JJMIE

Volume 9 Number 4, August.2015
ISSN 1995-6665
Pages 303 - 317

Jordan Journal of Mechanical and Industrial Engineering

Implementation of Systems Engineering Lifecycle-Tools-Model Framework on Large Industrial Scale

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Received 21 Dec 2014 *Accepted 29 Jun 2015*

Abstract

Systems Engineering Lifecycle-Tools-Model Framework (SELTMF), based on integrating ISO/IEC 15288 with seven point of view architecture framework, is presented. The developed framework considers the service oriented point of view in addition to the common points of view suggested in the British Ministry of Defense architecture framework. Studied Key Performance Indicators (KPIs) included financial, internal business, quality, innovation learning and integrated measures. The proposed framework is implemented on the Egyptian Company for Development Industries. The results helped in identifying the problems that face the company at different levels, including production and administration. After the implementation, it was found that the total production time decreased by 52.1% and the total productivity increased by 28.1%.

Keywords: *SELTMF, Lifecycle Analysis, KPIs, Productivity*.

1. Introduction

The application of Systems Engineering (SE) tools is considered an important task to reduce risks associated with the establishment of new systems and/or modifying complex systems. These tools are dependent on system lifecycle simulation and the evaluation of system performance. The identification and inclusion of performance indicators measures is a critical step to ensure that the system evaluation process is reliable. Overall Equipment Effectiveness is one of the performance evaluation methods that are most common and popular in the production industries [1]. Beilei *et al.* [2] discussed an evaluation methodology by considering a documentation matrix which included process flow diagram and value tool documentation to analyze the necessity and redundancy of the process. Ghader *et al.* [3] identified Key Performance Indicator measure (KPI) of the equipment and the production machinery in Idem Company, Tabriz, Iran. František [4] discussed financial KPIs in engineering companies. Overall equipment effectiveness is a kind of measurement tool used in total productive, repair and maintenance and shows how effectively the machinery functions [5, 6].

This work is a continuation of our previous work in which the implementation of total productive maintenance and overall equipment effectiveness evaluation were introduced and the presentation of tools-model framework application in industry was tested [7, 8]. These efforts proved that the framework could be used to improve both the productivity and the economy of the production process. In the present work, the framework is applied to a large-scale industry to identify the problems that face the establishment; then these problems are addressed by proposing changes in the routine work and finally the proposed changes are implemented on the process.

2. Systems Engineering Applications in Varied Fields

The Systems Engineering (SE) is applied to varied fields, such as education, lawmaking, energy, human integrations, etc., as it could be presented in industry or service. Applying SE in education describes or discusses (1) issues which need to be addressed for the creation of curricula and professional degree programs in Service Systems Engineering (SSE) at the graduate level; and (2) the development of an autonomous litter collecting robot as a vehicle for combining several systems design and engineering tools in a real multidisciplinary student project. Clyde and Yacov [9] investigated the needs, requirements, and challenges associated with the academic and professional certification of systems engineers, given the breadth and depth required of them, and especially the

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specific domain knowledge and expertise required supplementing their competence in SE. David [10] applied the methods of SE to the design of the laws of the government. The SE approach brings the knowledge and expertise of investigative science and engineering to bear upon the design, operation, follow up evaluation, and optimization of laws that effectively solve societal problems. The standards have been evolving from the United States (US) Military to international and commercial, with recent standards taking a broader scope. Two capability maturity models have been merged into a third, which is tied to the standards [11, 12].

SE can be applied on all projects: small, large, simple, or complex. The degree of formality and rigor applied to the SE process varies depending on the complexity of the project. This is called tailoring. All projects need to be assessed for the amount of formal SE processes needed. Projects can be tailored up, more formality, for more complex projects as well as tailored down for simpler projects. The SE discipline emerged as an effective way to manage complexity and change. Both complexity and change escalated in our products, services, and society. Reducing the risk associated with new systems or modifications to complex systems continues to be a primary goal of the systems engineer [13, 14].

3. Proposed KPIs

The Proposed KPIs are presented in Figure 1. Evaluation business trends are categorized into five classes: financial, internal business, quality, innovation learning and integrated measures. Proposed KPIs are used to assess the system and compare between the situation before and after applying the systems engineering tools framework (SETF). These measures are applied to the application firm during two periods one before applying the SELTMF and the other one is after the application of this proposed model as an assessment method. Each period is three months, i.e., a quarter of the year (Qtr.), the first Qtr. presents the firm state before applying the proposed SELTMF model and the second Qtr. presents the firm state after applying it.

4. The Proposed SELTMF Model Verification

The proposed model SELTMF presents a framework integrating the main three activities of SE, which contribute to system development in several ways. Simulation of the high level operating concept models can contribute to a deeper understanding of the big picture and the requirements; this puts on the System Of Interest (SOI). Executable models can also serve as a communication tool for different stakeholders to express their needs. An executable model depicting the big picture can also be used to try out alternative concepts; a prototype can, for example, be tested in this virtual operational environment to evaluate to what extent the suggested solutions can fulfill the stakeholders needs. Table 1 illustrates a simple comparison between this proposed model framework to one of the previous model frameworks: Tommy's model framework [15, 16, 17, 18]. Tommy, in his framework, depended on integrating the ISO/IEC 15288 system lifecycle processes and stages as illustrated in Figure 4. He used the architectural framework represented in British Ministry of Defense Architecture Framework (MODAF) with six viewpoints as illustrated in Figure 2, as an architectural tool, for the description of all solutions during a systems lifecycle, and M&S that made Systems Engineering more efficient, as in Figure 4. However, the proposed model of the present research depends on integrating ISO/IEC 15288 system lifecycle processes, stages and SETF, as in Figure 6, to serve at each stage and process for any system lifecycle. Also, developed the MODAF tool to the latest version with seven viewpoints as shown in Figure 3, and recommended the proper tools category for any process or stage during the system lifecycle. The two references made their specific proposed model. Tommy made his model where its pivot is modeling and simulation (M & S), as shown in Figure 6, where the proposed SELTMF model, of the present research, is based on SETF, as shown in Figure 7.

Table 1. Mapping the proposed SELTMF model to another model framework

Comparison Point	Tommy's model framework [19]	The proposed model framework SELTMF [1]
Used tools	Architecture framework (MODAF), and M & S	SE tools template (SETF)
The basic building block	MODAF and M & S	SETF
The standard	ISO/IEC 15288	ISO/IEC 15288
Adopted framework	Architectural framework; MODAF (only 6 viewpoints) See Figure 2	Developed MODAF (7 viewpoints) See Figure 3
System integration	Lifecycle processes and stages See Figure 4	See Figure 5
The main model	The interplay between SOI, ISO/IEC 15288, MODAF and M&S See Figure 6	See Figure 7

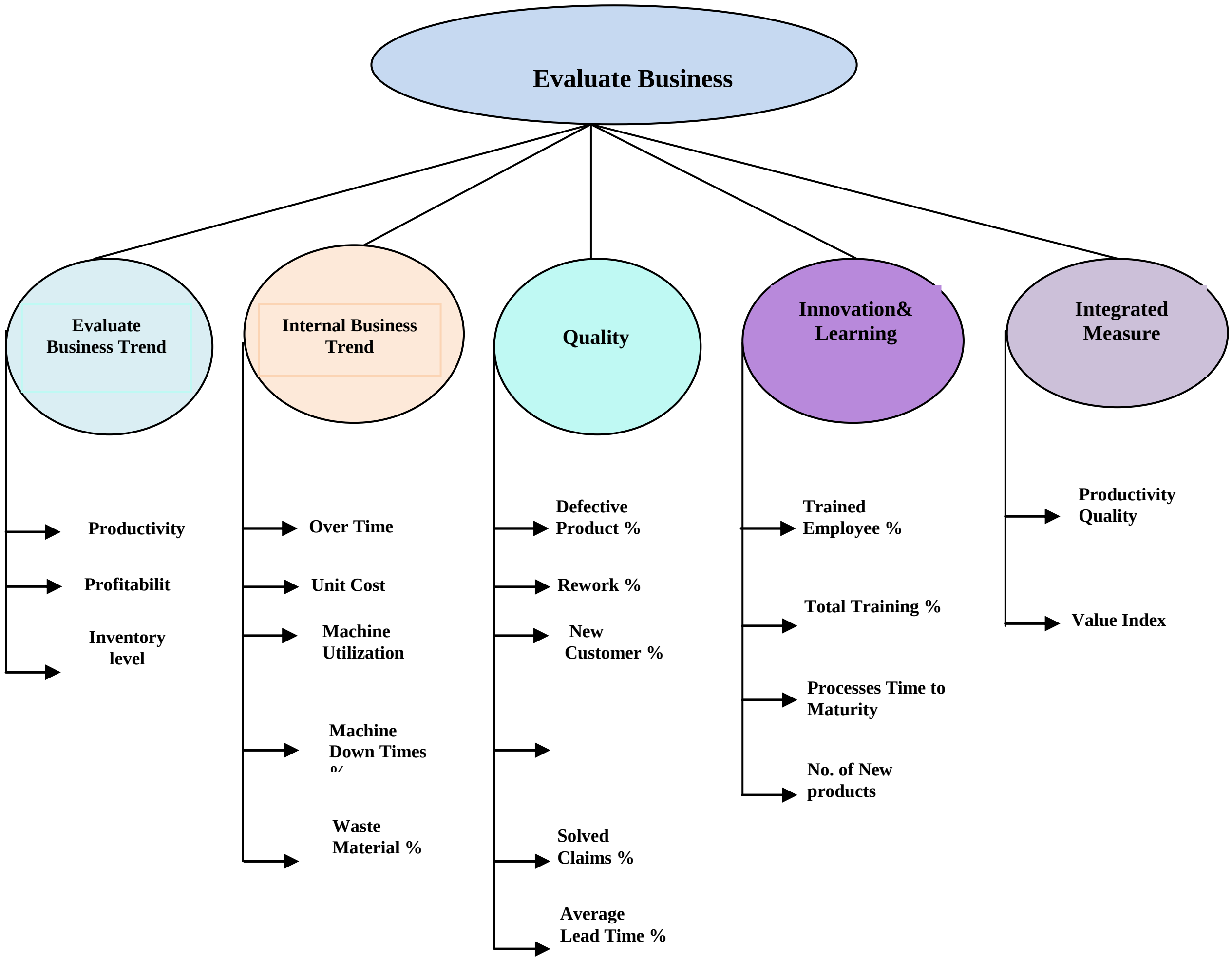


Figure 1. Proposed KPIs

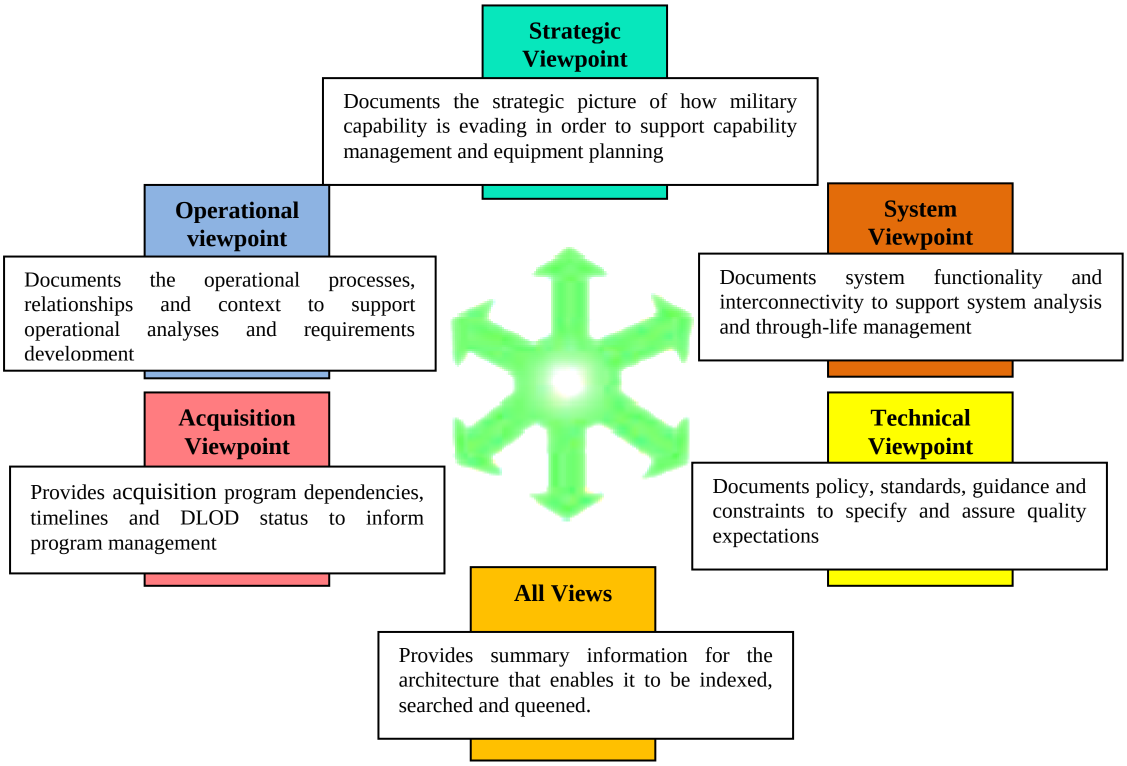


Figure 2. MODAF six viewpoints

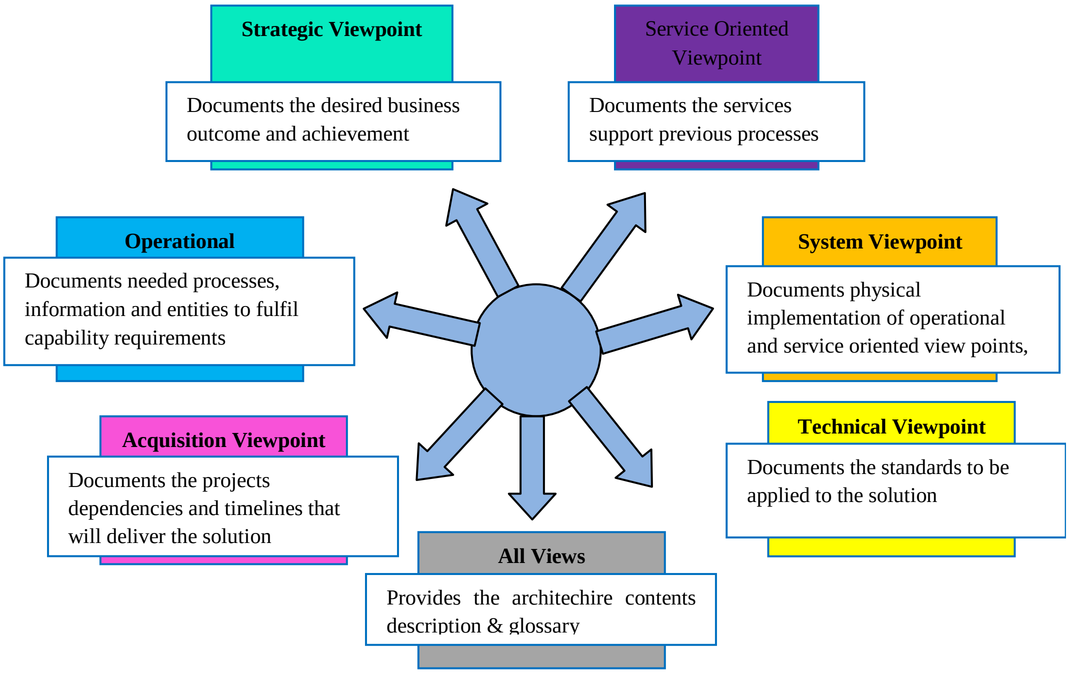


Figure 3. The modified MODAF seven viewpoints and SETF

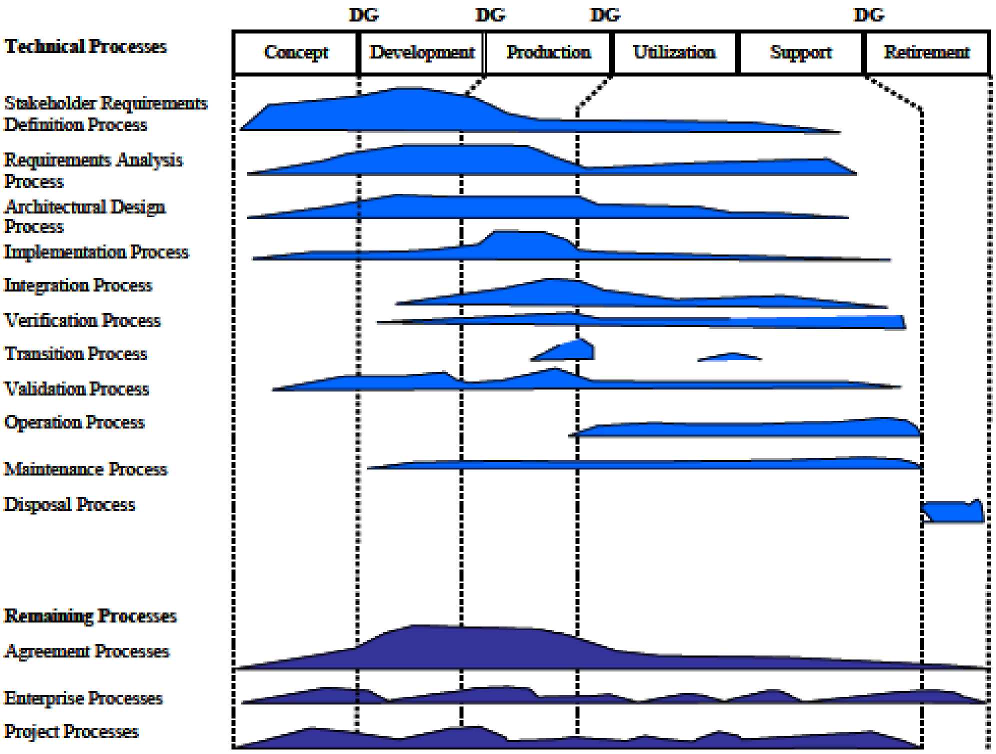
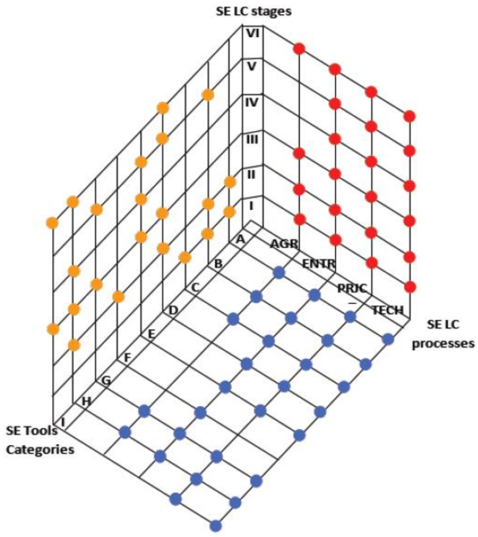


Figure 4. An example of the processes in relation to the lifecycle presented by ISO/IEC 15288



SELC stages:Systems Engineering lifesycle stages.
SE tools catogries: System Engineering Tools Catogreis.
SELC Processes : Systems Engineering lifesycle Processes.
I : Concept.
II : development.
III: Production.
IV: Utilization.
V: Support.
VI: retirement.
AGR : agreement
ENTER: Enterprise.
PRJC : Project.
TECH : Techincal.
A: Brainstorming and generating data.
B: Requrement Gathering and Data Analysis.
C: Creating and Optimizing Solution.
D: SOI Viewing.
E: System Modeling and Development.
F: System Architecture Frameworks.
C: System Elements Interfaces and Functions Relationships.
H: Verification and Deployment.

Figure 5. ISO/IEC 15288 lifecycle and SETF integration

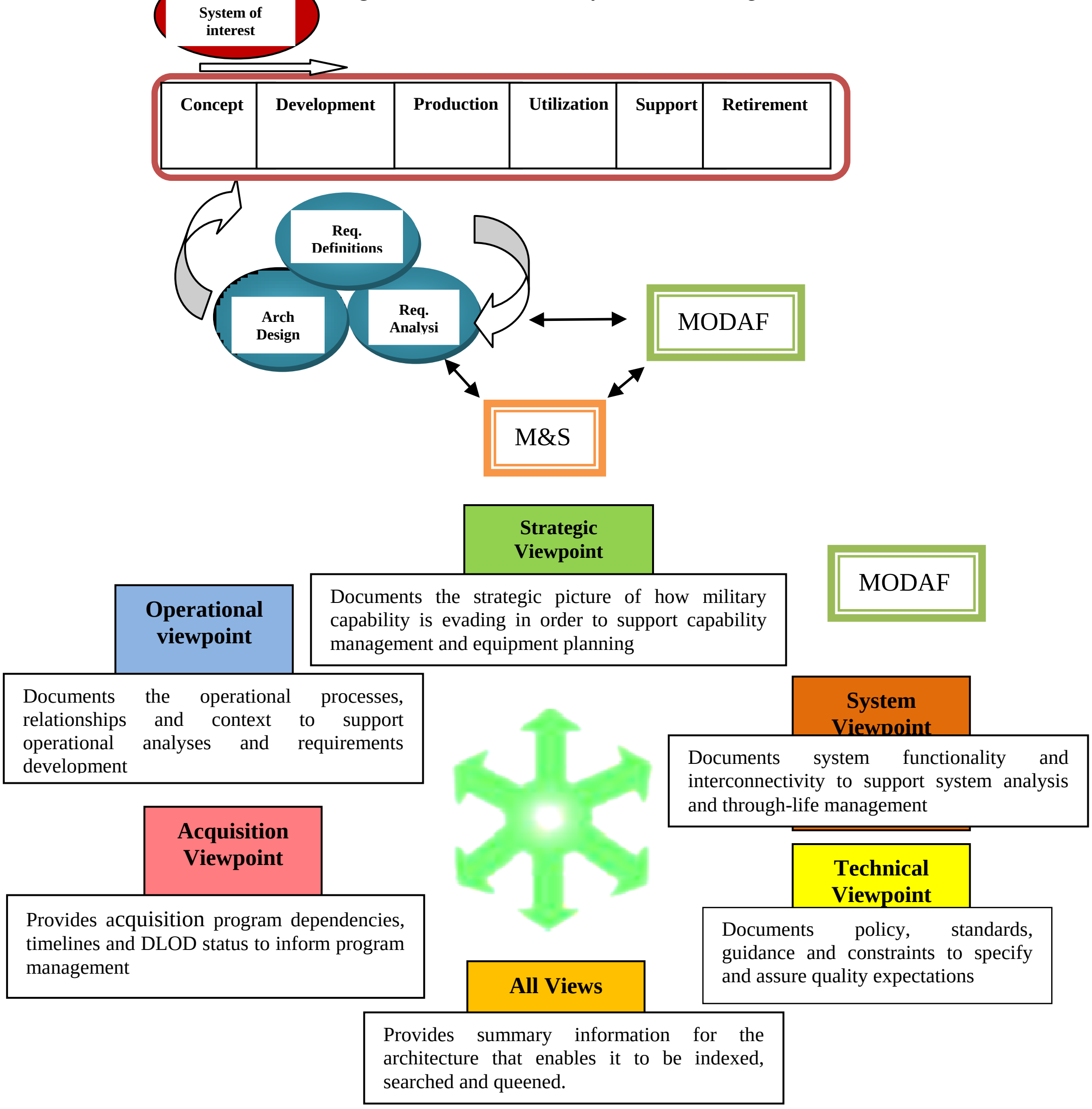


Figure 6: The interplay between SOI, ISO/IEC 15288, MODAF and M&S.

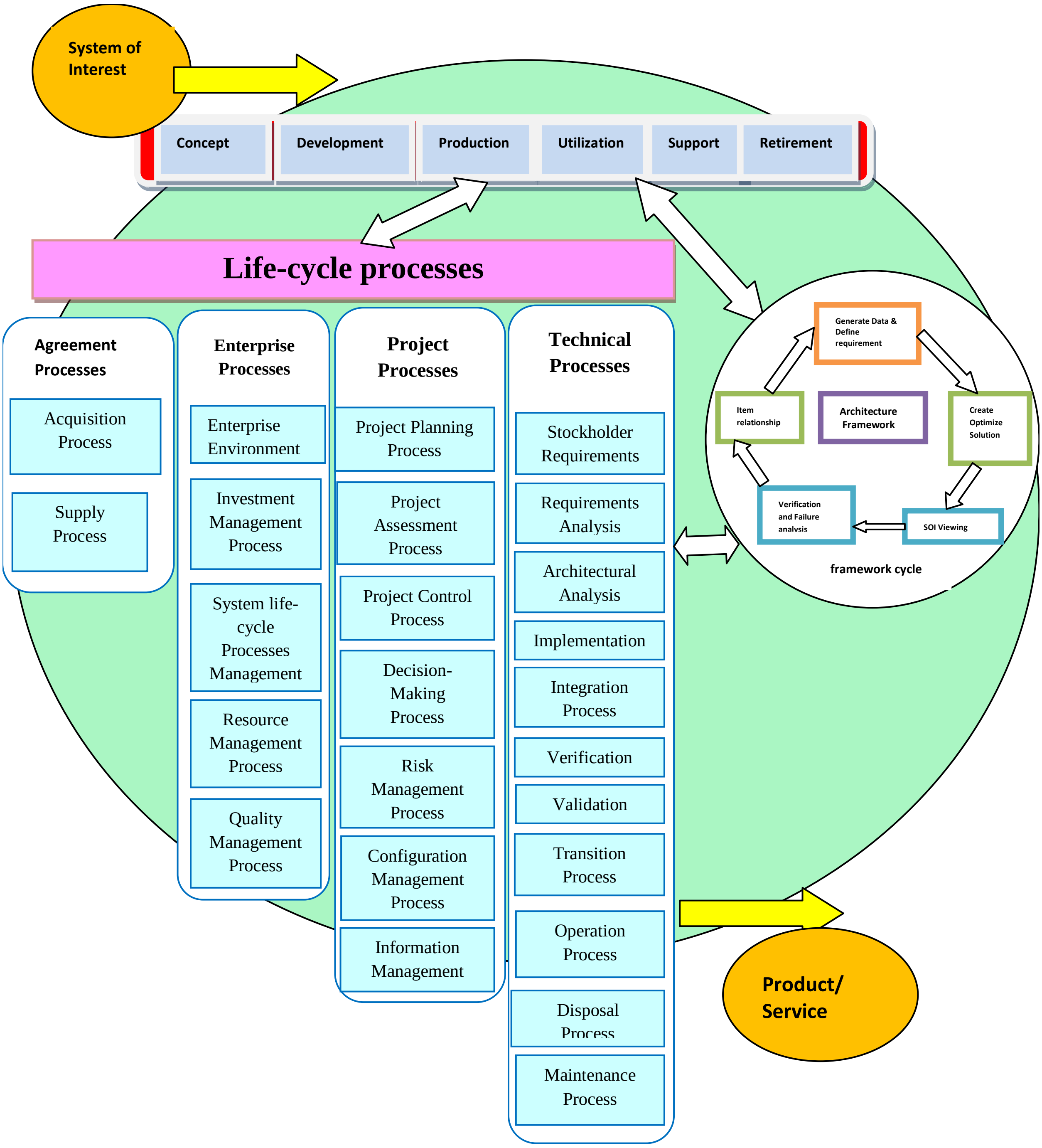


Figure 7. The proposed SELTMF

5. Result and Discussion

The proposed model is applied to an international company for development industries (ECDI); our organization of application has some branches around Egypt for fabricating vehicles metal parts, plastic parts and then delivering to the assembly companies. It is applied to ECDI company system during two quarters (each quarter has three months) one quarter before applying SE tools-model and the second one is after the application of this study. We got the following results. Figure 8 illustrates the average time spent in each main process in the product life cycle for Qrt.1 that presents the previous situation, e.g., before implementing SELTMF model of this research; Figure 9 presents the Qrt.2 state, e.g., after SELTMF model implementation. As shown in Figure 10, a significant decrease in process time of each process of the implemented quarter, Qrt.2, that gives a chance for more system improvement thus finding new businesses, acquiring new customers, increasing products, and increasing profit. Through performance analysis these results are presented in Table 2.

These results show that the increase of input (cost) with increases of output (revenue) consequently increasing material consuming, labor hiring, overtime, concerning products quality, decreasing rework, scrap, M/C downtime, and commitment to delivery time thus fulfillment customer needs and handling its claims properly. As a global result, increasing the number of customers and new products, and definitely increasing the value added as illustrated in Figures 11 up to 32. The analysis of the company performance ensures that due to SELTMF model application, the company started to improve its performance as illustrated by measures. Noticed is the increasing of the firm total productivity by 28.1% as shown in Figure 11. This may be due to the increase of the partial productivity. As shown in Figure 12, the increase of the labor partial productivity is 39.4%.

Moreover, material partial productivity increased by 16.7%, as shown in Figure 13. This may be due to the decrease of the material scrap. The inventory level of raw materials is increased by 40%, as shown in Figure 14. This may be due to the decrease of the material scrap and rework. Consequently, the increase of profit by 66.9%, as illustrated by Figure 15, that is for financial management improvement, takes place. According to internal business improvement, there is an increase by 20% for unit cost, meaning increasing its price, as shown in Figures 16 and Figure 17, illustrating that overtime is the same, but Figure 18 illustrates the significant positive decrease in overall cycle time of the product lifecycle.

On another side, the stability of downtime is given in Figure 19. To improve quality, the defective products percentage decreased as plotted in Figure 20; it must be prevented from the beginning through decreasing rework, as presented in Figure 23. Due to this improvement, the company acquired new customers, as shown in Figure 22, became deliver orders on time as required, as presented in Figure 23, thus the lead time has to be decreased, as shown in Figure 24. Based on improving quality programs, customer claims would be, as soon as possible, solved as illustrated in Figure 25. All this exertion would not be done without a human factor; so they should be update to get different training programs through establishing periodic training programs for all the employees, as shown in Figure 26 and recording each employee training hours by its own training card, as shown in Figure 27. From Figure 28, the total processing time decreased due to decreasing time spent in each process. They are doing the all work thus the company gets new products, as shown in Figure 29. The overall view is clear by measuring global indicators for the whole systems. So, measuring quality-productivity index indicates an increase by 27.6%, as illustrated in Figure 30. Of course, after all this effort, there must be a value added that truly increased by 54.3%, as shown in Figure 31; and if it is compared to the variable costs of material cost, for example, it indicates an increase by 23.8% of the value added percent, as shown in Figure 32.

5. Conclusion

An integrated system engineering framework was developed and tested for its implementation on a large industrial scale; from the results the following pertaining conclusions could be drawn:

- The adopted framework included service-oriented point of view that leads to a deeper understanding of the service requirements and its effect on the process.
- The implementation of the framework to first quarter data of a large-scale company that includes six different processes, indicating that assembly, injection and pre-treatment are the main prolonged processes
- After problem identifications and re-evaluation of the industrial process performance, the process time notably decreased for the six processes and epically for injection and assembly processes.
- The key performance measures were compared before and after the solution of the problems and it was found that the total and partial productivity increased considerably, the percentage of defective products reduced, and added values increased.

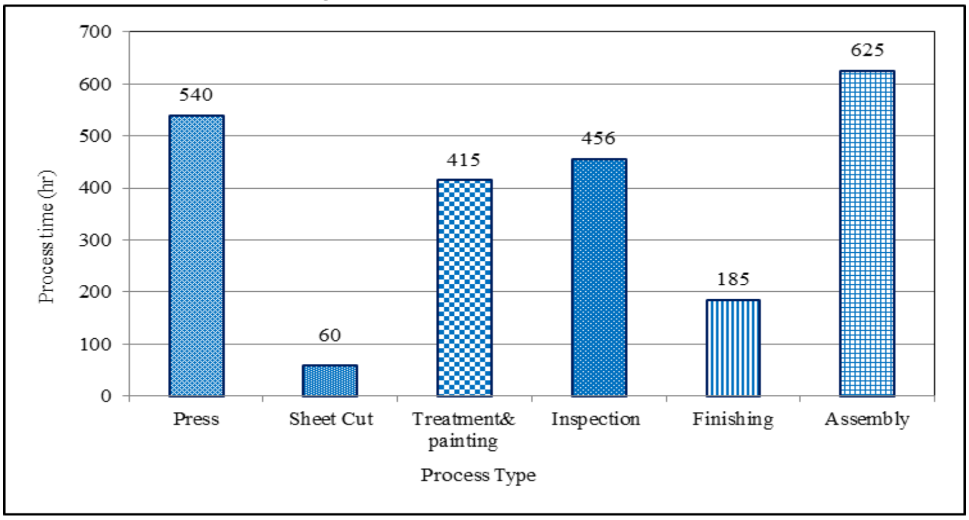


Figure 8. Time spent in each process - Qrt.1 (current) - for ECDI firm

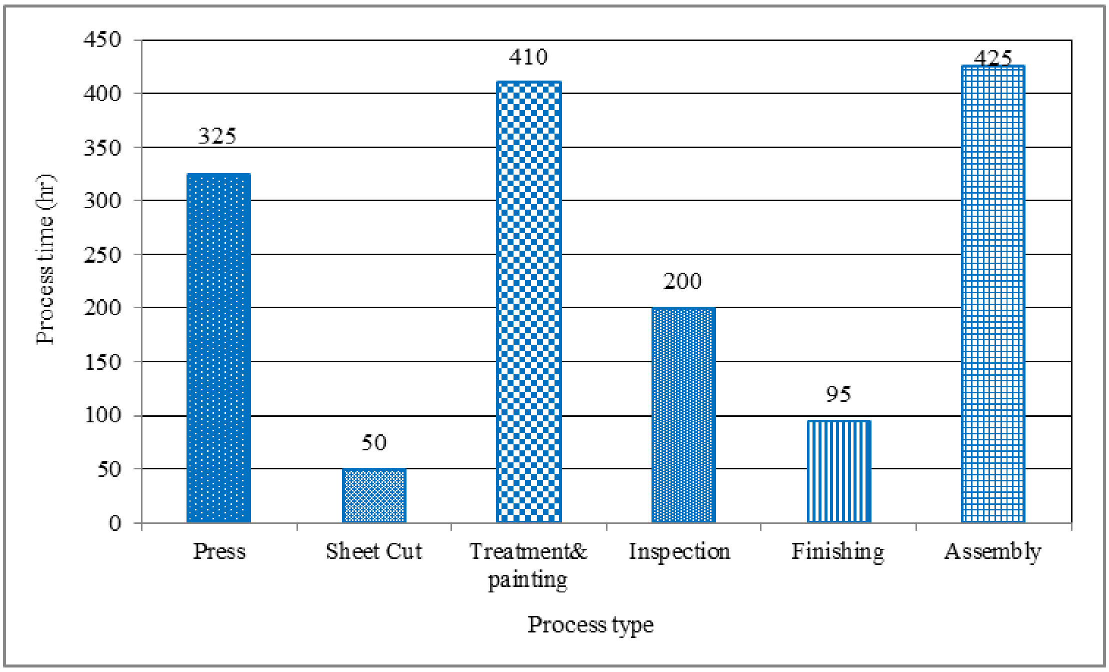


Figure 9. Time spent in each process - Qrt.2 (implemented) - for ECDI firm

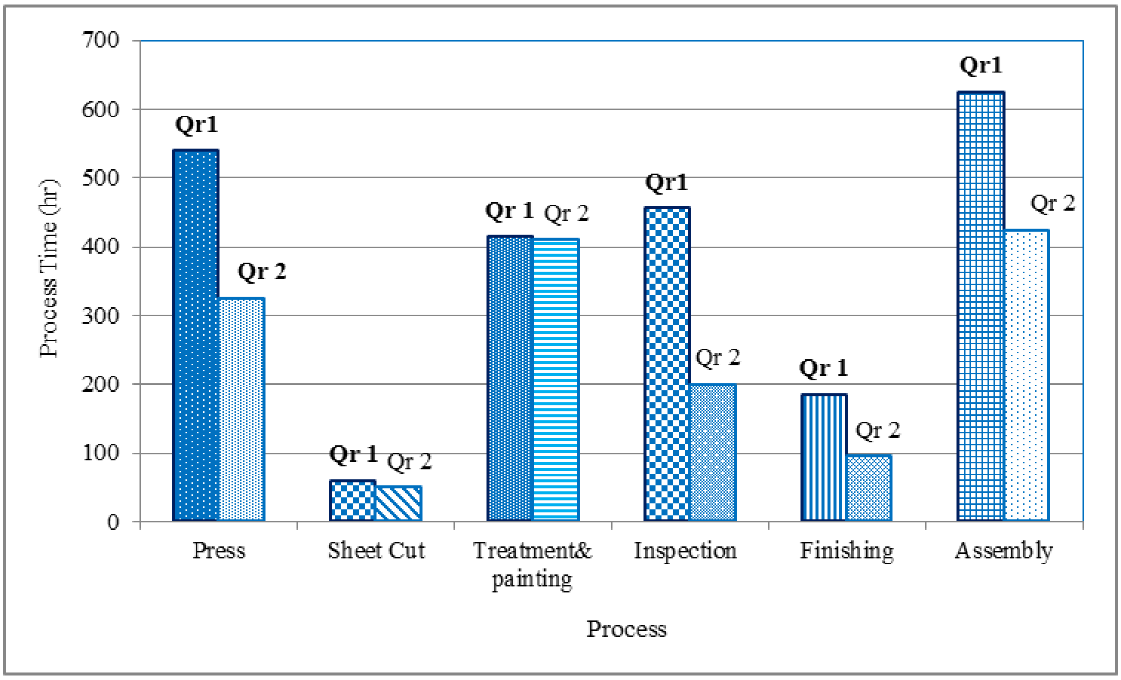
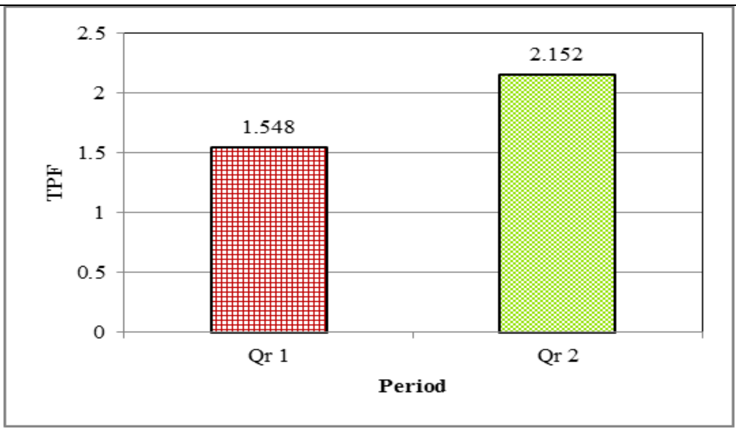
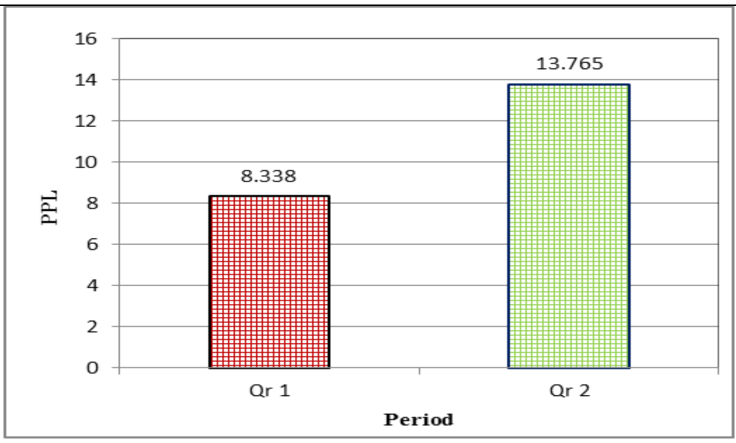
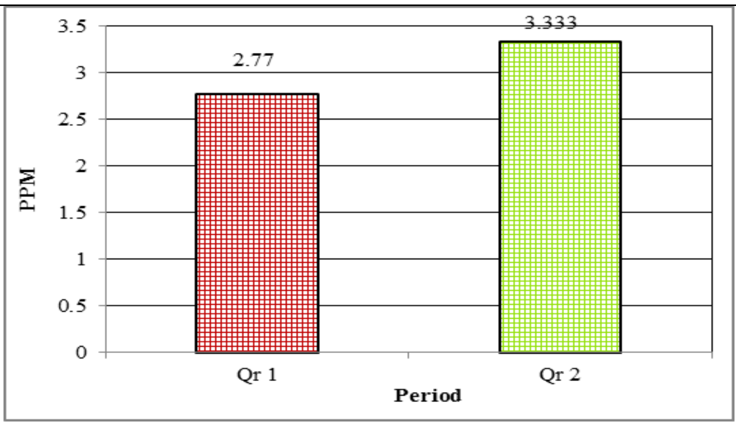


Figure 10. Comparison of time spent in each process for Qrt.1 to Qrt.2 - for ECDI firm

Table 2. KPIs results analysis

Perspective	KPIs	Period of comparison Qrt.1 (current) : Qrt. 2 (implemented)
Financial	Total Productivity of Firm (TPF)	 **Figure 11.** TPF comparison of Qrt.1 & Qrt2.
	Partial Productivity of Labors (PPL)	 **Figure 12.** Labors productivity comparison of Qrt.1 & Qrt.2
	Partial Productivity of Materials (PPM)	 **Figure 13.** Material productivity comparison of Qrt.1&Qrt.2

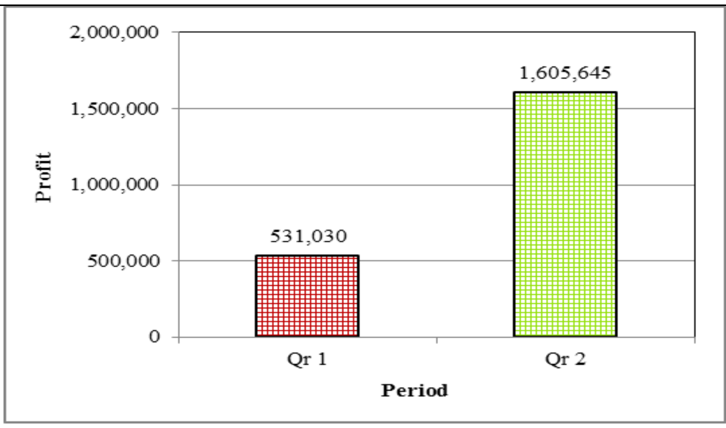
<table>
<tr><td rowspan="2">Perspective</td><td rowspan="2">KPIs</td><td>Period of comparison</td></tr>
<tr><td>Qrt.1 (current) : Qrt. 2 (implemented)</td></tr>
<tr><td rowspan="2"></td><td>Profit (L.E)</td><td>

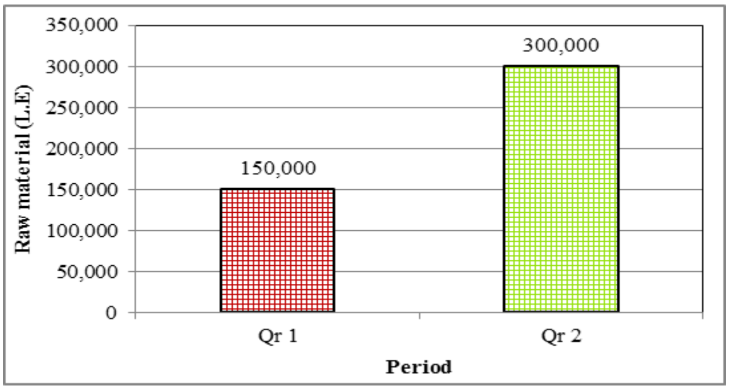
Figure 14. Profit comparison of Qrt.1 & Qrt.2</td></tr>
<tr><td>Inventory Level (Raw material) (L.E)</td><td>

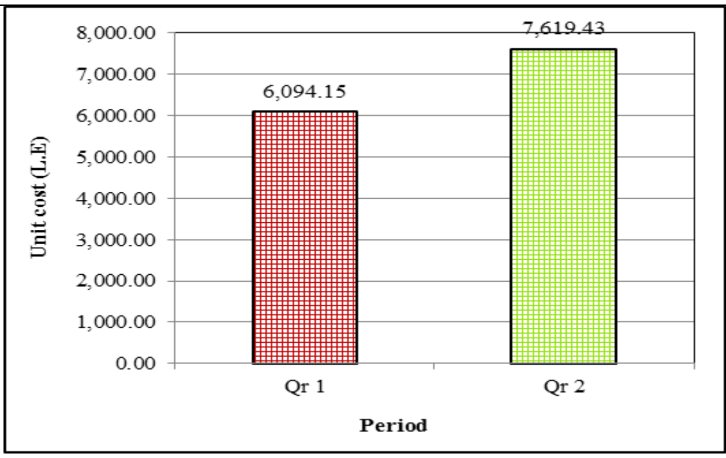
Figure 15. Material inventory comparison of Qrt.1 & Qrt.2</td></tr>
<tr><td>Internal Business</td><td>Unit Cost (L.E)</td><td>

Figure 16. Unit cost comparison of Qrt.1 & Qrt.2</td></tr>
</table>

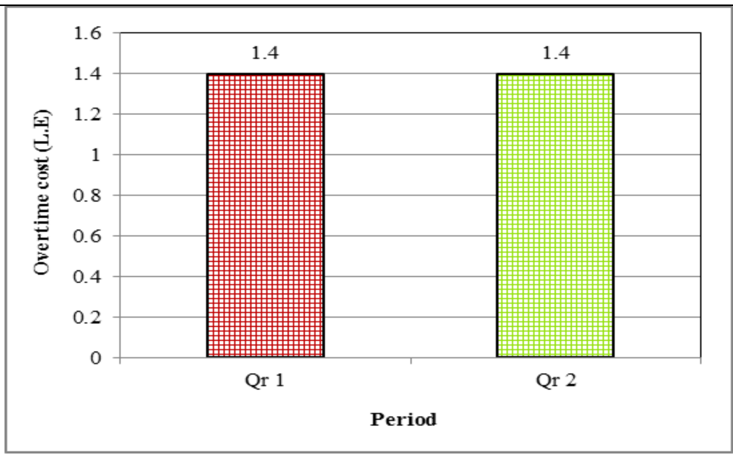
<table>
<tr><td rowspan="5">Perspective</td><td rowspan="2">KPIs</td><td>Period of comparison</td></tr>
<tr><td>Qrt.1 (current) : Qrt. 2 (implemented)</td></tr>
<tr><td>Over Time Cost (L.E)</td><td>

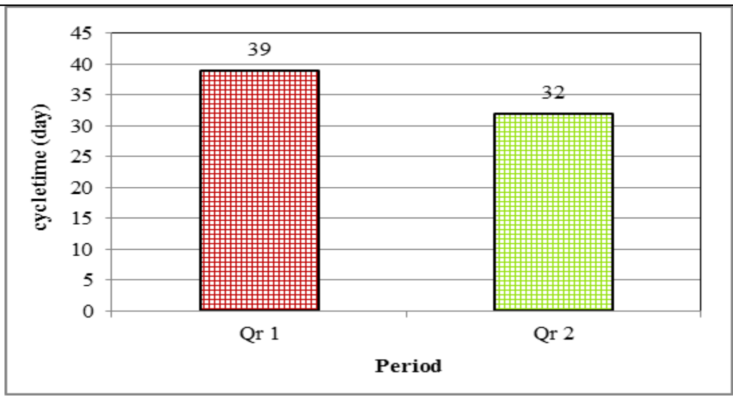
Figure 17. Overtime comparison of Qrt.1 & Qrt.</td></tr>
<tr><td>Overall Cycle Time (day)</td><td>

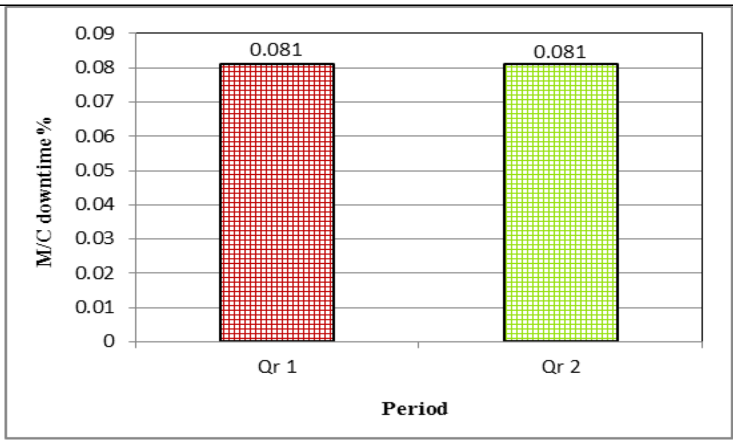
Figure 18. Time cycle comparison of Qrt.1 & Qrt.2</td></tr>
<tr><td>M/C Down Time %</td><td>

Figure 19. M/C downtime % comparison of Qrt.1 & Qrt.2</td></tr>
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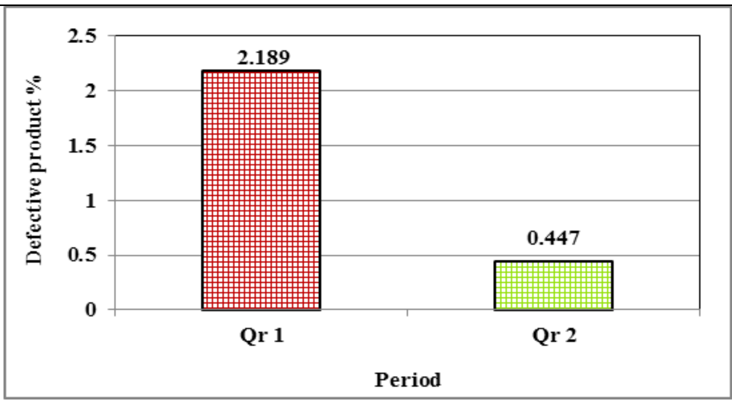
<table>
<tr><td rowspan="2">Perspective</td><td rowspan="2">KPIs</td><td>Period of comparison</td></tr>
<tr><td>Qrt.1 (current) : Qrt. 2 (implemented)</td></tr>
<tr><td rowspan="4">Quality</td><td>Defective products %</td><td>

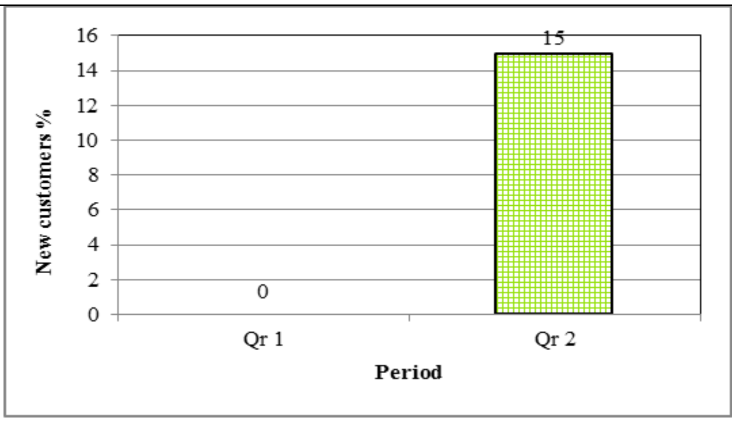
Figure 20: Defective products % comparison of Qrt.1 & Qrt.2</td></tr>
<tr><td>Rework %</td><td>

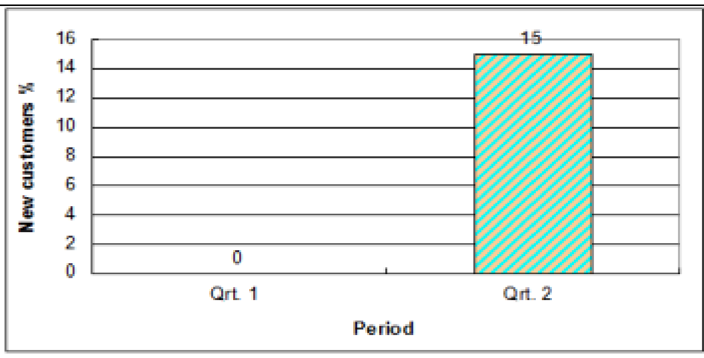
Figure 21. Rework % comparison of Qrt.1 & Qrt.2</td></tr>
<tr><td>New Customers %</td><td>

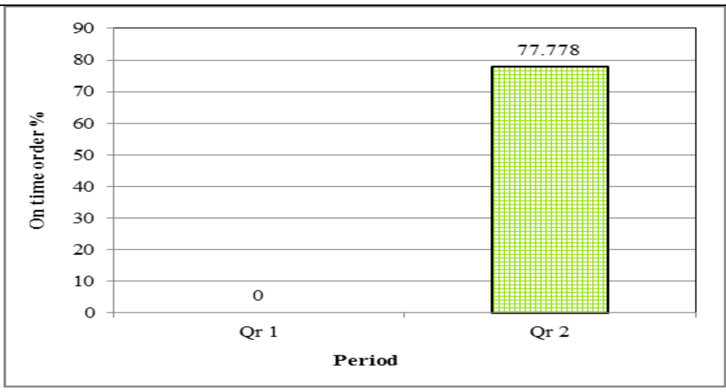
Figure 22. New customers % comparison of Qrt.1 & Qrt.2</td></tr>
<tr><td>On-Time Delivered Order %</td><td>

Figure 23. On-time delivered orders % comparison of Qrt.1 & Qrt.2</td></tr>
</table>

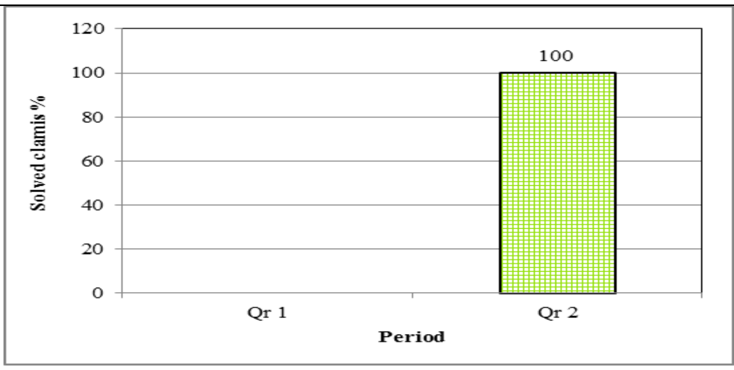
<table>
<tr><th rowspan="2">Perspective</th><th rowspan="2">KPIs</th><th>Period of comparison</th></tr>
<tr><th>Qrt.1 (current) : Qrt. 2 (implemented)</th></tr>
<tr><td></td><td>Solved Claims (Customer Complaints) %</td><td>

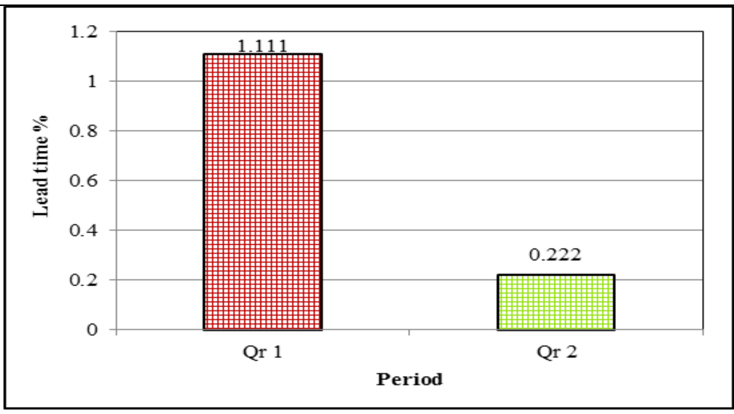
Figure 24. Solved claims % comparison of Qrt.1 & Qrt.2</td></tr>
<tr><td></td><td>Average Lead Time %</td><td>

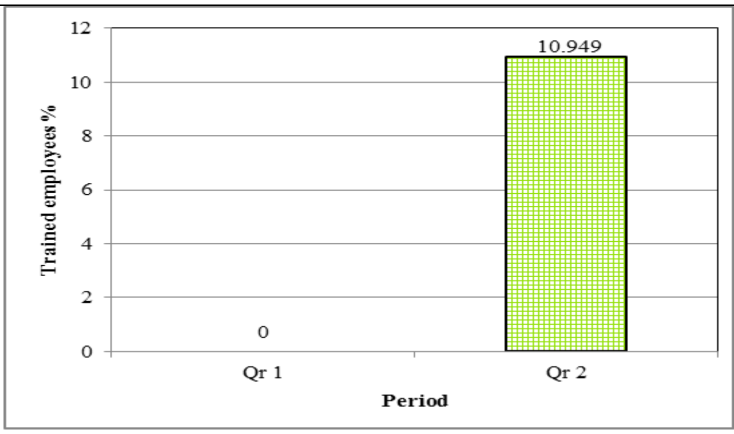
Figure 25. Average lead time comparison of Qrt.1 & Qrt.2</td></tr>
<tr><td rowspan="2">Innovation & Training</td><td>Trained Employees %</td><td>

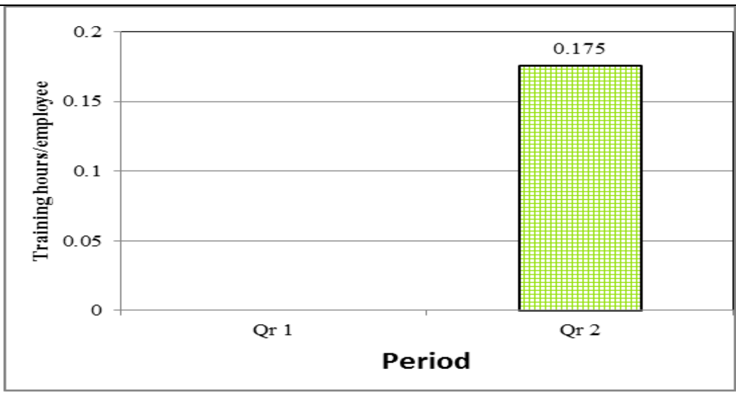
Figure 26. Trained employees % comparison of Qrt.1 & Qrt.2</td></tr>
<tr><td>Total Training hours / employee</td><td>

Figure 27. Total training hours / employee comparison of Qrt.1 & Qrt.2</td></tr>
</table>

<table>
<tr><td rowspan="2">Perspective</td><td rowspan="2">KPIs</td><td>Period of comparison</td></tr>
<tr><td>Qrt.1 (current) : Qrt. 2 (implemented)</td></tr>
<tr><td rowspan="2"></td><td>Process time to maturity (hr)</td><td>

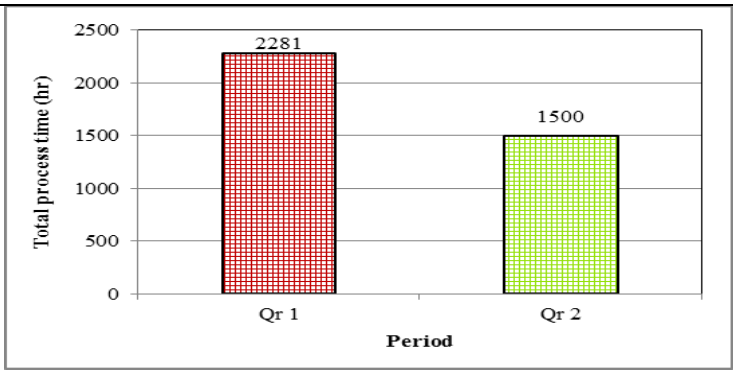


Figure 28: Total spent time in processes comparison of Qrt. 1 & Qrt. 2</td></tr>
<tr><td>No. of New Products</td><td>

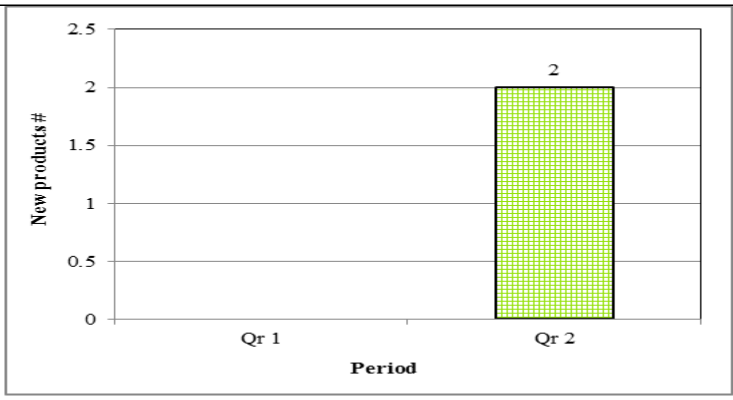


Figure 29. No. Of new products comparison of Qrt.1 & Qrt.2</td></tr>
<tr><td rowspan="2">Integrated Measures</td><td>Quality-Productivity Index</td><td>

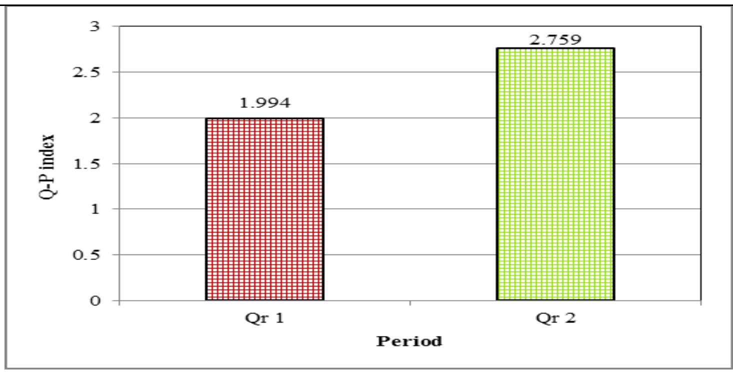


Figure 30. Quality-Productivity index comparison of Qrt.1 & Qrt.2</td></tr>
<tr><td>Value Added (VA) (L.E)</td><td>

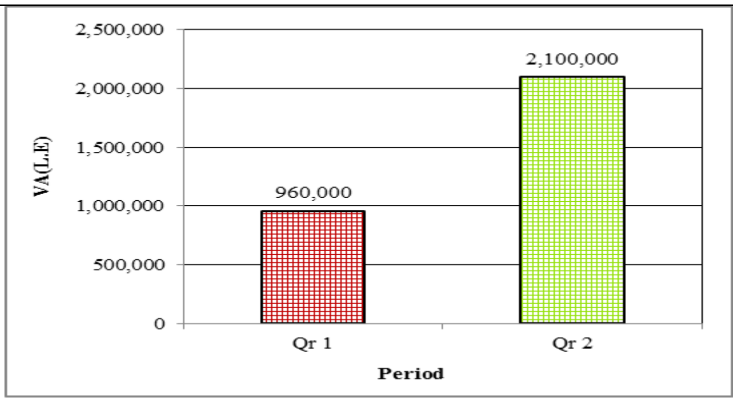
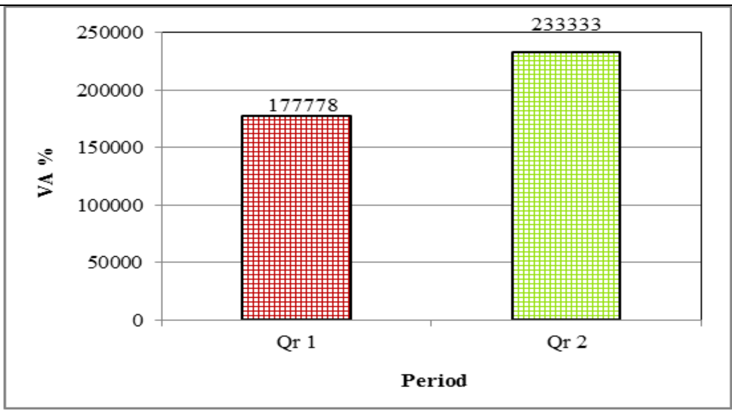


Figure 31. VA comparison of Qrt.1 & Qrt.2</td></tr>
</table>

Perspective	KPIs	Period of comparison
		Qrt.1 (current) : Qrt. 2 (implemented)
	Value Added %	 **Figure 32**. VA % comparison of Qrt.1 & Qrt.2

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