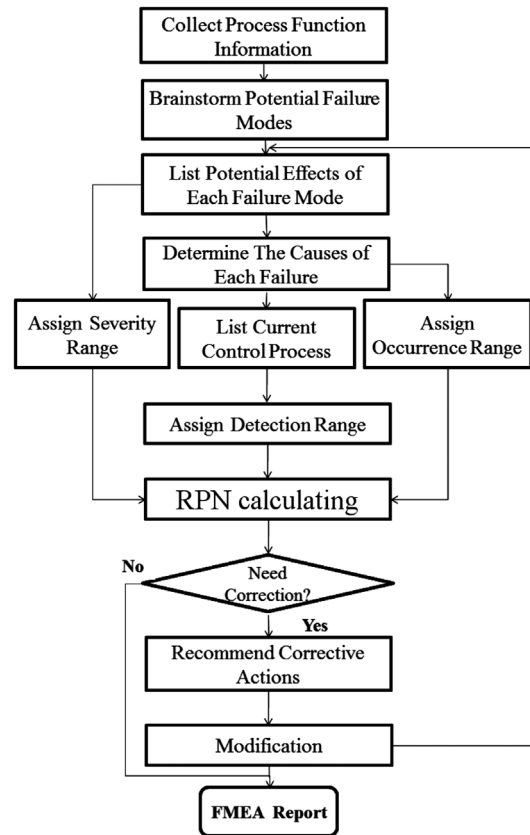
4. Objectives and contribution

This work has probed the effect of application of FMEA to the reduction of the flawed products, and thus, reduction of expenses and increase in the productivity of the apparel production line. In order to show the suggested problem, a method based on simulation optimization is applied for modeling the new quality control plan on the basis of FMEA system. A case study for T-shirt sewing section in an apparel production line will be implemented, and the consequences will be examined.

The suggested model will be explored by example using a genuine data representing quality control plan of apparel production.

5. Simulation modeling and optimization methodology

Computer simulation is a great technique for assessing complicated systems. These assessments are commonly used in forming the answers to questions of "what if" (Alibi, Fayala, Bhouri, Jemni, & Zeng, 2013; April, Glover, Kelly, & Laguna, 2003; Shokohyar & Mansour, 2013).

A simulation Experiment can be clarified as an examination or a series of examinations. Significant changes are made in the model of simulation input variables for observing and identifying the reasons for variations of the output variables.

When the experiment cost of the designed system is high and the simulation model is complicated, the simulation experiments become excessively costly (Blaga & Draghici, 2005; Carson & Maria, 1997; Kara, Rugrungruang, & Kaebernick, 2007; Saaty, 1980; Korytkowski, Wiśniewski, & Rymaszewski, 2013). In order to do this, a technique called simulation-based optimization has appeared for optimization of the simulation models. Simulation optimization can be clarified as finding process of the best input variables from all the possibilities with no evaluation of each one (Melouk,

Figure 2. Simulation-optimization implementing cycle.
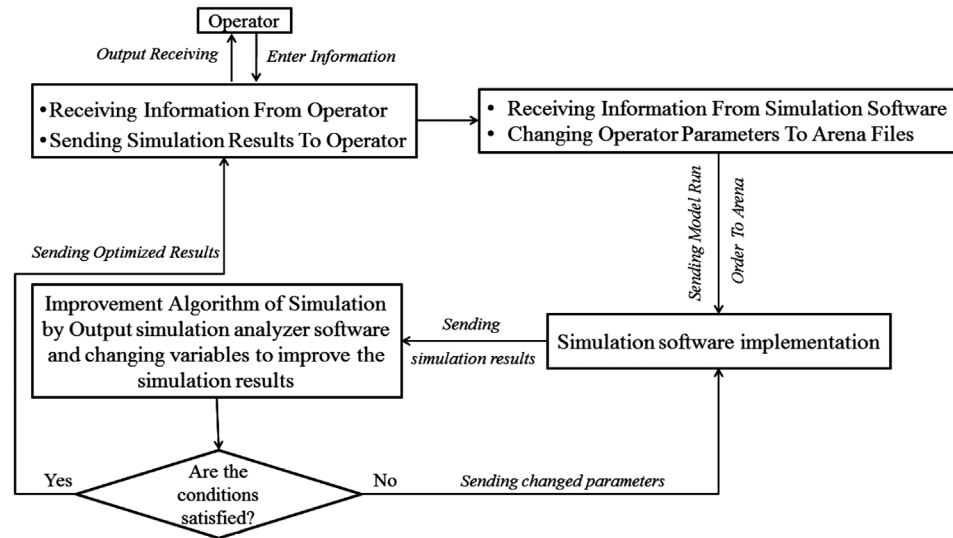
Freeman, Miller, & Dunning, 2013; Nguyen, Reiter, & Rigo, 2014; Shokohyar, Mansour, & Karimi, 2013).

In order to fulfil these purposes *Arena simulation software* was utilized in our work. Mentioned approach is employed to optimize the settled simulation model. *Opt-Quest software* is a widely- used applications for optimization of a simulation model.

This software combines meta-heuristics approach such as Tabu search, neural networks, and scatter search algorithm into simulation model and optimizes the blend of it. The optimization procedure in *Opt-Quest software* is demonstrated in Figure 2.

As demonstrated in this figure, simulation optimization is utilized to find the optimal settings of the input variables that optimize the objective function. Subsequent to each run of the simulation model, the objective function is calculated on the basis of simulation results, and new input parameters (on the basis of the above meta-heuristics approach) are set in the simulation model.

This process goes on until the predefined numbers of simulation runs are performed (Melouk et al., 2013; Shokohyar & Mansour, 2013; Shokohyar et al., 2013).

The developed simulation-based optimization model is applied to the FMEA system for determining the optimum quality control plan and eventually optimizing the number of controls, leads to the reduction in failure product rate, is built to determine the optimal solution to decrease the flawed products. The human resource restriction has been considered in the model of optimization process designed and the optimal quality control plan with higher productivity that finally leads to cost reduction are determined.

6. Case study
For validating the mentioned technique, a factory of apparel production was aimed. The main properties of the selected factory are demonstrated in Table 4. For implementation of the system, the sewing process of the one specific kind of apparel (T-shirt) was examined. The daily level of production is roughly 350 in unit number of apparel.

Seven operators in Seven stations are involved in the sewing of the product and one person is responsible for quality control of these stations.

Table 4. Selected factory main properties	
Establishment year	1997
Product type	Any kinds of apparel, including pants, T-shirts, and so on
Number of operators	152
Level of annual production in unit number of apparels	600,000

Table 5. RPN value for each station							
Station	1	2	3	4	5	6	7
RPN value	48	84	60	288	30	27	180

In the current condition, this inspector would evenly control %12 of production of all stations, regardless of the flawed product level in each station. Using this quality control system, the percentage of final flawed product is 13%.

Subsequent to FMEA system implementation, quality inspector, will control each station, with regard to the RPN number.

Therefore, the more the number of defects, the more samples will be controlled in each station. The RPN number for each station is shown in Table 5.

In order to compare the system efficiency before and after implementation of the FMEA system, sewing section was simulated using *Arena simulation software.*

The schematic picture of the sewing section that was simulated with the mentioned software is shown in Figure 3. This section consists of 7 stations. In first station the pocket part is joined to front part; in the second one, front and back parts is batch with each other and then finished sewing on the pocket, shoulder and collar sewing and the other finishing sewing is done in the subsequent stations. Finally, the last quality inspection is performed on the products and defected items are rejected.

In each station a number of products are possibly produced in a defective form and then an equal percentage of the each station's product is randomly controlled and the defective products are reformed. In Figure 4 one of the stations is demonstrated as a sample. As observed in this station, first, the front and back parts are joined to each other; then their quality is inspected and the defective items are repaired. At the end, the total products are transferred to the next station.
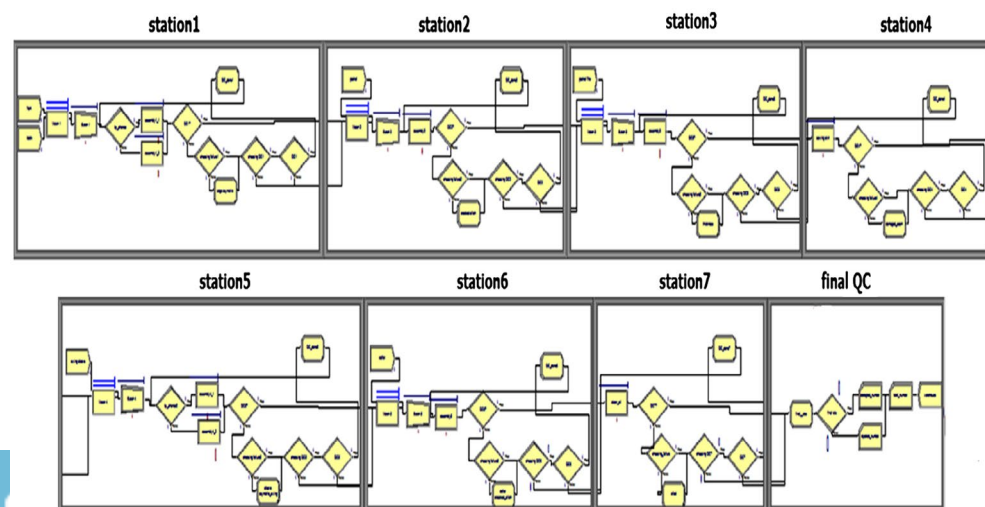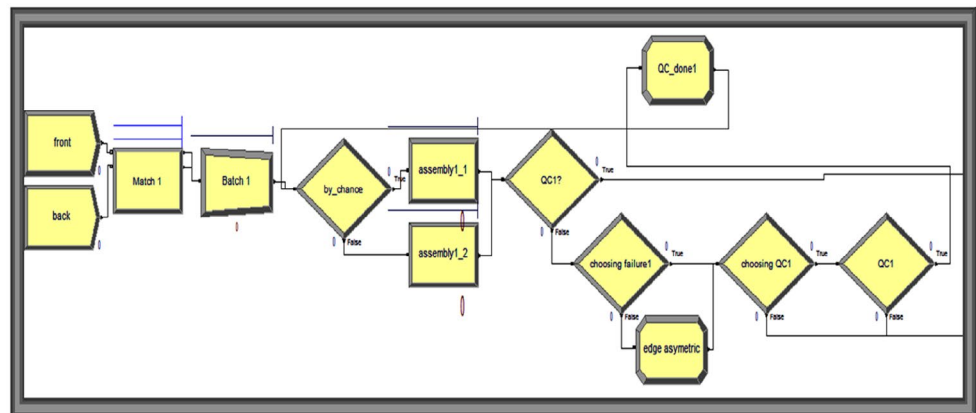
Figure 3. Simulated sewing section.

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Figure 4. Station sample.

For each station, the details of RPN value are mentioned as below values;

$$\text{Station 1: } (3 \times 4 \times 4) - \text{Station 2: } (7 \times 6 \times 2) - \text{Station 3: } (6 \times 2 \times 5) - \text{Station 4: } (8 \times 4 \times 9)$$
$$- \text{Station 5: } (3 \times 5 \times 2) - \text{Station 6: } (3 \times 3 \times 3) - \text{Station 7: } (3 \times 6 \times 10)$$

7. Results and discussions

Considering the fact that most of defects in the process of apparel production happen in sewing stage, if it were possible to enhance productivity by any decrease in the number of flawed products, a remarkable cost reduction will occur.

In this in an attempt to optimize the inspection activities of the operator, in order to enhance the chance of finding the flawed product in each station, and eventually to decrease frequency of flaws in products. To fulfill this aim, the control percentage dedicated to each station and the total defective product percentage are defined as a variable and objective function in the optimization toolbox of the Arena simulation software (Opt-Quest). It should be noted that the lower and upper limits of variables are 5 and 30% and their summation should be lower than 84%. The procedure of the simulation optimization searches for an optimum solution with regard to specific objectives. This process is repeated for defined number of simulation runs upon which results are dependent.

In our method optimal solution for the developed model was run 600 times, with every run being composed of 2 replications, as shown in Figure 5. The results of the optimization process are shown in Figure 6.
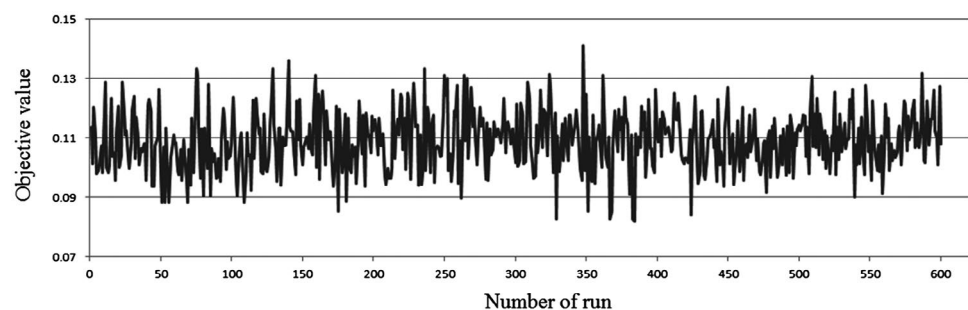
Figure 5. Optimal solution for the developed model.

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Figure 6. Main results of the optimization.

Figure 7. Comparison between control percent's, before and after optimization.
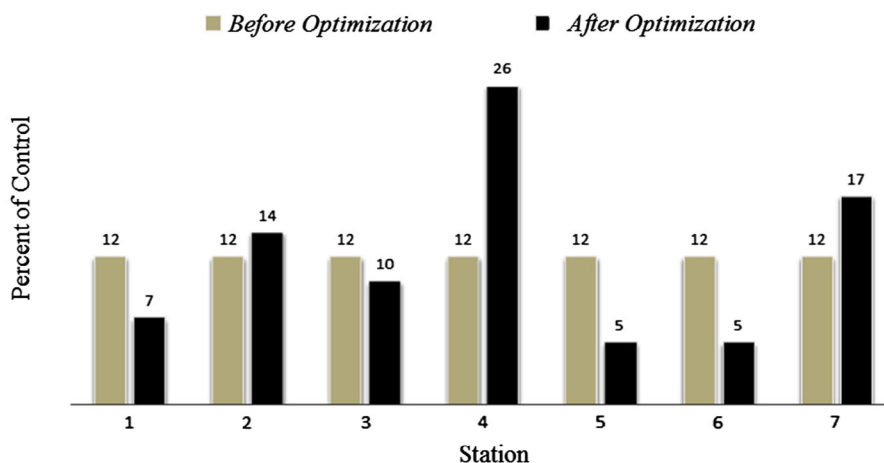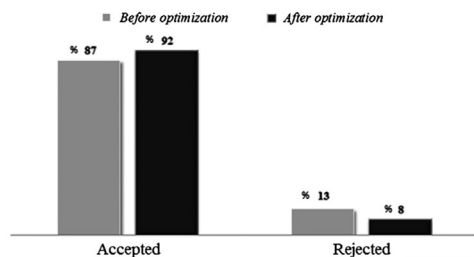

Figure 8. Comparison between percent of accepted and rejected products, before and after optimization.

According to Figure 6, the optimum controlled percentage for each station and the optimum total rejected products percentage are obtained. The comparison between these values and their primary values is illustrated in Figures 7 and 8. As illustrated in the Figure 7, the control percentages that were equal in the primary condition are calculated with respect to RPN values in the optimized condition (mentioned in Table 5). It is observed that for higher

RPN Values, more control percentages were dedicated. As a result, the quality control operator would be able apportion his time more efficiently among the stations, and thus, improve resource

allocation. In Figure 8, the percentage of the rejected product has diminished by almost 5%; consequently, this amount of reduction, cause the decreasing in total cost.

8. Conclusion

FMEA is simulated on an apparel production line, to examine improvability of efficiency. Simulation-based optimization technique is adopted and implemented using the *Arena Simulation Software*.

Final results reveal that FMEA can significantly improve allocation of inspection work to stations, based on the performance of each station, and thus result in a meaningful decrease in the number of defects and the amount of rework.

The other merits of this system can be quality improvement, enhancement of the certainty degree and security of the product, making the production process faster, decreasing the cost related to the defected products, and finally the improvement of customers' image of organization and increase in its competitive advantage in the market.

It should be noted that this method is not "once for all" and should always be regarded as a dynamic process. It means that, RPN ranks must be revised and remeasured periodically to avoid increasing defects.

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