INNOVATIVE RELIABILITY ANALYSIS OF A HEAVY DUTY HYDRAULIC DRIVEN MACHINERY*

Ağır Hizmet Tipi Hidrolik Tahrikli Bir Makinanın Yenilikçi Güvenilirlik Analizi

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ÖZET

Bu çalışmada, Güvenilirlik Merkezli Bakım (RCM) ve Hata Türleri Ve Etkileri Analizi (FMEA) metotları, hidrolik tahrikli enjeksiyon makinasının ekipmanlarının güvenilirliklerinin belirlenmesinde ve aynı zamanda risk seviyelerinin tanımlanmasında kullanılmıştır. Bu risk seviyelerini azaltmak için, RCM uygulamaları oluşturulmuş ve zaman periyodları belirlenmiştir. Ekipmanların ilgili FMEA bölümlerinde, belirlenen yüksek riskli hata türleri, görsel, fonksiyonel ve metalürjik inceleme yöntemleri ve makina mühendisliği yaklaşımıyla detaylandırılmış, hata giderme yöntemleri ve yenilikçi çözümler üretilmiştir.Hidrolik yağ hataları, tüm diğer hidrolik ekipmanların muhtemel hatalarına direk etki ettiği için, bu makalede sadece hidrolik yağ FMEA analizi detaylı olarak ele alınmıştır. Çalışmanın sonunda, tüm ekipmanların FMEA analizi ile sağlanan verimlilik değerleri ele alınmıştır.

Anahtar Kelimeler: Güvenilirlik Merkezli Bakım (RCM), Hata Türleri Ve Etkileri Analizi (FMEA), Hidrolik Sistemler, Makine Elemanları Hataları.

Abstract

In this study, Reliability Centered Maintenance (RCM) approach and Failure Mode and Effect Analysis (FMEA) are used for hydraulic driven injection molding machine to evaluate the reliability of components as well as to identify the technical risk levels. In order to minimize these risk levels, RCM tasks and time periods of maintenance tasks are developed. Also, high risky failure modes are elaborated in the related FMEA sections of components to develop troubleshooting keys and innovative solutions by using visual, functional and metallurgical examination methods in terms of mechanical engineering approach. FMEA of hydraulic oil is only detailed presented in this article because of the effect on the all possible failures of the other hydraulic system equipment. Achieved scores of productivity rates which have been provided by FMEA of all components are discussed at the end of the study.

Key Words: Reliability Centered Maintenance (RCM), Failure Mode and Effect Analysis (FMEA), Hydraulic Systems, Machinery Component Failures.

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Introduction

The goal of an RCM approach is to determine the most applicable effective maintenance technique to minimize the risk of impact and failure and to create a hazard-free working environment while protecting and preserving capital investments and their capability. In the RCM applications, failure analysis tools and methods are used for evaluating the failure mode, causes and their effects. FMEA method is one of the most powerful tools in the failure analysis and equipment condition monitoring. Thanks to this method, the equipment failures can be considered as the failures severity, occurrence and detection rates with the identified failure notations. Each potential failure mode and effect will be rated in each of these three factors on a scale ranging from 1 to 10, low to high. By multiplying the ranking for the three factors (severity × occurrence × detection), a Risk Priority Number (RPN) will be determined for each potential failure mode and effect. The RPN is used to rank the need for corrective actions to eliminate or reduce the potential failure modes (Mcdermott, 2009). The found RPNs of the failures are the pointers of the operational risks of the equipment. Failure root cause analysis methods are the support tools to the FMEA to examine the failure modes in the sub component of the equipment (Campbell and Jardine, 2001). Maintainability engineering is a dependent element of reliability engineering. It is intuitively obvious that part failure must occur to create the need for a system to be restored to full functionality. Maintenance management methods can be separated as Run-to-Failure Management, Preventive Maintenance, Predictive Maintenance and Total Productive Maintenance (TPM).Overall Equipment Effectiveness (OEE) is the benchmark used for TPM programs. OEE benchmark is established by measuring equipment performance. Measuring equipment effectiveness must go beyond just the availability or machine uptime. It must factor in all issues related to equipment performance. The formula for equipment effectiveness must look at the availability, the rate of performance, and the quality rate. This allows all departments to be involved in determining equipment effectiveness (Mobley, 2002). The formula could be expressed as: Availability x Performance Rate x Quality Rate=OEE, the OEE model is illustrated in Figure 1.

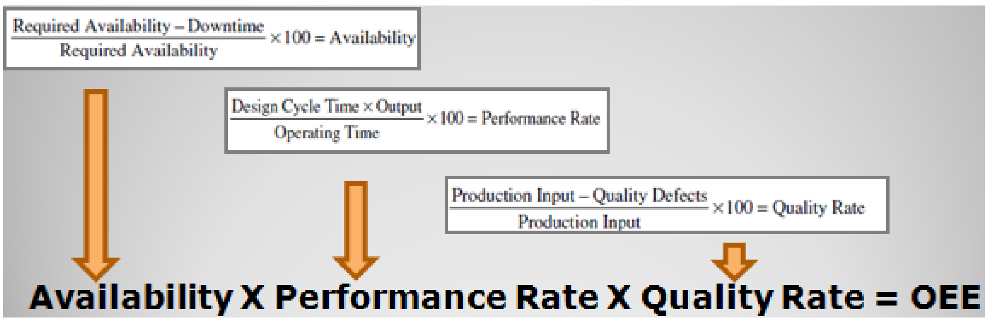

Figure 1. OEE model

In this study, building of RCM tasks with the support of FMEA is processed as Figure 2. which is the logic of processing of the FMEA and RCM analysis for identifying the technical risk levels and generating troubleshooting pointers of IMM components failures. Following tables and charts are the application of this logic on detailed FMEA of hydraulic oil. Determined hydraulic oil failure modes are associated with their causes and effects, the calculation of RPN concerning with the proper risk items are evaluated. Recommended RCM tasks are elaborated task procedures with related failure modes.

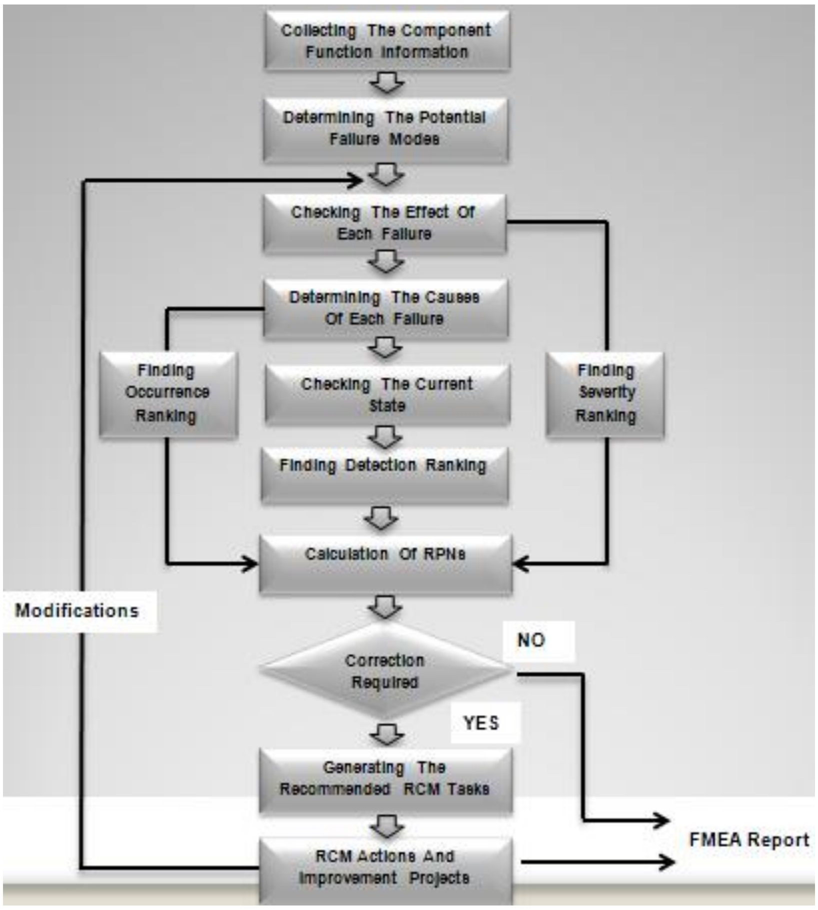

Figure 2. FMEA application flow of IMM analysis

Many FMEA utilized applications which evaluate the component or process reliabilities have been worked on the progressive improvements and innovation practices. These performance key applications are studied by scientist and industrial experts on different kinds of areas.

Souza and Álvares (2008) have worked on the reliability analysis of a kaplan type hydraulic turbine. The general objective of this work is to evaluate the application impact of the RCM methodology on a power generating system. They used the tools FMEA support the study of failures. Kumar et al. (2011) has descripted of FMEA methodology & its implementation in a foundry. The work was developed in an Indian foundry, in co-operation with part of the internal staff chosen as FMEA team members & was focused on the study of core making process. Afefy (2010) has described the application of reliability centered maintenance methodology to the development of maintenance plan for a steam process plant. The proposed PM planning results indicated a saving of about 80% of the total downtime cost as compared with that of current maintenance. Jafari et al. (2009) have studied on an application which is concentrated on a heavy duty machine and its failure modes. The most critical RPN results support the following performances. Machinery FMEA analysis was applied to analyze the risks of a tunnel boring machine using QS9000 and SAE J1739 recommendations. Yeh and Sun (2011) have explained the establishing of the preventive maintenance time points from the reliable processing of the equipment history data. Gurumeta (2007) examined the reliability centered system failure analysis of ENDESA Network Company by using RCM methodology, the root-cause analysis and its development planning. Haddad and Jaroon (2012) have studied a novel methodology for the implementation of TPM program in the healthcare industry. A TPM implementation methodology has been developed for increasing medical devices utilization and decreasing their failures by them. Tsarouhas (2012) investigated the relationship between the factory management and the operation of the Limon cello production line. The analysis of failure and repair data of the line over a period of 8 months was carried out. Descriptive statistics at machine and at line level were computed. In addition, the components availability (A), Performance Efficiency (PE), and Quality Rate (QR) of the OEE were calculated. Wakjira and Singh (2012) evaluated the contributions of TPM initiatives towards improving manufacturing performance in Ethiopian malt manufacturing industry. The study establishes that focused TPM implementation over a reasonable time period can strategically contribute towards realization of significant manufacturing performance enhancements.

Material and Method

During the performing the FMEA, initially is done a survey on the functions of each component, as well as on its failure modes and effects. Each failure mode is sequentially numbered, restarting the counting for each new component. This number will be used as a failure mode pointer, being referenced at the FMEA punctuation form (Table 1.). From the failure mode pointers, had been established indices for evaluation of the importance that each mode represents for the process. The RPN is simply calculated by multiplying the severity ranking times the occurrence ranking times the detection ranking for each item. The formulation can be used as RPN=SxOxD. These items are prepared with their numerical levels by using failure effects on the examined process.

Table 1. Considered failure punctuations

Severity		Occurrence	
1	Very insignificant effect, corrected immediately by the operation team	1	Without failure registry in the last 3 years
2	Insignificant effect, corrected immediately by the maintenance	2	Without failure registry in the last 3 years
3	Very insignificant effect, corrected immediately by the operation team	3	2 failures in the last 3 years
4	Moderate effect, the component does not execute its function, but the failure does not provoke TRIP in the machine and its maintenance does not demand stop of machine	4	3 failures in the last 3 years
5	Moderate effect, which does not provoke TRIP actuation in the machine, but whose maintenance demands stop of machine	5	4 or 5 failures in the last 3 years
6	Moderate effect, which provokes TRIP actuation in the machine and whose maintenance demands stop of machine during one day or less	6	6 failures in the last 3 years
7	Critical effect that provokes TRIP actuation in the machine and whose maintenance demands stop of machine for more than one day	7	7 failures in the last 3 years
8	Very critical effect that provokes TRIP actuation in the machine and brusquely interrupts the system functions	8	8 failures in the last 3 years
9	Very critical effect that provokes BLACKOUT actuation in the machine and collapse of the process	9	9 failures in the last 3 years
10	Catastrophic effect that can cause damages to properties or people	10	10 or more failures in the last 3 years

Detection	
1	Failure indicated directly by the instrumentation
3	Failure identified by the team operation daily inspections
5	Failure identified for abnormal noises, or indirectly by the instrumentation
7	Occult failure, impossible to be identified by the operator

Injection molding is the most widely used method for the production of products directly from the thermoplastic material by using molding process. The most common Injection Molding Machine (IMM) type is hydromechanics toggle clamping machine because of its compact design and low energy consuming. High hydraulic system pressures are used both for executing injecting the melted plastic material in to the mold cavities and clamping the mold pair in the closed position against high injection pressure. Proportional valves are also used for precise position control of the mechanical system. IMM process of present day is generally supported by industrial robot applications to enforce the transportation of finished products or part mounting issues for fastening the process cycle.

Research and discussion

The analysis of mechanical failures with FMEA method was examined by collecting failure modes and failure downtimes information of a 50 IMM capacity shop floor. The plant of the injection molding shop floor is the member of the most leading multinational company of the world dealing with the manufacturing of the polypropylene water management systems and going on its manufacturing mission in Turkey. The failure types of these machines are similar. Before the FMEA supported RCM applications, the inspected items of the productivity indicators showed that the percentage of the mechanical failure downtimes was the largest share in the total downtimes. During the FMEA process, main mechanical failures are identified in two component failure groups as hydraulic system failures and mechanical system failures. The components of hydraulic system involve hydraulic oil, hydraulic pump, hydraulic valves, hydraulic lines, heat exchanger and hydraulic motor. The components of mechanical system contains toggle clamp unit, injection unit, screw&barrel, industrial robot, chassis&covers, hydraulic cylinders and raw material silo. Detailed FMEA of hydraulic oil is discussed because of the critical influence on the all hydraulic equipment.

Table 2. is FMEA form of hydraulic oil and it is used for identifying the components function, determined failure modes, failure causes and effects.

Table 2. FMEA form of hydraulic oil

COMPONENT	COMPONENT FUNCTION	FUNCTIONAL FAILURE	FAILURE MODE	FAILURE CAUSE	FAILURE EFFECT
1.HYDRAULIC OIL	Transfering The Power	Noisy Running Of The Pump&Hydraulic Lines	1.1 Excessive Noises	1. problems because: a) fluid level too low b) viscosity too high (temperature too low)	Risk that the pump and line equipment breaks
				2. fluid contaminated and dirty, leading to damage and blockage of equipment	
				3. fluid foams	
		System Pressure is under the set pressure	1.2 Pressure too low	1. viscosity too low, excessive leakages	Disturbance in the system functions
				2. viscosity too high, excessive flow resistance	
				3. fluid foams	
		Fluctuation on the system pressure	1.3 Variations in pressure and delivery	1.hydraulic fluid dirty	Disturbance in the system functions
				2. hydraulic fluid foams	
		Fluctuation on the system functions	1.4 Power Take-off either does not turn at all, or - too Slowly	1. viscosity too low, excessive leakages	Disturbance in the system functions
				2. viscosity too high, excessive flow resistance	
				3. fluid foams	
		Oil temperature on the control panel display is above 50 C'	1.5 Excessive Operating Temperature	1. viscosity too low, excessive leakages	Risk that the pump and valves breaks
				2. viscosity too high, excessive flow resistance	
				3. fluid foams	
				4. fluid contaminated and dirty, leading to damage and blockage of equipment	
		Foam in the oil reservoir	1.6 Foaming of Hydraulic Fluid	1. unsuitable make	Risk that the pump and valves breaks
		Vibration&Noise on the hydraulic lines	1.7 Line Shocks when Switching Takes Place	1.Foaming of the hydraulic fluid	Risk that the pump and valves breaks

Table 3. is the RPN calculation table of hydraulic oil failures. RPN results show that the severity and occurrence rates of the failure modes are at high levels and these values causes high risk. However, the detection rates are not in though ranges, so the elimination of these risks can be executed by powerful control tasks. Furthermore, predictive maintenance tasks should be studied on the hydraulic oil condition monitoring to improve the stability of the hydraulic system. Targets of the recommended RCM tasks will be considered to minimize the RPN of failure modes by decreasing the occurrence and severity rates. Especially, improved occurrences will minimize hydraulic system failure downtimes, so developed equipment efficiency results will be able to reach.

Table 3. RPN calculation of hydraulic oil failure modes

HYDRAULIC SYSTEM FAILURES (HYDRAULIC OIL)				
ID Of Failure Mode	Factors For Failure Evaluation			
	Severity	Occurrence	Detection	General Evaluation (RPN)
1.1	9	9	3	243
1.2	9	9	3	243
1.3	9	9	3	243
1.4	9	9	3	243
1.5	9	9	1	81
1.6	9	9	3	243
1.7	9	9	3	243

The comparisons of RPNs and cumulative percent distributions are inspected in charts shown in Figure 3.

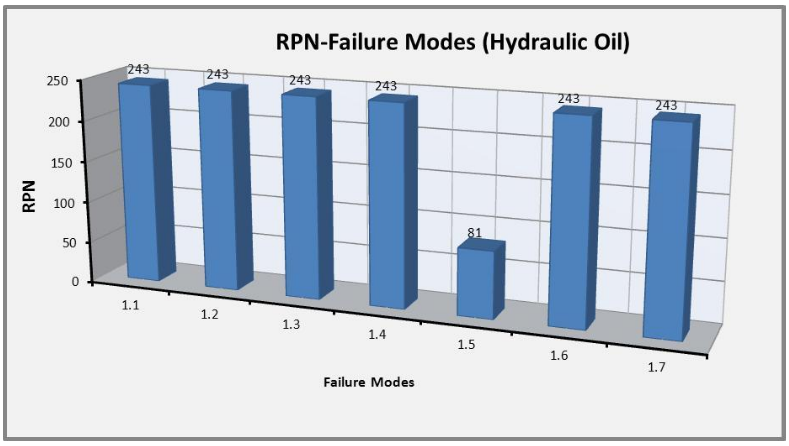

Figure 3. RPN rate charts of hydraulic oil failure modes

The recommended RCM tasks are executed in Table 4. by using the results of RPNs with the reliability based maintenance engineering approach. These tasks indicate the application procedure and time period for eliminating the technical risk level of each related failure mode thanks to numbered failure mode identification.
Condition monitoring of hydraulic oil is the most significant application for improving the reliability of hydraulic oil. The principle is recommended as autonomous daily checks for inspecting the failures at early stages; also application of laboratory hydraulic analysis is programmed for each 3 months for monitoring the condition of the oil and its contents such as lubrication data, viscosity data, water content, additive elements, wear elements. Evaluated results of the analysis avoid the unexpected oil failures; also minimize the technical risk levels of all hydraulic

system components. These cases are the leading tools for increasing the service life of hydraulic equipment.

Table 4. Recommended RCM Tasks

HYDRAULIC OIL MAINTENANCE TASKS			
Maintenance Procedure	**Failure Mode Number**	**Maintenance Task**	**Application Time**
Check the oil temperature	1.1,1.2,1.3,1.4,1.5,1.6,1.7	Autonomus	Daily
Check the oil reservoir level	1.1,1.2,1.4,1.5,1.6	Autonomus	Daily
Check the line oil leakage	1.2,1.4,1.5,1.6	Autonomus	Daily
Replace the oil	1.1,1.2,1.3,1.4,1.5,1.6,1.7	Planned	Yearly
Flush the hydraulic line	1.1,1.2,1.3,1.4,1.5,1.6,1.7	Planned	Yearly
Clean the reservoir	1.1,1.2,1.3,1.4,1.5,1.6,1.7	Planned	Yearly
Change the by pass filter	1.1,1.2,1.3,1.4,1.5,1.6,1.7	Planned	Yearly
Clean the suction filter	1.1,1.2,1.3,1.4,1.5,1.6,1.7	Planned	Yearly
Replace the suction filter	1.1,1.2,1.3,1.4,1.5,1.6,1.7	Planned	Yearly
Hydraulic oil Analysis	1.1,1.2,1.3,1.4,1.5,1.6,1.7	Predictive	3 Months
Filter the reservoir	1.1,1.2,1.3,1.4,1.5,1.6,1.7	Predictive	3 Months

For monitoring the overall technical risk information, the average RPN values of all system components are executed in Figure 4. This brief is the comparison map of risk levels and also used for score board of equipment reliability actions.

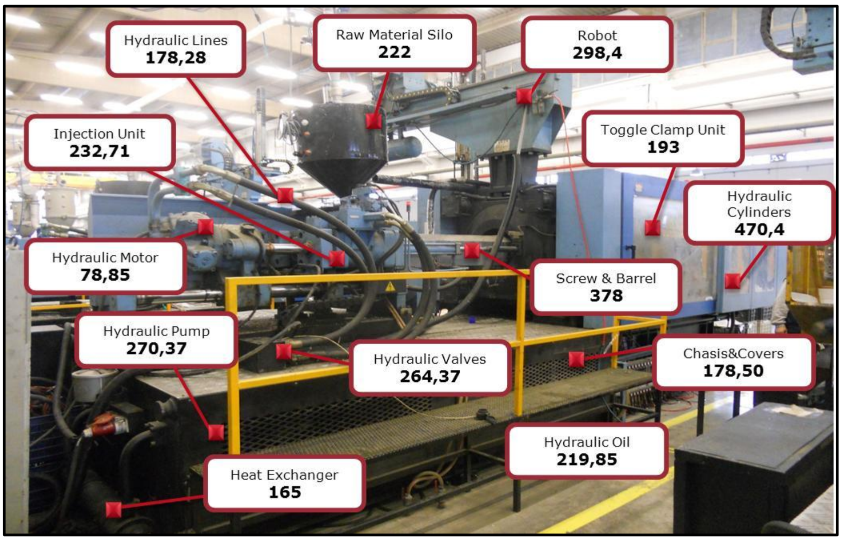

Figure 4. Average RPN results of IMM components

Conclusions

The shop floor of the studied IMMs was monitored by online productivity tracer software, also the productivity results such as downtimes, OEE and Mean Time Between Failures (MTBF) of the machines which are the most functional and consistent values in order to monitor the success of the FMEA supported RCM tasks studies could be calculated and evaluated by this software.

Continuously updates and traced productivity items which are shown in the below tables indicate that the mechanical failures sourced downtime has been decreased more than 60% in last two years, in addition to this, the Mean Time Between Failures have been seen as nearly 50% increased and it demonstrates the rates of the accuracy factors that could have improved in the significant manner. OEE value could have been increased from 64-65 % to 80, 9 % levels, so the results are graphically illustrated as shown in Figure 5.

Meanwhile, these achieved productivity rates have been played important roles for eliminating the operational and maintenance costs, maximizing the life cycle of equipment, efficient management of spare parts and developing the equipment safety.

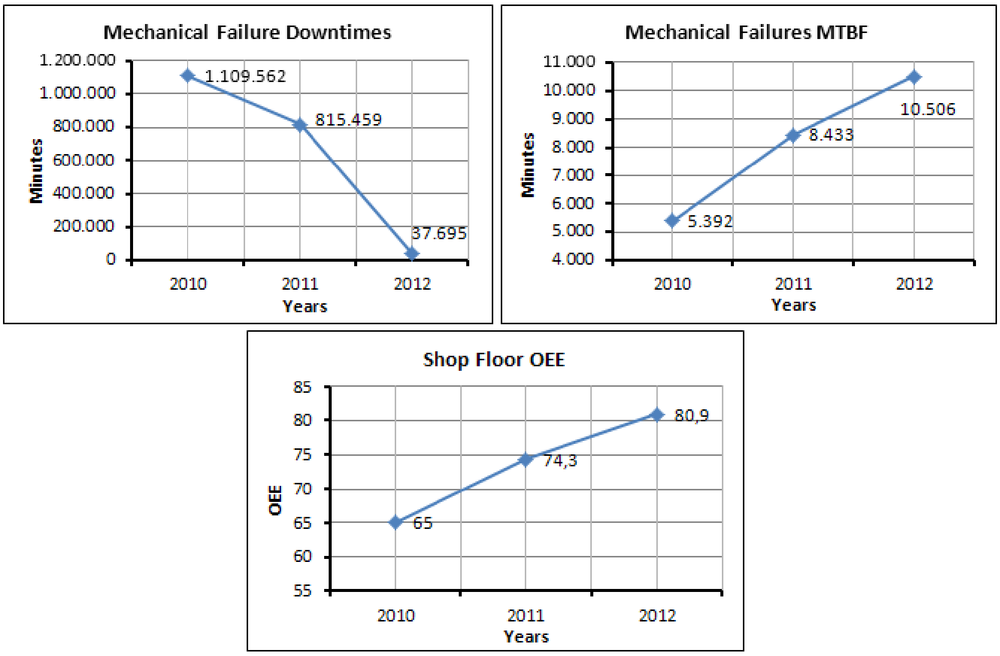

Figure 5. Achieved Productivity Scores

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