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EDITORIAL PREFACE

JJMIE had another great year. We have seen a significant increase this year in articles submission. The JJMIE editorial board members have been very busy throughout the year to maintain the quality of JJMIE publications. The board has kept the tradition of excellence in quality publication for accepted papers. As a result of this effort, JJMIE has been indexed by Scopus Elsevier and EBSCO.

As in prior two years, this sixth volume of JJMIE will include six issues, twelve manuscripts in each issue. In the coming year, it is my vision to have JJMIE publishes more outstanding manuscripts from distinguished scholars in the areas of mechanical and industrial engineering. In addition to that I will be working on the inclusion of JJMIE in ISI, which will lead to a good impact number. As you read throughout this inaugural volume of JJMIE, I would like to remind you that the success of our journal depends directly on the number of quality articles submitted for review. Accordingly, I would like to request your participation by submitting quality manuscripts for review and encouraging your colleagues to submit quality manuscripts for review. One of the great benefits we can provide to our prospective authors, regardless of acceptance of their manuscript or not, is the mentoring nature of our review process. JJMIE provides authors with high quality, helpful reviews that are shaped to assist authors in improving their manuscripts.

I would like to thank the JJMIE International Advisory board members for their continuous support of JJMIE. Furthermore, I would like to thank the JJMIE Editorial Board members for their exceptional work and continuous support to JJMIE. Separately, I would like to thank my assistant to the editor-in-chief, Ahmed Al-Ghandoor, the Hashemite University, for his continuous assistance. Moreover and as in prior years, I would like to highlight and proudly thank for the group of outstanding reviewers, throughout this past year, you all have done an amazing work, we’re honored to have you on our review list and for the valuable contributions you provided to authors. Your mentorships and substantial review comments to authors of all articles worthy of JJMIE review are what made JJMIE reached this remarkable rank among other international journals.

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Verification of New Sampling Methods On Small Scale Free Form Surfaces

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Abstract

The three recently developed algorithms by Obeidat and Raman in 2009 for sampling free form surfaces are applied on small scale parts created using milling machine. The three proposed algorithms and the two existing algorithms (equiparametric approach, and the patch-size-based sampling method) are applied in sampling the measuring points. A Browne & Sharpe MicroVal PFX™ 454 CMM was used in the measuring process. The comparison between the five algorithms shows that a reduction in the number of points of 73% with reduction in the accuracy of 7.5 % can be achieved in very complicated surfaces. A low inspection time is achieved using the proposed algorithms.

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Keywords: CMM; Inspection; Free Form Surfaces; Adaptive sampling; patch sampling; small scale parts sampling

1. Introduction

Sampling is a fundamental step in measurement. To verify that the part within tolerances specified, an inspection process is necessary. To accept the part or reject it, you need some criteria. One of the most important criterions is verifying that the part is close enough from the designed model. All parts created using any kind of manufacturing processes have errors; those errors need to be revealed using one of inspection methods, such as Visual inspection, scanning methods by laser, by X-Ray, by Coordinate Measuring Machine (CMM) or using any other convenient way.

For this purpose, the algorithms developed by Obeidat and Raman [1], applied on theoretical proposed Free Form surfaces, are applied in this work on actual created surfaces. In the proposed algorithms, Obeidat and Raman [1] assumed that there is a theoretical error on the surface and they proposed that error is affected by the curvature of the surface being created and then they made a comparison between the three proposed algorithms and the existing ones. In this work, the error is actual. Some free form surfaces are created using milling machine, and those surfaces are small compared to the surfaces used by obeidat and Raman[1], so the manufacturing parameters effect on the dimensional error is high, so the effect of the surface curvature is more on the manufacturing error in this case. The created surfaces were made using CNC milling machine. AL 7075-T6 was used as a workpiece material, and a HSS ball end mill cutter of diameter 0.5 inch was used. The parameters used in making those parts are the same in all parts to be easier in comparison between the tolerance zones: step over: 0.025 inch, cut angle: 180°, spindle speed: 7500 rpm, and the cut type was climb cut type.

The three proposed algorithms by Obeidat and Raman [1] and the two existing algorithms (equiparametric and the patch-size-based sampling techniques) are applied in sampling the measuring points. In milling operation, the cutter affects the surface by cutting force, and so the surface affects the cutter by a force in the opposite direction resulting in a cutter deflection as shown in Figure 1 .This deflection is proportional to the surface gradient in the direction of the cutting operation. There is an effect from the gradient of the surface in the vertical direction to the cutting direction but that effect is very small compared to the gradient in the cutting direction. Hence, the effect of the gradient that is significant is the gradient in the direction of the cutting operation.

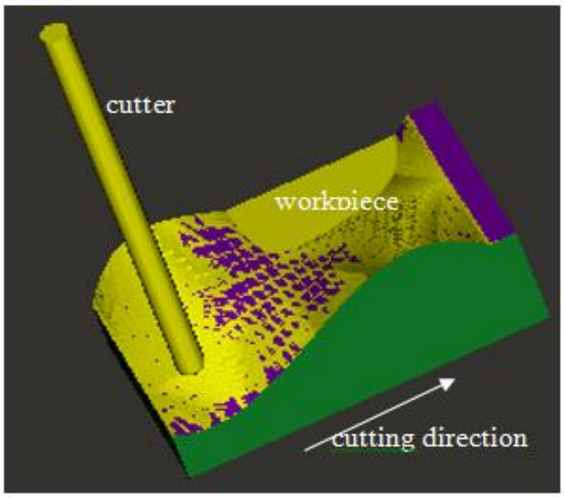

Figure 1: Free form surface created using end milling.

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Based on the proposed algorithms by Obeidat and Raman [1], in inspecting free form surfaces, critical points are obtained. The critical points are ranging from the points of highest Gaussian curvature to the points of the mean Gaussian curvature. And so, one of our objectives in this work is minimizing the number of inspection points using the critical points that represent the surface accurately.

2. Coordinate Measuring Machines

Measurement of free-form surfaces is a very critical issue because of the shape ,complexity, the lack of adequate datums and the large number of measurements that is needed to accurately represent free form surfaces, Ristic et al. [2]. Before inspection process, an alignment between the machine coordinate and the part to be inspected is made. this process has been studied by many researchers. Li and Gu [3] developed an automatic system that performs general localization and point – point localization between the measured part and the design model. Huang et al. [4] created algorithms for 3D feature localization and quantitative comparison. They applied their algorithms on free form surfaces. They created a very effective pseudoinverse algorithm for the localization process for two free form surfaces that are created using measurement data. Ainsworth et al. [5] developed an inspection system that depends and employs at each step of an inspection process the CAD model. Their system consists of a registration process, defining the measurement points on the surface, probe path generation, path optimization and verification and probe radius compensation. In the sampling process some sampling criteria have been used such as: uniform sampling, chord length, maximum sample density of the sampling points on the surface, and parameterization-based sampling criteria. Pahk et al. [6] developed an integrated precision inspection system for manufacturing molds that has CAD defined features. In their system they used a CAD environment to choose the feature to be inspected and then an inspection planning for each feature is performed. Some sampling techniques are used in their system, such as: uniform distribution, curvature dependent distribution and hybrid distribution of the two depending on the complexity of the sculptured surface.

All measurement processes have some extent of uncertainty, Feng et al. [7]. Many researchers have studied the factors that affect uncertainty in coordinate measuring machines and how that uncertainty can be reduced ((Schwenke et al.[8]), (Weckenmann et al. [9]), (Edgeworth and Wilhelm [10]), and (Shen and Duffie [11])), studied the factors that affect the measurement process.

The measurements obtained using the CMM include the manufacturing error, CMM errors and the measurement errors which include the errors in measuring the probe diameter, the error in measuring the probe length, etc.

In this study, the CMM error will not be detailed, nor the localization process. The manufacturing error is the most significant factor in this work.

3. Inspection Path Planning

Modern manufacturing can be characterized by low-volume, high variety production and close tolerance high quality products, Diaa et al. [12]. For any product there is a need for an inspection plan which is suitable for a specific part and its complexity. Yau and Menq [13] stated that, to achieve higher automation level in dimensional inspection, an intelligent and computer integrated inspection environment is needed. Hence, the inspection plan should be integrated with that system to ensure high accuracy. Many researchers have worked in the area of computer aided inspection planning. Consequently, many algorithms for computer aided inspection planning using CMM have been proposed. Some of them are detailed here.

Lin and Murugappan [14] developed a new algorithm for optimum collision free CMM probe path. In this algorithm ray tracing technique was used to detect the collision of the probe with the part. This algorithm used a mechanical desktop and its run time extension (ARX) as the application programming interface, which runs on Windows NT 4.0 platform. This algorithm used a querying CAD data base for the part geometry. This algorithm is useful in simple prismatic solids but doesn’t work for solids with curved surfaces and free form surfaces.

Chan and Gu [15]developed an object oriented inspection plan (OOIP) to be used as a tool for integration of CAD and CMMs using knowledge - based system techniques. They introduced some tools that can be used to classify inspection items into manual and machine inspection based on feature geometry and tolerance type. Some features or tolerances not crucial in terms of tolerances or are not economical when inspected by CMM, are inspected manually. Ketan et al. [16] generated automated inspection process plans based on feature based (FB)-computer aided inspection planning. They developed a computer internal model for a product to achieve direct integration between CAD and CAIP without requiring interface communication system. From this system they developed an NC code which can be generated for inspection process for only prismatic parts. Limaiem and Elmaraghy [17] used the Dijkistras shortest path algorithm combined with collision detection routines to develop a path planning module. Fan and Leu [18] introduced an integrated system for intelligent inspection path planning of CMM probes for feature-based objects for three types of surfaces: planar, cylindrical and conical. They developed a system that generates the measuring points automatically by linking with AutoCAD modeling of the surface model. They used a swept-volume method for probe collision detection and they developed a program to generate the measuring points of an object created by AutoCAD. A technique for collision detection and avoidance was created. Marefat and Kashyap [19] also developed an inspection planning program based on a CAD model. The information about the part including its edges, faces, slots and holes were extracted from the CAD model. They developed an interface between the CAD model and the inspection system. Tannock et al. [20] developed a Computer Aided Inspection Work station (CAIW) approach to shop-floor inspection. It is low-cost and more flexible than the systems based on (CMMs). In (CAIW), an intelligent Inspection Planning System (IPS) was developed. Detailed inspection plans can be generated. By (IPS) and (CAIW) inspection plan procedures, selection of the instruments, gauges and fixtures instructions, and on - screen graphics can be performed. IPS is different from systems that use (CMMs) because by (IPS) the information about the part geometry, nominal and tolerance attributes can be conveyed directly, while in the systems based on (CMMs) (DMIS) is used to convey the information about the part to (CMM). Merat and Radack [21]introduced an automated inspection planner that depends on the linking between geometric dimensioning and tolerancing (GD&T) feature class and an Inspection Plan Fragment (IPF). Tang and Davies [22] developed an inspection planning system called (INSPEX) based on knowledge transmitted from CAD systems. Fan et al. [23] developed software called "Auto Probe" to create the measurement path of the Probe. Also, they developed a software called "Auto-Wire" to create 3D-wireframe view of the part from its 2D projection views. From the 3-D wire frame created by "Auto-Wire", "Auto Probe" can be used to create the probe path by mouse, keyboard or a digitizer. Spitz et al. [24] introduced an algorithm for high level inspection planning using CMMs. High level planning means "to determine how to setup the work piece on the CMM table, which surfaces to inspect in each set up, which probes to use, and how to orient those probes". Menq et al. [25] introduced a method for determining the actual measured points by CMMs. This method was called optimal match algorithm.

Caulier and Bourennane [26] presented a general free-form surface inspection approach depending on the projection of a structured light pattern and the interpretation of the generated stripe structures by means of Fourier-based features. Xu and Li [27] presented a new way to match the coordinate system of measurement with CAD coordinate system.

4. Inspection Path Planning

Sampling is used to specify the number and the location of measuring points that give the best representation of the created surface, Obeidat and Raman [1].

In this paper three actual milled surfaces are used to demonstrate the methodology developed by Obeidat and Raman [1]. A comparison between those strategies and Equiparametric and patch size - based techniques, is performed.

The two well-known sampling methods for free form surfaces that were derived from literature to create a basis for comparison with the three sampling methods are:

1) Equiparametric Sampling: This method, as explained by Elkott et al. [28] distributes the sample points equally in the u-v space. It is simple and easy to apply. It is good for simple surfaces that do not have significant changes in curvatures. It is also insensitive to surface complexities such as sharp curvature changes and unequal surface-patch sizes. The algorithm is explained in figure 2.

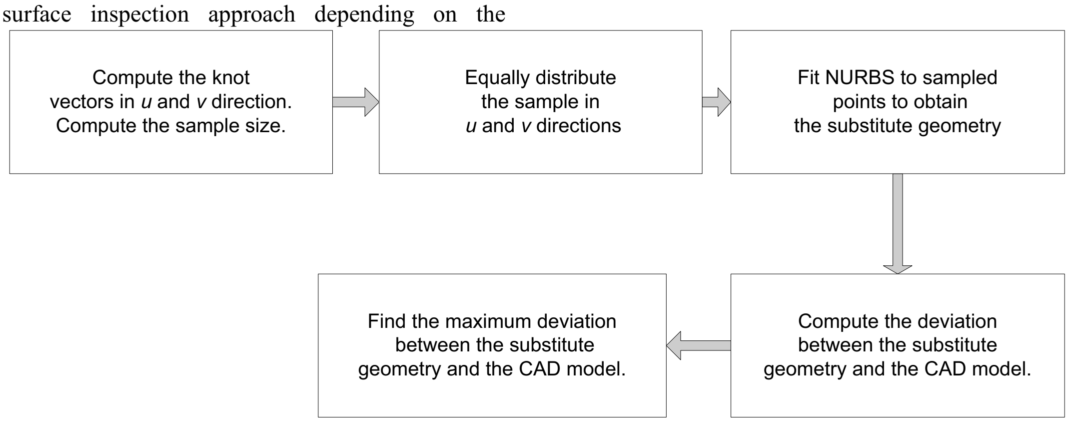

Figure 2: Flow diagram of the equiparametric sampling technique.

2) Patch size-based sampling: this method, as explained by Elkott et al. [28], divides the surface into its patches based on the knot vector. These patches are ranked based on their sizes, and the points are distributed based on the patches ranking, where the patch of higher rank has a high number of points proportional to its size. In this algorithm the very small patches are ignored which might have important variations in the surface curvature. Figure 3 explains the flow diagram of this sampling algorithm.

The three surfaces used for demonstration are different in complexity. Specific points are sampled using the developed algorithms by Obeidat and Raman [1]. NURBS are used to fit the data to obtain the substitute geometry from which the maximum difference between this resulting surface and the CAD model surface is obtained. The algorithms used are shown in figures 4, 5, and 6.

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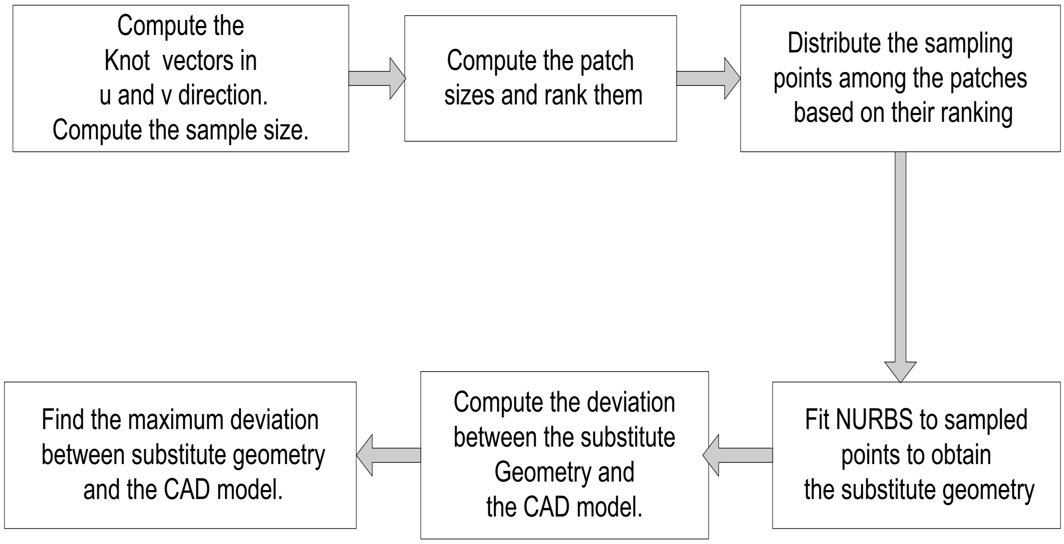


Figure 3: Patch size-based sampling flow diagram.

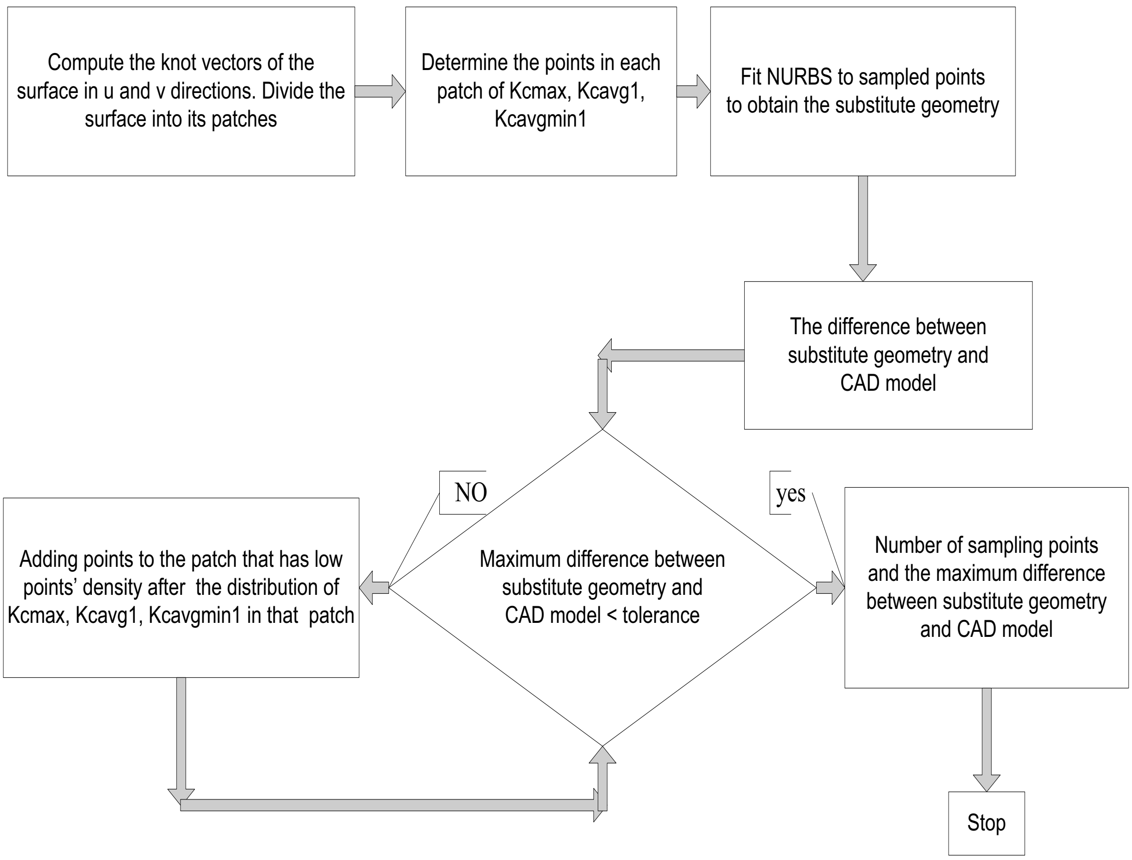


Figure 4: First algorithm, Obeidat and Raman [1]

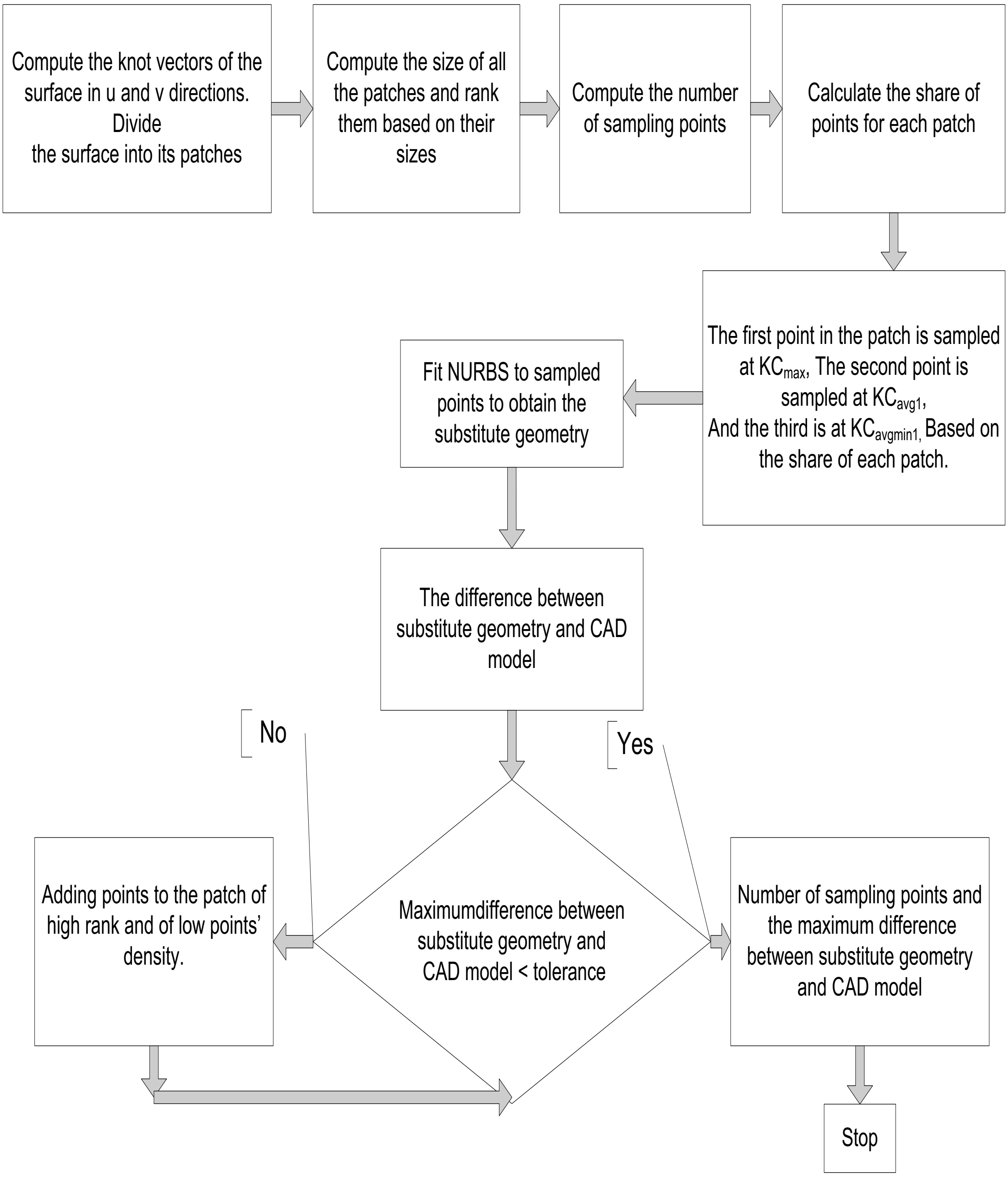


Figure 5: Second algorithm, Obeidat and Raman [1]

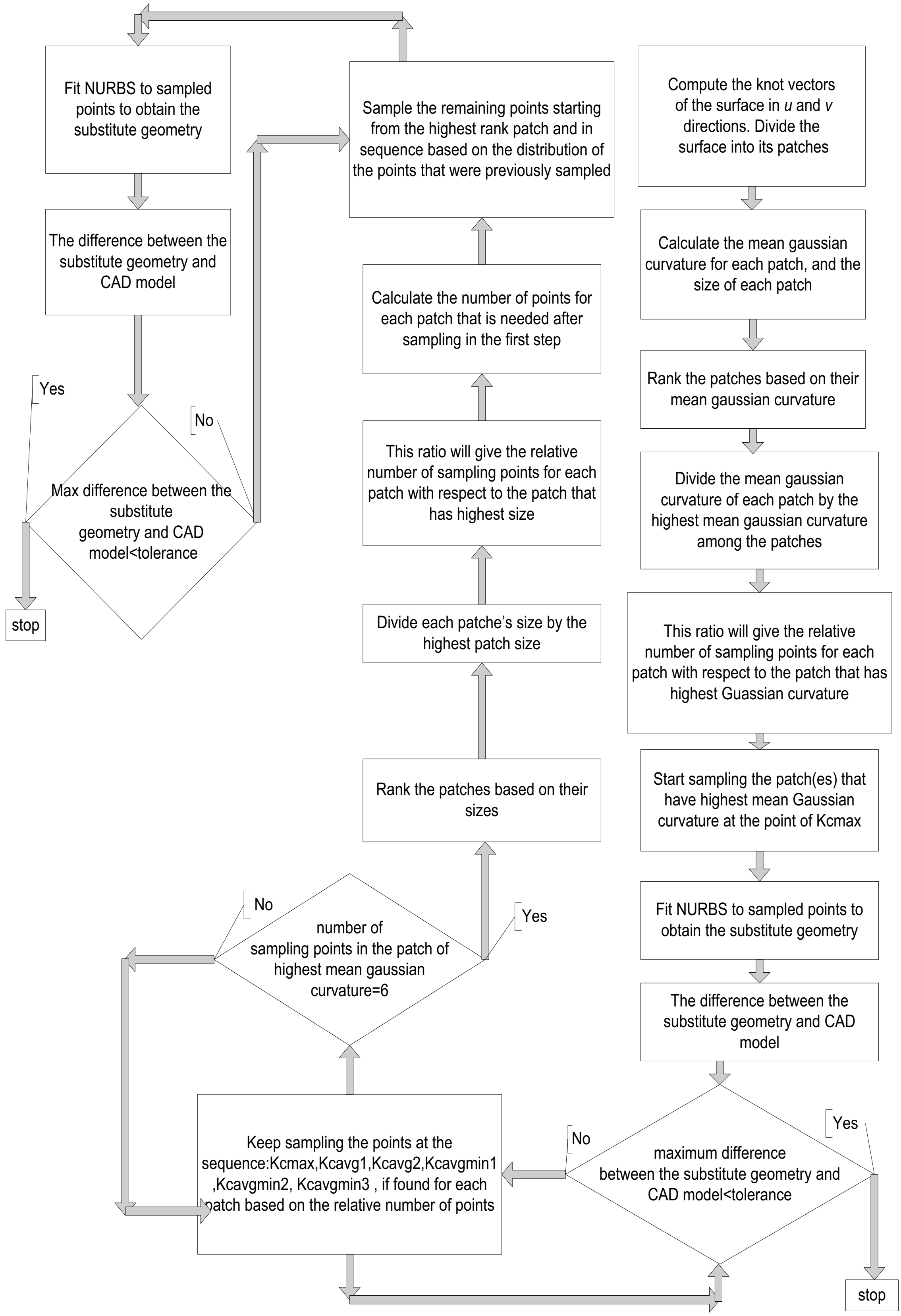


Figure 6: Third algorithm, Obeidat and Raman [1].

The surfaces that those algorithms were applied on are shown in figures 7, 8, and 9.

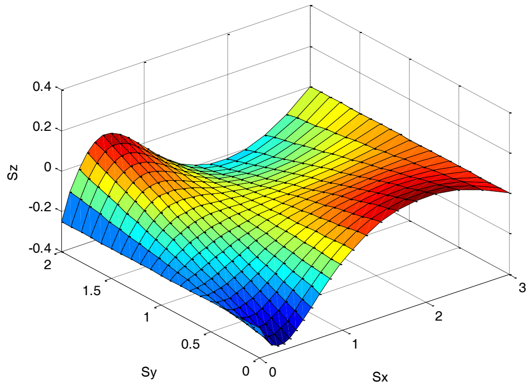
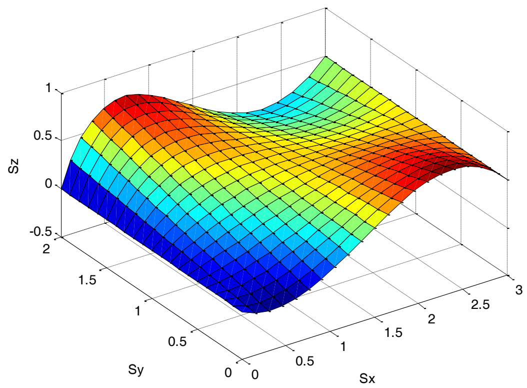


Figure 7: Surface part1.



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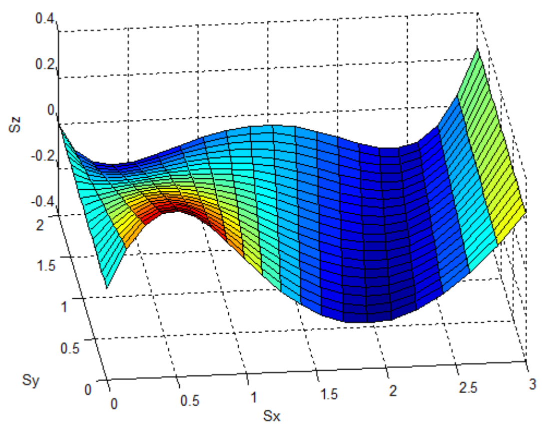

Figure 9: Surface part3.

5. Results and Discussion

As mentioned above, an inspection process has been performed on three surfaces made using milling machine. A Browne & Sharpe MicroVal PFX™ 454 CMM was used in the measuring process. The three algorithms developed by Obeidat and Raman [1] have been used in sampling the inspection points. The results obtained have been compared with those obtained using two existing sampling techniques (Equiparametric and Patch – size based). The surfaces made are ranging from simple to complicated surfaces.

The tolerance zones obtained using Equiparametric and patch size – based sampling techniques are used as basis for comparison. It is assumed that the correct tolerance zone is the one obtained using the two existing sampling techniques. This is acceptable assumption because 121 points are used in sampling the points using the two existing techniques.

Table 1 gives the tolerance zones and the number of points needed to get those tolerance zones for each sampling technique.

For surface part1 (least complexity), it can be noticed from Table 1 and figure 10 that the third algorithm using 30 points, gives the closest tolerance zone to those obtained using Equiparametric and patch – size based techniques with 121 points. This reveals the strength of the third algorithm in sampling simple surfaces. A reduction in number of points of 75% reduces the accuracy by 10% is a great development because this will reduce the inspection time by around 75%. This is because Equiparametric and patch size – based methods don't take into consideration the complexity of the surface, and so there is no need for this huge number of sampling points (121) as suggested by the new developed algorithms.

For surface part2 (moderate complexity), it can be noticed from Table 1 and figure 11 that the first algorithm using 22 points, gives the closest tolerance zone to those obtained using Equiparametric and patch – size based techniques with 121 points. This reveals the strength of the first algorithm in sampling moderate complexity surfaces.

For surface part3 (high complexity), it can be noticed from Table 1 and figure 12 that the first algorithm (29 points), second algorithm (29 points) and third algorithm (33 points), give great results. The three developed algorithms give tolerance zones that are very close to those obtained using Equiparametric and patch – size based techniques. By reducing the number of points by 73 % a reduction in accuracy of 7.5% is achieved is a great achievement. This will reduce the inspection time by 73 % if this amount of accuracy is ignored in very complicated surfaces. Also this reveals that the developed algorithms by Obeidat and Raman [1] are applicable for small size surfaces as well as for large scale surfaces. More over those algorithms can catch the maximum error faster and using less number of points compared to Equiparametric and patch – size based techniques.

Table 1: Comparison between the five sampling algorithms when applied on surface part1, surface part2, and surface part3.

Surface	Algorithm	Tolerance Zone (inch)	Number of points
Part 1	First	0.1405	22
	Second	0.1147	22
	Third	0.1872	30
	Equiparametric	0.2076	121
	Patch - size based	0.1897	121
Part 2	First	0.0448	22
	Second	0.0382	22
	Third	0.0357	30
	Equiparametric	0.0602	121
	Patch - size based	0.0567	121
Part 3	First	0.3859	29
	Second	0.3810	29
	Third	0.3812	33
	Equiparametric	0.3498	121
	Patch - size based	0.3356	121

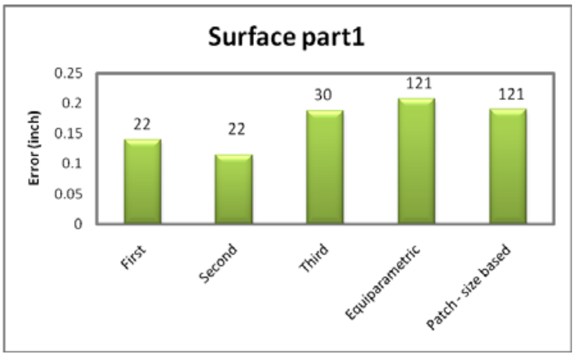

Figure 9: Dimensional error when the five algorithms are applied on surface part1.

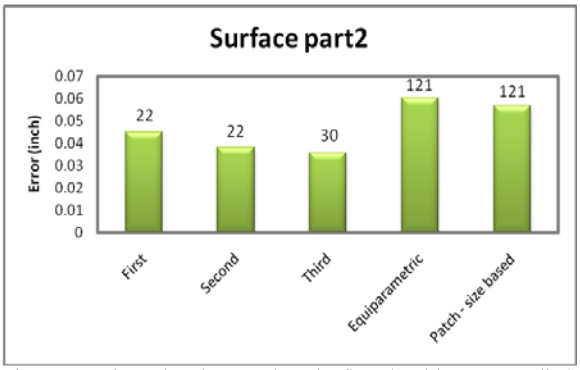

Figure 10: Dimensional error when the five algorithms are applied on surface part2.

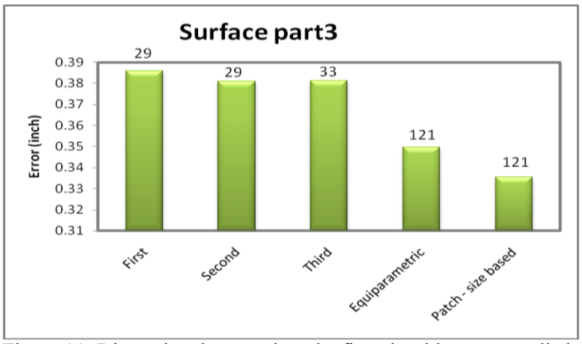

Figure 11: Dimensional error when the five algorithms are applied on surface part3.

6. Conclusion

In this work the three algorithms developed by Obeidat and Raman [1] were used. They were applied on actual surfaces made by end milling. The error is actual and is not proposed .The three kinds of surfaces are of small scale compared to those used by Obeidat and Raman [1].Three kinds of surfaces ranging in complexity from simple to very complicated surfaces, were used. The inspection points were obtained using the three developed algorithms and two existing sampling techniques (Equiparametric and patch – size based techniques).

It can be concluded that, the first algorithm is the best for simple surfaces giving a reduction in number of points of 75 % with a reduction in accuracy of 10%. Also, the three algorithms are better than Equiparametric and patch – size based techniques for very complicated surfaces with a reduction in number of points of 73% with a reduction in accuracy of 7.5%. A reduction in an inspection time is achieved which leads to big reduction in measurement cost.

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Noninvasive Transdermal Insulin Delivery Using Piston-Shaped PZT Transducers: In vivo Rabbits Evaluation

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Abstract

Noninvasive transdermal insulin delivery is investigated in this paper utilizing ultrasound transducers in order to improve the quality of life of Type 1 diabetic patients. This alternative technique is intended to replace the long-term dependence on multiple subcutaneous insulin injections. Different piston-shaped ultrasound transducers operating in the frequency range 100 – 1000 kHz were housed using silicone adhesive which included a reservoir to hold insulin during in vivo transdermal delivery. Twenty five local rabbits were divided into five groups and anesthetized using a combination of Ketamine hydrochloride and Xylazine to produce temporarily diabetic rabbit models during the period of experiments. Consisting of five rabbits in each experimental group, the control group (G0) did not receive ultrasound while exposure groups (G1-G4) received ultrasound for only ten minutes. Sweep driving mode of operation over a range of frequencies was applied to each exposure group with different frequency ranges. The swept frequency ranges were 100-200, 200-400, 400-650, and 650-1000 kHz for exposure groups G1, G2, G3, and G4, respectively. Initially, blood glucose level of rabbits (n = 25) was 157.2 ± 17.4 (mg/dl) and increased to 302.4 ± 78.1 mg/dl in one-hour period for the control group. In contrast, exposure groups (G1-G4) showed variable behaviors of glucose level reductions depending on driving frequencies with lowest value of 100.6 ± 17.9 (mg/dl) (G1) after one-hour from the starting of the ten minute exposure period. Compared to the control group, exposure groups showed reduction of blood glucose levels by 21.6%, 10.8%, 3.4%, and 3.7% for exposure groups G1, G2, G3, and G4, respectively, after twenty minutes from exposure period. The reduction of blood glucose levels continued till the end of the one-hour measurement period with maximum recorded reductions, compared to the control group, were 66.7%, 35.9%, 39.5% and 45% for groups G1, G2, G3, and G4, respectively. Ultrasound piston PZT transducers were found to facilitate insulin delivery across the skin of rabbits regardless of the driving frequency in the tested range from 100 to 1000 kHz. However, driving frequencies from 100 to 200 kHz were found to be the best facilitator of insulin delivery compared to other tested frequencies.

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1. Introduction

Noninvasive transdermal delivery (NTD) of insulin may help improving the quality of life of type 1 diabetes patients. It is a preferable technique for diabetic patients over the traditional invasive and painful subcutaneous insulin injections [1]. Few researchers managed to utilize ultrasound transducers for transdermal insulin delivery [2-11]. Aside from sporadic studies which used different commercial, large, and heavy ultrasound equipments to deliver insulin across the skin [12], light-weight compact cymbal transducers were investigated using various ex vivo and in vivo animal experiments [13-20]. Blood glucose levels were decreased immediately after administration of insulin via ultrasound energy for 60 minutes of pulsed driving. Cymbal transducers were tested on different small and large animals with blood glucose levels decrease by 49%, 46%, and 60% from normal baseline levels for pigs, rabbits, and rats, respectively [13,14,16-18]. These results were achieved for different administration of ultrasound periods and blood glucose testing intervals, with the operating frequency of the cymbal transducers being fixed at 20 kHz [1, 21-23]. Since the biological mechanisms of insulin delivery across the skin is not yet known, the need to test more operating frequencies is required to uncover the optimal frequency that may facilitate and enhance the permeability of skin layers for best possible delivery of insulin molecules to the blood stream. The outer layer of the skin (stratum corneum) attributes mainly to the low permeability of the skin to transdermal drug delivery. Ultrasound energy, however, was found to facilitate the transportation of insulin across the condensed keratinocytes of the stratum corneum. Low frequency ultrasound was believed to only facilitate the drug delivery across skin layers due to microbubbles generation within these layers, which allows water channels to be produced within the lipid bilayers [24-28]. Possible mechanisms of transdermal insulin delivery utilizing ultrasound include cavitation, thermal effects, generation of convective velocities, and mechanical effects [29]. Experimental results propose that amid all the ultrasound-related facts, cavitation plays the

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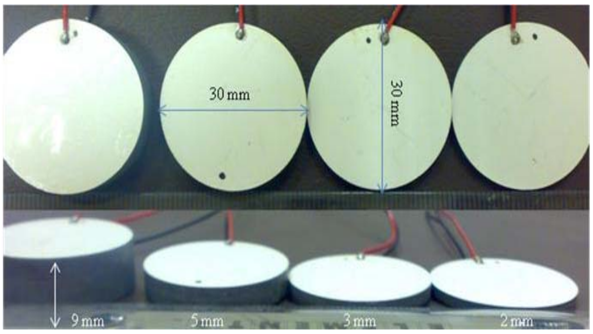
dominant role in ultrasound mediated drug delivery with low-frequency being more effective [30]. Based on the positive results from literature [13,14,16-18], the purpose of this study was to determine the feasibility of ultrasound mediated transdermal delivery of insulin in vivo specifically, using a portable ultrasound piston shaped device operating at frequencies from 100 to 1000 kHz.

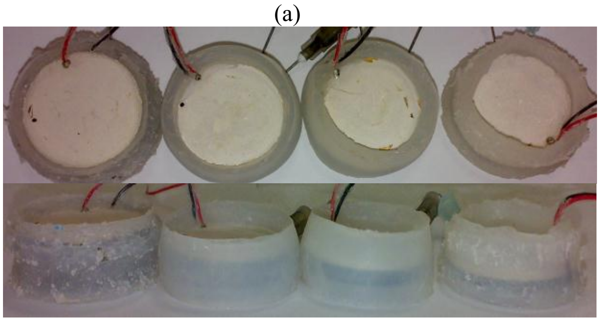
2. Materials and Methods

2.1. Ultrasound transducers and driving setup:

Different piston-shaped ultrasound transducers, fabricated using Lead Zirconate Titanate 4 (PZT-4) material, were used through this study (Piezo Kinetics, Inc., Bellefonte, PA, USA). PZT-4 was chosen because of its high failure voltage threshold compared to ceramics with similar efficiency. Table 1 show physical properties and driving conditions of used PZT transducers. With fixed outer diameter of 30.0 mm, the thicknesses, which determine their resonance frequencies, vary from 9.0 to 2.0 mm. However, the under-water (i.e. loaded transducer) resonance frequency is lower than its tabulated in-air resonance frequency due to extra mass loading on the faces of transducers [31]. To prepare the piston-shaped transducers for animal experiments, a silicone adhesive material (Diya®, Amman, Jordan) was molded to build a proper housing for the transducers that holds insulin during in-vivo animal experiments. The silicone was molded into 33.0 mm cylindrical shape and left to cure overnight. The cured silicone mold was reshaped into a hollow cylinder to incase the transducer. Ultrasound transducers were then housed using these cured pieces of silicone in a way that created a reservoir for insulin loading during animal experiments. Figure 1 shows actual photos of the transducers before and after building the appropriate silicone housing with insulin reservoir for in vivo animal experiments. The driving conditions of these transducers were chosen to span the range from 100 kHz to 1 MHz. Continuous driving mode of operation was selected with variable sweeping frequencies. The driving signals' frequencies were continuously varied from a specific lower frequency to a higher frequency (sweep frequency range) during ten seconds duration (sweep duration). The continuous driving period of the transducers (insulin delivery period or exposure period) was set to 10 minutes for rabbit experiments. To drive the piston transducer, a radio frequency (RF) signal was generated by a sweep function generator (BK Precision model 4017A, Yorba Linda, CA, USA) and amplified by an RF amplifier (Model 25A250, Amplifier Research, Souderton, PA, USA) as shown in Figure 2. The sweep period, frequency range, and output RF signal from the sweep function generator were monitored using an oscilloscope (Tektronix TDS 1002 B, Beaverton, OR, USA). For the experiments, the function generator operated at sweep mode with frequencies listed in Table 1 with sweep duration of 10 seconds, while the amplifier electrical output power was set to 4 W. Swept ultrasound was used to avoid heat build-up that may harm the transducers and the animals skin.



(a)



(b)

Figure 1: Upper and side views of the PZT transducers (a) before and (b) after building the housing.

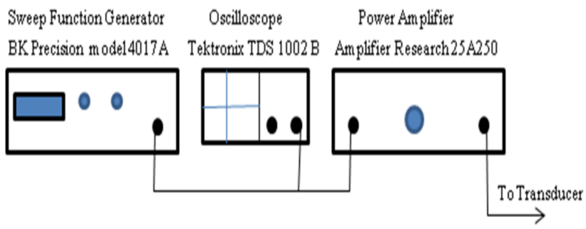


Figure 2: Schematic diagram of the driving setup of the ultrasound transdcuers. The sweep function generator feeds the sweep signal to an oscilloscope and to the power amplifier input port. The amplified signal is fed to the PZT transducer.

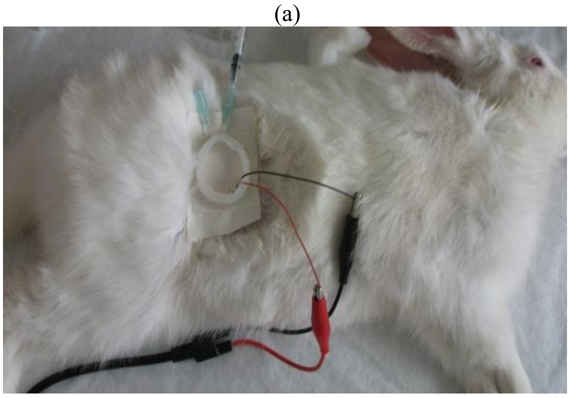
Table 1: Physical properties of PZT transducers and driving conditions for animal experiments.

Physical properties			Driving conditions		
Thickness (mm)	O.D. (mm)	Resonance freq (kHz)	Sweep freq range (kHz)	Sweep period (s)	Driving period (min)
9.0	30.0	225.8	100 – 200	10.0	10.0
5.0		406.4	200 – 400		
3.0		677.0	400 – 650		
2.0		1016.0	650 - 1000		

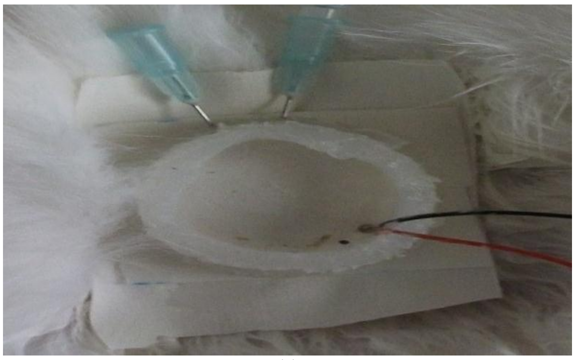
3. Animal experiments

The animals were anesthetized by procedures approved by the Animal Care Committee at the Hashemite University. Twenty five rabbits (1.5–2.5 kg) obtained from the local market were divided into five experimental groups. The first group (control group, G0) did not receive ultrasound exposure while the rest groups (G1-G4) were exposed to ultrasound using different sweep driving frequencies as explained in table 2. Insulin was held between the transducer and the skin during the 10 minutes exposure period. Each animal was pre-anesthetized intramuscularly with a combination of Ketamine hydrochloride (40 mg/kg, TEKAM 50 mg/ml, HIKMA Co., Amman, Jordan) and Xylazine (10 mg/kg, XYLA-JECT 20 mg/ml, Adwia Co. S.A.E., 10th of Ramdan City, Egypt). The abdomen areas of the rabbits were shaved using an electric shaver, and a depilatory agent was applied to the skin of rabbits to eliminate any remaining hair. A square shaped medical plaster with squared hollow in the middle was bonded over the shaved area. A double face foam tape was fixed over the medical plaster to hold the transducer with its housing close to the rabbit's skin. The transducer was then easily attached to the foam tape. Two 16 G needles were inserted via the silicone housing to the reservoir between the face of the transducer and the shaved skin (Figure 3). The reservoir was filled with 4 ml of insulin (Mixtard® 30, Novo Nordisk, Denmark) using a 10 ml syringe attached to one of the needles. The other needle allowed trapped air to escape while filling the reservoir. At the beginning of the experiment, blood samples (0.3 ml) were collected from the ear vein of each rabbit for a baseline glucose level analysis. The glucose level (mg/dl) in the blood was determined using Gluco-Track® (Teco Diagnostics, CA, USA) blood glucose monitoring system. During each experiment, multiple blood samples (2–4 each time) were taken every 10 minutes for 60 minutes. Additionally, an examination of the rabbit's skin was performed after exposure to look for visible lesions on the skin surface. Visual inspection of the ultrasound exposed rabbit's skin did not indicate any visible damage or change to the skin.

(a)



(b)



(c)

Figure 3: Photos of anesthetized local rabbits showing (a) the shaved abdominal area before fixing the transducer. A square-hollowed plaster is attached to the shaved area (b) that used to fix the transducer using double faced foam tape (c), where two needles are fixed to the housing for instant injection of insulin during experiments.

Table 2: Experimental groups of temporarly diabetic rabbits.

Experimental Group	Ultrasound frequncy range (kHz)	Transducer thikness (mm)	Number of Animals
G0	No ultrasound	--	5
G1	100 – 200	9.0	
G2	200 – 400	5.0	
G3	400 – 650	3.0	
G4	650 – 1000	2.0	

4. Results

Results of ultrasound mediated transdermal insulin delivery in temporarily diabetic rabbits for the five groups are graphed (Figure 4) as the change in the blood glucose level during the 60 minutes period experiments in terms of the mean and standard deviation error. After the rabbits were anesthetized, the average initial glucose level (zero time glucose level or base line) of the rabbits (n = 25) was 157.2 ± 17.4 (mg/dl). To normalize results to the base line value, the zero time glucose level value of each experimental group was subtracted from actual glucose level points to eliminate differences between groups' starting point (zero time point). Data was graphed in Figure 4 showing zero time point with zero glucose level for all groups. For the control group (G0), the glucose level increased to 173.4 mg/dl in 1 hour period. This increase of glucose level was measured immediately after the anesthesia of each rabbit. In contrast, exposure groups (G1-G4) showed lower increase of glucose levels after the 10 minutes delivery period with 45.0 mg/dl as the maximum increase (G3) at the 40 minutes time point (Figure 4). Exposure groups showed variable behaviors of glucose level reduction depending on driving frequencies with lowest value of -50.0 mg/dl (G1) after 1 hour from the starting of the ultrasound-mediated insulin delivery compared to the base line. To determine the statistical significance between the results in Figure 4 of the exposed groups (G1–G4) and control group (G0) at the 10 min increment time points, ANOVA was used to analyze this data (Table 3). The analysis showed that the results were statistically significant at a p-value of 0.05 or less for all time points except for the first point of group G2.

Table 3: p-values for the in-between control group (G0) and exposure groups (G1-4) over 60 minutes period.

Time (min)	Between groups p-values			
	G0 & G1	G0 & G2	G0 & G3	G0 & G4
10.0	0.0017	0.0944	0.0016	0.0007
20.0	0.0080	0.0146	0.0011	0.0009
30.0	0.0072	0.0112	0.0063	0.0016
40.0	0.0041	0.0253	0.0067	0.0006
50.0	0.0014	0.0178	0.0066	0.0002
60.0	0.0018	0.0066	0.0030	0.0002

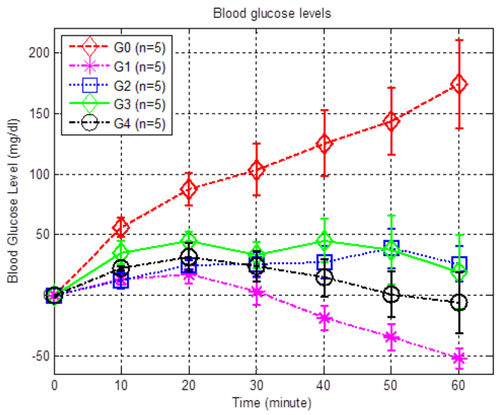


Figure 4: The change in blood Glucose concentrations for the temporarily diabetic rabbit model showing the control group (G0) and exposure groups (G1-G4).

5. Discussion

Both Figure 4 and Table 3 show actual blood glucose level (BGL) concentrations (mg/dl) over the one-hour recording period in ten-minute steps. Control group (G0) showed rapid glucose level increase from 129.0 ± 7.6 mg/dl at the zero time point to 302.4 ± 78.1 mg/dl at the sixty-minute point. Rapid linear increase was noticed during the first 20 minutes with almost linear increase after that but with different sloped line till the end of the one-hour experiment. With assumed linear increase starting from the twenty-minute time point, the slope was 2.12 mg/dl.min for the rest of timing points (from 20 to 60 minutes). Exposure groups, on the other hand, showed gradual increase to reach peak values at the twenty-minute time points with sharp linear reductions after that for both groups G1 and G4. Linear fitting showed that the slopes of these lines were -1.756 and -0.984 mg/dl.min for groups G1 and G4, respectively. However, groups G2 and G3 showed different behaviors. Under the same assumption of linear relationship (from 20 to 60 minutes period) for groups G2 and G3, calculated slopes of these assumed lines were 0.146 and -0.476 mg/dl.min, respectively. Compared to base line level, exposure group G1 showed an increase in blood glucose level during the ten-minute exposure period and continued to increase till the twenty-minute time point. BGL decreased linearly after that till the end of the experiments. Exposure group G2, on the other hand, produced elevated BGLs during the exposure period and continued to increase relatively sharply till the twenty-minute time point. Unlike exposure group G1's behavior, exposure group G2 continued to increase slowly after that to reach a maximum elevated point at the fifty-minute time point with a noticeable decrease after that to end with elevated BGL value compared to the base line level. Exposure group G3 showed elevated BGL for the first twenty minutes and then reduced at the thirty-minute time point with unexpected increase at the forty-minute time point then reduced back to an elevated level compared to the base line level. Exposure group G4, however, showed close behavior to group G1 with elevated BGL during the first 20 minutes after the start of the exposure period and gradually decreased to reach base line level at the fifty-minute time point and continued to decrease after that.

To further analyze these data, Table 4 shows the percentages of BGLs compared to the control group at each time point. Exposure groups (G1-4) showed elevated percentage BGLs compared to the control group immediately before the ultrasound-mediated insulin delivery process (the first 10 minutes). This elevated percentage BGL was due to the timing differences between exposure groups and control group due to the preparation of rabbits after anesthesia. In fact, readings of BGL in the control group started immediately after anesthesia of animals while readings of exposure groups started after shaving and adjustment of the ultrasound transducer on top of the double face foam tape as previously pointed out. The preparation time was kept during all experiments to less than 15 minutes from the injection of anesthesia. Immediately after the 10 minutes delivery period, both groups G1 and G2 showed reduction of BGL by 10.4% and 2.5%, respectively. However, groups G3 and G4 showed elevated BGL after the delivery period. At twenty minutes from the beginning of exposure, the results showed reduction of BGL by 21.6%, 10.8%, 3.4%, and 3.7% for exposure groups G1, G2, G3, and G4, respectively. Using linear curve fitting of these data starting from the twenty-minute time point, the slopes of the lines were -1.139, -0.577, -0.929, and -0.995 mg/dl.min for groups G1, G2, G3, and G4, respectively. The reduction of BGL continued for the measuring period with maximum recorded reductions of 66.7%, 35.9%, 39.5% and 45% for groups G1, G2, G3, and G4, respectively. Figure 5 shows the behavior of BGL for each group compared to control group during the 1-hour recording period. Group G1 showed faster delivery of insulin followed by group G4, while both groups G2 and G3 showed almost the same behavior of delivery. These data proved that ultrasound facilitated insulin delivery across the skin of rabbits regardless of the driving frequency in the tested range from 100 to 1000 kHz. However, driving frequencies from 100 to 200 kHz were the best facilitator of insulin delivery compared to tested frequencies from 200 to 1000 kHz. Sweep frequencies from 650 to 1000 kHz were found comparable to group G1 behavior but with less amount of insulin delivery; while groups G2 and G3 were the least effective in delivery in this study.

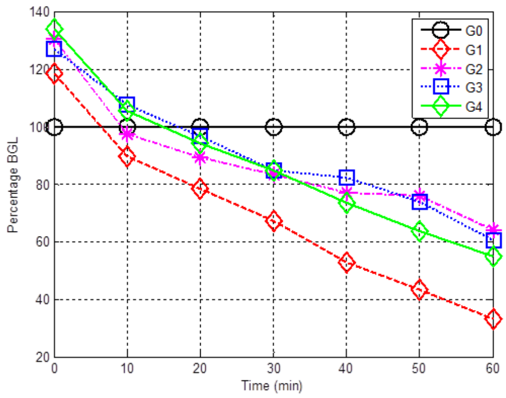


Figure 5: Percentages of exposure groups' BGL compared to control group (G0) over the course of recording period.

Table 4: Percentages of blood glucose concentrations of exposure groups compared to control group.

Time (min)	Percentages of blood glucose levels compared to control group			
	G1	G2	G3	G4
0.0	118.3%	130.2%	127.0%	133.8%
10.0	89.6%	97.5%	107.7%	105.4%
20.0	78.4%	89.2%	96.6%	94.3%
30.0	67.2%	83.5%	84.7%	84.7%
40.0	52.7%	76.9%	82.2%	73.5%
50.0	43.5%	76.0%	74.0%	63.8%
60.0	33.3%	64.1%	60.5%	55.0%

6. Conclusions

Piston transducers were found feasible in delivering insulin across the skin in a noninvasive manner. Compared to other transducers, piston transducers are cheaper, portable, smaller in size, and can be fabricated with predefined thicknesses for explicit frequency driving conditions. Specifically to this study, the sweeping mode of driving was used to reduce the driving periods on the resonance frequency which may lead to transducer failure under continuous driving conditions. Another reason for this choice is the excitation of a spectrum of frequencies that may lead to uncover the best driving frequency, or range of frequencies, for maximum delivery of insulin. Although, low frequency range (20 to 100 kHz) was suggested for drug delivery [12], piston transducers with driving frequencies from 100 kHz to 1.0 MHz gave good results with faster delivery when using driving frequencies from 100 to 200 kHz with the 9.0 mm thickness piston transducer.

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Shaking Force and Shaking Moment Balancing of Planar Mechanisms with High Degree of Complexity

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Abstract

Most of the research on the balancing of shaking force and shaking moment generated by planar linkages was limited to mechanisms with low degree of complexity. This paper attempts for complete shaking force and shaking moment balancing of planar mechanisms with high degree of complexity. Shaking force is balanced by the method of redistribution of mass and shaking moment by adding gear inertia counterweights. The method is illustrated for Stephenson's linkage (Mechanism with high degree of complexity) and Atkinson engine mechanism and also for Self-balanced slider-crank mechanical systems. The conditions for shaking moment balancing are formulated by using the copying properties of the pantograph linkage and the method of dynamic substitution of distributed masses by concentrated point masses. These mechanical systems find a successful application in engines, agricultural machines and in various automatic machines.

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Keywords: Shaking force; Shaking moment; Dynamic balancing

1. Introduction

Mechanisms particularly those that run at high speeds generate variable forces on their foundations. These forces cause noise,vibration,and unnecessary wear and fatigue. The balancing of a linkage would eliminate these undesirable qualities and maintains a peaceful and productive environment. Therefore the problems of shaking force and shaking moment balancing have attracted the attention of machine and mechanism designers for a long time.

One of the most effective methods for the reduction of these vibrations is the mass balancing of moving links of mechanism by Lowen and Berkof [1]. The effective method for balancing slider-crank mechanism was the method of duplicating mechanism [2, 3] by adding to the initial mechanism an identical mechanism which is a revolved mirror reflection of the initial mechanism. The disadvantages of such an approach are a partial balancing due to the shaking moment of inertia forces of the slider, as well as the greater friction losses due to the additional sliding pair. The method of adding idler loops can be used to entirely eliminate forces and moments of 4-bar 6-bar linkages [4].Kamenski [5] first used the cam mechanism for balancing of linkages. P.Nehemiah and Dr.B.S.K.Sundara Siva Rao[6]used a method to balance shaking moment by mounting gear inertia counterweights on the frame ,the planetary gear trains mounted on the links that are not connected directly to the frame in earlier methods are mounted on base by kinematically linking the gears with the corresponding links by a link of known mass and center of mass and moment of inertia .A more referred method in the literature is the method of linearly independent vectors[7],which makes total center of mass of the mechanism stationary. I.S.Kochev[8] presented a general method using ordinary vector algebra instead of the complex number representation of the vector for full force balance of planar linkages.Elliott and Tesar[9]developed a theory of torque,shak ing force,and shaking moment balancing by extending the method of linearly independent vectors.R.S.Berkof[10] proposed a method to balance shaking moment by inertia counterweight and physical pendulum.

I.Esat,H.Bahai[11];Z.YE,M.R.Smith[12];V.H.Arakelia n and M.R.Smith[13] achieved complete moment balancing by geared inertia counterweights.More information on complete shaking moment balancing can be obtained in a critical review by I.S.Kochev[14],and Arakelian and Smith[15].D.Ilia,A.Cammarata,and R.Sinatra [16] proposed the kinematics and dynamics of a five-bar linkage using a novel and simplified approach where the dynamic balancing of mechanism is formulated and solved as an optimization problem under equality constraints.H.Chaudhary ,S.K.Saha[17] used the equimomental systems for balancing of shaking forces and shaking moments of planar mechanisms.BrianMoore,Josef,and Gosselin[18] presented a new method to determine the complete set of force and moment balanced planar four-bar linkages using complex variables to model the kinematics of the linkage,the force

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and moment balancing constraints are written as algebraic equations over complex variables and joint angular velocities.Using polynomial divison,necessary and sufficient conditions for the balancing of planar four-bar are derived. The present work deals with the balancing of mechanisms with high degree of complexity,Atkinson engine mechanism and self-balanced slider-crank mechanical systems. The present work can be the extension of work contributed by V.H.Arakelian and M.R.Smitht[13],where they did for single slider-crank mechanism ,mechanism with low degree of complexity.In the present work Two identical slider-crank mechanism,mechanism with high degree of complexity,Atkinson engine mechanism ,where slider-crank mechanism is an integral part of it are balanced.

1.1. Definition: Mechanisms with Low and High degree of complexity:

In complex mechanisms some radii of curvatures, required for the computation of normal acceleration components are not readily available and consequently, indirect or special methods of solution must be used.

In a complex mechanism if only one radius of path curvature of one motion transfer point is not known such a mechanism is called a mechanism with low degree of complexity.In the mechanism shown in fig.1 the radius of curvature of motion transfer point B is not known ,so it is a mechanism with low degree of complexity.

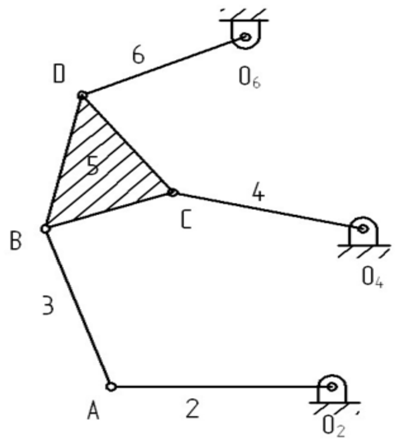

Figure 1: Mechanism with low degree of complexity.

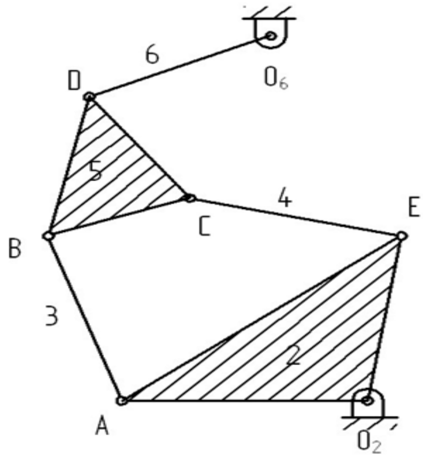

Figure 2: Mechanism with high degree of complexity.

In a complex mechanism if more than one radii of path curvature of motion transfer points are not known such a mechanism is called a mechanism with high degree of complexity. In the mechanism shown in fig.2 the radii of curvature of motion transfer points B and C are not known ,so it is a mechanism with high degree of complexity.

2. Complete Shaking Force and Shaking Moment Balancing of Sub Linkages

2.1. Articulation dyad:

An open kinematic chain of two binary links and one joint is called a dyad.

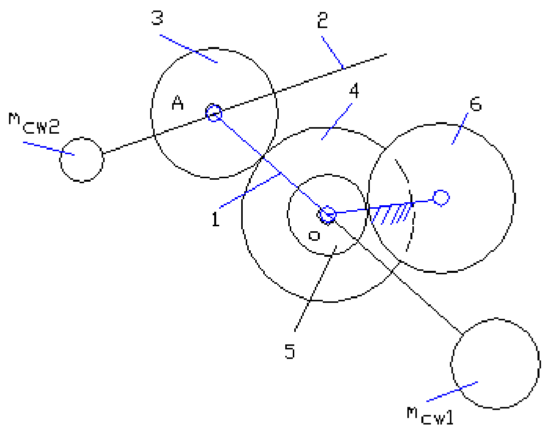

Figure 3: Complete shaking force and shaking moment balancing of an articulation dyad.

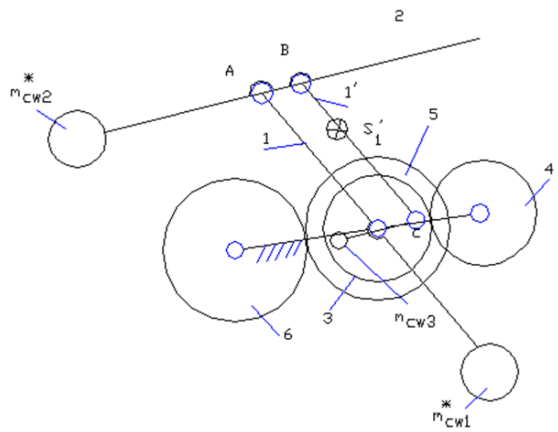

Figure 4: Complete shaking force and shaking moment balancing of an articulation dyad by gear nertia counterweights mounted on the base.

To link 2 is added a counterweight which permits the displacement of the center of mass of link 2 to joint A. then, by means of a counterweight with mass m_{cw_1} [fig.3] a complete balancing of shaking force is achieved. A complete shaking moment balance is realized through four gear inertia counter weights 3-6, one of them being of the planetary type and mounted on link 2 (Gao Feng,1990[19]).

The scheme used in the present paper [fig.4] is distinguished from the earlier scheme by the fact that gear

3 is mounted on the base and is linked kinematically with link2 through link $1'$.Let us consider the complete shaking force and shaking moment balancing of the articulation dyad with the mass and inertia of link $1'$ taken into account. For this purpose initially, we shall statically replace mass m_1' of link $1'$ by two point masses m_B and m_c at the centers of the hinges B and C

$$m_B = m_{1'} l_{CS_{1'}} / l_{BC}$$
$$m_C = m_{1'} l_{BS_{1'}} / l_{BC} \tag{1}$$

where, l_{BC} is the length of link 1, $l_{CS_{1'}}$ and $l_{BS_1'}$ are the distances between the centers of joints C and B and the center of mass S_1' of link $1'$, respectively. After such an arrangement of masses the moment of inertia of link $1'$ will be equal to

$$I_{S_1'}^* = I_{S_1'} - m_{1'} l_{BS_1'} l_{CS_1'} \tag{2}$$

where, $I_{S_1'}$ is the moment of inertia of link $1'$ about the center of mass S_1' of the link.

Thus we obtain a new dynamic model of the system where the link $1'$ is represented by two point masses m_B, m_C and has a moment of inertia $I_{S_1'}^*$. This fact allows for an easy determination of the parameters of the balancing elements as follows:

$$m_{CW_2} = (m_2 l_{AS_2} + m_B l_{AB}) / r_{CW_2} \tag{3}$$

where, m_2 is the mass of link 2, l_{AB} is the distance between the centers of the hinges A and B, l_{AS_2} is the distance of the center of hinge A from the center mass of S_2 of link 2, r_{CW_2} is the rotation radius of the center of mass of the counter weight with respect to A ,and

$$m_{CW_1} = [(m_2 + m_{CW_2} + m_B) l_{OA} + m_1 l_{OS_1}] / r_{CW_1} \tag{4}$$

where, m_1 is the mass of link 1, l_{OS_1} is the distance of the joint center O from the center of mass S_1 of link 1.

Also,

$$m_{CW_3} = m_C l_{OC} / r_{CW_3} \tag{5}$$

where, $l_{OC} = l_{AB}$, r_{CW_3} is the rotation radius of the center of mass of the counter weight.

2.2. Asymmetric link with three rotational pairs:

In previous work relating to balancing of linkages with a dynamic substitution of the masses of the link by three rotational pairs(see fig.5) two replacement points A and B are considered . This results in the need to increase the mass of the counter weight. However, such a solution may be avoided by considering the problem of dynamic substitution of dynamic substitution of link masses by three point masses. Usually the center of mass of such an asymmetric link is located inside a triangle formed by these points.

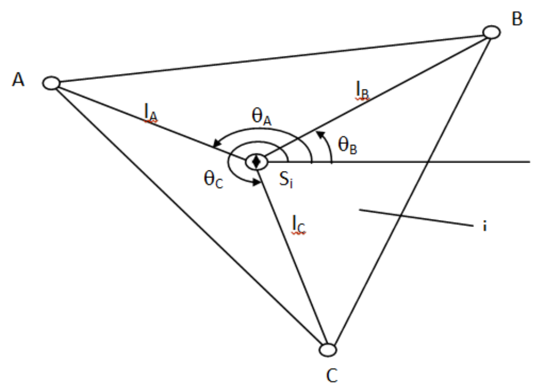

Figure 5: Dynamic substitution of the masses of the link by three rotational pairs.

The conditions for dynamic substitution of masses are the following:

$$\begin{bmatrix} 1 & 1 & 1 \\ l_A e^{i\theta_A} & l_B e^{i\theta_B} & l_C e^{i\theta_C} \\ l_A^2 & l_B^2 & l_C^2 \end{bmatrix} \begin{bmatrix} m_A \\ m_B \\ m_C \end{bmatrix} = \begin{bmatrix} m_i \\ 0 \\ I_{S_i} \end{bmatrix} \tag{6}$$

where, m_A, m_B and m_c are point masses, l_A, l_B and l_C are the moduli of radius vectors of corresponding points, θ_A, θ_B and θ_C are angular positions of radius vectors; m_i is the mass of link, I_{S_i} is the moment of inertia of the link about an axis through S_i (axial moment of inertia of link).From this system of equations the masses are obtained

$$m_A = D_A / D_i \,; m_B = D_B / D_i \,; m_C = D_C / D_i \tag{8}$$

where, D_A, D_B, D_C and D_i are determinants of the third order obtained from the above system of equations.

3. Application of the Method for Complete Shaking Force and Shaking Moment Balancing of Multiple Linkages.

3.1. Stephenson's link motion (Mechanism with high degree of complexity):

The method has been applied to a mechanism with high degree of complexity shown in fig.6.

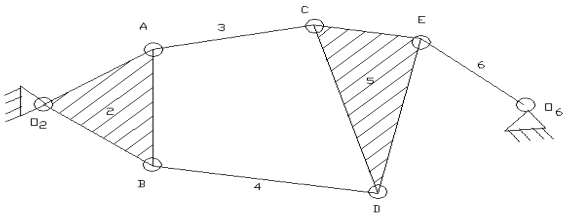

Figure 6: Mechanism with high degree of complexity (Stephenson's link motion).

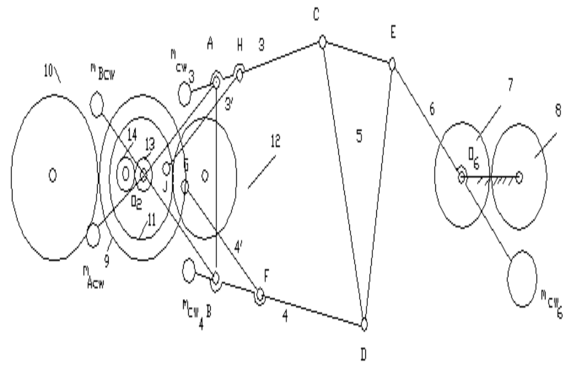
Figure 7: Balanced mechanism with high degree of complexity (stephenson's link motion).

3.1.1. Shaking force balancing of the mechanism:

Link 5 has been replaced by dynamic substitution of link masses by three point masses and .Link 6 has been dynamically replaced by two point masses and and attached a counterweight . For link 6 to be dynamically replaced by two point masses the condition to be satisfied is ,where, is the radius of gyration of link 6 about its center of mass, is arbitrarily fixed and is obtained from the above condition. Similarly other links can be dynamically replaced and force counterweights can be added to balance shaking force.

3.1.2. Shaking moment balancing of the mechanism:

The shaking moment of the mechanism is determined by the sum

$$M^{\text{int}} = M_6^{\text{int}} + M_2^{\text{int}} + M_A^{\text{int}} + M_{O_2}^{\text{int}} + M_B^{\text{int}} \tag{8}$$

Where

$$M_6^{\text{int}} = (I_{S6} + m_6 l_{O_6S_6}^2 + m_{E5} l_{O_6E}^2 + m_{CW_6} r_{CW_6}^2)\alpha_6$$

$$M_2^{\text{int}} = (I_{S_2} + I'^{*}_{S_3} + I'^{*}_{S_4} + (m_4 + m_{D5} + m_{CW_4} + m_F + m_{B2}) l_{O_2B}^2$$
$$+ (m_3 + m_{CW_3} + m_{C5} + m_H + m_{A2}) l_{O_2A}^2)\alpha_2$$

$$M_A^{\text{int}} = (I_{S_3} + m_3 l_{AS_3}^2 + m_{C5} l_{AC}^2 + m_H l_{AH}^2 + m_{CW_3} r_{CW_3}^2)\alpha_3$$

$$M_{O_2}^{\text{int}} = (2m_J l_{O_2J}^2 + 2m_G l_{O_2G}^2)\alpha_2$$

$$M_B^{\text{int}} = (I_{S_4} + m_4 l_{BS_4}^2 + m_{D5} l_{BD}^2 + m_F l_{BF}^2 + m_{CW_4} r_{CW_4}^2)\alpha_4$$

3.2. Atkinson engine mechanism:

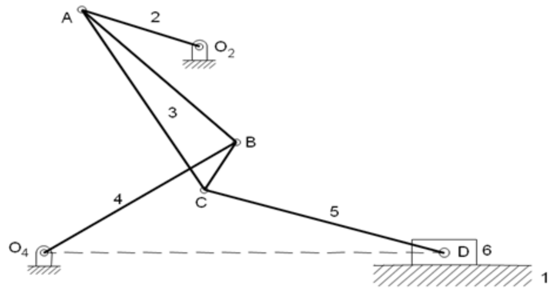

Figure 8: Atkinson engine mechanism.

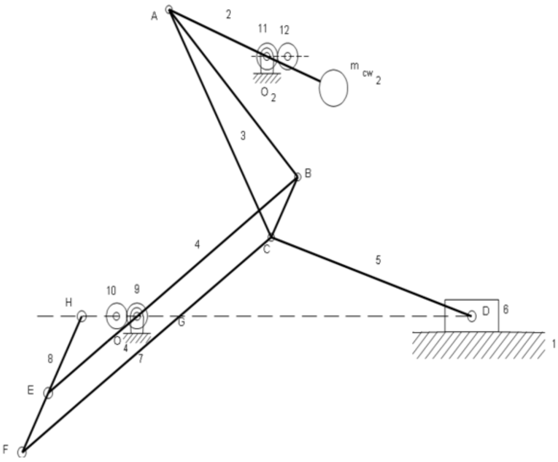

Figure 9: Balanced Atkinson engine mechanism.

To the mechanism an articulation dyad CFE is connected, which forms a pantograph with the initial mechanism OBCD. By selecting, for constructional reasons, the similarity factor of formed pantograph

$$K = \frac{l_{0_4E}}{l_{0_4B}} = \frac{l_{0_4H}}{l_{0_4H}} = \frac{l_{EH}}{l_{BD}} \tag{9}$$

The length of the articulation dyad is determined as:

$$l_{CF} = l_{0_4B} + l_{0_4E}$$
$$l_{FH} = l_{EF} + l_{EH} = l_{BC} + kl_{BD}$$

3.2.1. Shaking force balance:

Link 3 is dynamically replaced by 3 point masses m_{A3}, m_{B3}, m_{C3}. Link 4 is dynamically replaced by two point masses $m_{B4}, m_{E4},$ and a force counterweight $m_{CW_4},$ is added to balance the shaking force.Link 5 is statically replaced by two point masses $m_{C_5}, \& m_{D_5}$ .An articulation dyad CFE is added.Now link 4 (m_B $\& m_E$) is to be balanced about point 0_4. Link 7 (m_C $\& m_F$) about point G. Finally the masses

$m_G, m_D, m_6 \& m_H$ about point 0_4.The necessary conditions are as follows:

$$
\begin{aligned}
& m_B\, l_{0_4B} + m_4\, l_{0S_4} - m_E\, l_{0_4E} = 0 \\
& m_F\, l_{FG} - m_7(l_{CG} - l_{CS_7}) - m_c l_{CG} = 0 \\
& m_H = \left[m_D + m_6 + (m_C + m_F + m_7)\frac{l_{BC}}{l_{BD}} \right] / k \\
& m_F + m_E + m_H = m_8 \\
& m_F l_{FS_8} + m_E(l_{FS_8} - l_{EF}) - m_H(l_{FH} - l_{FS_8}) = 0 \\
& m_F l_{FS_8}^2 + m_E(l_{FS_8} - l_{EF})^2 - m_H(l_{FH} - l_{FS_8})^2 = Is_8
\end{aligned} \tag{10}
$$

where l_{0_4B}, l_{0_4E} and $l_{0_4S_4}$ are the distances of joint centers B, E and of the center of mass S_4 of the link 4 from the point O_4. l_{CG}, l_{FG} are the distances of the centers of the joints C, F from the working point G of the pantograph.

l_{CS_7} is the distance of the center of the joint C from the center of mass S_7 of Link 7. l_{BD}, l_{BC} are the distances of the centers of the joints D, C from the center of joint B. l_{FE}, l_{FH} are the distances of the centers of the joints E, H from the center of joint F., m_7 is the mass of link 7, m_F, m_E are point masses obtained after dynamic substitution., m_g is the mass of link 8, l_{FS_8} is the distance of the center of the joint F from the center of mass S_8 of link 8. , I_{S_8} is the axial moment of inertia of link 8.

The desired parameters are obtained as follows:

$$
\begin{aligned}
& m_8 = m_F + m_E + m_H \\
& l_{FS_8} = (m_E l_{EF} + m_H l_{EH}) / m_8 \\
& l_{S_8} = m_F l_{FS_8}^2 + m_E(l_{FS_8} - l_{EF})^2 - m_H(l_{FH} - l_{FS_8})^2 x
\end{aligned} \tag{11}
$$

Where

$$m_F = [m_c l_{cG} + m_7(l_{CG} - l_{CS_7})] / l_{FG}$$

$$m_E = (m_B l_{0_4B} + m_4 l_{0_4S_4}) / l_{0_4E}$$

Thus, a dynamic model of the mechanism fully equivalent to the real mechanism involving the rotating link 4 and 7 [The parameters of link 8 are selected so that the center of mass of link 7, with the point masses m_C, m_F taken into account, coincides with the working point G of the pantograph, due to which the motion of this link is represented as a translational rectilinear motion of its center of mass and a rotary motion relative to point G] and four point masses $m_6 + m_D$, m_F, m_H and m_G three of which perform a translational rectilinear motion in horizontal sense is obtained. As may be seen from this equivalent model, a complete shaking force balancing of the movable links of the mechanism has been achieved:

$$\bar{F}_H^{int} = \bar{F}_D^{int} + \bar{F}_6^{int} + \left(\bar{F}_G^{int} = \bar{F}_C^{int} + \bar{F}_F^{int} + \bar{F}_4^{int} \right) \tag{12}$$

where F^{int} (i, = C, D, F, G, H, 4, 6) – inertia forces from corresponding mosses).

3.2.2. Shaking moment:

The shaking moment of the mechanism is determined by the sum

$$M^{int} = M_4^{int} + M_7^{int} + M_{0_4}(F_i^{int}) \tag{13}$$

where M_4^{int} and M_7^{int} are the shaking moments of the rotating links 4 and 7 with the inertia of the replaced point masses taken into account.

$$M_4^{int} = (Is_4 + m_4 l_{0_4S_4}^2 + m_B l_{0_4B}^2 + m_E l_{0_4E})\alpha$$

$$M_7^{int} = (Is_7 + m_7 l_{GS_7}^2 + m_c l_{CG_4}^2 + m_F l_{FG_4})\alpha$$

Where Is_4 and Is_7 are the axial moments of inertia of links 4 and 7, $\alpha = \alpha_4 = \alpha_7$ is the angular acceleration of links 4 and 7, $Mo_4(F_i^{int})$ is the moment resulting from the force of inertia of the masses and m_H performing a transactional rectilinear motion relative to pivot $0_4 . m_6 + m_D, m_G$

The moments of rotating links may be balanced by means of the gears mounted on the base of the mechanism. The moment of inertia of such a gear is given by the following equation:

$$
\begin{aligned}
& I_{gear} = Is_4 + Is_7 + m_4 l_{o_4S_4}^2 + m_B l_{o_4B}^2 + m_7 l_{GS_7}^2 \\
& + m_C l_{CG}^2 + m_E l_{0_4E}^2 + m_F l_{FG}^2
\end{aligned} \tag{14}
$$

In most constructions of the mechanisms the moment $m_{0_4}(F_i^{int})$ is very small that in many balancing problems this moment may be neglected.

To balance this shaking moment gears 9 and 10 are mounted on the pivot point 0_4.

Link 2 is dynamically replaced by the point masses m_{A_2} and m_{F_2} and a counterweight m_{CW_2} is added to balance shaking force

$$m_{CW_2} = (m_{A_3} l_{Ao_2} + m_2 lo_2 s_2) / r_{CW_2}$$

Shaking moment: The shaking moment at point 0_2 is determined by the sum.

$$M_2^{int} = (Is_2 + m_2 l_{o_2s_2}^2 + (m_{A_2} + m_{A_3}) l_{Ao_2}^2 + m_{CW_2} r_{CW_2}^2)\alpha_2 \tag{15}$$

To balance this shaking moment gears 11 and 12 are mounted on the point 0_2.

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3.3. Self-balanced slider- crank mechanism:

In the two identical slider-crank mechanism shown in fig.10 shaking forces are balanced by two similar but opposite movements.

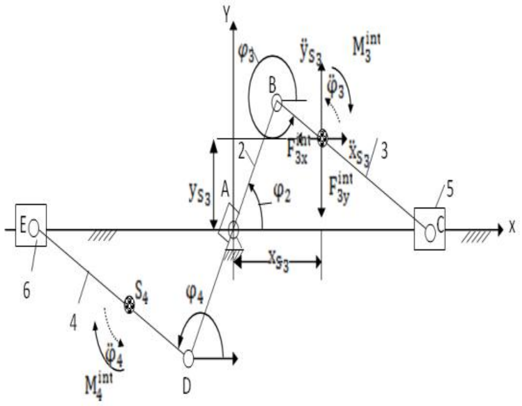

Figure 10: Self balanced slider – crank system.

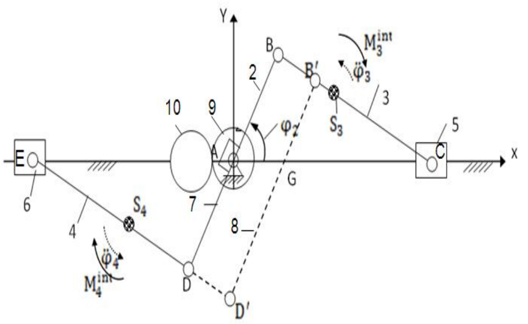

Figure 11: Self-balanced slider-crank system with an imagined articulation dyad $B'D'E$.

Fig.11 shows a self-balanced slider-crank system with an imagined articulation dyad $B'D'E$,which forms a pantograph with the initial system.The similarty factor of the formed pantograph is $k = l_{AD}/l_{AB}$ =1 and

$l_{BB'} = l_{DD'}, l_{B'D'} = l_{AD} + l_{AB.}$

By substituting dynamically the mass m_3 of the connecting coupler 3 by point masses at the centers B, B' and C and using following condition

$$\begin{bmatrix} 1 & 1 & 1 \\ l_{BS_3} & -l_{CS_3} & l_{B'S_3} \\ l_{BS_3}{}^2 & l_{CS_3}{}^2 & l_{B''S_3}{}^2 \end{bmatrix} \begin{bmatrix} m_B \\ m_C \\ m_{B'} \end{bmatrix} = \begin{bmatrix} m_3 \\ 0 \\ I_{S_3} \end{bmatrix} \tag{16}$$

where $l_{BS_{3,}}$, $l_{CS_3}, l_{B'S_3}$ are the distances of joint centers B, C and B' from the centers of masses S_3 of the link 3 ; I_{S_3} is the axial moment of inertia of link 3,we determine the value of the point masses

$$m_B = D_B / D_3; m_C = D_C/D_3; m_{B'} = D_{B'} / D_3 \tag{17}$$

where $D_{B'}, D_3, D_B, D_C$ are determinants of the third order obtained from the system of equations.

We now require imagined link $B'D'$ to be balanced about point G of the pantograph, i.e,

$$m_{D'} = m_{B'} l_{B'G} / l_{D'G}$$

The concentrated point masses $m_{G,} m_C, m_E$ to be balanced about center A, i.e,

$$m_E = (m_G l_{BB'} + m_C l_{BC}) / l_{DE}$$

where $l_{BB',} l_{BC}$ are the distances of joint centers B', C from the joint center B, l_{DE} is the distance of joint center D from the joint center E,

$$m_G = m_{B'} + m_{D'}$$

Finally the concentrated point masses m_B, m_D are also to be balanced about center A,i.e.,

$$m_D = m_B l_{AB} / l_{AD}$$

Thus we obtain the values of three concentrated point masses $m_{D'}, m_D, m_E$ which allow the determination of the mass and inertia parameters of the connecting coupler 4;

$$\begin{aligned} m_4^* &= m_{D'} + m_D + m_E \\ l_{ES_4}^* &= (m_D l_D s_4 + m_{D'} l_{D'S_4}) / m_4^* \\ I_{S_4}^* &= m_D l^2{}_{DS_4} + m_{D'} l^2{}_{D'S_4} + m_E l^2{}_{ES_4} \end{aligned} \tag{19}$$

Where

$$l_{DS_4}^* = l_{DE} - l_{ES_4}; l_{D'S_4} = l_{D'E} - l_{ES_4},$$

Shaking moment balancing:

$$\begin{aligned} M_2^{int} + M_7^{int} = (I_{S_2} + m_2 l_{AS_2}^2 + m_B l_{AB}^2 + \\ m_D l_{AD}^2 + m_7 l_{AS_7}^2 + I_{S_7})\alpha_2 \end{aligned} \tag{20}$$

$$M_8^{int} = (I_{S_8} + m_8 l_{GS_8}^2 + m_{D'} l_{D'G}^2 + m_{B'} l_{B'G}^2)\alpha_8 \tag{21}$$

Total Shaking moment generated by the mechanism:

$$M^{int} = M_2^{int} + M_7^{int} + M_8^{int} \tag{22}$$

The shaking moment generated by the mechanism is balanced by addition of gear inertia counter weights 9 and 10.

4. Numerical Example

The parameters of the self-balanced slider-crank system are the following:

$$l_{AB} = l_{AD} = 0.05m; l_{BC} = l_{DE} = 0.2m; l_{CS_3} = l_{ES_4} = 0.1m;$$
$$m_3 = m_4 = 0.35kg; m_5 = m_6 = 2kg;$$
$$I_{S_3} = I_{S_4} = 0.005kg - m^2; \omega_{AB} = 30\pi / s; \alpha_{AB} = 450\pi / s^2;$$
$$m_2 = m_7 = 0.3kg; I_{S_2} = I_{S_7} = 0.003kg;$$
$$l_{AS_2} = l_{AS_7} = 0.025m; I_{S_8} = 0.006kg - m^2; m_8 = 0.6kg$$

Figure 12 shows the variations of the shaking moment of the initial mechanical system (curve "a"). For cancellation of the shaking moment it is necessary to redistribute the masses of the second connecting coupler.By dynamically substituting the mass of the connecting coupler 3 by point masses at centres B,B' , C and taking into account conditions , we calculate the mass and inertia parameters of the connecting coupler4. Fig.12 illustrates the obtained results.so by optimal redistribution of the masses of the connecting coupler 4, the shaking moment is cancelled (curve 'b).

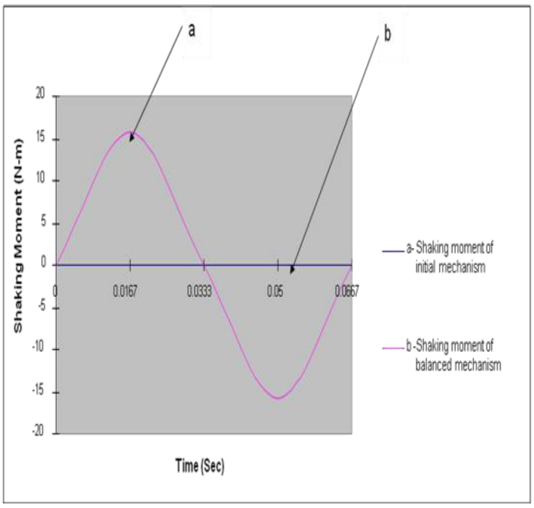

Figure 12: Shaking moment Vs Time.

5. Conclusions

The advantage of the schemes presented here is the fact that all the gear inertia counterweights needed for balancing shaking moment of mechanism with high degree of complexity are mounted on the frame of the mechanism, which is constructively more efficient. The method can be applied to any complex planar mechanism. The paper also presents a solution for improving the balancing of double slider-crank mechanical systems.In these systems the shaking force balancing is achieved by two identical slider-crank mechanisms,which execute similar but opposite movements.however the shaking moments are not balanced and can be a source of vibrations. By modifying the parameters of the second connecting coupler of the system the complete shaking moment balancing is achieved.The conditions for shaking moment balancing are formulated by using the copying properties of the pantograph linkage and the method of dynamic substitution of connecting rod mass by the concentrated point masses.A numerical example illustrates the application of the suggested solution.The method can be applied to any complex mechanism.

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Building Medical Devices Maintenance System through Quality Function Deployment

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Abstract

Over the past years, progress in the field of medical devices and their applications in hospitals became evident. Implementation of Maintenance Management Systems (MMS) should be used with appropriate maintenance activities for medical devices in order to improve medical devices systems targets. In this paper Quality Function Deployment (QFD) is being used as an improving method in MMS and as a guideline in highlighting the weak points in the performance and finding the suitable procedures to overcome them to achieve the customers' satisfaction.Through this research, the performance of Medical Devices Maintenance Systems (MDMS) in Prince Hamzeh Hospital (PHH) was investigated and studied to find appropriate solutions aiming to make the medical device more available, more reliable and more reproducible. A sample size of 903 operators' questionnaires has been used to perform this study in PHH. QFD requirements were employed to build the new required system. A comparison was made between PHH and the Specialty Hospital (SH) to benchmark its performance and measure how much PHH is away from achieving its targets.It was found that the failure response time was the most important performance aspect in the responsiveness category, the safe medical device was the most important performance aspect in the reliability category; the calibration of maintained device was the most important performance aspect in the reproducibility category and the spare parts availability was the most important performance aspect in the availability category. A new model has been suggested to be implemented for improving the performance of MDMS. This will lead eventually to better customers' satisfaction. The model consists of correlation between the requirements of the customers and technical capabilities of the provider with their correlation.

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Keywords: Quality Function Deployment; Medical Device Maintenance System; Critical Devices; Non Critical Devices

1. Introduction

Medical device is a major component of today's healthcare systems as it is utilized for patient diagnosis and treatment. Therefore a comprehensive and effective structured approach is essential to make sure that the device is fully utilized with maximum reliability and reproducibility.

During the last two decades, Medical Devices Maintenance System (MDMS) evidenced huge improvements in all its areas including process, strategy, policy, procedure and technology trying to introduce a high quality technical service for medical devices operators.

Maintenance systems have had a tremendous impact on organizations' ability to meet their objectives. The realization of this impact has directed the attention to maintenance quality and performance. It was also called the use of Total Quality Management (TQM) tools for improving maintenance quality [1].

Alot of methodologies and tools were established or improved throughout the last forty years like, TQM concept; International Standardization Organization (ISO), Just-in-Time (JIT) and Quality Function Deployment (QFD). Each one of these methodologies had its particularity properties, specifications and its influence on the service or production provided.

Any institution in the health sector depends basically on the customers to improve, support its position and to benchmark between the competitors. The scope of my research was to build MDMS through implementing QFD principles on hospitals in Jordan; this study encountered customers' (medical devices operators) satisfaction in Prince Hamzeh Hospital (PHH) and Specialty Hospital (SH) by customizing the techniques of QFD for designing effective MDMS.

Quality Function Deployment was required to provide a link between customers' requirements and the abilities of the system to fulfill the customers' requirements. Maintenance engineers were to make sure that all medical devices were accurate, reliable and reproducible.

Quality Function Deployment is a system and procedures to identify, communicate and prioritize customers' requirements so that an organization can optimize its products and services to exceed customers' expectations [2].

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It was evident that in order to improve quality of health care, medical devices must be operational all the time for optimum responsiveness, reliability, availability and reproducibility. This might be achieved by applying modern technical management concepts and administrative tools that are in line with worldwide economic development [9].

2. Related Work

2.1. Quality function deployment (QFD) in maintenance:

Kutucuoglu developed a general framework using QFD technique as a tool for Maintenance Performance Measurement System (MPMS). Using a case study example they were able to show how to develop a three stage-matrix approach: identification of key Performance Indicators (PI), selection of critical maintenance measurement units [3].

Other researches were conducted other frameworks of QFD researches such as value-based using of balance score card. Although they accounted for financial and non-financial impacts of maintenance strategies, however, they failed to provide control for improving maintenance performance on tactical and strategic level and didn't not take into account the impact of maintenance strategies on the extended value-chain i.e. suppliers etc.

Takata analyzed the technical role change of maintenance in product lifecycle and then presented a maintenance framework that showed management cycles of maintenance activities, including maintenance planning, maintenance task execution and lifecycle maintenance management. They found that Maintenance was the most efficient way to keep the function available during the product lifecycle [10].

Pramod proposed a maintenance QFD model based on QFD and Total Productive Maintenance (TPM) for enhancing maintenance quality of product, and then they checked the implementing feasibility of the proposed method through an automobile service station. They found that both QFD and TPM were popular approaches and several benefits of implementing them have been reported [12].

Lazreg proposed an integrated model linking two popular approaches (i.e. six Sigma and maintenance excellence) to improve the effectiveness of maintenance. Coupled with QFD, the model was used to deploy the design parameters in order to reduce variations and time and to eliminate the occurrence errors in the maintenance process [13].

Zhang applied QFD as a new approach for conceptual design of Product and Maintenance (P&M). In the layout process, the approach used an improved QFD tool to translate customers' requirements into concepts' specifications. An information exchange mechanism was developed to exploit the interrelation between P&M [4].

In the mechanism, a Failure Mode and Effects Analysis (FMEA) tool was used to identify and analyze failure modes and their effects on the product concept. Then maintenance concepts were generated based on the results of QFD and FMEA. The proposed approach was applied in a conceptual design case of a horizontal directional drilling machine with its maintenance.

Kianfar added the QFD methodology to Reliability-Centered Maintenance (RCM) to improve RCM capability in preserving the functions of the plants. Their objective was to preserve the plant functions with least resources. They found that more efficiency will be attained in RCM if the methodology of QFD was added to RCM [5].

In comparison with RCM, ,QFD provided additional valuable information about failure modes, in a compact form, which could be used by the maintenance design engineers when they were trying to select the best Preventive Maintenance (PM) tasks for the plants.

2.2. Quality function deployment (QFD) in medical sector:

Recent attempts to apply QFD principles to the healthcare sector concentrated upon gaining greater understanding of customers' needs and how to engineer the process to best meet these needs. In particular it has been realized that the patient was not necessarily the only customer and that it was better to consider stakeholders or strategically related interested groups. Examples of such groups were:

- Patients.
- Reference groups (consultant physicians).
- Local and national governmental authorities.
- Tax payer and/or insurance companies.
- Hospital management and staff.

Most of the early studies on QFD in medical sector were primarily conducted from the viewpoint of medical services and medical safety. In 1990, Puritan-Bennett, a medical equipment company, successfully used QFD to help redesigning its spirometry business in order to regain their market share.

Moore presented a study of the potential for applying QFD method in the analysis of the framework for safety management Regulations. He presented a first stage analysis of Ionizing Radiation Medical Exposure Regulations (IRMER) 2000 that assessed how patients' needs were expressed by the individual IRMER components of justification, optimization, clinical audit, expert advice, equipment and training. The analysis involved a QFD assessment by four radiation protection experts with over 100 man-years of experience [6].

A second stage analysis assessed how the individual IRMER components have been engineered into a safety management framework through specific requirements embodied in IRMER 2000.

Liu conducted a study in the field of shoulder surgery" A brief fatigue inventory of shoulder health developed by QFD technique". They used a QFD technique to develop an instrument to assess the severity of symptoms of neck and shoulder pain and to determine the origin of these symptoms [7]. Using QFD they were able to:

- Prioritize and assign weights to the items in the assessment scale and then make multiple comparisons to reduce error.
- Determine the risk in neck and shoulder pain.

Although this assessment tool was not able to measure outcomes, it might be able to help health care providers determining the source of patient complaints and identifying when treatment might be helpful.

3. The House Of Quality (HOQ)

The HOQ is the kernel of QFD. It is a matrix that consists of sub matrices that are related to one another. Each section in HOQ is called ‘room’. It is a structured and systematic representation of a product or process development.

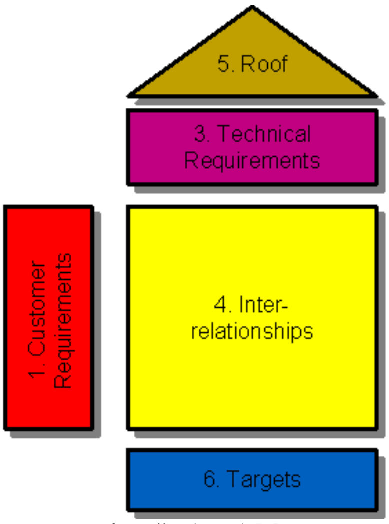

Figure 1: House Of Quality (HOQ) [8].

3.1. Customers' Requirements:

It is on the left side of the HOQ. This section documents the "VOC". It represents the "what's" of the system. Affinity diagrams and Tree diagrams are used to structure the requirements.

3.2. Planning Matrix:

It is on the right side of the HOQ matrix. It represents the customer competitive assessment. It Provides customers’ (any people who would benefit from the use of the proposed maintenance process) views on existing products. This matrix uses questionnaires to elicit information.

The requirements are usually short statements recorded and are accompanied by a detailed definition. After all the requirements were gathered, similar requirements were grouped into categories and written into a tree diagram.

3.3. Technical Requirements:

This section lists how the company will meet the customers' requirements. This is the "HOWs" of the system. It represents the engineering characteristics or voice of the company. It no longer takes on a VOC but instead the voice of the company.

These technical requirements should be controllable and measurable characteristics of the product and there could be more than one technical requirement corresponding one customer's requirement. The generation of technical requirements is a crucial part of HOQ. During this step the VOC will be translated into the design requirements to be implemented.

3.4. Relationship Matrix:

It occupies the middle portion of the HOQ diagram which is the largest portion. It uses the prioritization matrix. It shows how well customers' requirements are addressed by product features.

The QFD team must assign a weighting based on the question: "How important is technical requirement A is satisfying customer's requirement B?" During this step consensus between customers and development should be reached on the requirements mapping.

3.5. Roof:

The purpose of this step is to consider the impacts that the technical requirements will have on each other. , this step is critical in identifying engineering trade-offs between technical requirements.

For each pair of technical requirements, the QFD team must answer the following question:” Does improving one requirement cause deterioration or improvement in another requirement? ”The "direction of improvement" is important at this point as one needs to have a measurable quantity with which to determine improvement or deterioration. The impacts are recorded as positive (+), negative (-), or no effect.

3.6. Targets:

This the final section of HOQ matrix. The purpose of this step is to integrate the results from all the previous into a set of targets to be used during design and implementation. It summarizes the conclusions of the planning matrix. It includes three parts:

- Technical priorities (relative importance of each technical requirement).
- Competitive benchmarks (relative position of the existing product).
- Targets (engineering target values to be met by the new product design).

The crucial difference between QFD and more traditional approaches was that QFD generated targets based on repeatable and statistical analysis. The prioritization of the technical requirements was performed by summing the product of the interrelation weights with the overall weighting assigned during the planning step.

4. Methodology

4.1. The proposed approach:

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This study used the HOQ in QFD as the analysis model. QFD appeared to be able to provide MDMS with a better understanding of customers' translation of these expectations into appropriate service specifications and perform existing process assessment.

A generic QFD framework was applied as a reference model for MDMS. The six-phase implementation framework was presented, together with the findings of empirical research. A brief outline of the six phases and the research methodology adopted is shown below.

4.1.1. Research Model Phases:

4.1.1.1. Customers' Requirements:

The first phase of the process was to define all the external customers (medical device operators) and their requirements. There were multiple tiers of customers, such as:

- Radiology department staff.
- Laboratory staff.
- Operational theatres staff.
- Ophthalmology department staff.
- Haemodialasis department staff.

Identifying customers' expectations was the most crucial step of the QFD process and it involved the identification of what customers expect from the service. The questionnaires method was utilized to establish customers' expectations.

4.1.1.2. Planning Matrix:

The customers' requirements were ranked by applying interpolation method. The medical device operators' satisfaction was measured with available maintenance system by comparing it with a MDMS in other hospital.

A questionnaire survey comprising around 30 questions was conducted at two hospitals in Amman. This questionnaire was given to the staff of concerned departments.

Response ranking in this phase was done based on interpolation method. The performance aspect with the highest mean value was assigned 5, the one with the lowest mean value was assigned 1 and the interpolation method was applied to calculate the rank of each performance aspect based on its mean value.

The medical device operators' satisfaction with available maintenance system could be measured by calculating the following measures:

- Planned satisfaction rating
- Improvement factor

These measures were combined with the customer importance weighting to calculate the overall weighting for each customer's requirement.

4.1.1.3. Technical Requirements:

In this phase the medical device maintenance staff of the two hospitals was interviewed and all the measurable characteristics of the Medical Device Maintenance Process (MDMP); which they perceived they related to meet the operators' requirements; were identified.

4.1.1.4. Interrelations:

In this phase the requirements were translated as expressed by the customers into the technical characteristics of the MDMP. It has been identified in this phase where the interrelations between the customer and technical requirements were significant.

The level of interrelation discerned was weighted on a four point scale (high, medium, low, none). A symbol representing this level of interrelation was entered in the interrelation portion of HOQ. Each level of interrelation weighting was assigned a score. For instance; High=9, Medium=3, Low=1 and none=0.

4.1.1.5. Roof:

In this phase it has been identified where the technical requirements characterizing the MDMP supported or impeded one another. It has been worked through the cells of roof matrix considering the pairings of technical requirements these represent.

The key question was to be answered: In the case of improving one requirement, will that deteriorate or improve in the other technical requirements? If the answer was that will deteriorate, an engineering trade-off existed and a symbol (-) was entered into the cell to represent this answer. On the other hand if the answer was that will improve; a symbol (+) was entered into the cell to represent this answer.

4.1.1.6. Targets

In this phase the following sections were established:

- Technical priorities (relative importance of each technical requirement)
- Competitive benchmarks (relative position of the existing product)
- Targets (engineering target values to be met by the new product design)

The technical priorities were calculated by summing up the multiplication of overall weighting and interrelation weighting score for each requirement.

4.2. Case study:

This study aimed to make the necessary improvement on the MDMS procedures at the PHH hospital where the following was done:

- Prince Hamzeh Hospital in Amman was selected to improve MDMS through applying QFD methodologies.
- As competitor was needed, SH was identified to apply HOQ on it.

The first step in building the HOQ was the building the customers' requirements block by identifying the VOC. This step was done through and on-site observations and interviews with customers which were 903 operators from the different departments in PHH like radiology, laboratory, operations theaters, haemodialasis and ophthalmology. The operators were encouraged to describe their needs and problems.

Affinity diagrams were used to structure the list of requirements gathered before its entry to the HOQ. To build an affinity diagram the customers' requirements were arranged in groups. A title for each group was: chose which encapsulated the meaning contained within that group. The completed affinity diagrams have been used as the basis of the tree diagrams.

When applying on-site observations and interviews with operators, it was found that their needs and problems were divided into two sections: requirements and wishes as shown in Table 1.

Table 1: Requirements and wishes of medical devices operators.

responsiveness category	Short maintenance period	Existence of more than one workshop	Organization structure (the location of the workshop)	Failure Response time	The nature of maintenance system (hospital maintenance staff or contracted local agents)
reliability category	Safe medical device	High Mean Time Between Failures (MTBF) i.e. hard duty	Training the operators on the device(during installation and periodic training)		
availability category	Existence of redundant device	Spare parts availability	Speed of obtaining the spare parts.	Performing PM	
reproducibility category	Calibration the maintained device	Doing check up process for the device after the maintenance process and before delivering it to the operator			
Wishes	contact Existence of a person in the maintenance department in the hospital to follow up the different procedures	Assigning a person representing the maintenance department in the medical devices purchasing committee	Using the original agent spare parts in non critical medical device maintenance	Existence of a senior engineer in all work shifts (specially the night shift)	Existence of an integral full computerized maintenance system with an electronic troubleshooting database showing the cause of failures & presenting the suggested action to deal with that failure

Table 2: Importance weighting of VOC.

Importance weight		
8	Short maintenance period	Responsiveness

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3	Location and existence of more than workshop	
10	Failure response time	
4	Nature of maintenance system	
9	Safe medical device	Reliability
6	High MTBF	
4	Training of operators on installation	
8	Periodic training of operators	
10	calibration of maintained device	Reproducibility
5	Do check up after maintenance	
10	Spare parts availability	Availability
7	Spare parts obtaining time	
5	Doing PM	
4	Existence of redundant device	
4	Existence of administrative person	
4	Using original spare parts	

For each category, the data collected from the SH and three experienced persons representing the major sectors of MDMS in Jordan (public, private and military) were used to evaluate the value of importance weighting for each performance indicator. This value was put on the Customers' requirements on theleft side of HOQ as shown in Table 2.

From the table, it was remarked that the failure response time was the most important performance aspect in the responsiveness category, on the other hand, the location and existence of more than workshop was the least important performance aspect in the same category.

It was noticed also that the safe medical device was the most important performance aspect in the reliability category; on the other hand, the training of operators at installation was the least important performance aspect within the same category.

It was remarked that the calibration of maintained device was the most important performance aspect in the reproducibility category; on the other hand, doing checkup after maintenance process was the least important performance aspect in the same category.

It was observed that the spare parts availability was the most important performance aspect in the availability category; on the other hand, existence of administrative person, Existence of administrative person and using original spare parts were the least important performance aspect in the same category.

The second step was identifying the technical requirements block which was referred to as the engineering characteristic or the voice of the hospital. This information was generated by identifying all the measurable characteristics of the MDMS which they were perceive they were related to meeting the specified customers' requirements.

Affinity diagrams were applied to interpret the MDMS characteristics; an additional row was put to illustrate the direction of change in each of these variables which was considered to result in an improvement in MDMS performance. The technical requirements were represented in Table 3.

Table 3: Technical requirements and its direction of changes.

⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧	⇧
Administrative Procedures	Enough Staff	Infra-structure & transportation within hospital	Existence of work specialty	Enough budget	Types of spare parts contracts	Existence of suitable tools	Device Strength	Meet Standards	Continuous education and training

Table 4: Performance measures of PHH.

Performance measure		
3.65	Short maintenance period	Responsiveness
1.77	Location and	

	existence of more than workshop	
3.975	Failure response time	
0.71	Nature of maintenance system	
1.075	Safe medical device	Reliability
1.075	High MTBF	
2.325	Training of operators on installation	
2.825	Periodic training of operator	
4.4	calibration of maintained device	Reproducibility
1	Do check up after maintenance	
3.675	Spare parts availability	Availability
5	Spare parts obtaining time	
3.35	Doing PM	
3.225	Existence of redundant device	
5	Existence of administrative person	
5	Using original spare parts	

After the mean value for each performance indicator was found, the performance indicator speed of obtaining the spare parts was assigned a value of 5 because it had the highest mean value, the performance indicator check up the device after maintenance was assigned a value of 1 because it had the lowest mean value. The interpolation method was used to find the weight of each performance indicator. The other measures of operators satisfaction included in the planned matrix were:

- Planned satisfaction rating
- Improvement factor
- Overall weighting

The planned satisfaction rating quantified the level that PHH staff plan to arrive it to achieve the operators satisfaction. They were obtained from the maintenance staff of PHH. The results of planned satisfaction rating were illustrated in Table 5.

The improvement factor shown in Table 5 was calculated by subtracting the performance score of the MDMS of PHH from its planned performance score. This difference was divided by 5 to give the improvement factor. For example; the improvement factor for Short maintenance period was:

$$\frac{4-3.65}{5} = 0.07 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .3$$

The overall weighting has been calculated by multiplying the importance weighting by the improvement factor as illustrated in the Table 5. For example; the overall weighting for short maintenance was calculated as follow:

$$8 \times 0.07 = 0.56 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .4$$

Regarding the planned satisfaction rating, it was observed that the lowest operators' satisfaction was found in little performance aspects like periodic training of operators which was a requirement. The rest of performance aspects achieved the satisfaction.

Regarding the improvement factor, it was noted that the highest improvement needed to be done was found in doing check up after maintenance and existing of safe medical device. The lowest improvement needed to be done was found in periodic training of operators and spare parts availability which both were requirements.

It was remarked that the wishes of existence of administrative person and using original spare parts and spare parts obtaining time requirement did not need any improvement to be done.

Regarding the overall weighting, it was noted that the existing of safe medical device and do check up after maintenance requirements were the performance aspects had the highest priority to begin with because they had the highest overall weighting. The using of original spare parts wish, using original spare parts and spare parts obtaining time were the performance aspects had the lowest priority to begin with because they had the lowest overall weighting.

The interrelations matrix which formed the main body of HOQ was then constructed. The interrelations matrix combined the technical requirements and VOC. The level of interrelation discerned was weighted on a four point scale (High, Medium, and Low, None which represent with space) and a symbol representing this level of interrelation was entered in the matrix cell. To construct it, the matrices for PHH, SH and three experienced people's matrices were found as in the appendices and then brainstorming was made to construct the average matrix that represented all of them as shown in Table 6.

Each level of interrelation weighting was assigned a score, e.g. High=9, Medium=3; Low =1 and none =0. It was noticed from the table that the relationship between the short maintenance period and enough staff was high because in the case of having enough staff, a queue will not be existed and the maintenance process will take less time.

The relationship between high MTBF and enough staff was medium. The existence of enough staff affected the MTBF but its influence was not huge. When having enough staff, the device will be maintained quickly which will reduce the MTBF.

The relationship between safe medical device and enough staff was low. The safety of maintained devices did not change whether having five or ten maintenance staff.

The roof shown in Figure 2 of HOQ was constructed. The roof was used to identify where the technical requirements that characterized the MDMS supported or impeded one other. It has been worked through the cells of the roof asking the question: Does improving one requirement cause a deterioration or improvement in the other technical requirement?

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The roof highlighted where a focused design improvement could lead to a range of benefits to the MDMS. It focused attention on the negative relationships in the MDMS. This represented opportunities for innovative solutions to be applied.

To construct the roof, the roofs for PHH, SH and three experienced persons' matrices was found and then brainstorming was made to construct the average roof that represents all of them as shown in Figure 2.

Table 5: Planned satisfaction rating, improvement factor and the overall weighting of the performance indicators.

overall weighting	improvement factor	planned satisfaction rating		
0.56	0.07	4	Short maintenance period	Responsiveness
		They have just one workshop	Location and existence of more than workshop	
	0.205	5	Failure response time	
2.64	0.66	5	Nature of maintenance system	
7.065	0.785	5	Safe medical device	Reliability
3.51	0.585	4	High MTBF	
1.34	0.335	4	Training of operators on installation	
0.28	0.035	3	Periodic training of operators	
1.2	0.12	5	calibration of maintained device	Reproducibility
4	0.8	5	Do check up after maintenance	
1.65	0.065	4	5Spare parts availability	Availability
0	0	5	Spare parts obtaining time	
1.65	0.33	5	Doing PM	
0.62	0.0155	4	Existence of redundant device	
0	0	5	Existence of administrative person	
0	0	5	Using original spare parts	

Table 6: Interrelation matrix.

	Administrative Procedures	Enough Staff	Infra-structure & transportation within hospital	Existence of work specialty
Short maintenance period	H	H	M	H
Location and existence of more than workshop	M	M	H	L
Failure response time	L	H	M	M
Nature of maintenance system	M	H		H
Safe medical device	M	L	H	H
High MTBF	M	M	H	L
Training of operators on installation	H	H	H	L
Periodic training of operators	H	M	H	L
calibration of maintained device	H	L	M	L
Do check up after maintenance	H	L	M	L
Spare parts availability	L	H	H	L
Spare parts obtaining time	L	H	H	L
Doing PM	M	L	H	L
Existence of redundant device	L	H	M	M
Existence of administrative person	L	H	H	L
Using original spare parts	L	H	H	L

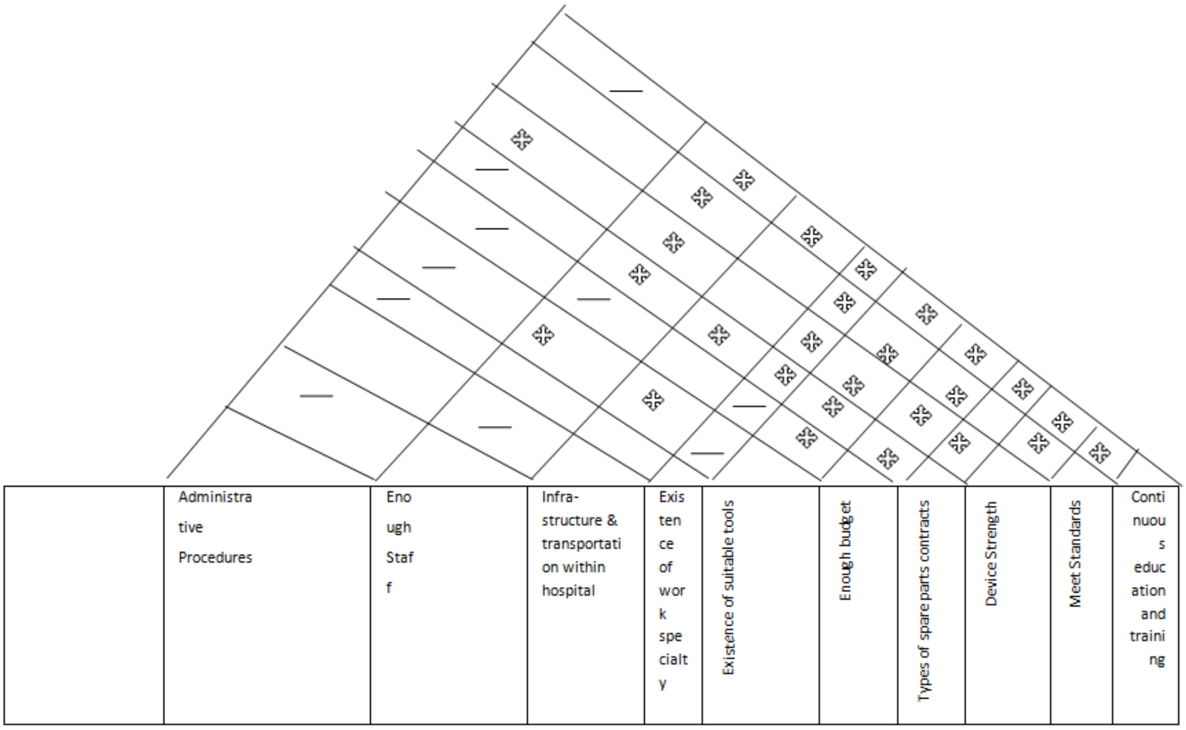

Figure 2: The roof.

In Figure 2, it was observed that the relationship between the enough staff and existence of suitable tools was direct. There was also an inverse relationship between the existence of work specialty and the enough budgets. There was no relationship between meet standards and infra structure and transportation within hospital.

The final part of HOQ which was the targets was constructed. The targets summarized the conclusions drawn from the data contained in the entire matrix. They were made up from three parts: Technical priority, Competitive benchmarking and Targets The technical priority was calculated by summing up the product of the overall weighting shown in Table 5 and the interrelations value shown in Table 6 as shown in Table 7. For example; the technical priority for continuous education and training was calculated as follow:

$$.56 \times 9 + 9 \times 2.64 + 9 \times 7.065 + 9 \times 3.51 + 3 \times 1.34 + 1 \times 028 + 1 \times 1.2 + 4 \times 1 + 9 \times 1.65 = 148.325$$

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Table 7: Technical priority, competitive benchmarking and targets.

		Administrative Procedures	Enough Staff	Infra-structure & transportation within hospital	Existence of work specialty	Existence of suitable tools	Enough budget	Types of spare parts contracts	Device Strength	Meet Standards	Continuous education and training
Technical priority		156.875	166.775	114.335	96.295	155.745	113.02	158.75	143.13	164.3	148.325
Bench-marking	PHH	One week for internal administrative procedures(from writing a spare part order to obtaining it) and three months for external	Low : 4 personmel (Need two more)	Excellent	Medium 60%	Enough budget with complexity with administrative procedures	Less than 20 % (with certain devices)	All the needed tolls existed	90%	100%	Low
	SH	One day for internal and around three days for external	It is enough	Excellent	Medium 50%	Enough budget with flexibility with administrative procedures	Less than 25 %(with certain devices	All the needed tolls existed	100%	100%	High
Targets		One hour for internal and less than one day for external	6 personmel	Excellent	High 80%	Enough budget with flexibility with administrative procedure	Less than 10 % (with certain devices)	All the needed tools existed	100% choosing the best device regardless the price	100%	High

It was noticed from the table that the enough budget performance aspect had the highest technical priority so it should be thought of it firstly and trying to solve its problems, it was also noticed that the continuous education and training had the lowest technical priority so it was not critical one.

The competitive benchmarking represented the measurement of the technical requirements identified for the MDMS for PHH and SH in Table 7. This illustrated the relative technical position of MDMS for PHH and identified the target levels of performance to be achieved.

The competitive benchmarking was obtained through direct observation of the performance aspect. For example; regarding the enough staff, it was found that there were 2 persons in SH and 4 person in PHH. Table 7 illustrated the competitive benchmarking.

It was noticed from Table 7 that, the situation of PHH in certain performance aspects like the existence of work specialty was better than that in SH. There were some cases, like the infrastructure and the transportation within the hospital, where our situation and the situation in SH were the same. The majority of the cases indicated that the situations of PHH in them were less than in SH.

The final stage of HOQ was a set of engineering target values to be met by the new MDMS .The process of building this matrix enabled these targets to be set and prioritized based on an understanding of the operators' needs, the competitor's performance and hospital current performance. It was needed to draw on all this information when deciding on these values.

The targets were obtained by observing the performance of PHH and SH in each performance aspect and comparing it to the typical situation known by the expertise opinions. For example; regarding the enough staff, it was found that it was enough in SH but it was not enough in PHH because there was a backlog and by asking the PHH staff and expertise about the optimum number needed, they suggested existing of 6 persons one of them for administrative affairs. Table 7 illustrated the targets.

It was noticed from the table that some targets were not met like the infrastructure and transportation within hospital. On the other hand a lot of targets were not met. Some targets needed a lot to do to be achieved like administrative procedures and some targets were easier to be achieved like enough staff.

The overall integration of the previous steps were gathered in Figure 3.

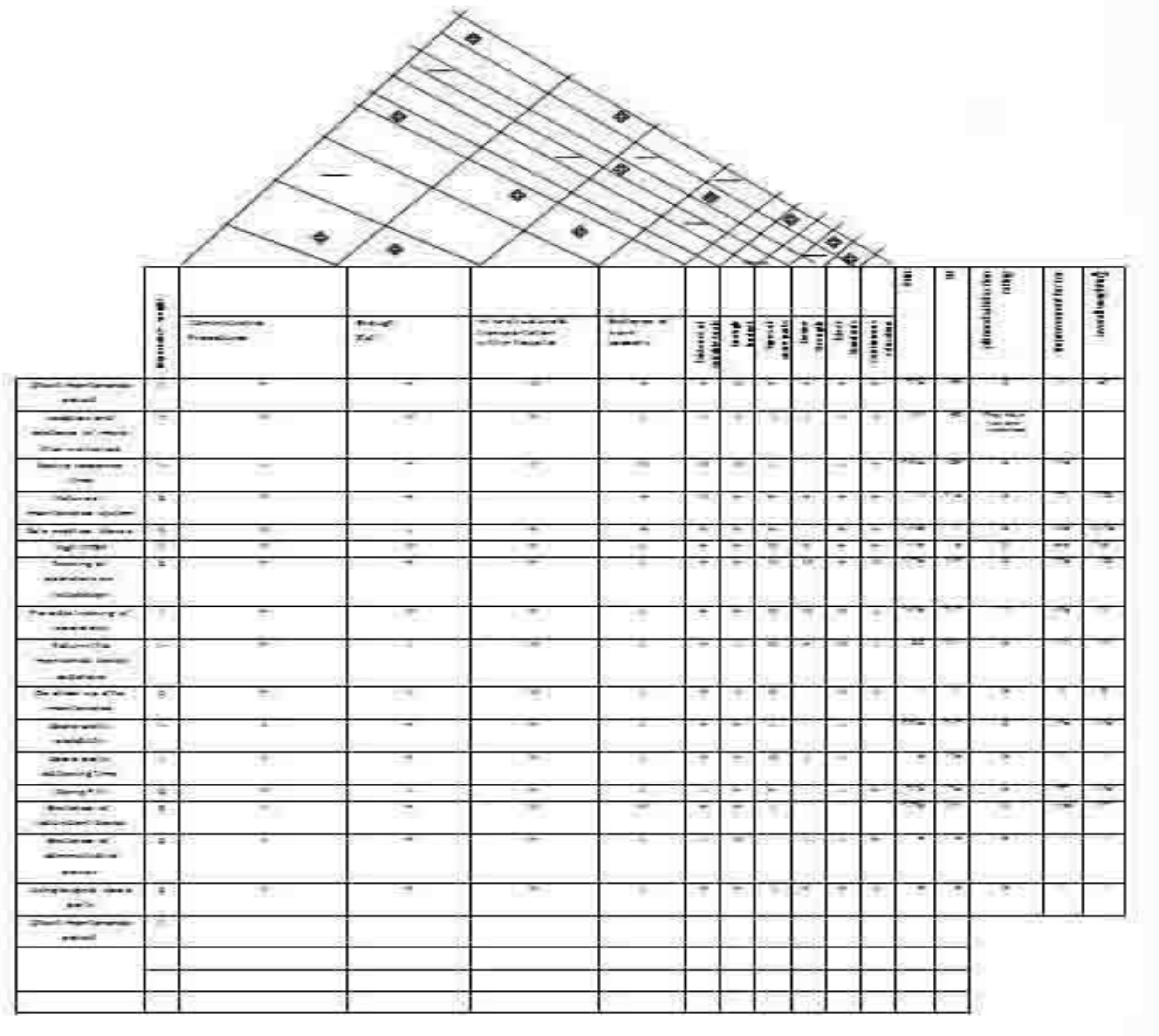

Figure 3: Overall integration of House Of Quality (HOQ).

5. Conclusion

This paper used QFD to build MDMS in PHH. It investigated the responsiveness, reliability, availability and reproducibility of medical devices in PHH. It included a questionnaire's analysis regarding the VOC.

Through this research, it could be seen that applying QFD in building MDMS clarified the targets and how to achieve them. Among ten targets three of them were achieve and the others could not be achieved by implementing the suggested procedures.

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This model could be used to show the decision makers which variables were mostly affecting the performance of MDMS and then reasonable decision should be taken on such variables to improve the performance.

For optimizing the planned satisfaction rating, the periodic training of operators should be only concentrated on. It was concluded that the highest improvement needed to be done was found in doing check up after maintenance process and the existing of safe medical device.

It was deduced that the existing of safe medical device and do check up after maintenance process requirements were the performance aspects that had the highest priority to begin with. It was concluded also that the enough budget performance aspect had the highest technical priority so it should be thought of it firstly and trying to solve its problems.

In general, it was drawn that the situation of PHH in some performance aspects such as; availability of work specialty was better than that in SH. There were some cases such as; the infrastructure and the transportation within the hospital, where the situation of PHH and SH were the same. The majority of the cases indicated that the situation of PHH was not better than in SH.

Administrative procedures in PHH should be studied and improved in order to reduce the routine time required for requesting spare parts. Some requirements of the QFD in PHH have not been met, such as; enough staff performance, types of spare parts contracts, availability of work specialty, devices strength and continuous education and training.

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Human Behavioral Aspects of Level Crossing Safety with Special Reference to Indian Railways

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Abstract

Railway level crossings (LC) are the interface between roads and railway tracks, and as such are the potential site for vehicle-train collisions and incidents. About 95 % of accidents are caused by road users' misuse. Behavioural science is an academic and applied discipline involving the scientific study of mental process and behaviour. There is currently considerable interest being taken to better understand road users' behaviour at LC, and to implement additional controls and upgrades to improve LC safety performance. The present paper describes various parameters of behavioural science related to LC. The present study indicates that on Indian Railways, gate closure time on most of the L.C is unusually long and beyond the tolerance of the road users. About 30 % of the vehicle drivers have reaction time more than 2 seconds which results in delayed decisions and actions, sometimes resulting into accidents.

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Keywords: Level Crossing (LC); Behavioural study; Road users; Reaction time

1. Introduction

Humans are the weakest link in any embedded system. Failure rates for humans as system components are several orders of magnitude higher than other parts of the system. Railway Level crossing gate operation requires involvement of a considerable no of persons. This results in more human errors and hence disastrous consequences [1].

A LC (also known as railroad crossing) is a crossing on one level ("at grade intersection") – without recourse to an over-bridge or under-pass. Early LC had a flagman in a nearby booth that would, on the approach of a train, wave a red flag or lantern to stop all traffic and clear the track. Manual or electrical closable gates that barricaded the roadway were later introduced. The gates were intended to be a complete barrier against intrusion of any road traffic onto the railway. In the early days of the railways, much road traffic was horse-drawn or included livestock. It was thus necessary to provide a real barrier. Thus, crossing gates, when closed to road traffic, crossed the entire width of the road. When opened to allow road users to cross the line, the gates were swung across the width of the railway, preventing any pedestrians or animals getting onto the railway line.

With the appearance of motor vehicles, this barrier became less effective. Many countries therefore substituted the gated crossings with weaker but more highly visible barriers and relied upon road users following the associated warning signals to stop.

In many countries, level crossings on less important roads and railway lines are often "open" or "uncontrolled", sometimes with warning lights or bells to warn of approaching trains. Level crossings without gates represent a safety issue; many accidents have occurred due to failure to notice or obey the warning. Railways in the United States are adding reflectors to the side of each train car to help prevent accidents at LC. In some countries, such as Ireland, instead of an open crossing there may be manually operated gates, which the motorist must open and close. These too have significant risks, as they are unsafe to use without possessing knowledge of the train timetable. Motorist may be instructed to telephone the railway signaler, but may not always do so.

The director of rail safety at the UK Railway Inspectorate commented in 2004 that "the use of level crossings contributes the greatest potential for catastrophic risk on the railways."

Fig.-1 shows LC risk weighed against the overall level of risk on the railway by the Safety Risk Model (SRM). It indicates that, excluding suicide, LC contributes approximately 6.2 % of the total risk. The right-hand pie chart shows that the majority of the risk comes from pedestrians being struck (57%), while the second highest risk arises from train collisions with road vehicle (35%). Of the risk at level crossings, over 95% is from human error and misuse; and less than 5% is caused by system failure. [2]

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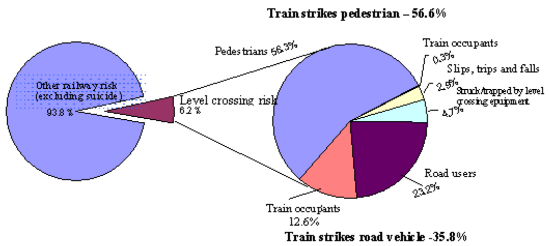

Figure 1: Level Crossing risk in context of overall railway risk. (Excluding suicide).

As on 31.03.2002, there were 21,792 unmanned and 16,549 manned LC on Indian Railway System. At present, 6446-manned LC is interlocked and 14,502 are provided with telephones. It has been found that around 80% accidents generally take place at those unmanned LC where traffic is low and visibility is clear. [3]

Recently in Australia there has been considerable recognition regarding the importance of human behavioural aspects of railway level crossing safety, particularly the ability to see a train and judge a safe gap to cross.

2. Level Crossing Safety Impediments

The Russian Federation Railways has identified the following factors as the main causes of LC accidents: [4]

- low level of public discipline and, as a consequence, mass violations by vehicle drivers of the rules relating to passing of LC;
- motor vehicle driver misjudgments concerning road conditions and the approach of trains on LC;
- motor vehicle driver misjudgments of vehicle speed and braking capabilities during the winter months.
- technical malfunction of road vehicles;
- non-compliance by highway authorities with the standards of road maintenance at the approaches to LC;
- poor maintenance of LC warning and protection devices;
- human error on the part of level crossing staff.

3. Behavioral Studies

An individual's observable response in a given situation with respect to a given target is known as behaviour. Ajzen [5] states that behaviour is a function of a compatible intentions and perceptions of behavioral control. The perceived behavioural control is expected to moderate the effect of intention on behaviour, such that a favourable intention produces the behaviour only when perceived behavioural control is strong.

Founded by John B. Watson and extended by Edward Thorndike, Cark L. Hull, Edward C. Tolman, and later B.F Skinner studied the mind via. 'Introspection'. The behaviourists (e.g. Watson) argued the contents of the mind were not open to scientific scrutiny and that scientific psychology should only be concerned with the study of observable behaviour. Behaviourism differs from other perspectives in a number of ways. Behaviourists focus on behaviour-environment relations and analyses overt and covert behaviour as a function of the organism interacting with its environment. [6]

95 % of accidents are caused by the road users including vehicle drivers and pedestrians. Therefore, there is a need to conduct behavioural studies for the road users to find out suitable methodology to educate them in order to minimise accidents at LC.

3.1. Road user psychology:

Road user psychology is young, expanding and wide field in psychology. It is primarily related to the study of the behaviour of road users and the psychological process underlying that behaviour as well as to the relationship between behaviour and accidents, individual and social factors in the movement of people and goods and travel demand management [7]. There is no single theoretical framework in road user psychology, but, instead, many specific models explaining, for example, the perceptual, intentional, cognitive, social, motivational and emotional determinants of mobility and traffic behaviour. One of the most prominent behavioural models divides the various tasks involved in traffic participation into three hierarchical levels, i.e. the strategic, the tactical and the operational level. The model demonstrates the diversity of decision and control tasks which have to be accomplished when driving a vehicle. However, until now, most of the psychological models have had a rather heuristic nature, e.g. risk theories such as the risk compensation hypothesis, Fuller's task capability model, and thus are not sufficiently precise to allow for concrete behavioural prediction and control.

3.2. Road rage:

It is aggressive or angry behaviour by a driver of an automobile or other vehicle. Such behaviour may include rude gesture, verbal insults, deliberately driving in an unsafe or threatening manner, or making threats. Road rage can lead to altercations, assaults and collisions which result in injuries and even deaths. It can be considered as an extreme case of aggressive driving [8].

3.3. Behavior and accident:

This is particularly in relation to different groups of road users (age groups, modes of transport), but also in relation to road design and motor vehicles. Explaining and predicting road user behaviour depends on the development of valid and reliable models about the role of human factors in mobility behaviour, and, especially, driver performance. Psychological traffic accident and behaviour research deals with matters such as: analysis of the driving task, changing conceptually from a traditionally rather sensory-motor task to a task with high monitoring impact, perception, cognition and attentiveness when driving, driver information processing and expectations, the driver's state, workload, alertness and fatigue.

- driver personality, risk-taking, attitudes, motives for driving, excited ness and emotion,
- interactions and the social psychology of driving,
- the relationship between the personal and environmental background of behaviour, overt behaviour, emerging conflicts and accidents,
- work on risk compensation theory.

3.4. Accident prevention and improvement of road users' safety:

This comprises education and information, above all following the "4 Es": enforcement, education, engineering, encouragement/economy. The main goal is promoting safety in influencing and modifying behaviour. [9]

3.5. Research and counseling:

This includes differentiation between transportation needs of special groups and main topics are:

- mobility needs and travel demands, choice of means of transport,
- travel behaviour research, above all activity-based approach,
- altering mobility behaviour and modal split, problems of habituation and resistance to change, car dependence,
- design and acceptance of travel demand management, above all of road pricing measures [10]
- psychological aspects in road design and traffic environment,
- quality management, especially quality of service, usability and well-being.

3.6. Psychological assessment and counseling:

This kind of assessment and counseling is for drivers who display irregular behaviour. It involves driver assessment, training and rehabilitation.

4. Total Reaction Time

Total reaction time of the driver is the time taken from the instant the object is visible to the driver to the instant the brakes are effectively applied or any other decision is finally executed. During this time the vehicle travels a certain distance at the original speed. With increase in reaction time of the driver, the stopping distance increases or final decision is prolonged. [11]

4.1. PIEV Theory:

According to this theory the total reaction time of the driver is split into four parts, viz, time taken by the driver for:

- Perception.
- Intellection.
- Emotion.
- Volition.

Perception time is the time required for the sensations received by the eyes or ears to be transmitted to the brain through the nervous system and spinal chord. Perception involves the process of not only detecting an object in a general sense, but also comprehension of its significance. [12]

Intellection time is the time required for understanding the situation completely. It is also the time required for comparing the different thoughts, regrouping and registering new sensations.

Emotion is the complex psycho-physiological experience of an individual's state of mind as interacting with biochemical (internal) and environmental (external) influences. In humans, emotion fundamentally involve s "physiological arousal, expressive behaviours, and conscious experience" [13]

Emotion time is the time elapsed during emotional sensations and disturbances such as fear, anger or any other emotional feelings such as superstition etc. with reference to the situation.

Volition is the cognitive process by which an individual decides on and commits to a particular course of action. Volition time is the time taken for the final action. [14] It is also possible that the driver may apply brakes or take any avoiding action, even without thinking, i.e. under reflex action. Reflex actions are instinctive and require the shorter time as they involve no thinking [15]. Most driving does not involve reflex action. However, when a strong unexpected stimulus is presented to a driver, a reflex action may result. Such reflex actions are usually wrong and can be disastrous. The PIEV process has been illustrated in fig. 2 [16]

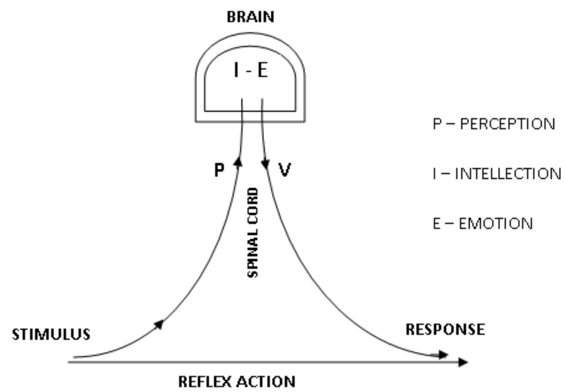

Figure 2: Reaction time and PIEV process.

The PIEV time of a driver depends on several factors such as physical and psychological characteristics of the driver, type of the problem involved, environmental condition and temporary factors (e.g., motive of the trip, travel speed, fatigue, consumption of alcohol, etc.). Thus, it may be concluded that the total reaction time of a driver is an important parameter for the study of drivers' behavioural characteristics.

Perception and volition times of the driver combined together can be satisfactorily measured by a simple arrangement of time measurement as observed by a vehicle driver between changes of light signals observed. This measured time may be called as reaction time of the driver

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and is a convenient measure for comparing the efficiency of the drivers.

5. Level Crossing Elements

The components of railway level crossing safety have been illustrated in fig.3. Principally there are two agencies contributing to rail-road accidents at level crossings i.e. (i) train driver, and (ii) road users. It is almost impossible for a train driver to stop and prevent the collision even if he notices a road vehicle on the crossing from a distance of 500 to 600 meters nor is it possible to change the course of a train similar to that of road vehicle.

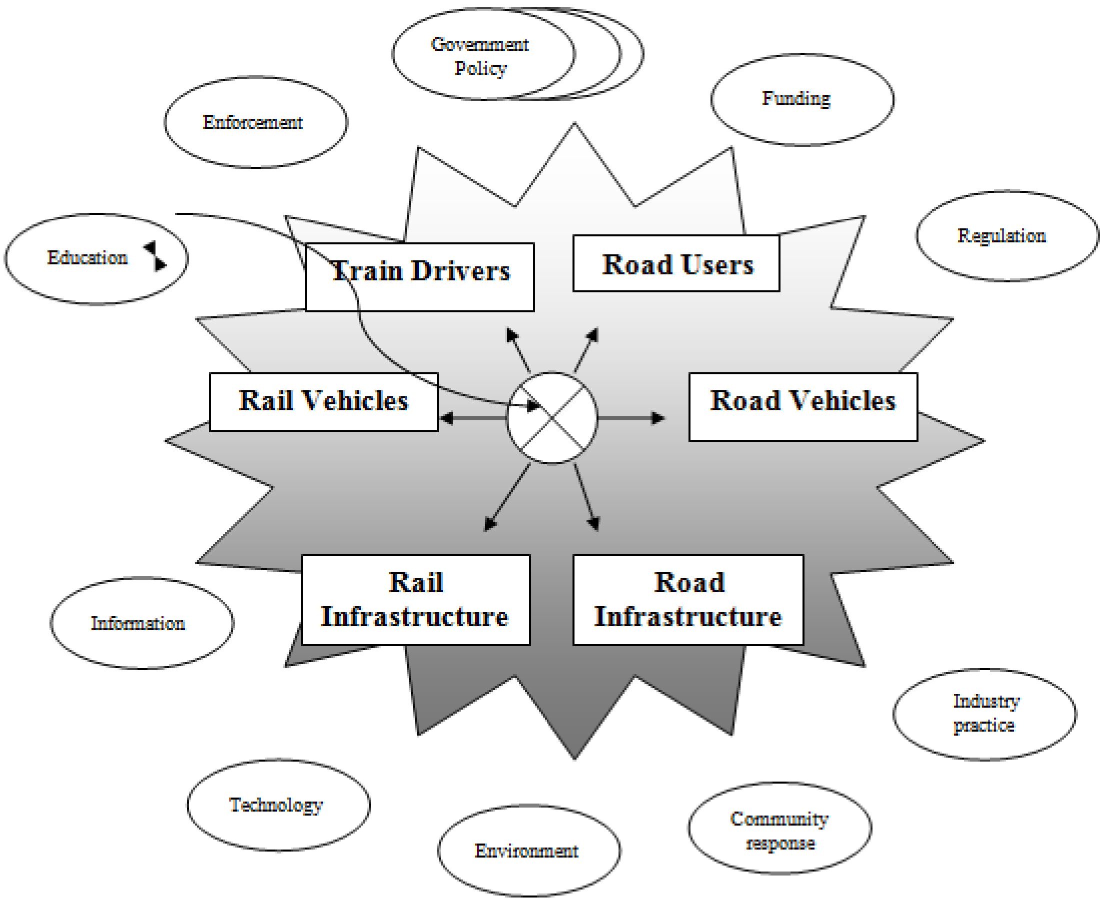

Figure 3: Components of railway level crossing safety.

The road users in India comprises of:

- Trucks and heavy vehicles,
- Cars and light vehicles,
- Motorcycles and scooters,
- Animal driven carts,
- Cycles,
- Pedestrians.

At the level crossings with barriers, motor cyclists, scooterists, cyclists, and pedestrians have major contribution to the accidents; whereas all types of road users contribute equally at uncontrolled L.C. This clearly indicates that the behaviour of road users including pedestrians is of prime importance in accident control.

6. Present Study

The present study was aimed at exploring some human behavioural aspects responsible for the accidents at LC in the context of Indian Railway. At 5 nos. of manned and 3 nos. of unmanned LC gates on main line and branch line of E.C Railway, the gate closing time, train crossing duration, gate opening time and approximate no of stranded three and four wheeler vehicles were observed. During the gate closure period, some of the vehicle drivers were interviewed to know their reactions on the obstruction due to the gate closure. The purpose was to assess the status of their minds when obstructed or crossing LC. The questionnaire included name, age, educational qualification, marital status, number of children, other liabilities, origin, destination, purpose of journey, How they felt while crossing a LC, and what they felt when obstructed with a closed LC gate? The behaviour of other occupants of the vehicle influences the mental status of the driver.

During the present study, the reaction times of 150 drivers at LC were measured by the method stated above and are presented in Table-1.

Table 1: Total no of drivers tested for reaction time: 150.

S.N	Reaction Time Range (in millisecond)	No. of drivers & Age group (in years)					Total	%
		< 25	25 - 40	40 - 50	50 - 60	> 60		
1	< 0.20	5	9	3	1	-	18	12.0
2	0.20 – 0.40	7	12	4	3	-	26	17.3
3	0.40 – 0.75	3	7	4	2	2	18	12.0
4	0.75 – 1.00	4	8	5	1	2	20	13.3
5	1.50 – 2.00	2	5	7	4	7	25	16.6
6	2.00 – 3.00	2	4	4	6	10	26	17.3
7	>3.00	2	2	3	5	5	17	11.3

6.1. Observations at manned level crossings:

- The gate closing time varied from 3 minutes to 15 minutes at a time, whereas the actual time consumed by a train to cross LC varied from 20 seconds to 1 minute 30 seconds.
- The number of four wheelers being stopped on both sides of the LC gate for one closure on national highway- rail road crossing ranged between 50 and 100, besides a good number of two wheelers.
- It was observed that not a single pedestrian or cyclist stopped at the crossing due to closure of the gate; they generally stopped about 2 m away from the track when the train was crossing the LC.
- Most of the two wheelers also attempted to sneak the closed LC gate and stopped along with pedestrians only when the train is actually crossing the gate.
- As the four wheelers had no option but to stop at closed LC gate, they stopped without any exception but instead of stopping in their own lane only, they had no hesitation in occupying the full width of the highway. This created utter confusion and chaotic situation when the gate is lifted for the passage of the traffic resulting in much more delay.
- The number of vehicles at the state highways / other roads-rail road crossings varied between 5 and 30 per LC gate closure. However, this number was 20 to 50 in and around a city. Alertness of the cabin / gate men on branch line LC was observed much less than those on main line.
- About 80 % of the truck and car drivers felt annoyed and obstructed by the LC gate closure. They were quite pessimistic in estimating probable waiting time at the gate. Most of the drivers were illiterate or had education up to primary level and had neither knowledge of railway working nor the safety consciousness. They thought gate closure as an obstruction on the road. The rest 20 % of the truck / bus and car drivers understood the importance of the gate closure but they were quite worried about the probable delay in reaching their respective destinations.
- The two wheelers had a different concept altogether about a closed LC gate. 90 % of them thought that the gate closure was not meant for them and they can proceed further by sneaking the closed LC gate.
- Pedestrians and cyclist considered themselves to have more freedom and flexibility over two- wheeler drivers while crossing a closed LC, though they contributed to good number of accidents while crossing a forbidden railway track.
- The average reaction time of the drivers is 1.51 seconds and it has a tendency to increase with age after attaining an age of 50 years [Table -1].

6.2. Observations at unmanned level crossings:

- The unmanned LC are generally provided on unimportant roads having very little traffic in order to save the expenditure of installing and maintaining the LC infrastructure.
- During the present study the drivers of the vehicle were interviewed at several railroad crossings. About 85 % of the drivers were illiterate and unconscious about the safety requirements. About 30 % of the tractor pulled trolley drivers had no valid driving license even.
- Each and every driver was found to be in great hurry while crossing the LC.
- The capability of the drivers to estimate the speed of the train, distance of the train from the crossing and expected travel time of the train up to the crossing were far from being accurate. In other words it can be said that 'Reaction time' for most of the vehicle drivers were quite more and were prone to misjudgment.
- The behaviour of the two-wheelers and pedestrians were no different than those at the manned level crossings.
- Animal driven carts have some special problems. Their drivers had to face and tackle the erratic behaviour of the animal(s) occasionally at the LC gates besides other factors.
- Most of the unmanned LC in India has no alarm/light system for the road traffic which makes the situation 'Free for All' at unmanned LC.

6.3. Analysis of the Observations:

The variation in gate closure time is quite considerable and unpredictable on Indian Railways. This makes the road users impatient and uncomfortable. The study shows that drivers frequently take unnecessary risks at the LC and are placing themselves and their passengers in situations of high risk and that there is a need to focus on factors to improve driver safety performance. It may be further analysed as follows:

- The ignorance and poor education among majority of the drivers make them unconscious about the necessity and safety requirements at LC.
- The poorly designed LC or unauthorised constructions along the track do not provide sufficient visible distance of the railway track to the road traffic at many places.

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- At most of the manned LC the light signals have been provided for the road traffic but sound alarms are missing.
- There is no light or sound signal at unmanned LC in India. Only danger sign posts have been placed on either sides of the LC which do not give the desired effect to the road traffic.
- The purpose of journey can also make vehicle drivers impatient at times.
- The vehicle drivers/pedestrians give priority to false time saving exercises over the safety rules. Some of them have higher 'Reaction Time' which can lead them very close to the accidents.
- A good number of vehicles are not worthy of running on the road.
- Animal(s) driven carts require much more time to cross LC. The unpredictable behaviour of the animal(s) may add up some more time to the above. If the cart driver is not aware and alert about these contingency situations, sometimes he may be trapped in an accident.
- The drivers of long distance vehicles are most of the time over fatigued due to long hours of continuous driving without reasonable sleep/rest. This makes them irritated and frustrated when they are stopped at LC.
- To overcome the mental stress on any count, at least 10-15 % vehicle drivers are addicted to alcohol or some drugs and this brings behavioural change and this is not conducive to safe driving and observance of safety rules.

The author summarises the scope for the study of behavioural characteristics of road users in the fig. no. 4 with special reference to railroad crossings.

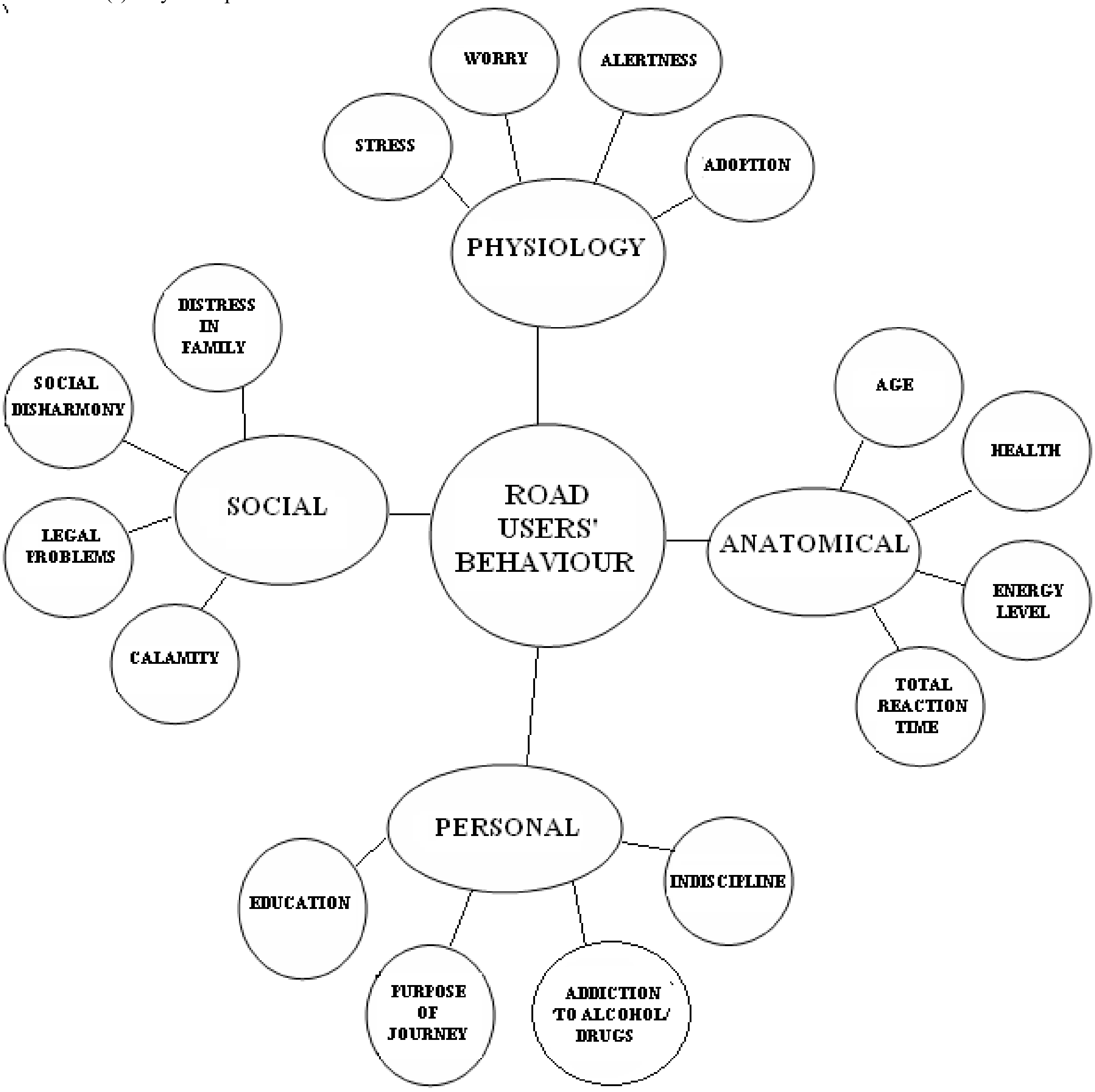

Figure 4: Scope for Behavioural Studies of Road Users.'

7. Conclusions and Suggestions

- On the Indian Railways system the barrier closure time on some level crossings is unusually long. Such closure times are much longer than those which would normally be tolerated by the road users. Excessively long barrier closure times tend to be a feature of the Absolute Block System as this system requires barriers to be closed immediately after a train's departure from a neighbouring station.
- 29.6 % drivers have reaction time more than 2 seconds indicating their delayed decisions and actions, which may sometime result in to accident.
- The 'deliberate risk taking' behaviour results in major risks, particularly where heavy, long or slow vehicles are involved. It is more prevalent in the people who know the site well, young people and truck drivers.
- Sometimes drivers fail to identify that a train is approaching.
- Some drivers fail to judge a safe gap to cross in front of an approaching train at unmanned railway crossings, particularly as operational train speeds are increasing.
- There are a range of options available for improving safety at level crossings and their implementation requires integrated, tailored solutions involving both the road and railway authorities. However, economic requirements put restrictions on the implementation of these.
- Even if all the safety measures are adopted at LC, the number of the accidents is likely to be considerable unless the road users become quite responsive. To understand the psychology and limitations of the road users there is no other way but to conduct behavioural studies on them regularly and in accordance to the findings the remedial measures are undertaken.
- In issuance and renewal of driving license, in addition to driving skill tests, behavioural competence of the driver including reaction time determination need be conducted.

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Effects of ISO 9001 Certification and KAAE on Performance of Jordanian Firms

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Abstract

This research investigates the effects of ISO 9001 certification and King Abdullah II Award for Excellence (KAAE) on Jordanian firm's performance. Four scale measures of firm's performance were considered, including quality outcomes, customer satisfaction, business performance, and innovation. ISO 9001 certification effect on performance measures was investigated in 130 Jordanian firms from both service (52 %) and industrial (48%) sectors. While, KAAE effect on performance measures was surveyed in twenty four firms. Structural Equation Modeling (SEM) was used to analyze the measurement and structural models for ISO 9001 certification, whereas t-test was used to test the hypotheses related to KAAE. The results showed that the ISO 9001 certification has significant effects on quality outcomes, customer satisfaction and business performance; however, it has no significant effect on innovation. In addition, the KAAE positively affects quality outcomes customer satisfaction, business performance, and innovation. In conclusion, ISO 9001 requirements and guidelines improve the efficiency and effectiveness of quality management systems in Jordanian firms, but they fail to motivate innovation. In order to achieve performance excellence, this research encourages Jordanian firms to participate in KAAE or include its guidelines in their quality management systems.

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Key words: ISO 9001 certification; KAAE; firm's performance; SEM

1. Introduction

The International Organization for Standard (ISO) firstly published ISO 9001 quality management system in 1987. Since then, ISO 9001 was revised in the years 1994, 2000 and 2008 respectively. ISO 9001 quality management system requires certain documentation on the operational procedures and managerial actions used to achieve customer requirements [1]. Although intense global competition highlights the importance of quality many years ago [2], only recently the Jordanian manufacturers have realized the need of effective quality system to prove their right to compete in the global market. This understanding has its signs in the increasing number of Jordanian firms holding the ISO 9001 certificates, whose number has already reached 292 firms [3].

Further, the success of the Deming prize in Japan that was established in the 1950's, inspired the establishment of the Malcolm Baldrige National Quality Award (MBNQA) in the year 1987 in the USA and the European Quality Award in the early 1990's [4]. Subsequently, there has been a trend for national quality awards around the world, many of which has been based on the MBNQA constructs, including leadership, quality information and analysis, customer and market focus, strategic quality planning, human resource management, and quality results. In coherence with the international goals of national quality awards, the King Abdullah II Award for Excellence (KAAE) was established in the year 2000 to benefit the Jordanian firms through acting as a guide for performance excellence. Award recipients are recognized as national and international models for performance excellence and receive special preference by Jordan Institution of Standards and Metrology (JISM), the Jordan Customs Department, and Jordan Enterprise Development Corporation. The award is based on complying with five criteria, including leadership, strategic planning, process management, resources management, and results [5].

In most studies, three ISO 9000 related performance constructs, including consistent quality outputs, satisfied customers, and business performance, are the scale measures for evaluating firm's performance [6]. Consistent quality outputs indicates that: (1) when organization's processes are in control and stable, the quality of the outputs would be uniform and consistent [7] and (2) organizations with solid operations and processes will be in the best position to influence the quality of their products and services [8]. Some of the measures commonly used to indicate consistent quality output are costs relating to quality of products, rates of defective products, product performance and reliability levels [9,10]. Further, customer satisfaction, which has been a long sought aim for the organizations, has indications in the

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level of customer service, perceived product quality by customers, and the number of quality audits performed by customer if any [11,12]. Finally, business performance is the final aim for any organization, regardless its mediation by customer satisfaction or quality outcomes. Measures of business performance include profit, cash flow, demand for product, market share and others. Yet, there still exists a significant shortage of literature analyzing the relation between quality management practices and innovation. In this context, this paper considers four scale measures of firm's performance including, consistent quality outputs, satisfied customers, and business performance, and innovation.

A progression of quality improvement programs, including MBNQA and ISO 9000, share a focus on improving and adhering to repeatable organizational processes as the mechanism for improving quality, efficiency, and financial performance [13]. Yet, the success of these processes in achieving their objectives is still debated. Casadesus and Gimenez [14] investigated the effects of the ISO 9001 quality standard implementation on 288 Spanish companies. Results showed that in 65 percent of companies positive internal and external effects of the ISO 9001 standard implementation were recorded. Magd et al. [15] studied the costs, benefits and the satisfaction level with ISO 9000 implementation in 140 ISO 9000 certified manufacturing companies in Saudi Arabia. The results revealed the benefits of ISO 9000 certification exceed the costs of attaining the standards, and ISO 9000 contributed to organizational survival and success. On the other hand, the results of an ISO 9000 mail survey conducted in Japan, South Korea, Hong Kong and Taiwan showed that ISO 9000 certification resulted in improved corporate image, quality improvement, increased customer satisfaction, and improved internal procedures [16]. Dick, et al. [17] studied ISO 9000 certification and its effect on firm's performance represented by return on assets values of the firm. The data was obtained from four hundred ISO 9000 certified manufacturing, construction, retail and service companies as well as another four hundred ISO 9000 non-certified companies in Spain. The results indicated that quality management system certification had some causal influence on business performance. Padma, et al. [18] investigated the effect of ISO 9001 certification on firm's performance, as perceived by the Indian managers. Thirty seven firms were surveyed and the obtained results confirmed that certificated firms experienced more reduction in quality related costs, which justified company's seeking for certification of ISO 9001. Benner and Veloso [13] studied the ISO 9000 practices effects on financial performance of companies from a technological perspective. They concluded that: (1) firms that had a very narrow or very broad technological focus had fewer opportunities for complementary interactions resulting from process management practices and thus benefited less than those with limited breadth in technologically related activities, and (2) while performance advantages accrue for earlier adopters in industry, they were competed away over time for later adopters. Singh [6] investigated the relationship between ISO 9000 quality management practices and Australian firm's performance. Three performance constructs including: consistent quality outputs, satisfied customers and business performance, were developed based on the advocated outcomes of the standard. Four hundred and eighteen ISO 9000 certified companies were surveyed. The results showed that: (1) management policies, plans and actions were negatively related to steady processes, (2) focus on customers and steady processes relationship was statistically insignificant, (3) top management team plays a ubiquitous role, albeit an indirect one increasing steady processes, and (4) strong focus on customers could be of little value in creating steady processes.

Little literature has been directed toward investigating the effects of ISO certification and KAAE on the firms' performance of Jordanian. Therefore, this paper aims at investigating the effects of ISO 9001 certification and KAAE on consistent quality outputs, satisfied customers, business performance, and innovation in Jordanian firms. The remaining of this paper is organized as follows. Section two presents conceptual framework. Section three provides data analysis and discussion. Section four summarizes research results. Finally, section five provides conclusions.

2. Conceptual Framework

2.1. Hypotheses of ISO 9001 certification model:

Quality is now a familiar word that has a variety of interpretations according to its use. Linguistically, it originates from the Latin word 'qualis' which means 'such as the thing really is'. ISO 9001 defines quality as the degree to which a set of inherent characteristics fulfils the requirements [19]. Although quality is a non-quantifiable variable, it has already been established that quality management represents a competitive advantage that sets one company from another [1]. Further, the stated goals of the ISO 9000 series of standards include ensuring to meet the customer's quality requirements and the applicable regulatory requirements, while aiming to enhance customer satisfaction [11]. It is argued that quality is essential to customer satisfaction [20]. Furthermore, the effect of ISO 9001 certification may affect firm's innovation. On the other hand, being the highest level of recognition of quality in Jordan, the KAAE aims at enhancing the competitiveness of Jordanian businesses by promoting quality awareness and performance excellence, recognizing quality and business achievements of Jordanian organizations, and publicizing these organizations' successful performance strategies and sharing them [5].

Consequently, the following hypotheses are built to investigate effect of the ISO 9001 certification and KAAE on firm's performance:

- H1a: ISO 9001 certification/KAAE positively influences firm's quality outcomes.
- H1b: ISO 9001 certification/KAAE positively effects on business performance.
- H1c: ISO 9001 certification/KAAE enhances customer satisfaction.
- H1d: ISO 9001 certification/KAAE has a positive effect on firm's innovation.

Figure 1 depicts the conceptual model relating KAAE with the four performance measures.

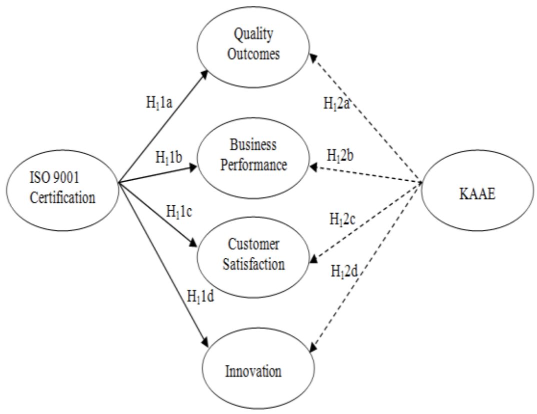

Figure 1: The hypothesized ISO 9001 certification and KAAE models.

2.2. The Survey Instruments:

The data is collected from Jordanian firms received the ISO 9001 certification and those participated in KAAE. The survey adopted in this paper consists of three parts. The first part contains the general and the structural environment of each firm, such as the type, size and status of certification. While the second part is concerned with firms' performance measured by customer satisfaction, quality outputs, business performance and innovation. The third part is dedicated to firms participated in or won the KAAE. The instrument used to measure the scale measure of firm's performance is adapted from literature [21,22]. A five-point Likert scale ranged from very dissatisfactory to a very satisfactory performance is used. Two copies of the survey are prepared in both English and Arabic languages. A pre-test of the questionnaire was done by asking recommendations from ten experts of quality management in academic and industry, who their participation was voluntary. Then, the final copies of the questionnaires were modified based on the feedback received from the pre-test sample. The population for this research covers manufacturing and service ISO 9001 certified Jordanian firms. The firms were contacted through e-mail as well as in person interviews with the company representatives. The total number of firms approached reached 245, however only 130 responded to the questionnaire, and hence a response rate of 53 % was encountered. Similarly, twenty four Jordanian firms participated or won KAAE were contacted with a response rate of 100 %.

3. Data analysis and Discussion

The collected data from ISO 9001 certified firms and KAAE participants were analyzed and are introduced as follows.

3.1. Descriptive analysis:

The general and structural characteristics data of the one hundred and thirty ISO 9001 certified firms were analyzed and depicted in Fig. 2, where the following remarks are obtained:

a. Regarding the type of organization, 52 % of the firms belong to service whereas 48 % belong to manufacturing.
b. Considering firm size, the medium-size firms; between 50 and 250 employees, constituted the largest percentage of the responding firms with a percentage of 40 %. The small firms of less than 50 employees constitute 22 %, whereas large firms of more than 250 employees contribute 38 % of the surveyed firms.
c. For the size of the quality department, the largest portion (= 67 %) of the firms has less than 10 employees working quality departments.
d. Regarding the respondent position, 57% of the respondents belong to quality and production management, whereas 43% of the respondents belong to the other positions, such as consultant, division managers, and production engineers. Whereas, 13% of the respondents are quality managers, engineers, and inspectors.

Further, 39.2% from the firms possessed more than one quality certificate; such as ISO 9000 and ISO 14001, while 60.8% of the firms gain only the ISO 9000 certification. Furthermore, 10.7 % of the firms obtained the ISO 9000 certification through their personal effort, whereas 89.3 % obtained it through joint effort between a consulting company and the firms' employees. For the duration taken to obtain certification, 70% of the firms took them three months to one year to get ISO 9000 certification, whereas 30% of the firms spent more than year. Finally, 81% of the firms that possess ISO 9001 certification obtained it after the year 2000.

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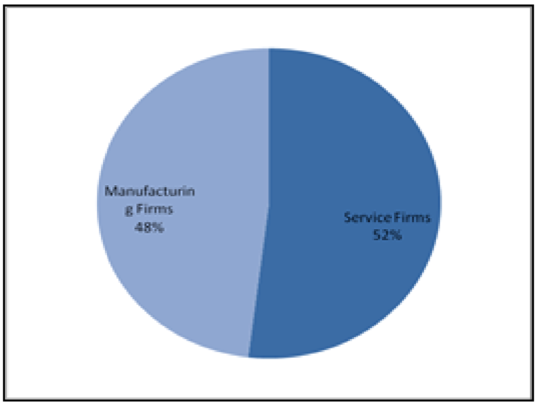
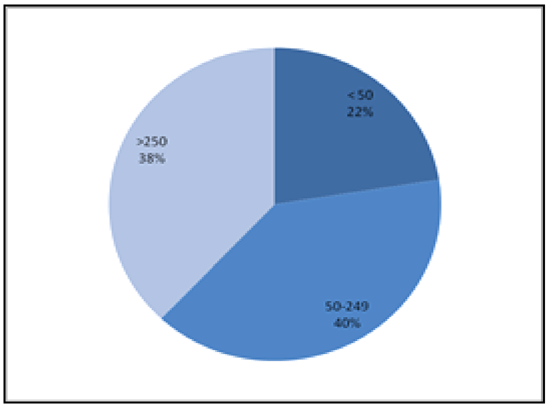
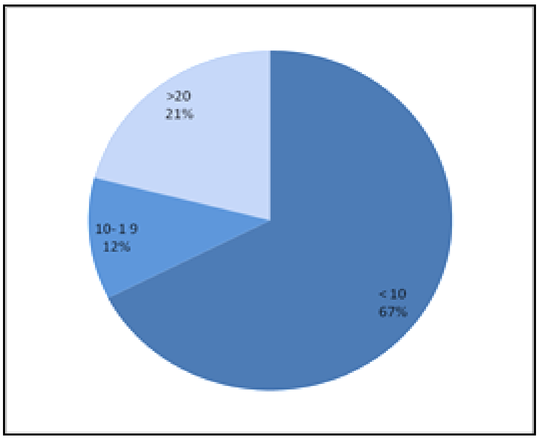


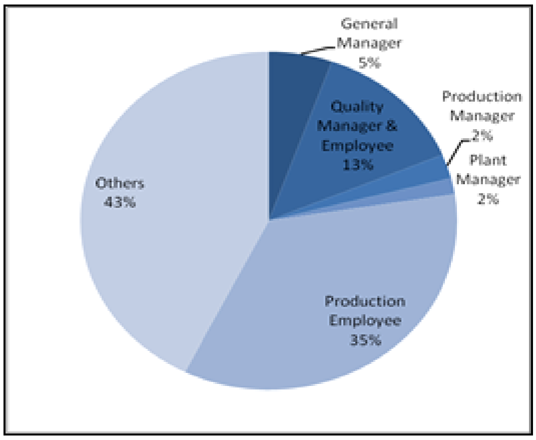
(a) Types of firms.



(b) Size of firms.



(c) Size of the quality department.



(d) Position distribution.

Figure 2: Descriptive analysis of firms' data.

For KAAE, almost all the responding firms belong to large-size firms. In addition, 80% of these firms participated once, whereas 20 % participated more than one time.

3.2. Psychometric Properties of Constructs for ISO 9001 certification model:

Structural equation modelling (SEM) was employed to analyze the collected data using AMOS software [23]. Because the structural portion of a full structural equation model involves relations among only latent variables and the primary concern in working with a full model is to assess the extent to which these relations are valid, it is critical that the measurement of each latent variable is proved psychometrically sound [24]. Thus, the validity of the models was checked using three popular tests, including multicollinearity test between each pair of items, the reliability test of the measurement variables, and confirmatory factor analysis (CFA). Table 1 displays the scale measures of each performance measure.

Table 1: The scale measure of firm's performance

Performance Measure	**Scale Measures**
Quality Outcomes	Costs relating to quality of products (QO1) Nonconforming products rate (QO2) Product performance and reliability (QO3)
Business Performance	Profits (BP1) Demand for products made at the registered site (BP2) Market share (BP3)
Customer Satisfaction	Perceived product quality by customers (CS1) Consistency in documentation (CS2) Customer service (CS3)
Innovation Performance	Level of newness (IN1) Use of latest technology (IN2) Speed of product development (IN3) Number of new products (IN4) Early market entrants (IN5)

3.2.1. Multicollinearity test:

Multicollinearity measures the degree by which items measure the same entity and a value of 0.9 or above indicates the possibility that two or more items measure the same entity [25]. In this context, the inter-item correlation coefficients for the measured items were calculated then displayed in Table 2. It is noted that the largest inter-item correlation value is about 0.62, which indicates the absence of multicollinearity.

Table 2: Inter-Item Correlation Matrix for ISO9001 certification model.

Item	ISO 9001	IN3	IN4	IN5	IN1	IN2	BP1	BP2	BP3	CS1	CS2	CS3	QO1	QO2	QO3
ISO 9001	1.000														
IN3	0.114	1.000													
IN4	0.088	0.563	1.000												
IN5	0.056	0.357	0.506	1.000											
IN1	0.055	0.498	0.499	0.361	1.000										
Inn2	0.082	0.585	0.553	0.408	0.594	1.000									
BP1	0.016	0.087	0.074	0.023	0.015	0.007	1.000								
BP2	0.034	0.067	0.042	0.045	0.023	0.047	0.501	1.000							
BP3	0.019	0.041	0.050	0.051	0.026	0.056	0.376	0.572	1.000						
CS1	0.014	0.053	0.095	0.097	0.072	0.070	0.032	0.038	0.038	1.000					
CS2	0.001	0.013	0.034	0.121	0.042	0.076	0.004	0.022	0.013	0.547	1.000				
CS3	0.030	0.053	0.110	0.056	0.040	0.095	0.014	0.007	0.008	0.456	0.600	1.000			
QO1	0.039	0.093	0.054	0.029	0.101	0.026	0.480	0.436	0.393	0.017	0.007	0.012	1.000		
QO2	0.026	0.102	0.064	0.035	0.067	0.017	0.549	0.371	0.397	0.023	0.003	0.017	0.616	1.000	
QO3	0.048	0.064	0.050	0.007	0.024	0.025	0.565	0.393	0.411	0.053	0.000	0.026	0.556	0.608	1.000

3.2.2. Reliability test:

In order to assess the internal consistency between the latent variables Cronbach's alpha (α) reliability coefficient was calculated for all the constructs as shown in Table 3. Cronbach's α value of 0.6 or above indicates reliability of each construct. In Table 3, it is obvious that all the Cronbach's α coefficients range are larger than the threshold 0.7, which implies good internal consistency. In addition, the overall Cronbach's α is 0.831.

Table 3: Factor loading and reliability coefficient estimates for ISO certification model.

Construct	Unstandardized estimates*				Standardized Estimate**	Cronbach's α
	Scale	Estimate	Standard Error (SE)	p value		
Quality Outcomes	QO1	0.971	0.136	< 0.001	0.668	0.778
	QO2	1.119	0.138	< 0.001	0.772	
	QO3	1.000			0.797	
Business Performance	BP1	0.979	0.135	< 0.001	0.752	0.777
	BP2	1.000			0.727	
	BP3	0.840	0.119	< 0.001	0.723	
Customer Satisfaction	CS1	1.186	0.160	< 0.001	0.801	0.813
	CS2	1.276	0.172	< 0.001	0.794	
	CS3	1.000			0.716	
Innovation	IN1	1.000			0.940	0.974
	IN2	1.013	0.033	< 0.001	0.969	
	IN3	1.000		< 0.001	0.940	
	IN4	1.050	0.035	< 0.001	0.967	
	IN5	0.926	0.050	< 0.001	0.877	

3.2.3. Confirmatory Factor Analysis (CFA):

Confirmatory Factor Analysis (CFA) model is a structural equation modelling technique where the constructs are all co-varied with each other and the goodness-of fit of this model is analysed. Figure 3 shows the CFA model used to test for the validity of ISO certification model.

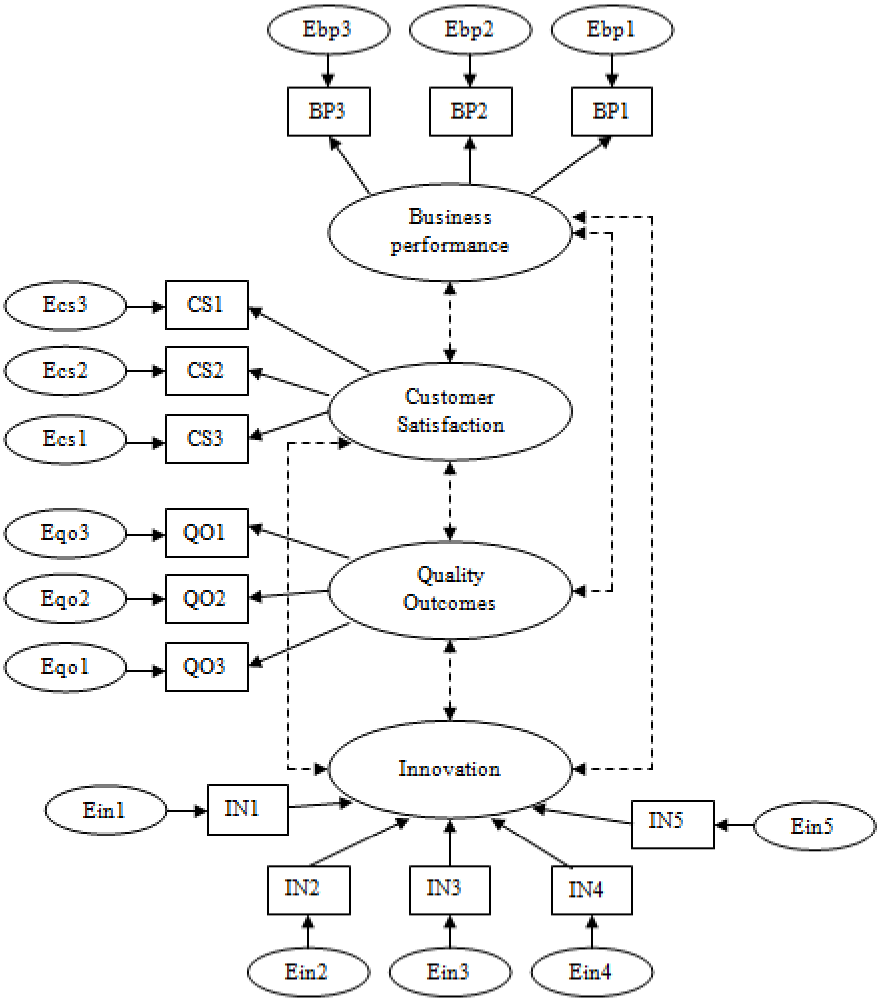


Figure 3: The measurement model.

Byrne [24] provided a description of various indices for CFA, including: (1) Goodness-of-Fit Index (GFI), a measure of the relative amount of variance in the sample covariance matrix that is jointly explained by sigma, (2) Adjusted Goodness-of-Fit Index (AGFI), which differs from GFI only in the fact that it takes account of the degrees of freedom in the specified model and incorporates a penalty for the inclusions of additional parameters. The GFI and AGFI can be classified as absolute indices of fit because they basically compare the hypothesized model with no model at all. Both indices have a range of values between zero and one but values close to one are more indicative of good fit, (3) Normed Fit Index (NFI) and Comparative Fit Index (CFI), which are two indices classified as incremental or comparative indices of fit and have values that range from zero to one but a value of 0.9 has been considered an indicative of good fit. They are derived from the comparison of a hypothesized model with the independence model and each provides a measure of complete co-variation, and (4) Root Mean Square Error of Approximation (RMSEA), that has been recently considered one of the most informative criteria in covariance structure, takes into account the error of approximation in the population. Values of RMSEA above 0.10 indicate a poor fit and a value near 0.06 indicate a good fit.

The estimate values of standardized and unstandardized regression coefficients (factor loading) obtained by conducting CFA analysis are also displayed in Table 3. Obviously, the estimates for each construct are greater than 0.7 with p value less than 0.001 for all items. This result indicates that the measurement constructs demonstrate convergent validity. Further, the GFI= 0.925, AGFI= 0.892, NFI= 0.945, CFI= 0.994 and RMSEA= 0.029, respectively, indicate an acceptable model goodness of fit and reveal the exceptional discriminant and convergent validity of ISO 9001 certification measurement model. Consequently, a structural equation model shown in Fig. 4 is conducted to test the hypotheses relating firm's performance constructs with ISO 9001 certification. The obtained results are: GFI value of 0.924, AGFI value of 0.894, NFI value of 0.944, CFI value of 0.995 and RMSEA value of 0.025. These values of indicate an acceptable model. Consequently, the hypotheses are tested as shown in Table 4.

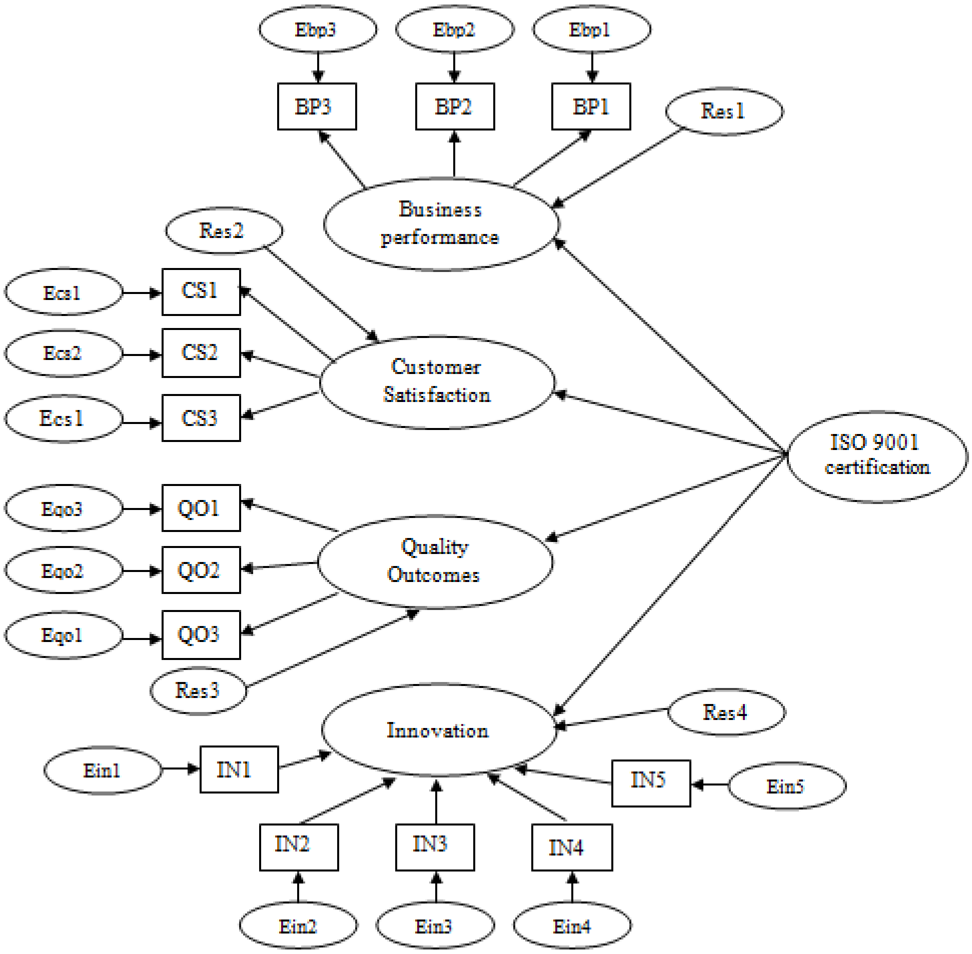


Figure 4: The structural equation model of ISO 9001 certification.

Table 4. The output for the structural equation model for ISO certification model.

Path analysis	Hypothesis	Estimate	*p* value	Decision
Quality Outcomes <--- ISO 9001 certification	$H_1$1a	0.613	< 0.001	Supported
Business Performance <--- ISO 9001 certification	$H_1$1b	0.605	< 0.001	Supported
Customer Satisfaction <--- ISO 9001 certification	$H_1$1c	0.182	0.002	Supported
Innovation <--- ISO 9001 certification	$H_1$1d	0.080	0.540	Not supported

In Table 4, it is found that ISO 9001 certification affect positively firm's performance measured by quality outcomes, customer satisfaction and business performance. That is, hypotheses H11a, H11b, and H11c are supported. However, ISO 9001 certification has no positive effect on firm's innovation; that is, hypothesis H11d is not supported.

3.3. Analysis of KAAE model:

Twenty four firms participated in KAAE were surveyed. The collected data revealed that 79 % of the respondents participated once. The remaining 21 % participated more than once. Due to small sample size, the KAAE model will be analyzed using t-test. The measurement model of KAAE was tested by establishing correlation matrix as shown in Table 5. Obviously, the correlation values are less than 0.8, which indicate that no significant correlation is concluded between each pair of these measures. In addition, the KAAE measurement model is tested with t-test and reliability analysis as shown in Table 6, where it is noted that all t values are significant with less than 0.025 probability level. In addition, all the Cronbach's α values are larger than 0.6. Finally, the overall the overall Cronbach's α equal 0.864. The above results indicate the validity of the measurement model.

Table 5: Bivariate correlation matrix for KAAE measures.

	QO1	QO2	QO3	BP1	BP2	BP3	IN1	IN2	IN3	IN4	IN5	CS1	CS2	CS3
QO1	1													
QO2	0.367	1												
QO3	0.370	0.499	1											
BP1	-0.135	-0.087	0.159	1										
BP2	0.139	-0.060	0.554	0.603	1									
BP3	0.059	-0.062	0.525	0.526	0.632	1								
IN1	0.380	0.250	0.576	0.274	0.684	0.643	1							
IN2	0.509	0.243	0.538	0.075	0.420	0.435	0.399	1						
IN3	0.170	0.193	0.622	0.044	0.560	0.624	0.560	0.343	1					
IN4	0.253	0.231	0.622	0.000	0.483	0.477	0.640	0.148	0.776	1				
IN5	0.211	0.061	0.470	0.168	0.637	0.728	0.530	0.268	0.655	0.775	1			
CS1	0.247	-0.140	0.058	0.000	0.281	0.238	0.040	0.164	0.130	-0.132	0.106	1		
CS2	0.130	-0.215	-0.109	-0.165	0.136	0.184	-0.317	0.226	0.122	-0.158	0.169	0.628	1	
CS3	-0.239	0.000	0.351	0.332	0.729	0.742	0.364	0.265	0.610	0.290	0.421	0.233	0.402	1

Table 6: Descriptive analysis and Cronbach's α estimate for KAAE model.

Construct	Scale measure	Average	Standard Deviation (SD)	*t*-statistic*	*p* value	Cronbach's α
Quality Outcomes	QO2	4.1250	0.53670	10.269	0.000	0.664
	QO3	4.4583	0.58823	12.145	0.000	
Business Performance	BP1	4.0000	0.93250	5.254	0.000	0.864
	BP2	3.8750	0.85019	5.042	0.000	
	BP3	3.9167	0.97431	4.609	0.000	
Customer Satisfaction	CS1	4.1250	0.79741	6.912	0.000	0.662
	CS2	4.1667	0.56466	10.122	0.000	
	CS3	4.3333	0.70196	9.305	0.000	
Innovation	IN1	4.1250	0.85019	6.482	0.000	0.847
	IN2	4.0417	0.62409	8.177	0.000	
	IN3	3.8333	1.04950	3.890	0.001	
	IN4	3.5833	1.13890	2.509	0.020	
	IN5	3.7917	0.83297	4.656	0.000	

Regarding the effect of participating in KAAE on the firm's performance, the t-test for the data averages of each of the four performance constructs is conducted at mean of 3 to test the following hypothesis:

$$H0: \mu i = 3, \; i = 1,\ldots,4 \qquad (1)$$

$$H1: \mu i > 3$$

where i represents the performance measure. The obtained t values are displayed in Table 7, where it is found that all the p values are less than 0.001. This means that null hypothesis in Eq. (1) is rejected for all the four performance measures. In other words, the hypotheses H12a, H12b, H12c, and H12d relating KAAE to the four firm's performance are supported. Hence, KAAE has positively affected quality outcomes, business performance, customer satisfaction, and innovation.

Table 7: The t-test output for the structural equation model for KAAE model.

Path	Hypothesis	N	Mean	SD	Degrees of freedom	*t* statistic	*p* value	Decision
Quality Outcomes <--- KAAE	$H_1$2a	24	4.2917	0.48715	23	12.989	0.000	Supported
Business Performance <--- KAAE	$H_1$2b	24	3.9306	0.81637	23	5.584	0.000	Supported
Customer Satisfaction <--- KAAE	$H_1$2c	24	4.2083	0.53670	23	11.030	0.000	Supported
Innovation <--- KAAE	$H_1$2d	24	3.8750	0.72186	23	5.938	0.000	Supported

4. Results

The ISO 9001 quality management systems standard has been widely accepted around the world. This research reveals two important results. First, a positive understanding and use of ISO 9001 standard by Jordanian firms are reported. Thus, ISO 9001 certification is considered an important tool for improving the efficiency and effectiveness of quality management systems as reflected by improving quality outcomes, customer satisfaction, and business performance. This result was also reached by previous studies conducted in literature. Nevertheless, according to the ISO 9001 certified firms in Jordan, the ISO certification does not motivate firms' innovation, which is due to sticking to standard requirements and operational procedures. The second result is that KAAE acts as effective guidelines for performance excellence and results in positive effects on quality outcomes, business performance, customer satisfaction, and innovation. This research recommends ISO 9001 certified Jordanian firm to integrate KAAE guidelines in their quality management system in order to achieve competitive performance.

5. Conclusion

This research investigates the effects of ISO 9001 certification and KAAE on Jordanian firm's performance using structural equation modelling and t-test, respectively. Four scale measures for firm's performance were considered, including quality outcomes, customer satisfaction, business performance, and innovation. First, the data were collected from one hundred and thirty ISO 9001 certified firms. Results showed that ISO 9001 certification has significant effect on quality outcomes, business performance, and customer satisfaction. However, it showed insignificant effect on innovation. Then, KAAE effect on these four measures was surveyed in twenty four firms. According to respondents, this award showed positive effects on all the four performance measures. The results of this research provide evidence to quality managers that KAAE act as effective guidelines for achieving competitive performance, and hence they may consider the implementation of its requirements in their quality management systems.

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Influence of Melt Treatments on Dry Sliding Wear Behavior of Hypereutectic Al-15Si-4Cu Cast Alloys

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Abstract

The purpose of the present work is to investigate the microstructure and dry sliding wear behavior of hypereutectic Al-15Si-4Cu cast alloys with grain refinement, modification and/or refinement. Pin-On-Disc wear tests were conducted under dry sliding conditions on the hypereutectic Al-15Si-4Cu cast alloy after various melt treatments for varying loads ranging from 20N to 100N with constant sliding speed of 1 m/s and for a constant sliding distance of 1000m. Tests were also conducted on the hypereutectic Al-15Si-4Cu cast alloy for sliding distance of 2000m with constant sliding speed of 1 m/s and at a normal load of 60N. Results indicate that the addition of grain refiner (Al-1Ti-3B), modifier (Sr) and refiner (P) to the hypereutectic Al-15Si-4Cu unmodified cast alloy converts large α-Al grains in to fine equiaxed α-Al grains and forms fine fibrous silicon particles and fine CuAl2 particles in the interdendritic region. This improves the wear properties of the cast alloy.

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Keywords: Modification; Grain refinement; hypereutectic Al-15Si-4Cu cast alloys; Wear rate; sliding distance

1. Introduction

The development of aluminum silicon alloys is very important due to their high strength to weight ratio, high wear resistance, low coefficient of thermal expansion, high thermal conductivity, high corrosion resistance, good cast performance, good weldability etc which makes them attractive candidate material in many tribological applications, aerospace and other engineering sectors where they can successfully replace ferrous components in heavy wear applications. These applications demand the study of techniques to improve the wear properties of these alloys. For this purpose, many researches had been done to enhance their wear properties. Al-Si alloys are mainly used in cast form in important components like pistons , engine blocks , cylinder liners, rocker arms, air conditioner compressors, brake drums etc. The improvement in the sliding wear resistance and mechanical properties depends on number of material related properties like shape, size and size distribution of the second phase particles in the matrix and microstructures in addition to the operating conditions such as sliding speed , sliding distance , temperature load etc. With the development of automobile industry, the need of hypereutectic Al-Si alloys increasing greatly. Al-Si alloys containing more than 13 wt% silicon are known as hypereutectic Al-Si alloys. The hypereutectic Al-Si alloys contain hard primary particles of non-metallic silicon embedded in an Al-Si eutectic matrix. These alloys have serious machinability problems due to the presence of the hard primary silicon phase which acts as abrasives. In order to obtain the best machinability and low wear rate the size of silicon phase must be controlled through melt treatment. Wear rate of the material decreases with increase in hardness of the material. It should be noted that it is the hardness of the contacting asperities that will improve the wear resistance.

Wear resistance in Al-Si alloys is primarily due to the presence of silicon in the aluminum matrix. Increasing the silicon content in Al-Si alloys increases the wear resistance and strength at the expense of machinability. Aluminum silicon alloys can be strengthened by adding small amount of Cu, Ni or Mg and the presence of silicon provides good casting properties. Copper results in the precipitation of CuAl2 particles in the structure. A very important finding is that alloys with the same chemical composition can have different microstructures and mechanical properties due to variations in the casting process, the use of a refiner, modifier and grain refiner. This means that different processing techniques can result in a range of mechanical properties, which affect the wear resistance of the alloys. A number of studies have been reported on the dry sliding wear behavior of the cast Al-Si alloys. These reports are very conflicting in nature.

A.D.Sarkar and J.Clarke [1] investigated the dry sliding wear behavior of aluminum silicon alloys using pin-on-disk wear machine and reported that silicon composition in aluminum alloy does not appear to be a dominant factor in the calculation of wear resistance. B.N.Pramila Bai and S.K.Biswas [2] studied the wear behavior of aluminum silicon alloys and concluded that wear rate of an alloy with out silicon is significantly higher than the binary modified

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alloys containing silicon composition between 4% and 24% and also concluded that there is no systematic trend in wear of aluminum silicon alloys containing 4-24% wt silicon. Shivanath et al. [3] investigated the sliding wear behavior of aluminum silicon alloys reported that wear resistance is good for the hypereutectic aluminum silicon alloys. A.D. Sarkar [4] studied the wear of Al-Si alloys against hardened steel disc and gray cast iron and reported that the hypereutectic alloys wear more than the hypoeutectic alloys. A. Somi Reddy et al [5] investigated the wear and seizure behavior of Al-Si alloy containing silicon content up to 23 wt% using Pin-On-Disc wear testing machine under various loads. It was observed that addition of silicon to aluminum increases the wear and seizure resistance. C.Subramanian [6] studied the effect of sliding speed on wear behaviour of aluminium silicon alloys and reported that the wear rate decreases with increasing sliding speed up to a critical speed. M. Harun et al [7] has investigated the effects of element additions on the wear of Al-Si alloys. S.A.Kori and M.S.Prabhudev [8] investigated on the wear rate of hypoeutectic Al-Si alloys with minor additions of copper at elevated temperatures and concluded that wear rate increases with the normal pressures, sliding speeds and sliding distances at a constant temperature of 3000C. Elmadagli et al [9] have done a parametric study of the relationship between microstructure and wear resistance of Al–Si alloys and concluded that increasing the alloy hardness and Si volume fraction increased the transition loads but did not have a significant effect on the wear coefficients. A.S.Anasyida et al. [10] has investigated the effect of cerium addition to the Al-Si alloys and found that increasing the cerium content up to 2% wt. increases the wear resistance of the alloys and then decreases. T.M.Chandrasehekharaiah and S.A. Kori [11] investigated on the wear resistance of eutectic Al-Si alloys and suggested that wear resistance increases with the addition of grain refiner and modifier. D.K.Dwivedi [12] reported that the addition of alloying element to the Al-Si alloy not only reduces the wear rate but also increases the transition load. K.G.Basava Kumar et al [13] investigated on the wear resistance of hypoeutectic Al-Si alloys using copper and reported that grain refined and modified cast alloys work hardened to a greater extent than the untreated alloys. Ibrahim.S [14] investigated the wear behavior of aluminum silicon alloys under different velocities and temperatures by adding small amount of copper. Y.P.Lim [15] investigated the effects of grain refiner and modifier on the aluminum silicon alloys and found that the mechanical properties improve with the addition of M51 grain refiner and strontium modifier. V.Abouei et al. [16] has investigated the dry sliding wear behaviour of hypereutectic Al-Si piston alloys containing iron-rich intermetallics and reported that the addition of 1.2 wt% Fe to the LM28 alloy increased the wear rate due to the formation of needle beta intermetallics. H.R. Saleh [17] reported that the hardness property could be improved by using Sb as a modifier to the aluminum silicon alloys. M.Babic et al. [18] concluded that the heat-treated alloys improve the tribological properties like wear rate and coefficient of friction over as cast ones for all the loads of sliding conditions. A.K.Prasada Rao et al.[19&20] investigated the wear behavior of hypo eutectic aluminum silicon alloys using grain refiners and modifier and reported that wear resistance depends on the microstructure of the alloys. T.R.Ramachandran et al. [21] proposed the techniques for achieving better refinement along with melt treatment for minimization of hydrogen and dissolved elements such a sodium and calcium. Gang Liu et al. [22] studied the modification response of hypereutectic Al-Si alloys with different Sr additional levels and concluded that wear behaviors are optimal in the range of 0.04-0.06 wt% Sr and concluded that wear volumes of Al-Si alloys are inversely proportional to the hardness.

From the above investigations, it is observed that the dry sliding wear behavior of polyphase alloys is difficult and it is not a simple function of composition. The present work investigates the influence of either grain refiner or modifier/refiner and combined addition of all on dry sliding wear behavior of hypereutectic Al-15Si-4Cu cast alloys against a hardened steel disc by using a Pin-On-Disc wear and friction testing machine.

2. Experimental Procedure

Six different hypereutectic cast Al-15Si-4Cu alloys were used during the present investigation. P-1 was the unmodified one. Cast alloy P-2 was modified with strontium and alloy P-3 was refined with phosphorous. Alloy P-4 was refined and modified with strontium and phosphorus respectively. Alloy P-5 was grain refined with Al-1Ti-3B in addition to the modification and refinement. Similarly, cast alloy P-6 was grain refined with Al-5Ti-1B in addition to the modification and refinement.

The main aim is to find the load bearing capacity (wear resistance) of the pin compositions. So experiments were carried out at different loads (20N to 100N insteps of 20N at constant velocity and constant sliding distance) and for a maximum sliding distance of 2 km at a constant speed and load. The details of the alloys, modification, refinement and grain refinement treatment of various alloys are given in Table 1.

Table 1: Test specimens of Al-15Si-4Cu cast alloys.

Sl No	Alloy designation	Alloy composition	Addition level of GR (wt %)	Addition level of modifier and/or refiner (wt %)
1	P-1	Al-15Si-4Cu	-	-
2	P-2	Al-15Si-4Cu-0.04Sr	-	0.04
3	P-3	Al-15Si-4Cu-0.04P	-	0.04
4	P-4	Al-15Si-4Cu-0.04Sr-0.04P	-	0.04
5	P-5	Al-15Si-4Cu-0.04Sr-0.04P-1M13	1.0	0.04
6	P-6	Al-15Si-4Cu-0.04Sr-0.04P-1M51	1.0	0.04

Note: Grain refiners: M13=Al-1Ti-3B,M51=Al-5Ti-1B

Modifier : Strontium (Sr)

Refiner : Phosphorus (P)

Hypereutectic Al-15Si-4Cu alloy was prepared by melting high purity aluminum (99.7%) with master alloys Al-20%Si and Al-30%Cu in graphite crucible in a furnace and the melt was held at 8500C. Melt was degassed with 1% solid hexachloroethane before the addition of modifier/grain refiner. Modification was done by the addition of 0.04%wt strontium in the form of Al-10%Sr master alloy. Refinement of the Al-15Si-4Cu was done by the addition of 0.04%wt phosphorus in the form of red phosphorus. Grain refinement was done with the master alloys Al-1Ti-3B or Al-5Ti-1B. The melt was stirred for 30 seconds after the addition of modifier, refiner and grain refiner. The melt was poured into a cylindrical graphite mould of 25mm internal diameter and 150mm in height.

Table 2 gives the details of the chemical analysis of master alloys.

Table 2: Chemical analysis of master alloys.

Alloy	Composition(% wt)						
	Fe	Si	Sr	Cu	Ti	B	Al
Al	0.15	0.08	-	-	-	-	balance
Al-20Si	0.1	20.2	-	-	-	-	balance
Al-10Sr	0.19	0.12	10	-	-	-	balance
Al-30Cu	0.18	-	-	30.3	-	-	balance
Al-1Ti-3B	0.17	0.16	-	-	1.13	2.25	balance
Al-5Ti-1B	0.17	0.15	-	-	5.62	1.04	balance

A pin on disc type wear and friction machine (TR-20LE, DUCOM, Bangalore) with data acquisition system was used to evaluate the wear behavior of aluminum silicon alloys. Figure1 shows the photograph of the test specimen on the tribometer disc.

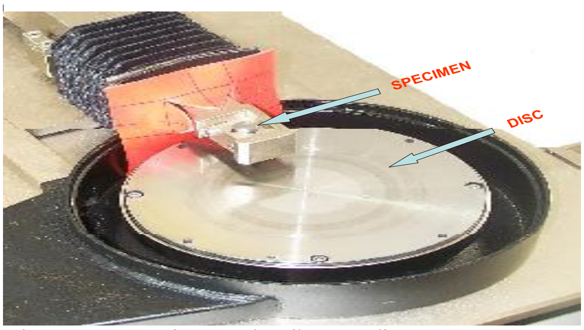


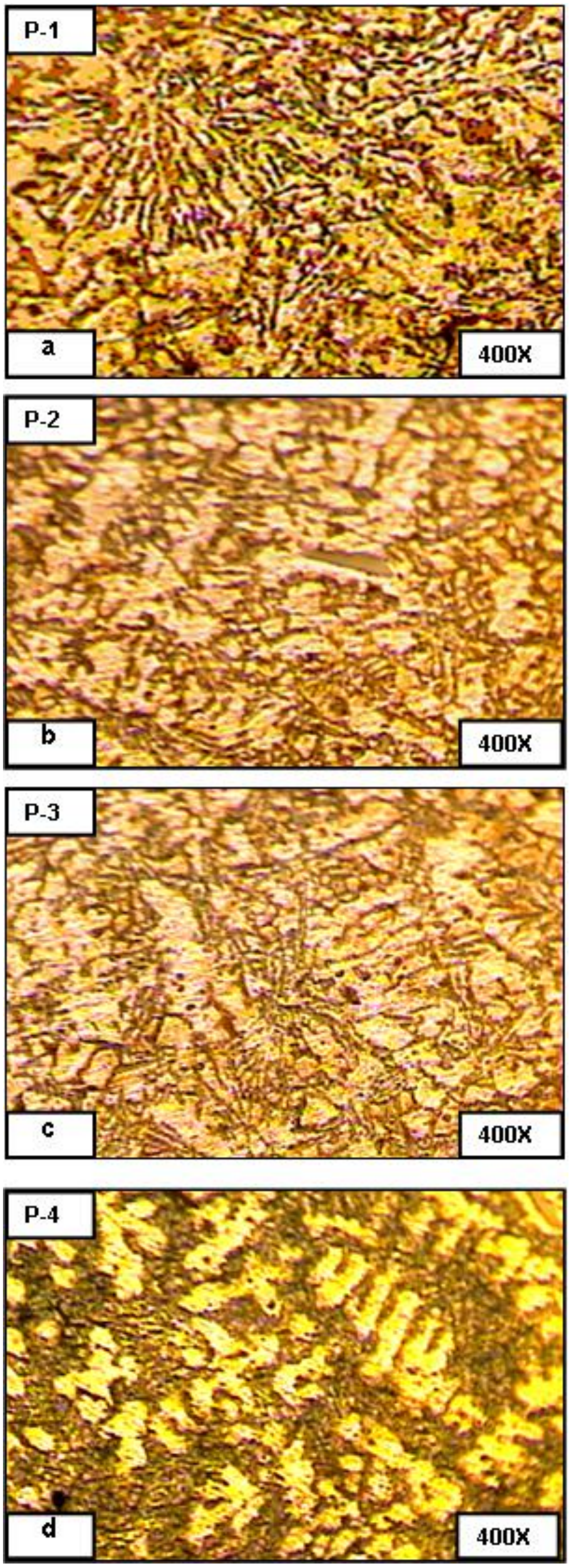
Figure 1: Test specimen on the tribometer disc.

The pins of 8 mm diameter and 25 mm length were fabricated from castings against hardened ground steel (En-31) disc having hardness of HRC 62 and surface roughness (Ra) 0.1µm. The wear tests were carried under varying loads (20, 40, 60, 80 and 100N)) with sliding speed 1 m/s and for a constant sliding distance of 1000m. Track diameter of 100 mm was selected for the analysis. During sliding change in the height of the specimen was recorded using linear variable differential transformer (accuracy ±1 µm with maximum displacement of ±2 mm). The friction force was recorded during the experiment by using a load cell. It has a maximum load capacity of 200N and measures the frictional load at an accuracy of ± 0.1 N in the load range of 0-200N. Frictional force (N) was measured as a function of time. The pins were weighed before and after each test to measure the change in weight for wear loss calculations. Before the test, the polished pins were cleaned and degreased using ultrasonic cleaner, first with water and soap, followed by ethanol and finally with acetone. Cleaned samples were dried in an oven for 30min at 800C. Figure 2 shows the photograph of the controller of the pin on disc wear and friction testing machine.

Figure 2: Controller of the wear and friction-testing machine.

3. Results and Discussion:

The microstructures of the test samples that had been cut in the longitudinal direction were studied. Dry sliding wear behavior of Al-15Si-4Cu cast alloys depends on the size, shape of the silicon particles, size distribution of the α-Al grains and CuAl2 particles in the interdendritic region. Figure 3 (a) shows the microstructure of unmodified Al-15Si-4Cu alloy. The microstructure contains needle/plate type silicon particles. Unmodified acicular silicon acts as internal stress riser in the microstructure and provides easy path for fracture. Figure 3(b) shows the microstructure of Al-15Si-4Cu alloy after modification. The addition of modifier (Sr) to Al-15Si-4Cu cast alloy changes the needle like silicon to fine particles in the interdendritic region, while α- Al grains remain dendritic. In hypereutectic alloys, refinement is also achieved through the addition of phosphorus. The phosphorus has a marked effect on the size, shape and distribution of the primary silicon. The addition of phosphorus to Al-15Si-4Cu alloy significantly refines the coarse platlet, star-like and irregular primary silicon to fine and uniformly distributed silicon particles possibly due to aluminum phosphide (Al P) acting as nucleating agent for silicon. This is shown in the Figure3(c). After the addition of refiner and modifier (Figure 3(d)), the microstructure shows fine fibrous silicon particles. Grain refiners are materials added to alloys to aid in nucleation, and lead to the production of fine and uniform grain size. There are several types of grain refiners available for aluminum–silicon alloys, based on aluminum-titanium or aluminum-titanium-boron master alloys, and titanium or titanium-boron containing salt tablets for hypereutectic alloys. Figure 3 (e and f) shows the optical microphotographs of Al-15Si-4Cu cast alloy with grain refiners (by 1% of Al-1Ti-3B and 1% of Al-5Ti-1B master alloys) in addition to the combined addition of modifier (0.04% Sr) and refiner (0.04% P). The additions of grain refiners (Al-1Ti-3B and Al-5Ti-1B), modifier (Sr) and refiner (P) converts large α-Al grains in to fine equiaxed α-Al grains and forms fine fibrous silicon particles and fine CuAl2 particles in the interdendritic region. This improves the wear properties of the cast alloy. The results also suggest that, the addition of Al-1Ti-3B master alloy along with Sr and P to the alloys show more uniformly distributed α-Al grains, fine broken grains of silicon and fine CuAl2 particles in the interdendritic region compared to the microstructure obtained with individual additions of modifier and/or refiner.



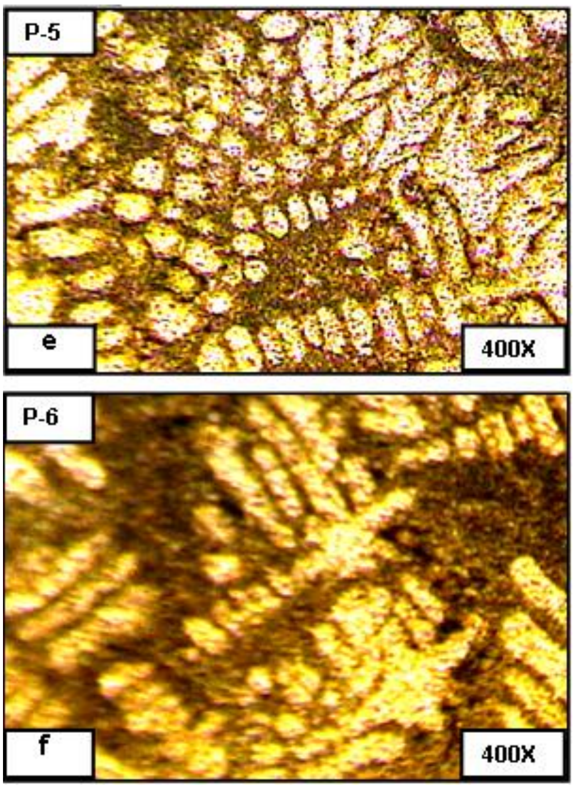
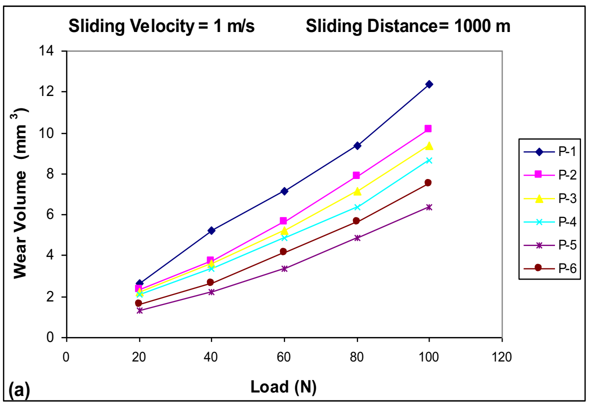


Figure 3 : Optical microphotographs of Al-15Si-4Cu cast alloy: (a) un-modified (b) with modifier (0.04% Sr) (c) with refiner (0.04% P) (d) combined addition of modifier (0.04% Sr) and refiner (0.04% P) (e) with grain refiner (1% of M13) in addition to the combined addition of modifier (0.04% Sr) and refiner (0.04% P) (f) with grain refiner (1% of M51) in addition to the combined addition of modifier (0.04% Sr) and refiner (0.04% P).

During the test, when the applied load on the pin is increased, the actual contact area would increase towards the nominal area which increases the frictional force between two sliding surfaces. The increased frictional force gives high wear. Figures 4 (a)-(d) show the influence of refinement or modification and grain refinement on the dry sliding wear behavior of the hypereutectic Al-15Si-4Cu cast alloys under different loads varying from 20N to 100N in steps of 20 N with constant sliding speed of 1 m/s for a sliding distance of 1000m.

The wear test of the Al-15Si-4Cu unmodified cast alloy was carried out at the highest load of 100 N. It was observed that seizure does not take place up to this load. Seizure is a phenomenon of the test specimen becoming welded to the wear disc at high loads and higher sliding speeds of the disc due to wear. At seizure there will be more noise and vibrations. Tests were stopped at this load. The wear volume and volumetric wear rate of the alloys under different conditions is shown in Figure 4(a) & 4(b). It is observed that the wear volume and wear rate are more at higher loads for untreated Al-15Si-4Cu alloy. During the test, when the applied load on the pin is increased, the actual contact area would increase towards the nominal area which increases the frictional force between two sliding surfaces. The increased frictional force gives high wear volume and hence high wear rate. The wear volume and volumetric wear rate are less for the combined addition of modifier, refiner and grain refiner. The formation of fine equiaxed α-aluminum grains, fine fibrous silicon particles and fine $CuAl_2$ particles in the interdendritic region due to the addition of grain refiner

(Al-1Ti-3B), modifier (Sr) and refiner (P) reduces the wear volume and volumetric wear rate of the cast alloy. The wear resistance of the un-treated alloy decreased continuously with increasing wear load as shown in figure 4(c). Better wear resistance should be achieved through fine equiaxed primary α-aluminum grains and uniform distribution of the second phase particles. The combined grain refined and modified Al–15Si–4Cu cast alloy recorded higher wear resistance at the highest load. The additions of modifier (Sr), refiner (P) and grain refiner (Al–1Ti–3B) convert large α-aluminum grains into fine equiaxed α-aluminum grains and eutectic silicon plates into fine particles and fine CuAl2 particles in the interdendritic region leading to better mechanical properties and hence improved wear resistance. The overall wear resistance increased due to appreciable work hardening of the grain refined, modified and/or refined alloys. On the contrary, the wear resistance of the un-treated Al–15Si-4Cu alloy (alloy P-1; Fig. 4(c)) continued to decrease with increasing load due to low work hardening rate. The cast alloys, which were only refined and/or modified, have shown the intermediate results. The coefficient of friction increases uniformly with increasing load in most of the cases. The coefficient of friction in the case of the modified, refined and/or grain refined Al–15Si–4Cu cast alloy was lower at all the loads as shown in Fig. 4(d). The rise in the coefficient of friction with the increase in wear load may be attributed to (a) enhanced accumulation of the wear debris consisting of large volume fraction of hard aluminide and silicide particles pulled out of the matrix during wear at the pin and disc interface and (b) oxidation of the wearing surface. Temperature measurement of wear pin during the sliding wear was carried out using thermocouple. Temperature of the pin was recorded with the help of digital temperature indicator of the wear and friction monitor. Figure 5 indicates that the temperature of the pin is more for the untreated Al-15Si-4Cu cast alloy during sliding and is less for the treated alloys. During wear at high loads, the temperature increases (Fig. 5) appreciably lowering the strength of the materials in contact resulting in increased contact area and coefficient of friction. Rise in temperature within limits increases the ability of soft aluminum matrix to accommodate hard and brittle second phase silicon particles.



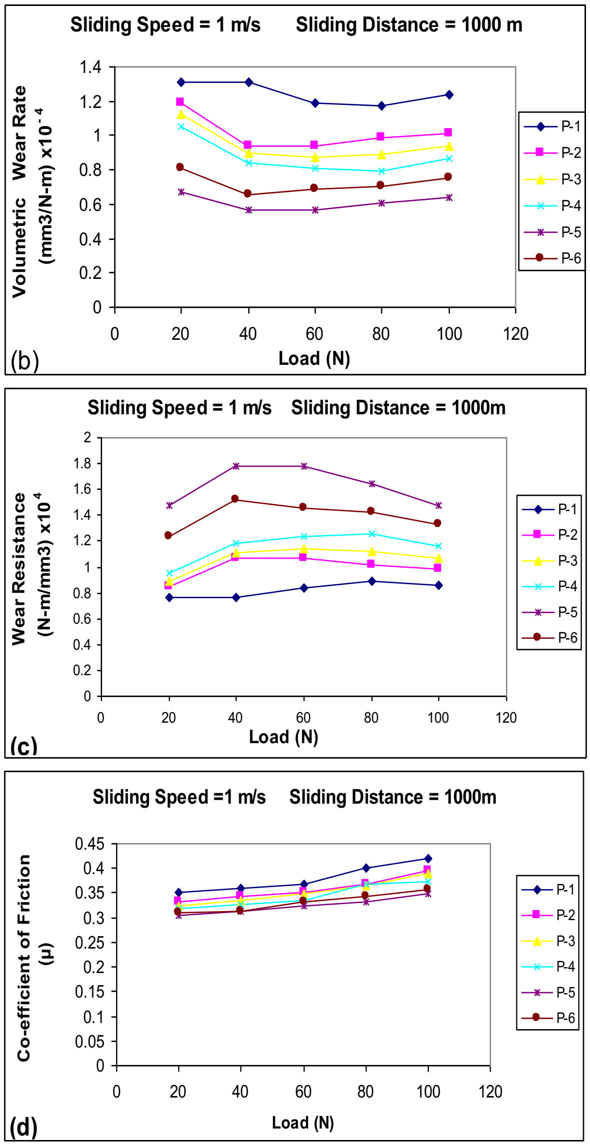


Figure 4: Variation of (a) wear volume (b) volumetric wear rate (c) wear resistance (d) coefficient of friction, with different loads at 1 m/s sliding speed and 1000m sliding distance.

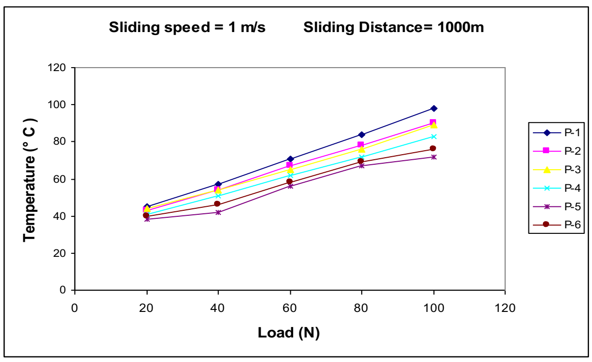


Figure 5: Variation of temperature vs. different loads at 1 m/s sliding speed and 1000m sliding distance.

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Dry sliding wear tests were also conducted for load bearing capacity of the pin compositions for a long sliding distance of 2 km with sliding speed of 1 m/s and at a normal load of 60N. Figure 6 (a-c) shows the wear volume, volumetric wear rate and wear resistance of the test specimens for sliding distance of 2000m with sliding speed of 1 m/s and at a load of 60N. Results indicate that wear volume, wear rate are more and wear resistance is less for the untreated Al-15Si-4Cu cast alloy. The additions of grain refiner M13, modifier (Sr) and refiner (P) to the unmodified alloy grain refiner (Al-1Ti-3B), modifier (Sr) and refiner (P) reduces the wear volume, wear rate and increases the wear resistance of the cast alloy. Figure 7 shows one of the photographs of the data acquisition report of the specimen with sliding velocity 1 m/s, normal load 60N and for a sliding distance of 2000m.

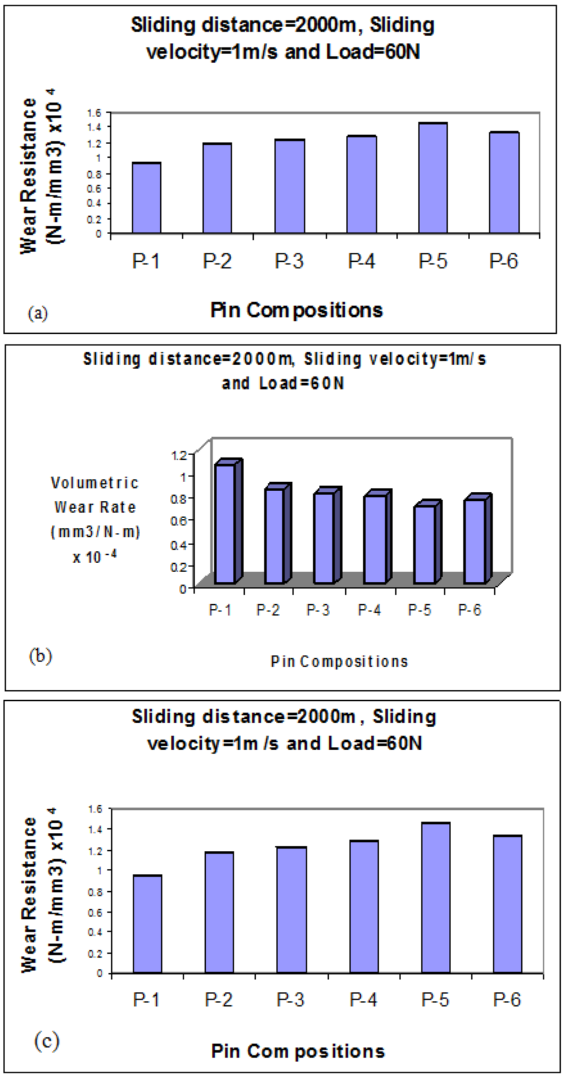

Figure 6 (a-c): Wear volume, wear rate and wear resistance of test specimens for sliding distance of 2000m, sliding velocity of 1m/s and at a normal load of 60N.

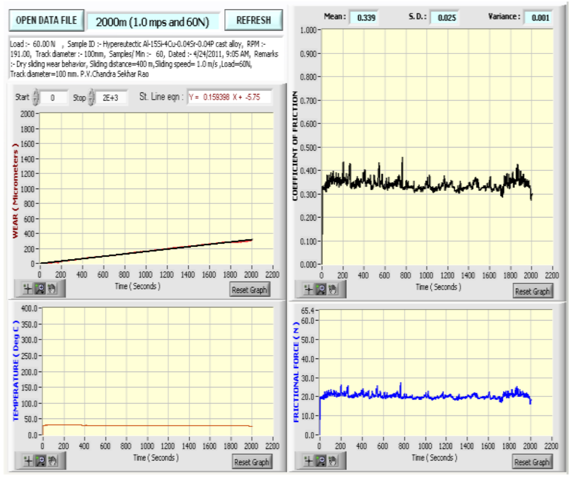

Figure 7: Data acquisition report of the specimen.

4. Conclusions

The influence of grain refiners, modifier and refiner on wear - friction behavior of hypereutectic Al-15Si-4Cu cast alloy was investigated and the following conclusions were drawn:

- Dry sliding wear behavior of the hypereutectic Al-Si cast alloys depend on the size, shape and size distribution of α- aluminum grains and secondary phase particles in the matrix.
- The additions of modifier (Sr), refiner (P) and grain refiner (Al–1Ti–3B) to the unmodified Al-15Si-4Cu alloy convert large α-aluminum grains into fine equiaxed α-aluminum grains and eutectic silicon plates into fine particles and fine CuAl2 particles in the interdendritic region leading to better mechanical properties and hence improved wear resistance.
- Combined modification, refinement, and grain refinement minimizes the oxidation of the matrix. The best combined modification, refinement, and grain refinement (Al-15Si-4Cu-0.04 Sr-0.04P-1M13) alloy recorded minimum coefficient of friction and temperature at high wear load.
- The hypereutectic Al–Si alloys investigated exhibit work hardening and plastic deformation during dry sliding wear testing; the modified, refined and grain refined Al–15Si–4Cu cast alloys work-hardened to a greater extent than the un-treated alloys.

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Experimental Study of Solar Powered Air Conditioning Unit Using Drop – In Hydro Carbon Mixture to Replace R-22

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Abstract

In this study the performance of a one ton split air conditioning unit (A/C) was experimentally investigated. The unit was originally designed to use R-22 as refrigerant. Liquefied Petroleum Gas Mixture (LPGM) of 30 % propane, R-290 and 70 % butane, R-600, (weight ratio) was evaluated as a drop in replacement for the R-22. This work is part of the worldwide efforts to explore replacements for the Chlorofluorocarbons and Hydrochlorofluorocarbons. Ozone depletion and climate changes warranted such efforts. It is a well-known fact that air conditioners (A/C) power consumption has a large share from the total building sector energy consumption. As a result of that, solar electricity was attempted in powering this unit. A photo voltaic array of twelve modules was used as an electrical generator. The performance of the unit was studied for both refrigerants used and then compared with each other. Experiments of day-long runs were carried out. Performance parameters were studied as dependent variables such as: coefficient of performance (COP); capacity; power consumption of the compressor; heat rejection and mass flow rate of refrigerant. In addition, changes of independent variables such as: evaporation temperature (Te); and condensing temperature (Tc) were evaluated. It was found experimentally that the COP of the system using LPGM as refrigerant and the capacity are lower than that using the R-22. Both the COP and the capacity are 25% lower at optimum working conditions. In spite of that LPGM has other advantages such as: higher refrigeration effect; lower mass rate of flow; lower compressor exit temperature and lower power consumption. The power consumption of the compressor when using LPGM was found to be 35% lower than that when using R-22. This gives an advantage of using LPGM as a refrigerant to replace R-22 especially when the A/C system is powered by solar energy.

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Keywords: Air Conditioning; LPGM; R-22; Solar powered systems; R290/R600

Nomenclature

Abbreviations

A/C	Air conditioning system
AC	Alternating Current
CFC	Chlorofluorocarbon
DC	Direct Current
COP	Coefficient of performance of split air-conditioning unit
HC	Hydrocarbon
HCFC	Hydrochlorofluorocarbon
HR	Heat rejection rate (kW)
I	Current (Amp)
LPGM	liquefied petroleum gas mixture of 30% propane and 70% butane

Symbols

I	Electrical current
H	Enthalpy (kW)
P	Electrical compressor power consumption (kW)
RE	Refrigeration effect (kJ/kg)
T_c	Condensation temperature (^{o} C)
T_e	Evaporation temperature (^{o} C)
V	Voltage (Volt)

Greek symbols

$\dot{m}$	The mass rate of flow (kg/s)
$\dot{q}$	Cooling capacity (kW)
$\dot{w}$	Compressor work (kW)
ζ_e	Electrical efficiency
ζ_m	Mechanical efficiency

1. Introduction

Hydroflourocarbons and Hydrochloroflourocarbons, (HFCs and HCFCs) are widely used as refrigerants in air conditioning and refrigeration systems since they provide the characteristics and properties required for optimal performance. According to the Montreal protocol; this initiated world-wide controls on production and phase out

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time table of CFCs and HCFCs because of their significant role in Ozone depletion and global climate changes. They have high Ozone depletion potentials and make a significant contribution to global warming when emitted to atmosphere. These effects were the incentive for scientists and engineers to explore suitable replacements for these refrigerants. During the last few years, several studies have been conducted to investigate physical and thermodynamic properties, system performance and environmental effect for different alternative refrigerants. Any alternative refrigerant must have suitable physical and thermodynamic properties, chemical and thermal stability, good miscibility with the used lubricant, low toxicity and low flammability. Hydrocarbon (HC) refrigerants are considered as a good alternative to replace R-22 and other refrigerants. Many experimental studies were conducted to investigate the performance of HC refrigerants in refrigerators, A/Cs and heat pump systems. It was found that using a mixture of propane and butane R290/R600 is the best alternative to replace these refrigerants as drop in method. The only problem associated with HC is the flammability; this may be disregarded when the amount of charge of HC in the system is so minimal, safety precautions are considered and installed in large volume places.

Considering the problem of peak load of electricity consumption in summer due to air conditioning systems, solar powered air-conditioning systems could be an effective solution of energy conversion, reduction of peak electric power and global environmental problems. Moreover, since the electric power demand reaches peak in summer especially in the daytime, the load pattern agrees well with the Photovoltaic power output pattern.

2. Literature Review

Many studies had focused on substitutes for R-22 and R-12 using HCs mixtures as alternative refrigerants. Abuzahra [1] investigated experimentally the performance of a 1.4-ton window type A/C unite when replacing R-22 refrigerant with methane and LPG. He found that methane gas was not a suitable replacement for R-22 in this type of A/C due to compressor overheating problems. But LPG can be used satisfactorily.

Purkayastha and Bansal [11] studied experimentally the use of a mixture of propane (R290) and LPG as a refrigerant that replaced R22 in a heat pump. They found that COP with R290 and LPG mixture is higher than R-22 by about 18% and performed better than R290 alone but with a small loss of condenser capacity. Hammad and Tarawnah [6] studied the performance of 2.5-ton split A/C unit when the R-22 was replaced by a mixture of butane and propane with different ratios without any modifications or adjustments made to the A/C unit. It was shown that the mixture of 90% propane gives equal pressure as R-22 with higher COP while the mixture of about 60% propane gives equal COP, with lower pressure. It was found also that the capacity and compressor work decreased when propane percentage increased. It was concluded that all mixtures of propane and butane can be used as possible alternative refrigerants to R-22 and 100% propane mixture has the highest COP values among all hydrocarbons. They found that 90% propane mixture is the most suitable alternative refrigerant to R22 based on both higher COP and equal saturated pressure.

Nofal [10] studied the performance of a chest freezer when LPG was used as a substitute refrigerant for R134a. The results showed that LPG refrigerant had higher COP than R-134a by 20%. Lower refrigeration capacity and slightly lower power consumption were noticed.

Devotta et al [3] studied the performance of a 5.13 kW window air conditioner designed for R22 when filled with propane. The performance of the air conditioner with R290 was compared with the performance with R-22. It was concluded that the COP for R290 was 7.9% higher at lower operation conditions and 2.8% higher at higher operating conditions.

Jung [9] studied the thermodynamic performance of two pure HC and seven mixtures composed of propylene (R1270), propane (R290), HFC152a and R170 in residential A/C. Heat pump with capacity of 3.5 kW was used in these experiments. Results showed that the COPs of all alternative refrigerants were up to 5.7% higher than that of R-22, except that for the R1270 which was 0.7% lower than that of R22.

Chang and Kim [2] compared experimentally the performance of a heat pump system when the R22 was replaced with propane, isobutene, butane, propylene and a mixture of propane/isobutene and propane/butane. It was concluded that the capacity and the COP of R290 were slightly higher than that of R22 which was an indication of a possible use as alternative in air conditioning and heat pump application.

Jabaraj et al [7] studied the possibility of using HFC407C/R290/R600 as a refrigerant mixture to substitute R22 in a window A/C and to evolve an optimal composition for the mixture. HC blend considered was of 45.2% of R290 and 54.8% of R600a. It was found that the COP was 8.19% to 11.15% higher than that of R22 at various condenser inlet air temperatures and the power consumption was 2.34% to 10.45% higher than that of R-22. It was found that among the mixtures considered, the above mentioned mixture would be the best choice for R-22 window air conditioners without changing the mineral oil.

Hammad and Alsaad [5] studied the possibilities of replacing R12 refrigerant with a mixture of propane, butane and isobutene. Four ratios of mixtures were studied experimentally. It was concluded that the mixture with 50% propane, 38.3% butane and 11.7% % isobutene is the most suitable alternative refrigerant with the best performance among all other HC mixtures investigated in the study.

Jawad [8] studied the performance of a domestic refrigerator when R12 was replaced with a mixture of 50% propane and 50% butane. These results showed that the best performance was for 90 grams charge mass and it gave 15% saving in input power. COP was higher than that of R12 by 10.2%. It was concluded that the hydrocarbon blend is a good substitute for R12.

Solar cooling system using absorption refrigeration cycle has been studied by several researchers such as Bong et al. [13], Duffy et al. [14], and Zhai et al. [12]. Some other works have been concerned on cooling systems using solar power based on photovoltaic principle such as

Kunio et al. [15], Habib et al. [4]. The main problems facing solar cooling systems are its initial cost, low system performance and solar energy usage for part of the day operation. Researchers suggested some improvements on the main components of the solar cooling systems to obtain better performance and reduce the initial cost.

This experimental work is meant to study the performance of solar powered A/C split unit of one ton of refrigeration capacity using an environmental-friendly alternative refrigerant. Experiments were carried out using LPGM as drop-in replacement of R-22 in existing air-conditioning system. The effects of the solar energy power variation during the operating time when using R-22 and LPGM as a refrigerant in air-conditioning system operation were investigated. Furthermore, in this experimental study a comparison between LPGM and R-22 was carried out under the same working conditions and using solar power. Parameters such as: refrigeration effect; cooling capacity; compressor power; compressor exit temperature; COP; mass flow rate of refrigerant and heat rejection were considered. These were dealt with as functions of evaporating temperature and condensing temperature.

3. Experimental Apparatus and Procedures

The schematic diagram of the system and its components are shown in Figures 1 and 2. It consists of 12 solar modules, battery system, inverter, controller and split air conditioning system. The specifications of the individual components of the system are shown in tables 1, 2 and 3.

The electrical energy produced by the PV modules will be stored in the batteries. Batteries DC will be inverted to AC power by the inverter. The photovoltaic solar array used 12 modules. Each six parallel modules were connected as two series parts.

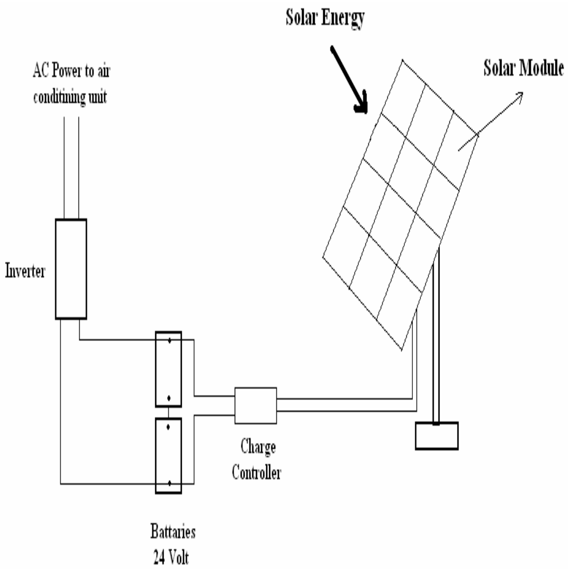

Figure 1: Solar system diagram.

Table 1: Specification of A/C unit.

Type	CHIGO Split Unit
Model	KF-32GW/AC30
Voltage	220-240/50/1
Capacity	12000 BTU (3.5kW)
Power input	1250 W (cooling mode)
Operating current	5.6 Amp
Refrigerant	R22
Air flow	550 m^3/h
Indoor unit	Three speed fan

A set of eleven copper-constantan (K-type) thermocouples with an accuracy of ±1 oC were installed at different points of the A/C refrigerant flow circuit to measure the refrigerant temperatures at different locations.

Table 2: Specification of photovoltaic unit.

Made	China
Model	C75D/80D
V max (V)	17 V
Voc(V)	21.5 V
I max (A)	4.42-4.71 Amp
I sc (A)	4.85-5.17 Amp
Power (W)	80 W
Dimension	670×990×40 mm
Weight	7 kg

Table 3: Specification of battery, inverter and controller.

Inverter	Model	Mass sine 24/1500-230V/50Hz
	Nominal Battery Voltage	24 V
	Nominal Capacity	1200 VA
	Peak Power	2900 VA
	Efficiency	92%
	Switch off volt	19 V
	Switch on volt	22 V
Battery	Model	OUTDO model OT120-12 deep cycle lead acid
	Nominal Battery Voltage	12 V
	Rated Capacity	72Ah, 95Ah, 120Ah
Charge Controller	Model	Prostar-30 version PS-30M
	Voltage	24 V
	Current	30 A

These thermocouples were installed; fixed and well insulated at their locations as shown in Figure 2. Their locations are described in Table 4. Temperature - Entropy (T-S) diagram is shown in Figure 3 for a typical vapor compression cycle. The points of measured temperatures are shown.

Table 4: List of measured temperature points.

Suction of the compressor	T1	Outlet of the evaporator	T7
Discharge of compressor	T2	Ambient temperature	T8
Midpoint of the condenser	T3	Air temperature out of condenser	T9
Outlet of the condenser	T4	Inside air temperature	T10
Inlet of the evaporator	T5	Air temperature out of evaporator	T11
Midpoint of the evaporator	T6		

The pressures at the suction and the discharge lines were measured using pressure gauges with an accuracy of ± 1 kPa.

A clamp meter and voltmeter were used to measure the current and voltage of the compressor with an accuracy of ±0.5 A and ±0.5 V respectively.

A digital scale was used to weight the charge of the refrigerants with an accuracy of ±1g.

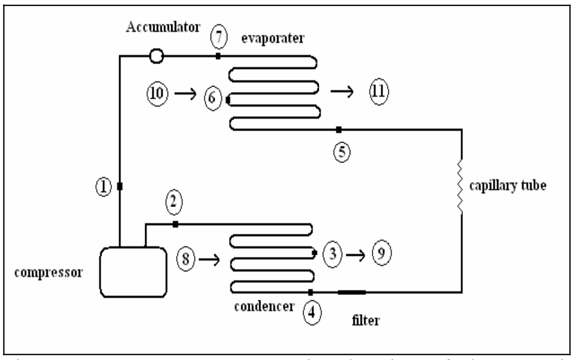

Figure 2: Temperature measuring location of the test air conditioning.

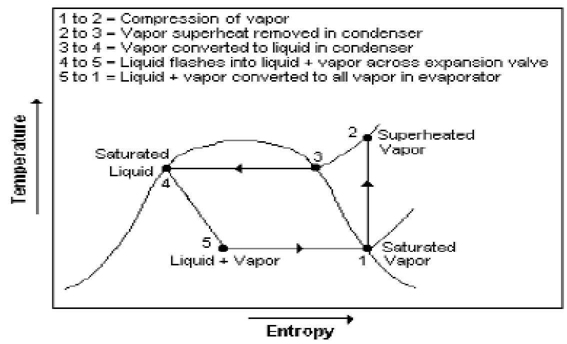

Figure 3: Temperature - Entropy diagram for ideal vapor compression cycle.

LPGM locally filled bottle with weight ratio of 30% propane and 70% butane was used. This LPGM refrigerant is a zeotropic blend charged in liquid phase acts with its composition shift and temperature glide. Drop-in experiments were carried out without any modifications to the experimental apparatus. Air speed regulation and evaporation cooling were used to change both condensing temperature, Tc and evaporating temperature, Te.

4. Mathematical Model

Following are the mathematical relations used in the analysis process:

Mass rate of flow = (Power consumption /work input) * (ζ_m * ζ_e)

$$\dot{m} = [(I*V) / (h_2 - h_1)] *(\zeta_m*\zeta_e) \quad (1)$$

Where (ζ_m*ζ_e) is the product of the mechanical and electrical efficiencies of the compressor, respectively which assumed to be 0.8.

The refrigeration effect:

$$RE = (h_1 - h_5) \quad (2)$$

Cooling capacity:

$$\dot{q} = \dot{m}*(h_1 - h_5) \quad (3)$$

Compressor fluid work:

$$\dot{w} = \dot{m}*(h_2 - h_1) \quad (4)$$

Compressor electrical power consumption:

$$P = I *V \quad (5)$$

Heat rejection in the condenser:

$$HR = \dot{m}*(h_2 - h_4) \quad (6)$$

State points and their numbers are shown on figure 3.

5. Results

5.1. Optimal charging value:

In order to find the optimal charge value for the drop in LPGM refrigerant, seven different LPGM charge quantities were investigated. The variation of the COP with the seven different LPG charges 200, 250, 300, 350, 400, 500, and 650g were tested and presented in Figure 4. The best charge, (that provides maximum COP) was found to be 425 grams. This procedure of finding the best charge was recommended by literature works such as Abuzahra [1]. This amount of charge was used for all experiments of this work. It was found that the weight of LPGM charge used in this air conditioning system was less than that of the R-22 refrigerant by 44%.

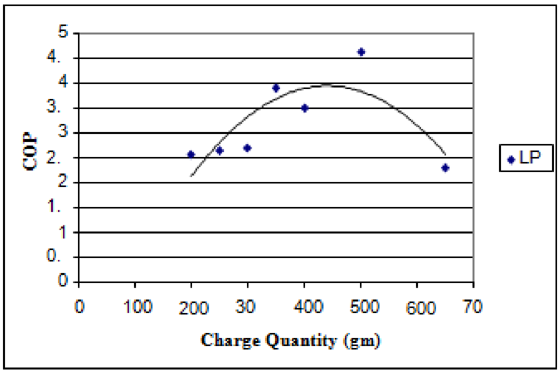

Figure 4: Coefficient of performance vs. charge quantity of LPG.

5.2. Power input:

Since the intensity of solar radiation is not constant along the day, this variation affects the total power generation of the used solar system. The variation of solar energy during the day will affect the power available in the batteries of the solar air-conditioning system. Thus, shutdown is expected to happen when the batteries can not provide enough power. When the batteries are recharged the A/C will restart again. The batteries working voltage ranged from 26.8 V down to 18 V. Between the shut down time and restart time, the batteries were recharged. Both, figures 5 and 6 show shutdown and restart periods for the A/C unit. Because of the fact that power consumption using LPGM was less than that using R-22 as will be discussed later, the A/C unit ran longer times in the case of using LPGM.

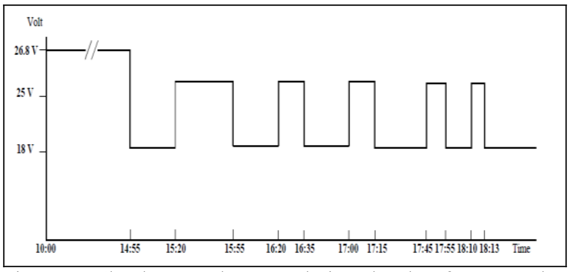

Figure 5: Shutdown and restart during the day for R22 when powered with solar energy.

The operating time considered was from 10:00 AM to 5:00 PM. The performance was measured in terms of the refrigeration effect, COP, cooling capacity, mass flow rate, power consumption, and compressor exit temperature.

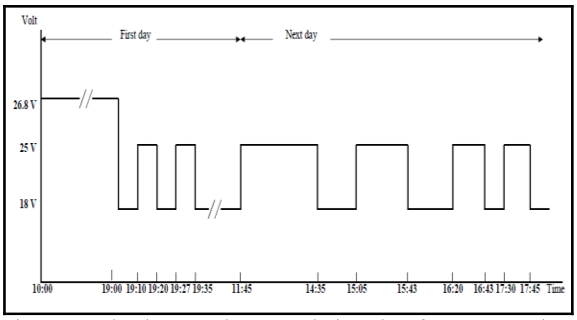

Figure 6: Shutdown and restart during day for LPGM when powered with solar energy.

5.3. Operating periods:

Figure 7 shows a typical day history of power consumption. This figure shows that the R-22 consumed more power than LPGM over the operating time considered in this study. The lower power consumption of LPGM is an encouraging factor to use solar energy as a source in driving the air conditioning system.

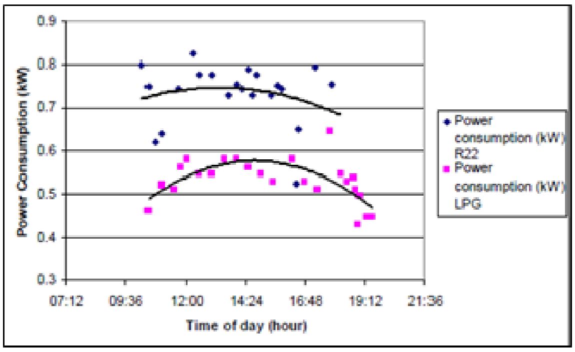

Figure 7: Power consumption using R-22 and LPGM.

Typical day history of refrigeration effect is shown in Figure 8. This figure shows that the refrigeration effect for the LPGM is higher than that of R-22 and thus the capacity required can be reached using lower mass rate of flow, . This effect produced lower power consumption, as discussed earlier.

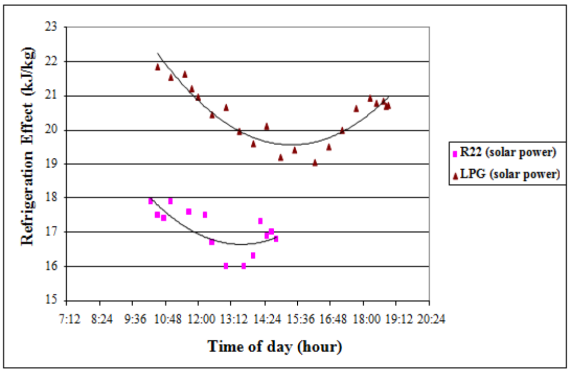

Figure 8: Refrigeration effect using R-22 and LPGM.

The mass flow rate through the compressor is proportional to the displacement rate in liters per second, the volumetric efficiency and inversely proportional to the specific volume of gas entering the compressor. As the suction pressure drops, the specific volume entering the compressor increases and this reduces the mass rate of flow at low evaporating temperatures. As shown in Figure 9 the mass flow rate of R-22 was higher than LPGM and the mass flow rate of R-22 decreased as the time of the day increased where the mass flow rate of LPGM is almost constant during the operating time. This is caused by the fact that the specific volume of LPGM is higher than that of R-22.

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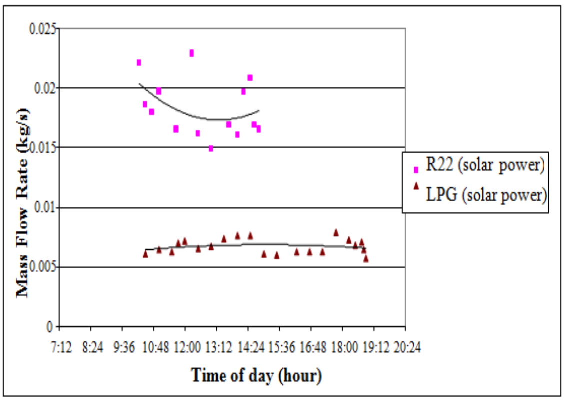

Figure 9: Mass flow rate using R-22 and LPGM.

The cooling capacity of the unit depends on the mass rate of flow of the refrigerant. The variation of cooling capacity versus time of the day is shown in Figure 10. This figure shows that the cooling capacity of the solar A/C unit using R-22 was higher than that when using LPGM by an amount of 25% at optimum conditions.

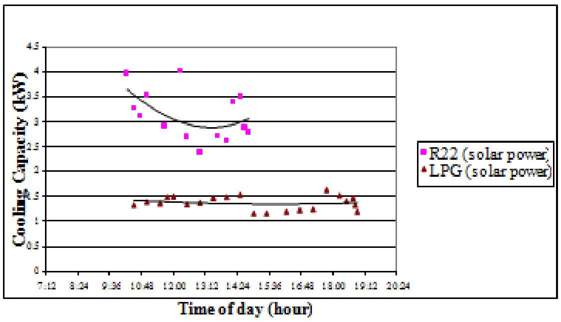

Figure 10: Cooling capacity using R-22 andLPGM.

The cooling capacity using R-22 changes during the time of the day while cooling capacity for LPGM is almost constant during the working period.

Figure 11 shows a daily history of the COP for R-22 and LPGM. The power consumption using LPGM is lower than that using R-22 and the cooling capacity using R-22 is higher than that using LPGM. The COP for R-22 is higher than that of LPGM during the operating period by amount of about 25% at best conditions.

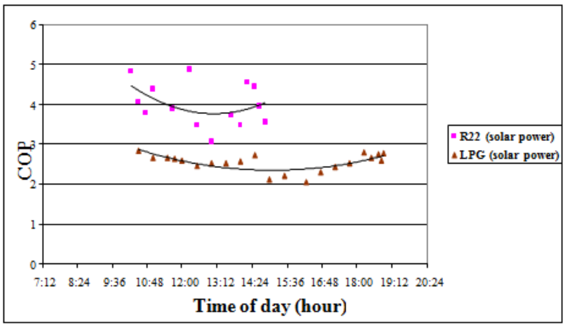

Figure 11: Coefficient of performance using R22 and LPGM.

Comparison of the compressor exit temperature between both refrigerants is shown in Figure 12. This figure shows that the compressor exit temperature for the A/C unit using R-22 is higher than that for the compressor exit temperature using LPGM. This is due to the fact that the LPGM has larger specific volume than R-22 which causes a lower compression ratio. This leads to a safer operation conditions.

Figures 5, 6, 7, 8, 9 and 10 show that the operating periods during the day using LPGM as a refrigerant were longer than that using R-22. As a result of these day time histories of performance, a good comparison between the use of LPGM and the use of R-22 was considerably discussed.

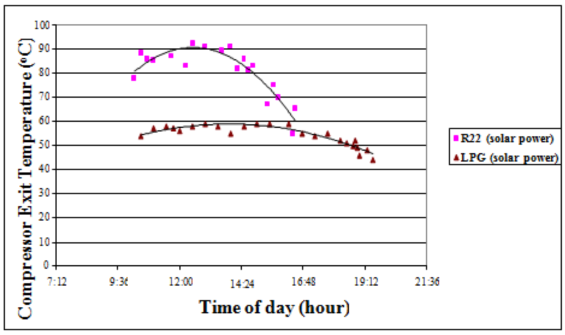

Figure 12: Compressor exit temperature with R22 and LPGM.

5.4. Evaporating temperature effect:

Figure 13 shows the variation of COP with evaporating temperature (Te) for LPG and R-22 using solar power. It is clear that COP for R-22 refrigerant was higher than LPGM and it increased as Te increased for both refrigerants.

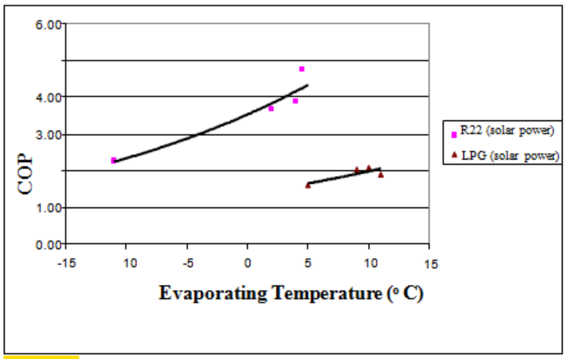

Figure 13: COP vs. Evaporating Temperature for R22 and LPGM at Tc = 45 °C.

The cooling capacity of the unit using R-22 was higher than that when using LPG refrigerant, while it increased for both with increasing of Te as shown in Figure 14.

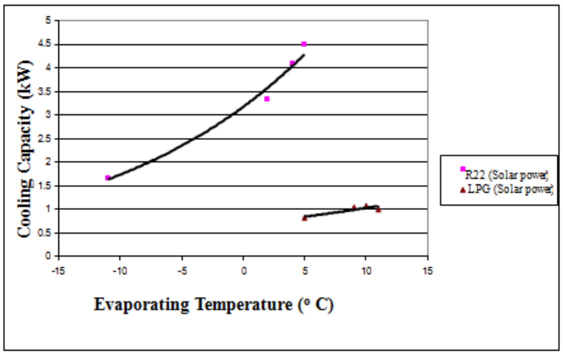

Figure 14: Cooling Capacity vs. Evaporating Temperature for R22 and LPGM at Tc = 45 °C.

The variation of power consumption with respect to Te was represented in Figure 15. It was shown that as Te increased the power consumption increased for both refrigerants, while that of R-22 was higher than that of LPGM.

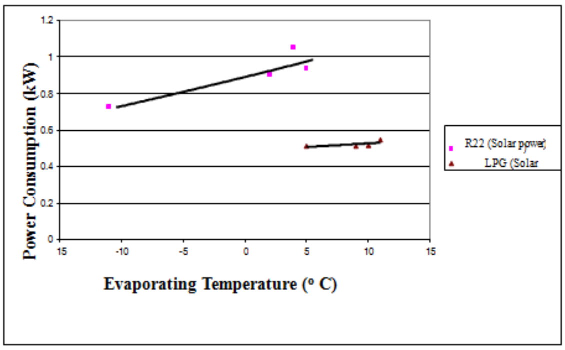

Figure 15: Power Consumption vs. Evaporating Temperature for R22 and LPGM at Tc = 45 °C.

For the heat rejected from both refrigerants, Figure 16 shows that it increased as Te increased and it was higher for R-22 than LPGM.

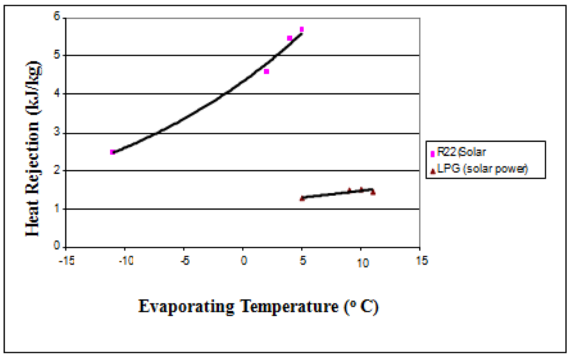

Figure 16: Heat Rejection vs. Evaporating Temperature for R22 and LPGM at Tc = 45 °C.

5.5. Condensing temperature effect:

Figure 17 shows the variation of COP with Tc for LPG and R-22. From this figure it was noticed that COP for R-22 refrigerant was higher than LPGM and it decreased as Tc increased for both refrigerants.

The cooling capacity of the unit using both R-22 and LPGM refrigerants decreased as Tc increased as shown in Figure 18. The cooling capacity using R-22 was higher than that of LPGM.

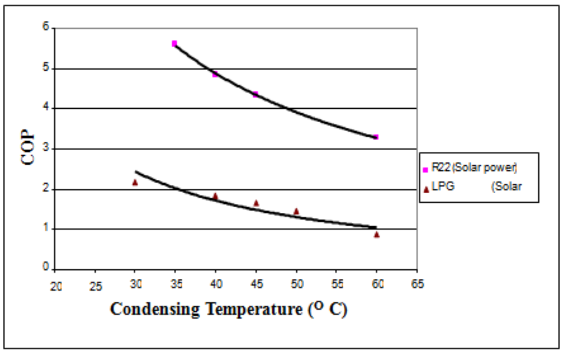

Figure 17: COP vs. Condensing Temperature for R22 and LPGM at Te = 5 °C.

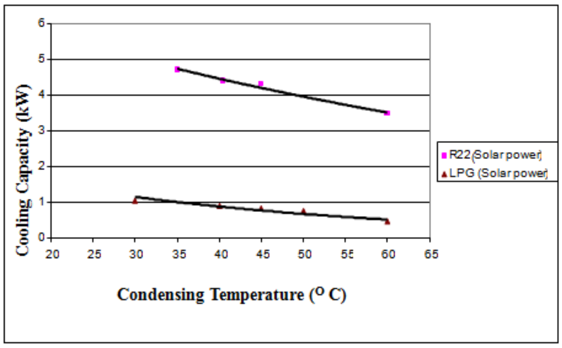

Figure 18: Cooling Capacity vs. Condensing Temperature for R22 and LPGM at Te = 5 °C.

The power consumption variation represented in Figure 19 with respect to Tc. It was found that as Tc increased the power consumption increased for both refrigerants.

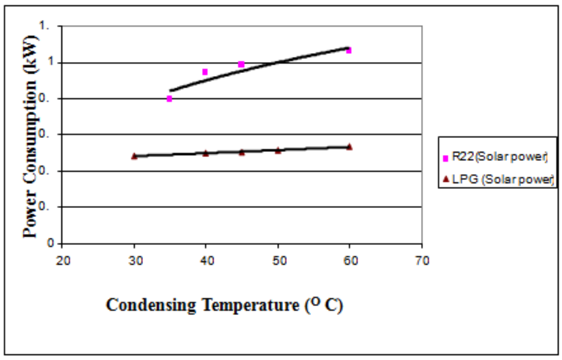

Figure 19: Power Consumption vs. Condensing Temperature for R22 and LPGM at Te = 5 °C.

The heat rejection for both R-22 and LPGM was illustrated in Figure 20. It can be seen from the figure that it decreased when Tc increased for both refrigerants.

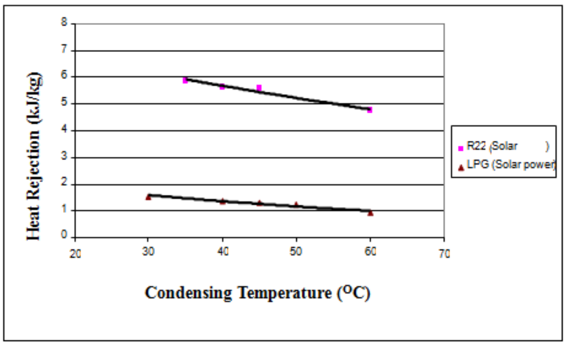

Figure 20: Heat Rejection vs. Condensing Temperature for R22 and LPGM at Te = 5 oC.

6. Conclusion

The refrigerant mixture LPGM used in this study was found to be a possible drop-in replacement for R-22 in the air conditioning system without considering any changes to the system.

The A/C system using LPGM refrigerant consumed less power than that with R-22. Energy conserved found to be more than 35%. This gave an advantage for using

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LPGM as refrigerant, especially when the A/C system was powered by solar energy.

The solar powered air conditioning systems using LPGM as a refrigerant had more continuous operation periods than that using R-22. This increased the reliability of the system.

Although systems using LPGM had lower COP and lower capacity than those using R-22, the first systems had the advantages of higher refrigeration effect, lower mass flow rate, lower energy consumption and lower compressor exit temperature.

Acknowledgment

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Identification and Analysis of Engine Speed and Noise in In-line Diesel Engine

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Abstract

For the cylinder power imbalancing/balancing methods proposed earlier in this research work by the authors, measurements of the angular speed of the crankshaft with sufficient quality is essential. In this paper different aspects of speed measurement are presented. A method is in addition is outlined for identification of the torque-noise component due to Quantization noise & Geometric errors in the speed measurement setup. As the influence of mass torque and noise due to geometric noise is constant on the reconstructed oscillating torque for small fuel injection adjustments, the resulting change in the oscillating torque can be directly attributed to the fuel injection and gas torque change. The phase-angle diagram of the engine can consequently be identified through parameter estimation.

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Keywords: Geometric noise; Speed Measurement; Quantization noise

1. Introduction

Internal combustion engine noise has been drawing significant attention from automotive to power generation manufacturers. To effectively reduce the noise level, the first step is the identification of noise sources, which relies on the noise signal analysis. From the aspect of condition monitoring or manufacture/assembly quality assessment, abnormal noise signals usually indicate abnormal conditions or problems in the manufacture quality. To pick up the problem, the abnormal signal source should be found first. This also depends on the signal analysis. Internal cylinder pressure (or torque) estimation is an important engine parameter with significant implications for diagnostic and control applications in internal combustion engines.

Unfortunately, direct measurements of internal cylinder pressure or torque production are expensive and currently not feasible for field applications. Instead, methods based on direct speed measurements [1–2] or engine block vibrations [5-7] are often employed for internal cylinder pressure or torque estimation. The advantage of crankshaft speed measurement-based algorithms is the fact that they rely on the existing crank and camshaft sensors and require no additional instrumentation. Speed-based cylinder health diagnostics are generally executed in the crank-angle domain, in which the position of the crankshaft replaces time as the independent variable [1]. The main advantage of formulating and executing in the crank-angle domain is the synchronisation of speed sampling with the engine cycle. Loss of critical cylinder health information can also be prevented by avoiding the re-sampling of the speed signal in the time-domain. A great deal of cylinder health information is periodic throughout an engine cycle, thereby limiting the frequencies of interest to integer frequencies in the crank-angle domain. Many speed-based diagnostics methods employ models of the engine dynamics. In [8], the signature analysis of crankshaft speed fluctuations is utilised for detection of misfiring cylinders. In [1, 2], dynamic engine models with flexible crankshafts are used to construct high-gain non-linear observers for indicated pressure or torque. The estimated indicated pressure or torque can be directly used for cylinder health diagnostics as well as controls. In [9], frequency-response function models of the speed signal is used for cylinder diagnostics. In [11], a survey of previously existing diagnostics methods based on Fourier analysis and correlation methods is provided and is followed by three different cylinder health diagnostics methods. A diagnostics method based on the measurement and comparison of the speed fluctuations at the flywheel and at the front end of the engine over an engine cycle is presented in [12].

The vibratory signal measured at any point on the internal combustion engine structure, is composed of a very complex superposition of the contributions of different vibratory sources modified by their respective transmission paths. These sources originate from several internal phenomenons in the engine and excite the natural modes of the engine. The vibration is amplified at the natural frequencies of the engine. Therefore, the produced vibration and the noise radiated from the engine result

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from the combination of the excitations and the dynamic response of the structure. Diesel engine vibration & noise is caused by combustion, mechanical, and the combination of both sources, such as combustion forces, piston slap, inertia forces, injection forces, the distribution system forces due to impacts of the intake and exhaust valves on their seats as well as the excitation of the valve tails by the rocker arms, applied sometimes simultaneously at different phases of the engine cycle.

1.1. Diesel Engine Mechanical Noise Model:

With reference to the above discussion on the composition of the engine noise in section 1, a noise signal can be mathematically described by Eq.1 as;

$$x(t) = \sum a_i \cos(\omega t + a_i) + \sum\sum b_{ij}(t)u(t - t_j) * \cos(\omega_{ij} t + \alpha_{ij}) \quad (1)$$

where a_i and $b_{ij}(t)$ denote the amplitude of a signal component, ω_i and ω_{ij} represent the frequency, $u(t)$ is the step function, t_j is the instant at which an event occurs, and α_i and α_{ij} are phases of signal components. That is, a noise signal component can be characterized with four quantities: amplitude, frequency content, time, and phase. The first part of this equation is major harmonic components. The signal is dominated by this harmonic components i.e., if the first term of this equation is removed, it can be seen that the signal contains many transient components which are the second term of the equation.

In this work a method for identification of the torque-noise component due to Quantization noise & Geometric errors in the engine speed measurement setup is outlined, as the measurements of the angular speed of the crankshaft with sufficient quality is essential for engine health diagnostics.

2. Experimentation and Measurement

2.1. Measurement & Calculation of Angular Speed & Noise of Multi-cylinder Diesel Engine:

Crankshaft angular speed of internal combustion engines is usually measured by means of a toothed flywheel or measurement disk and an inductive speed-pickup. As the teeth or mark passes the sensor, a step formed voltage is generated. The so-called pulse train, which is generated as the wheel rotates, can then be used for calculating the angular speed of the wheel. In Fig. 1(a, b) the speed sensor and the toothed flywheel is shown for a 6-cylinder diesel engine SL90-SL8800TA.

The estimation algorithm used to calculate the angular velocity at every new edge from the transmitter wheel signal is based on finite automaton theory. The crankshaft angle can be measured only every six degrees, i.e when a positive edge on the transmitter wheel occurs. The estimation algorithm uses the last calculated angular velocity to decide the position of the crank shaft. The angular velocity is calculated, when a positive edge appears, using this differential Eq. 2;

$$\omega = \frac{\Delta\varphi}{\Delta t} \quad (2)$$

where $\Delta\varphi$ is the known sector angle described by the set of pulses for which the engine speed is measured and Δt is the measured time. The time is usually measured by a digital timer which is controlled by the zero-crossings of the pulse signal.

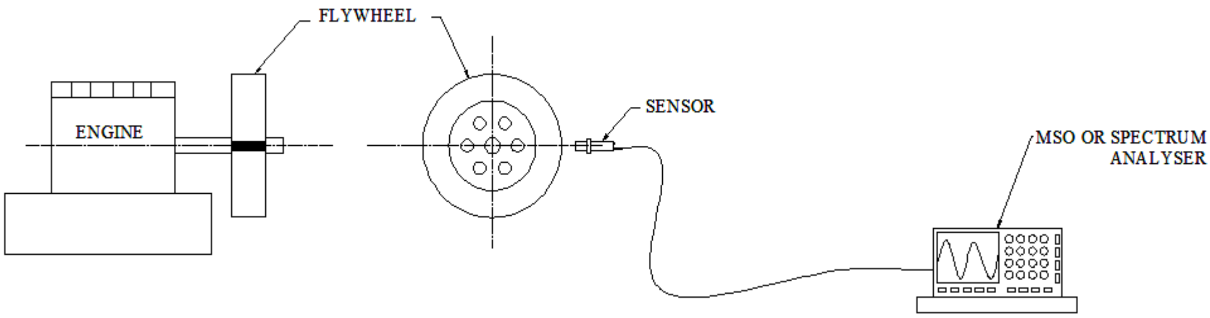

Figure 1: (a). Schematic Layout of test set up for Measurement of flywheel speed.

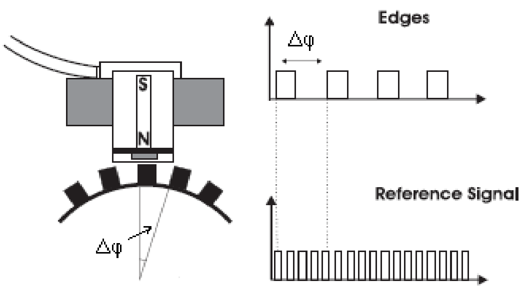

Figure 1 (b). Time measurement between two edges.

2.2. Measurement Noise:

From the experimental investigations it is found that the measured engine speed will now contain mainly two types of measurement noise:

1) Quantization noise.
2) Geometric noise.

2.2.1. Quantization Noise:

The quantization noise is due to the finite sample rate of the timer, which has a limited time resolution. In other words, the faster the shaft rotates, the higher the quantization noise *'q'* becomes. The quantization noise in rpm can be expressed as function of the timer frequency and the rotational speed of the engine as;

$$q = N_r \left[\frac{1}{1 - \frac{f_s(N_r)}{f_t}} - 1 \right] \tag{3}$$

where N_r is the engine speed in rpm, f_t is the timer frequency and f_s is the sample frequency of the engine speed. Note that f_s is a function of the rotational speed N_r. In Fig. 2 the dependency between the quantization noise and the rotational speed given by Eq. 3.

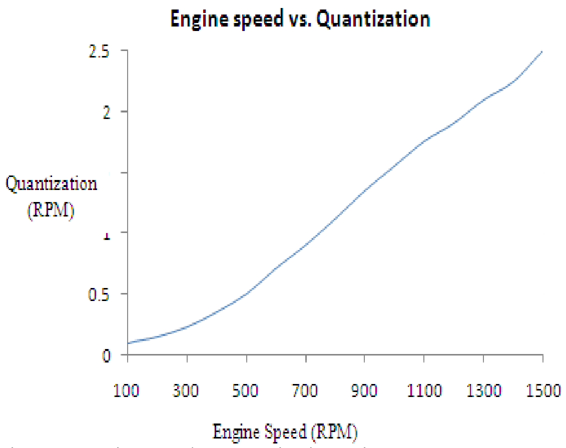

Figure 2: Engine speed vs. quantization noise.

quadratic with the engine speed. As a consequence, the information from orders with low amplitudes will be deteriorated or even lost. There are several methods to reduce the influence of quantization noise. One revisited method is to introduce dither, i.e. with noise, to the signal before performing the A/D conversion. However, considering the used measurement technique this was not directly applicable.

Quantization noise is a broadband noise which is distributed uniformly throughout the whole frequency band of the signal. As the gas and mass torques excite a known subset of frequencies, the total influence of the quantization noise can be reduced by considering only the known frequency orders which should be in the signal by using, for example, Discrete Fourier Transform analysis. Since the number of interesting frequencies are quite few there are, however, more effective approaches. For applications where only a limited set of frequencies are needed it can be more efficient to use a Goertzel filter instead for determining the Fourier series. Several Kalman filter approaches have also been suggested in order to damp the effects of quantization noise, where the dynamics of the system are taken into account, (Kiencke, 1999).

2.2.2. Geometric Errors:

The second source of noise is due to the geometric errors of the sensor disk, e.g. the flywheel. As all mechanical processing of the flywheel is done with a given accuracy, the teeth or holes drilled to the sensor disk include geometric errors. Consequently, the angle $\Delta\varphi$ includes an unknown error, which affects the measured angular speed ω. An interesting property of the geometric noise is that it repeats itself after each revolution. This implies that that the energy due to the geometric noise is concentrated to integer multiples of the rotational frequency of the shaft.

A number of methods have been proposed to tackle the problem of sensor wheel having geometric errors. Assuming that the torque affecting the shaft is constant, the measured torsional vibration of the shaft depends only on natural frequencies of the shaft and geometric errors. Assuming that the period of the natural frequencies are not orthogonal to the rotational speed of the shaft, the geometric errors can be determined by averaging the oscillations over several rotations. This would also be possible for internal combustion engines. However, since the gas torques contain multiples of half the rotational frequency, half of the frequencies from the geometric errors will coincide with a subset of the torque orders and cannot be separated from each other. A method has been proposed where a lumped-mass model is used for producing a reference signal to the measured angular speed. The discrepancy between the reference and measured signal is then associated to the geometric errors of the sensor disk.

2.3. Identification of the Torque Noise Due to Geometric Errors:

Several methods have been proposed for identification and compensation of geometric errors of a sensor disk. None of these make use of fuel-injection adjustments and the known resulting behaviour of the vibratory orders of the crankshaft. In this paragraph, a method for identification of the geometric error for a given order is outlined.

Suppose that the gas torque of an engine is reconstructed from angular speed measurements by using, for example, a lumped-mass model. The reconstructed gas torque order T_p vector can now be expressed by Eq.4 as;

$$T_p = \dot{T}_p + e_p \tag{4}$$

where $\dot{T}_p$ is the actual complex-valued gas torque of order p and e_p is the complex-valued error due to the geometric errors of the sensor wheels. As the order-wise geometric errors are independent of changes in the fuel-injection durations, it follows that e_p can be determined by parameter estimation through adjustments of the cylinder-wise torque contributions.

To visualize this, the torque noise can be illustrated geometrically, Fig. 3. Suppose the gas torque vector T_p for a specific order p has been reconstructed from measurements of angular speeds, where, $T_1 = \hat{T}_1 + e_p$. By performing a small decrease in the overall output power of the engine, a new vector T_2 for the same order p can be calculated. Since the relative change in the torque profile of the cylinders is zero, it can be assumed that $\hat{T}_1$ and $\hat{T}_2$ have the same phase, but different amplitudes. Note that the torque noise vector e_p is unaffected by the change in gas torque. A line L_1 can now be drawn between the coordinates of T_1 and T_2 which is parallel with the true unknown gas-torque vectors $\hat{T}_1$ and $\hat{T}_2$. Consequently, it can be established that the end point of the torque-noise vector e_p is somewhere on the line L_1.

Let now the relative torque profile of the cylinders change significantly, in such way that the phase of the new torque vector T_3 is different from T_1 and T_2. By again performing a change in the overall engine output power, a new torque order vector T_4 can be established. In analogy with T_1 and T_2, a *line* L_2 can be determined on which the end point of the torque-noise vector e_p resides. As a result, the torque-noise vector is described by the vector between origin and the intersection of L_1 and L_2.

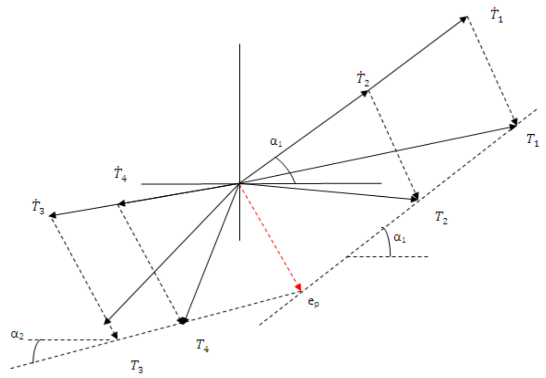

Figure 3: Graph of the relationship between the gas torque and the geometric torque noise.

3. Conclusions

The method proposed in this paper for identification and compensation of geometric errors of a transmitter wheel make use of fuel-injection adjustments and the known resulting behaviour of the vibratory orders of the engine crankshaft. From the performed analysis it is found that as the influence of mass torque and noise due to geometric noise is constant on the reconstructed oscillating torque for small fuel injection adjustments, the resulting change in the oscillating torque can be directly attributed to the fuel injection and gas torque change. As the quantization noise increases quadratic with the engine speed cause the information from orders with low amplitudes will be deteriorated or even lost.

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Activity-Based Cost Estimation Model for Foundry Systems Producing Steel Castings

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Abstract

Attention in this work is directed to estimate the manufacturing costs by using Activity-Based Costing (ABC) method for the castings that are produced by steel foundry. ABC is a cost accounting method that can overcome many of the limitations of Traditional Cost Accounting (TCA) methods. Cost rates for each department in the foundry are estimated by engineering procedures. Consequently, cost- estimating relationship model that mathematically describes the cost of final castings as a function of all consumable resources is constructed. A Work-In-Process (WIP) flow through the different production centers is analyzed and costs of available resources are allocated for all foundry centers, cost rates are derived, accordingly the ABC method for estimating production cost is discussed and presented. Comparison between the results of ABC method and the results of TCA method has been carried out. Finally results are discussed, recommendations are presented, and avenues for related future works are proposed.

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Keywords: ABC; Manufacturing cost; Foundry cost; Activity-based management; Casting technology.

1. Introduction

Manufacturing organizations are looking to produce high-quality products more quickly and with the lowest possible cost. To achieve that, companies are required to become more productive, integrated, highly flexible, and to have a realistic and more precise cost estimation approach. Managers need to fully understand the cost, time, and quality of activities performed by employees or machines throughout an entire organization. Traditionally direct labor was typically chosen as the base for assigning overhead cost to products and there was a high correlation in most foundries between direct labor and the incurrence of overhead cost. Presently automation has greatly decreased the amount of direct labor required, and a total overhead cost has increased to the point that a correlation no longer exists between it and direct labor. Wherever these changes have exist, foundries that have continued to use direct labor as a basis for overhead assignment has experienced major distortions in unit costs.

In order to overcome these problems some foundries can use Activity Based Costing (ABC) method. ABC involves a two-stage allocation process, with the first stage overhead costs are assigned to cost centers, the centers represent a set of activities, such as casting design, drawing, measurement, prototyping, pattern making, quality control, melting, molding, etc. In the second stage, cost rates are assigned to jobs according to the nature of activities required. The roots of ABC approach were introduced in 1984 by respected professor, Dr. Robert Kaplan of Harvard Business School who began to expound the shortcomings of TCA method, and who developed the new ABC method [1, 2, 3]. From these beginnings, ABC gained attention and spread widely over the world. ABC models the relationships between products and the resources used in their production at all production centers that enable managers to cost out measurements to business simplification and process improvement. ABC provides a more accurate and consistent way of calculating manufacturing costs [4, 5] Costing systems accumulate data and aggregate them into information for financial reporting and managerial decision-making. It is important, therefore, that the definitions of costing parameters are understood by industrial engineers and production managers to make accurate decision. ABC method attempts to provide an accurate interpretation of factors generating all the cost. Improper classification of costs can distort management's perception of the process and lead to poor decision- making, therefore, decision-makers must be careful when using costing data to know precisely what is included and how the data relate to their engineering choices [6]. Recently, the remarkable success implementations of ABC introduced a new paradigm to literature of the manufacturing cost accounting and, ABC has been increasingly used in multi-level complex manufacturing organizations. A number of sources about ABC are available on [7, 8, 9, 10]. Several researchers applied ABC in different real life application can be found in the literature, among these [11, 12, 13, 14, 15].

Ginoglou D., 2002 [1] addressed that ABC improves the costing system of organizations in the following ways:

- ABC increases the number of cost pools used to accumulate overhead costs. Rather than accumulating all overhead costs in a single, company wide pool, or

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accumulating them in departmental pools, costs are accumulated by activity.

- ABC changes the base used to assign overhead costs to products. Rather than assigning costs on a basis of direct labor or some other inaccurate measure of volume, costs are assigned on a basis of the portion of cost-driving activities that can be traced to the products.
- ABC changes also a manager's perception of many overhead costs in that costs that were formerly thought to be indirect (such as power, inspections and machine setup) are identified with specific activities and therefore are recognized as being traceable to individual products.
- As a result of having more accurate product costs, managers are in position to make better decisions relating to product retention, marketing strategy, product profitability and so forth
- Moreover ABC leads to better-cost control because it eliminates distortions that are caused by the labor-based costing systems and also helps investment decisions. Labor-based cost systems under cost capital intense processes, while over costing labor intense processes. ABC provides more accurate process cost information, which lays the foundation for better capital justification. Using activity-based costing, companies not only know what each process' real overhead amounts to, but what it consists of. The system tells management how much tooling, maintenance and utilities each process consumes. These costs can be used in capital justifications or as targets in cost reduction programs.

The primal objective of this paper is to present a costing model that uses ABC to estimate the production costs of steel castings an experimental case study will be conducted to demonstrate the costs calculation under specific production conditions to gain an insight into the effects of production parameters on costs. The output of the ABC model will be considered separately in order to be distinguished and to be compared with the result obtained by TCA under the same production environment.

2. Modeling of Foundry Activities Resources Consumption

This paper is considering a multi products steel foundry system that uses mainly Ferro-alloys, steel scrap and return, to convert them into finished steel castings, and finally deliver the finished casting to the customers. This considered foundry has the layout shown by figure1 the produced castings conforming to DIN, JIS, ASTM, BS, and some other international quality standards. The foundry includes all the necessary production lines to manufacture, produce casting and form the different types of steel castings used in industry, agriculture, construction, and the infrastructure for the engineering industries and supported engineering complementary industries, which depend on castings. The initial product mix comprises steel castings, but in the longer term, the foundry can support further development of mechanical engineering industries in the region. The product mix of the foundry includes but not limited the following main casting alloy types: low alloy steel castings; stainless steel; 12/14 Mn-steel castings (Mn-B1); 2Cr- 14 Mn-steel castings (Mn-C); heat resistance steel castings (H.R.SCH22, H.R.SCH13); Ni-hard cast iron; high Chrome cast iron (High Cr-CI); 25 Cr-12 Ni steel castings; and ductile rolls.

Different mould sizes and heights can be accommodated within a reasonable range. Box molding produces components falling outside the range. Medium frequency coreless induction furnaces each of 1.5 tones capacity are installed, rated at 1.8 tones of molten metal per hour, during which the metal temperature should be raised to more than 1650 ^{o}C.

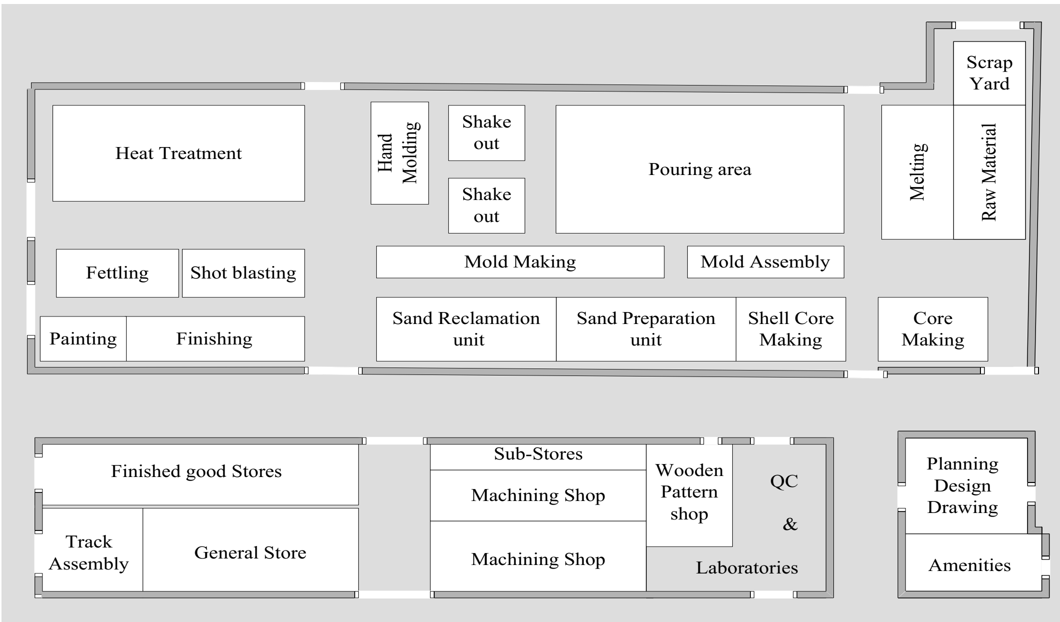

Figure1: Layout of the proposed steel foundry and its support departments

Pouring operations on pattern flow molding section is utilizing crane ¬suspended ladles suitable for bottom pouring. In the site plan, the plant occupies one separate manufacturing building for melting, molding, pouring operations, and casting cleaning and finishing operations.

New silica sand handling, chemically bonded sand reclamation plant, and core shop facilities are housed in the ancillary production bay alongside the main casting production building. Other service departments, such as laboratories, garage, pattern shop, general stores, maintenance department, compressor house, and electrical sub-station are established in separate buildings on the site. The manufacture of casting is described as shown in figure 2. Starting from the development of foundry technology (casting design), chemical composition is selected, mass calculations is performed, dimensions and tolerances are prepare. If customer order can be fulfilled, the needed technology, production method, requirements, and documents, are prepared, than production is triggered and flow as in the sequence described in figure 2.

Capacity Factor (CF) is defined as the ratio of the average output production to the maximum production capacity over a year. As depicted in figure 3, the average CF of the foundry over the past five years is equal to (0.50).

To achieve the objective of our work a capacity factor of 0.5 is considered, only line molding process is considered, and only furan cores are used. Under this scenario, cost rates for every used resource is derived to be used to estimate total production cost by TCA and/or ABC methods.

The monthly production can be estimated by spreading the average of the actual yearly production over the working months (12 month), therefore the monthly estimated production quantity is:

$$MP = Monthly\ production = \frac{Average\ actual\ \ production\ output}{Working\ months\ per\ year}$$

$$= \frac{700}{12} = 58000\ Kg\ of\ saleable\ casting$$

2.1. Activities and activity centers:

Figure 2 indicates that, many activities being carried out in the foundry. These activities represent the process of acquisitioning raw materials, casting them into finished products in accordance with the general sequence depicted in figure 2, and delivering them to customers. In the case of this paper more than fifteen main activity centers are traced, some of these centers are: melting center, automatic molding, furan core making, shakeout, shot blasting, cutt-off, grinding, heat treatment, machining, track assembly, painting, shipping, testing and inspection (QC), planning, design and technology, maintenance, and administration center.

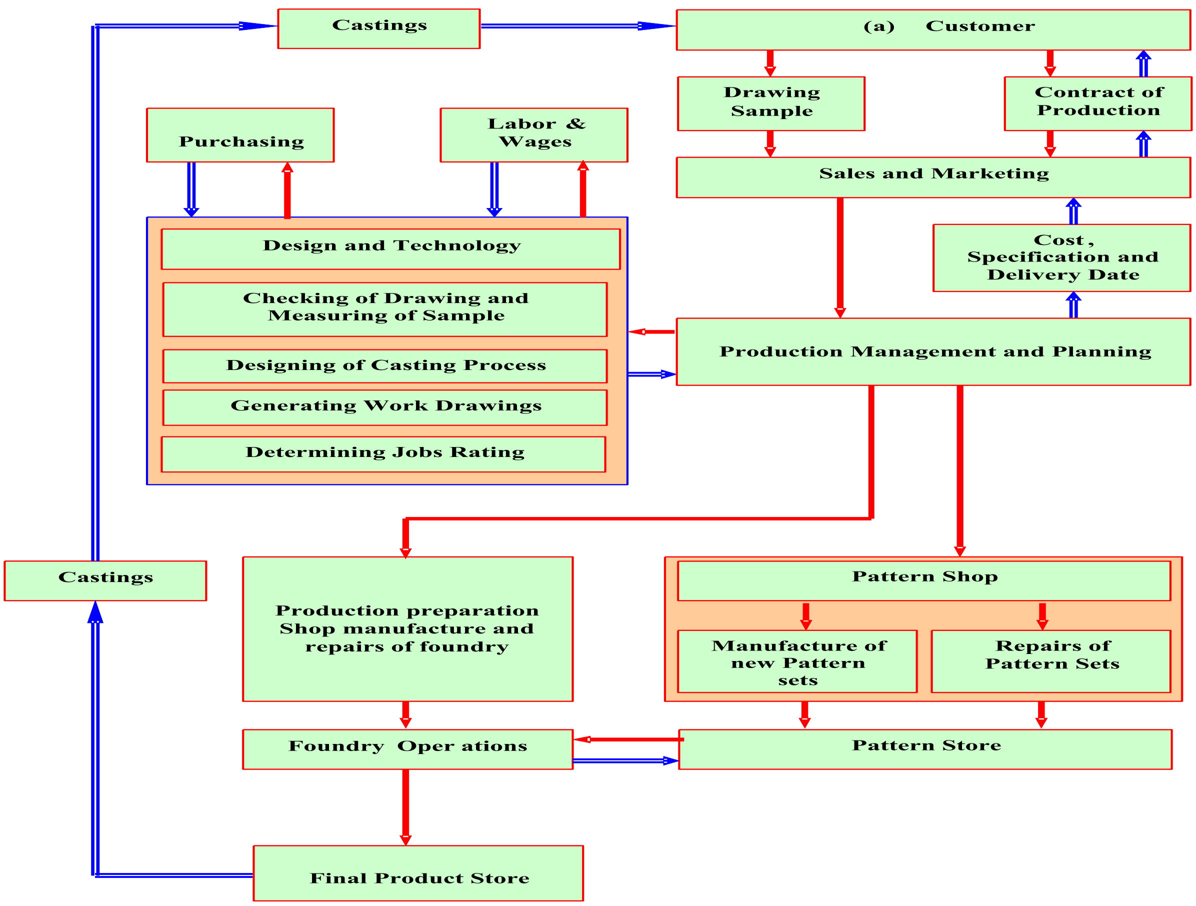

Figure 2: Standard sequence of operations for the manufacture of casting in the considered foundry.

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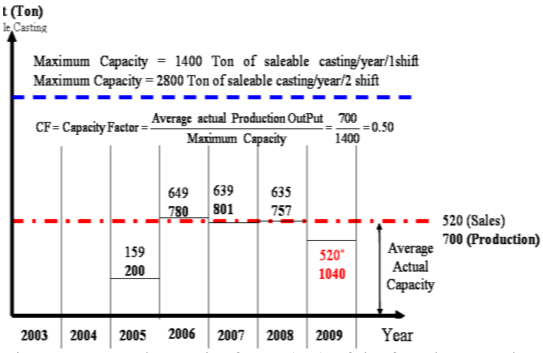

Figure 3: Actual capacity factor (CF) of the foundry over the past five years.

It is assumed that these centers consume certain levels of resources. The resource consumption is calculated using utilization levels of these centers per Kilogram of production.

2.2. Resources and resource consumption:

The major goal in ABC is to calculate the activity costs. The calculation of total product cost is a secondary operation. The aim is to manage the activities that contribute to the total product cost (PC) cost. In this context, the total cost of a product is the summation of the costs of activities that take place to produce that product. Therefore, after determining the activities, one should calculate how much resource each activity consumes. Different resources are available in the foundry, see figure 4. These can be classified into four categories: 1) Production Cost (PC) related resources, or casting cost, 2) resources related to Manufacturing Overhead Cost (MOC), 3) resources related to Selling Cost (SC), and 4) Administrative Cost (ADC) related resources, these classes are demonstrated by figure 4, and are explained in the following paragraphs.

2.2.1. Production or casting cost (PC):

This represents the converted values disbursement of direct labor and direct materials. The major cost items involved in this resource consumption are:

- Direct Material, (DM): Is the material whose cost is directly charged to the casting. The sum of charges for materials that accumulate against the product during its passage through the plant constitutes the total direct material cost. This cost element is considered as furnaces charging materials, molding materials such as silica sand, furan resin, catalyst, mold coating materials, release agent, consumed materials for core making and coating, and consumed materials during the assembly of some products.
- Direct Labor, (DL). It is the labor whose cost is charged directly to the casting. This cost element includes wages and salaries of blue dress workers in melting; molding; fettling; heat treatment and finishing; painting and shipping.

2.2.2. Manufacturing Overhead Cost (MOC):

MOC is converted to a cost figure when they are used for the purpose of manufacturing throughout the years. This cost embraces all expenses incurred in the production of castings that are not directly charged to the products as direct material or direct labor. Costs such as indirect material and indirect labor are combined, with other cost that cannot be directly related to the product being manufactured. The major cost items involved in this resource consumption are:

- Indirect Material, (IDM). These are small amount of a number of consumed items of material that are not directly charged to the casting. Indirect materials assumed as; materials consumed in melting, particularly, lining materials, refractory bricks, nozzles, and stoppers, and supplies used in the foundry that includes water, lighting current, heating fuel, electric power and maintenance supplies.Also steel shots, consumed materials for cutting off, grinding, and heat treatment of castings (grinding wheels, heat treatment media, cutting off tools etc.), lubricant, coolant and painting materials. Indirect elements of material cost are charged to manufacturing overhead expense as shown in figure 4.
- Engineering Cost, (IDL). The labor of personnel engaged in, engineering department (Eng), technology office (Tech), planning (Plan), quality control, inspection, quality check, and laboratories (Labs), production maintenance, services, and stores (PMS); Indirect labor is charged to manufacturing overhead expense as shown in figure 4.
- Factory Capital Recovery (CRF). CRF includes deprecation of physical place of production shop, depreciation of production equipment and production facilities, taxes, insurance, interest, rent, and maintenance of production buildings.
- Maintenance and service (MS). PMS represents the cost of all necessary services for survival of the organization and it covers all maintenance services, equipments, materials, labor, etc.
- Laboratories and quality cost (Labs). This cost item includes the money spent to buy machines for laboratories, spare parts, standards, references, manuals, and other needed materials. It also includes salaries of operators, and calibration cost.

2.2.3. Selling expense (SC):

Selling expense includes salaries, commissions, operation of office equipments and automobiles, travel, market surveys, entertainment of customers, displays (exhibition), sales space and other selling everyday expenditure.

2.2.4. Administrative expense (ADC):

- Administrative expense arises from expenditures for such items as; salaries of executive, clerical, and technical personnel; offices supplies; travel, and fees for legal, technical and auditing services that are necessary to direct the enterprise as a whole.

- Capital Recovery (CRA). CRA is considered to be independent of production volume, it represent the depreciation on such equipments as cars, land, offices, Computer hardware and software systems used, and other facilities belong to the company but not related directly to the production, CRA can be nominated as Indirect capital recovery.
- Total Capital Recovery (CR) which is the summation of CRF and CRA.

3. Cost of Resources and Cost of Activity Centers Based on ABC Method

An activity cost is the summation of costs of resources that are used by that center. The determination of which activity consumed which resource and how much of the resource is used by that activity is the means by which activity cost can be estimated.

Production cost consists of direct materials like charging materials, molding materials, consumed materials for core making and coating, consumed materials for assembly, and direct wages and salaries of blue dress workers in melting; molding; fettling; heat treatment and finishing; painting; shipping; and all other working centers. Manufacturing overhead cost consists of indirect, indirect labor cost, depreciation on factory equipments, tools, and devices, maintenance and storing cost, and quality cost. Selling cost includes salaries, commissions, operation of office equipments and automobiles, travel, market surveys, entertainment of customers, etc. Administrative cost includes of executive, clerical, and technical personnel; capital recovery of land, cars, office equipments and depreciation on such equipments as cars, land, offices, computer hardware and software systems used, and other facilities belong to the company but not related directly to the production, CR can be nominated as indirect capital recovery. Input-output relationship between resources and activity centers are demonstrated by figure 5.

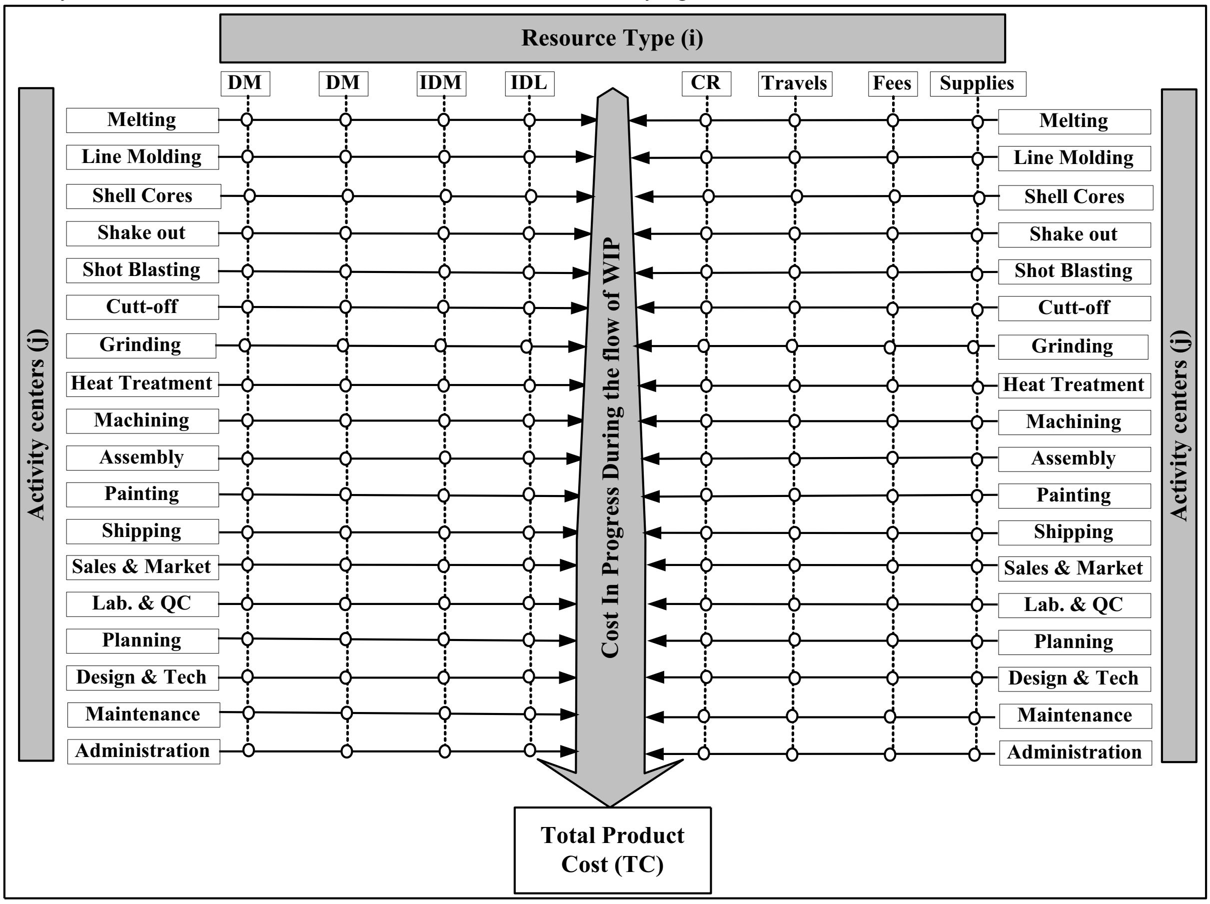

Figure 5: WIP flow and input-output relationship between resources and activity center.

Figure 5 shows that the cost of castings is accounted for as casting's components physically move from activity center to the other through the deferent department of the foundry. The production cost of final products reflects summery data indicating the Work-In-Process (WIP) inventory cost accounts at each activity center of the foundry [16].

4. Activity Based Calculation (ABC) of Total Product Cost

The following notation is used to describe the mathematical expression built to calculate the total product cost,TC, based on ABC:

- TC Total product cost of a considered product ($/product)
- W Saleable weight of the product (Kg)
- I Total available number of resources
- i Resource index (i = 1, 2. . . . I)
- J Total available number of activity centers
- j Activity center index (j = 1, 2 . . . . J)
- Rij Cost rate of consuming the ith resource at the jth activity center for producing a product of one Kilogram weight ($/1Kg)

$$TC = W\sum_{i=1}^{I}\sum_{j=1}^{J} R_{ij} \qquad (1)$$

The flow of WIP represented by figure 5 is a general illustration for any type of casting. For a specific casting type some modifications are needed. For example some castings are requested by the customer to be used as cast – without machining- therefore this type of casting is not pass through the machining center and hence the allocated machining cost that will be added to the summation in equation (1) is zero. Also few castings pass through the assembly activity; therefore a value of assembly cost equal to zero will be allocated for most of the products.

4.1. ABC cost rates:

The main concern of this paper is to estimate the manufacturing costs by using ABC method then to compare that with the cost obtained by TCA; therefore the work will not consider the detailed explanation of how the rates (Rij) are derived. ABC cost rates for each consumed resources at each work center are computed by engineering procedures method at a low level of detail. The computation of these rates is highly depending on the skills and on the experience of the industrial engineers of the foundry. As a result of this work phase cost rates are presented in table 1. These cost rates covering the whole range of the product mix which represented by 10 family groups as indicated previously in section two of this paper.

4.2. ABC calculations:

Using the cost information given in table 1 and the activity-resource relationships shown in figure 5

Total production cost for any casting type can be calculated by the mathematical expression presented in equation (1). This equation states that the total production cost of a casting is the sum of the allocated costs for each activity center the part undergoes in its production process. Consider a product of a weight equal to 12 Kilogram made from Mn-B1 alloy type. The total production cost of this item is the summation of cost for all consumed resources.

As it is shown in table 2 total production cost covers direct and indirect material cost, indirect and indirect labor cost, depreciation cost, travels and transportation cost, fees and insurances cost, and cost of consumed supplies.

The allocation of cost to the considered casting from all the resource areas associated with its production is shown in figure 6. The allocation has been shown as a percentage of the total production cost for clarity.

Table 1: Resource cost rate at each activity center for each alloy type Rij ($/Kg) of saleable casting.

Resource cost rate at each activity center for each alloy type, R_{ij}($ per one saleable Kilogram)																					
			Activity Center (j)																		
Resource Type (i)	Alloy type	Alloy Yield%	j =1 = Melting	j = 2 = Line Molding	j = 3 = Shell core	j = 4 = Shake out	j = 5 = Shot blasting	j = 6 = Cutt-off	j = 7 = Grinding	j = 8 = Heat treatment	j = 9 = Machining	j = 10 = Assembly	j = 11 = Painting	j = 12 = Shipping	j = 13 = Sales & Market	j = 14= Labs & QC	j = 15 = Planning	j = 16 = Design/ Tech	j = 17 = Maintenance	j = 18 = Administration	Sub-Total
i = 1 = DL	*Mn-B1*	39	0.064	0.060	0.040	0.001	0.002	0.010	0.001	0.006	0.000	0.042	0.001	0.001	0.011	0.054	0.000	0.023	0.004	0.000	**0.32**
	Mn-C	50	0.050	0.047	0.031	0.000	0.002	0.008	0.000	0.005	0.000	0.000	0.001	0.001	0.009	0.042	0.000	0.018	0.003	0.000	**0.22**
	low alloy	55	0.045	0.042	0.028	0.000	0.002	0.007	0.000	0.004	0.004	0.000	0.001	0.001	0.008	0.038	0.000	0.016	0.003	0.000	**0.20**
	cast iron	65	0.038	0.036	0.024	0.000	0.001	0.006	0.000	0.004	0.004	0.000	0.001	0.001	0.007	0.032	0.000	0.014	0.002	0.000	**0.17**
	High Cr-CI	55	0.045	0.042	0.028	0.000	0.002	0.007	0.000	0.004	0.020	0.000	0.001	0.001	0.008	0.038	0.000	0.016	0.003	0.000	**0.22**
	H.R.SCH13	50	0.050	0.047	0.031	0.000	0.002	0.008	0.000	0.005	0.016	0.000	0.001	0.001	0.009	0.042	0.000	0.018	0.003	0.000	**0.23**
	H.R.SCH22	50	0.050	0.047	0.031	0.000	0.002	0.008	0.000	0.005	0.016	0.000	0.001	0.001	0.009	0.042	0.000	0.018	0.003	0.000	**0.23**
	Ductile Iron	65	0.038	0.036	0.024	0.000	0.001	0.006	0.000	0.004	0.008	0.000	0.001	0.001	0.007	0.032	0.000	0.014	0.002	0.000	**0.17**
	Stainless	50	0.050	0.047	0.031	0.000	0.002	0.008	0.000	0.005	0.014	0.000	0.001	0.001	0.009	0.042	0.000	0.018	0.003	0.000	**0.23**
	Ductile rolls	70	0.035	0.033	0.022	0.000	0.001	0.006	0.000	0.004	0.008	0.000	0.001	0.001	0.006	0.030	0.000	0.013	0.002	0.000	**0.16**
i = 2 = DM	*Mn-B1*	39	0.240	0.020	0.020	0.000	0.000	0.000	0.000	0.000	0.000	2.240	0.000	0.000	0.008	0.000	0.000	0.000	0.051	0.000	**2.58**
	Mn-C	50	0.240	0.020	0.020	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.000	0.000	0.000	0.040	0.000	**0.33**
	low alloy	55	0.240	0.020	0.020	0.000	0.000	0.000	0.000	0.000	0.067	0.000	0.000	0.000	0.005	0.000	0.000	0.000	0.036	0.000	**0.39**
	cast iron	65	0.240	0.020	0.020	0.000	0.000	0.000	0.000	0.000	0.067	0.000	0.000	0.000	0.005	0.000	0.000	0.000	0.031	0.000	**0.38**
	High Cr-CI	55	0.240	0.020	0.020	0.000	0.000	0.000	0.000	0.000	0.335	0.000	0.000	0.000	0.005	0.000	0.000	0.000	0.036	0.000	**0.66**
	H.R.SCH13	50	0.240	0.020	0.020	0.000	0.000	0.000	0.000	0.000	0.268	0.000	0.000	0.000	0.006	0.000	0.000	0.000	0.040	0.000	**0.59**
	H.R.SCH22	50	0.240	0.020	0.020	0.000	0.000	0.000	0.000	0.000	0.268	0.000	0.000	0.000	0.006	0.000	0.000	0.000	0.040	0.000	**0.59**
	Ductile Iron	65	0.240	0.020	0.020	0.000	0.000	0.000	0.000	0.000	0.134	0.000	0.000	0.000	0.005	0.000	0.000	0.000	0.031	0.000	**0.45**
	Stainless	50	0.240	0.020	0.020	0.000	0.000	0.000	0.000	0.000	0.235	0.000	0.000	0.000	0.006	0.000	0.000	0.000	0.040	0.000	**0.56**
	Ductile rolls	70	0.240	0.020	0.020	0.000	0.000	0.000	0.000	0.000	0.134	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.029	0.000	**0.45**
i = 3 = IDM	*Mn-B1*	39	0.077	0.087	0.087	0.000	0.008	0.015	0.003	0.000	0.000	0.000	0.008	0.003	0.004	0.114	0.000	0.002	0.007	0.000	**0.42**
	Mn-C	50	0.060	0.068	0.068	0.000	0.006	0.012	0.003	0.000	0.000	0.000	0.008	0.003	0.003	0.089	0.000	0.002	0.005	0.000	**0.33**
	low alloy	55	0.055	0.062	0.062	0.000	0.005	0.011	0.003	0.000	0.009	0.000	0.008	0.003	0.003	0.081	0.000	0.002	0.005	0.000	**0.31**
	cast iron	65	0.046	0.052	0.052	0.000	0.005	0.009	0.003	0.000	0.009	0.000	0.008	0.003	0.002	0.069	0.000	0.001	0.004	0.000	**0.26**
	High Cr-CI	55	0.055	0.062	0.062	0.000	0.005	0.011	0.003	0.000	0.045	0.000	0.008	0.003	0.003	0.081	0.000	0.002	0.005	0.000	**0.34**
	H.R.SCH13	50	0.060	0.068	0.068	0.000	0.006	0.012	0.003	0.000	0.036	0.000	0.008	0.003	0.003	0.089	0.000	0.002	0.005	0.000	**0.36**
	H.R.SCH22	50	0.060	0.068	0.068	0.000	0.006	0.012	0.003	0.000	0.036	0.000	0.008	0.003	0.003	0.089	0.000	0.002	0.005	0.000	**0.36**
	Ductile Iron	65	0.046	0.052	0.052	0.000	0.005	0.009	0.003	0.000	0.018	0.000	0.008	0.003	0.002	0.069	0.000	0.001	0.004	0.000	**0.27**
	Stainless	50	0.060	0.068	0.068	0.000	0.006	0.012	0.003	0.000	0.032	0.000	0.008	0.003	0.003	0.089	0.000	0.002	0.005	0.000	**0.36**
	Ductile rolls	70	0.043	0.049	0.049	0.000	0.004	0.009	0.003	0.000	0.018	0.000	0.008	0.003	0.002	0.064	0.000	0.001	0.004	0.000	**0.26**
i = 4 = IDL	*Mn-B1*	39	0.060	0.006	0.005	0.000	0.001	0.003	0.000	0.000	0.000	0.013	0.000	0.000	0.000	0.069	0.023	0.030	0.001	0.019	**0.23**
	Mn-C	50	0.047	0.006	0.004	0.000	0.001	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.053	0.018	0.023	0.001	0.015	**0.17**
	low alloy	55	0.043	0.006	0.003	0.000	0.001	0.002	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.049	0.016	0.021	0.001	0.013	**0.16**
	cast iron	65	0.036	0.006	0.003	0.000	0.000	0.002	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.041	0.014	0.018	0.001	0.011	**0.13**
	High Cr-CI	55	0.043	0.006	0.003	0.000	0.001	0.002	0.000	0.000	0.010	0.000	0.000	0.000	0.000	0.049	0.016	0.021	0.001	0.013	**0.17**
	H.R.SCH13	50	0.047	0.006	0.004	0.000	0.001	0.003	0.000	0.000	0.008	0.000	0.000	0.000	0.000	0.053	0.018	0.023	0.001	0.015	**0.18**
	H.R.SCH22	50	0.047	0.006	0.004	0.000	0.001	0.003	0.000	0.000	0.008	0.000	0.000	0.000	0.000	0.053	0.018	0.023	0.001	0.015	**0.18**
	Ductile Iron	65	0.036	0.006	0.003	0.000	0.000	0.002	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.041	0.014	0.018	0.001	0.011	**0.14**
	Stainless	50	0.047	0.006	0.004	0.000	0.001	0.003	0.000	0.000	0.007	0.000	0.000	0.000	0.000	0.053	0.018	0.023	0.001	0.015	**0.18**
	Ductile rolls	70	0.034	0.006	0.003	0.000	0.000	0.002	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.038	0.013	0.017	0.001	0.010	**0.13**
i = 5 = CR	*Mn-B1*	39	0.224	0.206	0.025	0.000	0.010	0.038	0.027	0.048	0.000	0.019	0.003	0.002	0.004	0.019	0.000	0.000	0.071	0.239	**0.93**
	Mn-C	50	0.175	0.161	0.020	0.000	0.008	0.030	0.021	0.037	0.000	0.000	0.002	0.001	0.003	0.015	0.000	0.000	0.056	0.187	**0.71**
	low alloy	55	0.159	0.146	0.018	0.000	0.007	0.027	0.019	0.034	0.010	0.000	0.002	0.001	0.003	0.014	0.000	0.000	0.052	0.170	**0.66**
	cast iron	65	0.134	0.123	0.015	0.000	0.006	0.023	0.016	0.029	0.010	0.000	0.002	0.001	0.003	0.011	0.000	0.000	0.044	0.144	**0.56**
	High Cr-CI	55	0.159	0.146	0.018	0.000	0.007	0.027	0.019	0.034	0.050	0.000	0.002	0.001	0.003	0.014	0.000	0.000	0.052	0.170	**0.70**
	H.R.SCH13	50	0.175	0.161	0.020	0.000	0.008	0.030	0.021	0.037	0.040	0.000	0.002	0.001	0.003	0.015	0.000	0.000	0.056	0.187	**0.75**
	H.R.SCH22	50	0.175	0.161	0.020	0.000	0.008	0.030	0.021	0.037	0.040	0.000	0.002	0.001	0.003	0.015	0.000	0.000	0.056	0.187	**0.75**
	Ductile Iron	65	0.134	0.123	0.015	0.000	0.006	0.023	0.016	0.029	0.020	0.000	0.002	0.001	0.003	0.011	0.000	0.000	0.044	0.144	**0.57**
	Stainless	50	0.175	0.161	0.020	0.000	0.008	0.030	0.021	0.037	0.035	0.000	0.002	0.001	0.003	0.015	0.000	0.000	0.056	0.187	**0.75**
	Ductile rolls	70	0.125	0.115	0.014	0.000	0.006	0.021	0.015	0.027	0.020	0.000	0.001	0.001	0.002	0.011	0.000	0.000	0.041	0.133	**0.53**
i = 6 = Travels	*Mn-B1*	39	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.057	0.000	0.000	0.000	0.000	0.000	**0.06**
	Mn-C	50	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.045	0.000	0.000	0.000	0.000	0.000	**0.04**
	low alloy	55	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.041	0.000	0.000	0.000	0.000	0.000	**0.04**
	cast iron	65	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.034	0.000	0.000	0.000	0.000	0.000	**0.04**
	High Cr-CI	55	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.010	0.000	0.000	0.000	0.041	0.000	0.000	0.000	0.000	0.000	**0.05**
	H.R.SCH13	50	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.008	0.000	0.000	0.000	0.045	0.000	0.000	0.000	0.000	0.000	**0.05**
	H.R.SCH22	50	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.008	0.000	0.000	0.000	0.045	0.000	0.000	0.000	0.000	0.000	**0.05**
	Ductile Iron	65	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.034	0.000	0.000	0.000	0.000	0.000	**0.04**
	Stainless	50	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.007	0.000	0.000	0.000	0.045	0.000	0.000	0.000	0.000	0.000	**0.05**
	Ductile rolls	70	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.032	0.000	0.000	0.000	0.000	0.000	**0.04**
i = 7 = Fees	*Mn-B1*	39	0.013	0.001	0.001	0.000	0.000	0.001	0.000	0.000	0.000	0.003	0.000	0.000	0.010	0.000	0.000	0.000	0.000	0.000	**0.03**
	Mn-C	50	0.010	0.006	0.001	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.007	0.000	0.000	0.000	0.000	0.000	**0.02**
	low alloy	55	0.009	0.006	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.007	0.000	0.000	0.000	0.000	0.000	**0.02**
	cast iron	65	0.008	0.006	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.000	0.000	0.000	0.000	0.000	**0.02**
	High Cr-CI	55	0.009	0.006	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.007	0.000	0.000	0.000	0.000	0.000	**0.02**
	H.R.SCH13	50	0.010	0.006	0.001	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.007	0.000	0.000	0.000	0.000	0.000	**0.02**
	H.R.SCH22	50	0.010	0.006	0.001	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.007	0.000	0.000	0.000	0.000	0.000	**0.02**
	Ductile Iron	65	0.008	0.006	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.000	0.000	0.000	0.000	0.000	**0.02**
	Stainless	50	0.010	0.006	0.001	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.007	0.000	0.000	0.000	0.000	0.000	**0.02**
	Ductile rolls	70	0.007	0.006	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.000	0.000	0.000	0.000	0.000	**0.02**
i = 8 = Supplies	*Mn-B1*	39	0.036	0.003	0.003	0.000	0.000	0.002	0.000	0.001	0.000	0.007	0.000	0.000	0.000	0.002	0.000	0.000	0.005	0.055	**0.12**
	Mn-C	50	0.028	0.002	0.002	0.000	0.000	0.001	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.004	0.043	**0.08**
	low alloy	55	0.026	0.002	0.002	0.000	0.000	0.001	0.000	0.001	0.006	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.003	0.039	**0.08**
	cast iron	65	0.022	0.002	0.002	0.000	0.000	0.001	0.000	0.001	0.006	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.003	0.033	**0.07**
	High Cr-CI	55	0.026	0.002	0.002	0.000	0.000	0.001	0.000	0.001	0.030	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.003	0.039	**0.11**
	H.R.SCH13	50	0.028	0.002	0.002	0.000	0.000	0.001	0.000	0.001	0.240	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.004	0.043	**0.32**
	H.R.SCH22	50	0.028	0.002	0.002	0.000	0.000	0.001	0.000	0.001	0.024	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.004	0.043	**0.11**
	Ductile Iron	65	0.022	0.002	0.002	0.000	0.000	0.001	0.000	0.001	0.012	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.003	0.033	**0.08**
	Stainless	50	0.028	0.002	0.002	0.000	0.000	0.001	0.000	0.001	0.012	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.004	0.043	**0.10**
	Ductile rolls	70	0.020	0.002	0.001	0.000	0.000	0.001	0.000	0.001	0.012	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.003	0.031	**0.07**

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Table 2: Computations of total production cost ($) for a 12 Kg Mn-B1 alloy casting.

Resource cost rate at each activity center (R_{ij}) for Mn-B1 alloy type ($ per one saleable Kilogram)																					
			Activity Center (j)																		
Resource Type (i)	Alloy type	Alloy Yield%	j = 1: Melting	j = 2: Line Molding.	j = 3: Shell core	j = 4: Shake out	j = 5: Shot blasting	j = 6: Cutt-off	j = 7: Grinding	j = 8: Heat treatment	j = 9: Machining.	j = 10: Assembly	j = 11: Painting	j = 12: Shipping	j = 13: Sales & Market	j = 14: Labs & QC	j = 15: Planning	j = 16: Design=tech	j = 17: Maintenance	j = 18: Administration	**Sub-Total**
DL	Mn-B1	39	0.064	0.060	0.040	0.001	0.002	0.010	0.001	0.006	0.000	0.042	0.001	0.001	0.011	0.054	0.000	0.023	0.004	0.000	**0.32**
DM	Mn-B1	39	0.240	0.020	0.020	0.000	0.000	0.000	0.000	0.000	0.000	2.240	0.000	0.000	0.008	0.000	0.000	0.000	0.051	0.000	**2.58**
IDM	Mn-B1	39	0.077	0.087	0.087	0.000	0.008	0.015	0.003	0.000	0.000	0.000	0.008	0.003	0.004	0.114	0.000	0.002	0.007	0.000	**0.42**
IDL	Mn-B1	39	0.060	0.006	0.005	0.000	0.001	0.003	0.000	0.000	0.000	0.013	0.000	0.000	0.000	0.069	0.023	0.030	0.001	0.019	**0.23**
CR	Mn-B1	39	0.224	0.206	0.025	0.000	0.010	0.038	0.027	0.048	0.000	0.019	0.003	0.002	0.004	0.019	0.000	0.000	0.071	0.239	**0.93**
Travels	Mn-B1	39	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.057	0.000	0.000	0.000	0.000	0.000	**0.06**
Fees	Mn-B1	39	0.013	0.001	0.001	0.000	0.000	0.001	0.000	0.000	0.000	0.003	0.000	0.000	0.010	0.000	0.000	0.000	0.000	0.000	**0.03**
Supplies	Mn-B1	39	0.036	0.003	0.003	0.000	0.000	0.002	0.000	0.001	0.000	0.007	0.000	0.000	0.000	0.002	0.000	0.000	0.005	0.055	**0.12**
																				Total cost ($/Kilogram) =	**4.6779**
						For a casting of wieght, W = 12 Kg														**Total Production Cost, TC($) =**	**56**

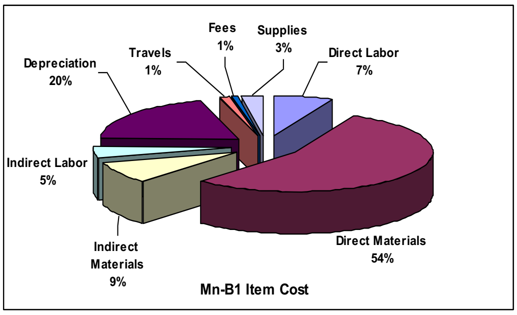

Figure 6: Division of the contributing costs of Mn-B1 Item cost.

5. Traditional Calculation of Total Cost

The following notation is used to describe the mathematical expressions built to calculate the total product cost based on TCA:

W	Saleable weight of a product *(Kg)*
MC	Total manufacturing related cost *($/Kg)*
NMC	Total non-manufacturing related cost ($/Kg)
PC	Production (casting) cost of a product of one Kilogram weight ($/Kg)
DM	Direct material cost for a product of one Kilogram weight ($/Kg)
DL	Direct labor cost for a product of one Kilogram weight ($/Kg)
IDM	Indirect material cost for a product of one Kilogram weight ($/Kg)
MP	Monthly production (Kg)
IDL	Indirect labor cost for one month of production ($/Month)
IDL2	Indirect management cost for one month ($/Month)
CRF	Monthly depreciation cost of foundry equipments ($/Month)
CRA	Monthly depreciation cost of administration facilities ($/Month)
MS	Maintenance cost for one month of production ($/Month)
SC	Selling cost for one month of production ($/Month)
QC	Laboratories and QC cost for one month of production ($/Month)
MOC	Manufacturing overhead cost for one month of production ($/Month)
Supplies	Electricity, oil, diesel, water, and other material cost consumed by administration during a one month of production ($/Month).
Engineering	Engineering cost for one month of production ($/Month).
Technology	Technology and design cost for one month of production ($/Month).
Plan	Planning cost for one month of production ($/Month)
Travels	Transportation and traveling cost for one month ($/Month)

$$TC = MC + NMC \tag{2}$$

$$MC = PC + MOC \tag{3}$$

$$PC = DM + DL \tag{4}$$

$$\mathrm{MOC} = \mathrm{IDM} + \mathrm{IDL} + \mathrm{CRF} + \mathrm{QC} + \mathrm{Supplies} \tag{5}$$

$$\mathrm{IDL} = \mathrm{Engineering} + \mathrm{Technology} + \mathrm{Planning} \tag{6}$$

$$NMC = ADC + SC \tag{7}$$

$$\mathrm{ADC} = \mathrm{IDL2} + \mathrm{SUP} + \mathrm{CRA} + \mathrm{Travels} \tag{8}$$

5.1. TCA cost rates:

Total production cost is split into two categories: manufacturing related and non-manufacturing related cost. Manufacturing related costs include the cost of operating processes on several work centers that relate directly to the produced products like melting cost, molding cost, and core making cost, shake out cost, and others as shown in table 3.

Manufacturing related costs rates are derived and presented in table 3, these TCA rates are measured as follows: direct labor (DL) is measured by $ per month, depreciation in $, and the rest of the rates are measured by $ per oneKilogram of Saleable Castings ($/Kg).

Table 3: Manufacturing related TCA Cost rates at each work center for each alloy type. Measuring unit is $/Kg except where indicated.

Cost Element	Casting alloy type	Yeild %	TCA Costs Rate in Each Work Center for Each Casting Type									
			Melting	Molding	Core	shake	shot	Fettling and H.T			Track	paint
				Line	Shell	out	blast	Cutt	Grind	H.T.	Asmb.	shipp
DL $/Month	All Casting	52	2786	4357.00		2800						
(DM)	Mn-B1	39	0.240								2.24	
	Mn-C	50	0.240									
	low alloy	55	0.210									
	cast iron	65	0.150									
	High Cr-CI	55	0.400	0.02		0.00						
	H.R.SCH13	50	2.000									
	H.R.SCH22	50	2.500									
	Ductile Iron	65	0.450									
	Stainless	50	1.800									
	Ductile rolls	70	0.600									
(IDM)	Mn-B1	39	0.077	0.087	0.087		0.008	0.015	0.0034			0.011
	Mn-C	50	0.060	0.068	0.068		0.006	0.012	0.0034			0.011
	low alloy	55	0.055	0.062	0.062		0.005	0.011	0.0034			0.011
	cast iron	65	0.046	0.052	0.052		0.005	0.009	0.0034			0.011
	High Cr-CI	55	0.055	0.062	0.062	0.000	0.005	0.011	0.0034	0.00		0.011
	H.R.SCH13	50	0.060	0.068	0.068		0.006	0.012	0.0034			0.011
	H.R.SCH22	50	0.060	0.068	0.068		0.006	0.012	0.0034			0.011
	Ductile Iron	65	0.046	0.052	0.052		0.005	0.009	0.0034			0.011
	Stainless	50	0.060	0.068	0.068		0.006	0.012	0.0034			0.011
	Ductile rolls	70	0.043	0.049	0.049		0.004	0.009	0.0034			0.011
Supplies	Mn-B1	39	0.277									
	Mn-C	50	0.216									
	low alloy	55	0.196									
	cast iron	65	0.166									
Electricity	High Cr-CI	55	0.196									
Water	H.R.SCH13	50	0.216									
Diesel	H.R.SCH22	50	0.216									
	Ductile Iron	65	0.166									
	Stainless	50	0.216									
	Ductile rolls	70	0.154									
(CRF) $/Month	All Casting		117520	108036	13241	0.000	5491	33952		24976	9730	2329
Engineering			3975 $/Month									
Technology			2472 $/Month									
Planning			1049$/Month									
QC			20348 $/Month									
(PMS)			85018 $/ Year									

Non-manufacturing related operations directly relate to the administration unit of the foundry and non-engineering operations like selling cost, general expenses cost, and salaries, for the general administration. TCA cost rate of these non-manufacturing related operations is also analyzed and categorized as indicated in table 4. Total administration salaries are 9813 $/Month. And over all expenses that included supplies, capital recovery, travels and other fees and auditing cost is 154397 $/Month. Selling cost SC is also computed, SC is equal to 20038 $/Month. This amount represents salaries of salesmen and representatives, and all other selling expenses.

TCA rates in table 3 and table 4 are presented in different cost unit, for example direct labor is presented by $ per month, and direct material is presented by $ per kilogram of saleable casting, where as the depreciation cost is presented by $ per year. To compute and derive a reasonable and accurate cost value for any product the units must be consistence. The best unit consistency is found when the monthly production is estimated.

Table 4: Non-Manufacturing related TCA Cost rates.

ADC				SC
Salaries of IDL2 $/Month	Supplies $/Year	Travels $/Year	CRA $/Year	Salaries $/Month
9813	28833	17888	125564	2195
Total $/ Month		24170		2195

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5.2. TCA Calculations:

The complete cost figures of the products of any alloy type under TCA are given table 5. Consider again the product that is made from Mn-B1alloy type. The total production cost of this item under TCA is $32, see table 6. this cost value covers direct and indirect material cost, direct labor cost, cost of supplies, depreciation cost, engineering cost, technology cost, planning cost, QC cost, maintenance cost, administration cost and sales cost. The allocation of cost to the considered casting from all cost elements associated with its production is shown in figure 7.

Table 5: Complete cost under TCA in $/Kg.

Cost Element	Alloy Type	Yeild (%)	Complete Cost figure $/Kg Saleable casting
(DL)	All Casting	52	0.17
(DM)	Mn-B1	39	0.32
	Mn-C	50	0.32
	low alloy	55	0.29
	cast iron	65	0.23
	High Cr-CI	55	0.48
	H.R.SCH13	50	2.08
	H.R.SCH22	50	2.58
	Ductile Iron	65	0.53
	Stainless	50	1.88
	Ductile rolls	70	0.68
(IDM)	Mn-B1	39	0.45
	Mn-C	50	0.35
	low alloy	55	0.32
	cast iron	65	0.27
	High Cr-CI	55	0.32
	H.R.SCH13	50	0.35
	H.R.SCH22	50	0.35
	Ductile Iron	65	0.27
	Stainless	50	0.35
	Ductile rolls	70	0.25
Supplies Elictricity Water Diesel	Mn-B1	39	0.28
	Mn-C	50	0.22
	low alloy	55	0.20
	cast iron	65	0.17
	High Cr-CI	55	0.20
	H.R.SCH13	50	0.22
	H.R.SCH22	50	0.22
	Ductile Iron	65	0.17
	Stainless	50	0.22
	Ductile rolls	70	0.15
(CRF)	All Casting		0.40
Engineering			0.07
Technology			0.04
Planning			0.02
(QC)			0.34
(MS)			0.12
ADC	All Casting		0.38
SC			0.06

Table 6: Cost calculation under TCA of an item of 12 Kg made from Mn-B1 Alloy.

Cost Element	Alloy Type	Yeild (%)	Complete Cost figure $/Kg Saleable casting
Direct Labor	All Casting	52	0.17
Direct materials	Mn-B1	39	0.32
Indirect Materials	Mn-B1	39	0.45
Supplies	Mn-B1	39	0.28
Depreciation	All Casting	52	0.40
Engineering		52	0.07
Technology		52	0.04
Planning		52	0.02
Quality Control		52	0.34
Maintenance		52	0.12
Adminstartion	All Casting	52	0.38
Selling		52	0.06
Production cost ($/Kilogram) =			2.63
For a casting of wieght,W, in Kg =			12
Total Production Cost, TC($) =			32

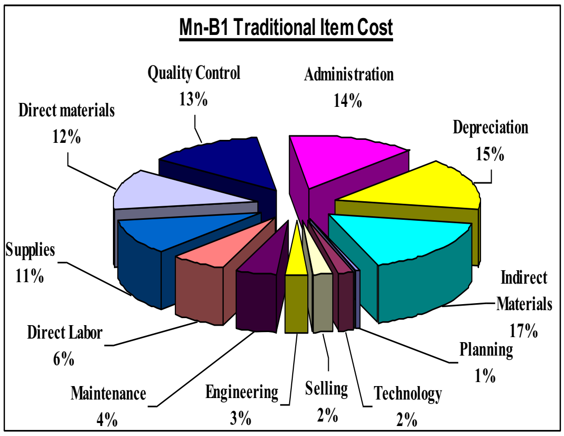

Figure: 7: Division of the contributing costs of Mn-B1 item cost under TCA.

6. Discussion and Concluding Remarks

A comparison of producing the different alloy types under variant production rate is carried out based on ABC and TCA, the comparison as shown in figure 8, indicates that, the target of the company should be to produce 2800 ton of saleable casting per one year in two shifts with the full designed capacity. This logical result has been concluded based on both TCA and ABC as shown by figure 8 and figure 9 respectively. For any alloy type the production cost under a production rate of 2800 tons per year per 2 shafts is smaller than the production cost under a production rate of 1400 tons per year per 1 shaft as will as a production rate of 700 tons per year per 1 shaft.

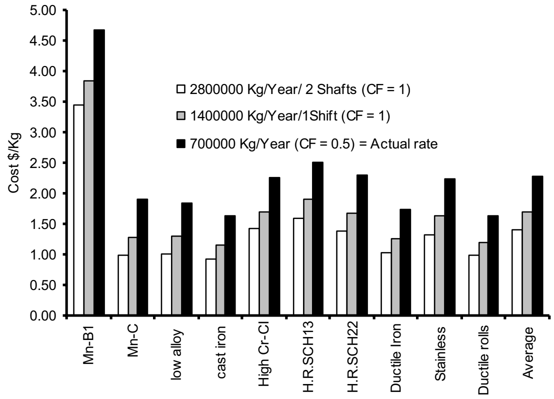

Figure 8: A comparison of cost of different alloy types under variant production rate based on ABC.

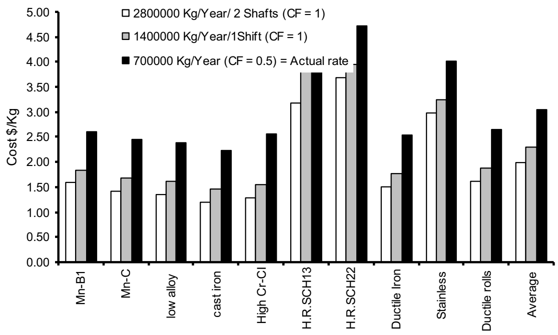

Figure 9: A comparison of cost of different alloy under variant production rate based on TCA.

Based on ABC, the most expensive alloy in all scenarios is Mn-B1 that accurately reflects the cost of the assembly center, while the cheapest alloy is the cast iron alloy. Based on TCA, the most expensive alloy in all scenarios is H.R.SCH22 alloy, while the cheapest one is cast iron alloy. One advantage for ABC over TCA is that ABC can be used as a continuous improvement tool for internal cost reduction; ABC results can provide quantitative figures to determine the cost effectiveness of the foundry and to justify strategic production policies. It can be used to investigate the effectiveness of consuming the available resources by every activity center independently. These advantages relate to the way the costing process is assessed and the improved visibility of cost items. ABC improves the visibility of costs and shows how costs are passed down to products by activities as depicted by figure 10, which shows the allocation of cost as a percentage to a stainless steel casting from all available resources areas associated with every activity center.

The process of allocating cost from resources to activities is a second benefit of ABC. By understanding the hierarchy of costs and the way products consume the lower cost items, the visibility of overhead cost is improved. Under TCA, the attention of management would be drawn only to the higher cost elements, which in this case as shown in figure 11, are the direct and direct materials, capital recovery, supplies and quality cost.

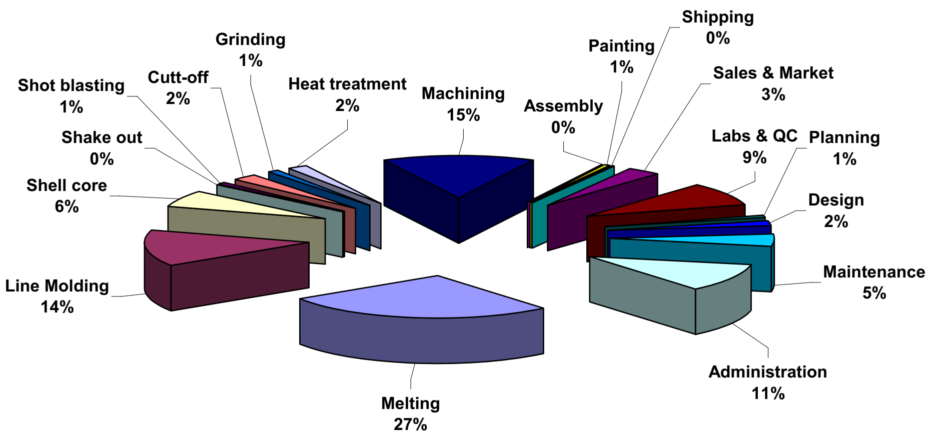

Figure 10: Resources consumption % by activity centers under ABC for stainless steel.

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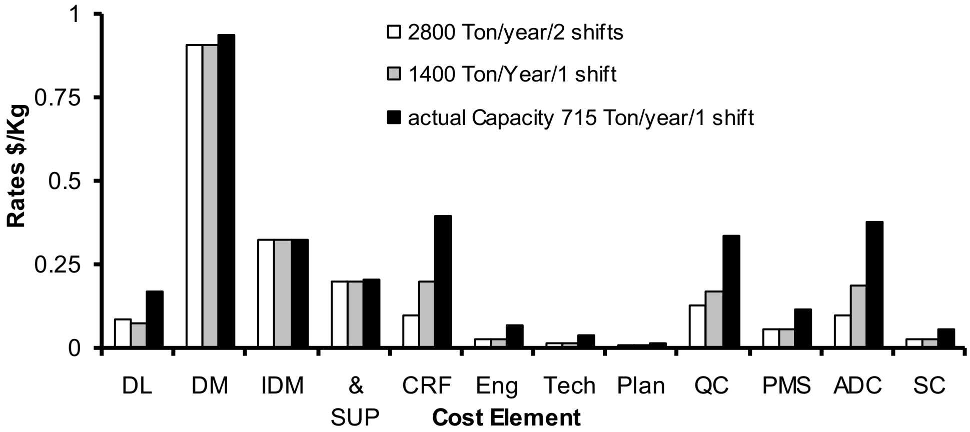

Figure 11: Cost rates for every cost element under different production scenarios based on TCA.

Figure 7 as well as figure 6 show that the most important cost parameters are direct material, indirect material, quality cost and capital recovery. The final production cost is highly sensitive to such highlighted parameters. For model verification purposes, the proposed costing model has been implemented on a local big foundry, and then results are compared to that obtained using the traditional costing model. It has been concluded that the analysis and the methodology followed in this work is valuable for many foundries and expected to be used as a tool for accurate cost analysis for strategic production decision.. As seen ABC has been developed considering current foundry practices, and therefore is amore credible costing system, since it traces cost from resources according to the way they are consumed by castings, rather than by some arbitrary basis.

ABC calculation also implies that the dynamic cost of components whenever they pass from one resource centre to another can be calculated. This also gives the cost of WIP or finished casting at any stage of the production process at any time. ABC improves the costing systems of organizations but also has some limitations such as: high measurement costs that are required for its operation. As the number of activities involved in the production process increases, the cost of gathering data for ABC system becomes higher. Also it is more difficult to gather activity data in service companies, since so many of the activities tend to involve human tasks that cannot be automatically recorded. A study that included a sufficient analysis to each one of such important cost parameters recommended to be carried out as a future work.

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Perspectives in Reverse Supply Chain Management(R-SCM): A State of the Art Literature Review

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Abstract

Environmental and economic issues have significant impacts on reverse supply chain management and are thought to form one of the developmental cornerstones of sustainable supply chains. Perusal of the literature shows that a broad frame of reference for reverse supply chain management is not adequately developed. Recent, although limited, research has begun to identify that these sustainable supply chain practices, which include the reverse logistics factors, lead to more integrated supply chains, which ultimately can lead to improved economic performance. The objectives of this paper are to: report and review various perspectives on design and development of reverse SC, planning and control issues, coordination issues, product remanufacturing and recovery strategies, understand and appreciate various mechanisms available for efficient management of reverse supply chains and identify the gaps existing in the literature. Ample opportunities exist for the growth of this field due to its multi-functional and interdisciplinary focus. It also is critical for organizations to consider from both an economic and environmental perspective. The characteristics of RSCM provided here can help the researchers/practitioners to advance their work in the future.

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Keywords: Reverse supply chain management; Remanufacturing; Recycling; Reverse logistics

1. Introduction

Reverse logistics, which is the management or return flow due to product recovery, goods return, or overstock, form a closed-loop supply chain. The success of the closed-loop supply chain depends on actions of both manufacturers and customers. Now, manufacturers require producing products which are easy for disassembly, reuse and remanufacturing owing to the law of environmental protection. On the other hand, the number of customers supporting environmental protection by delivering their used products to collection points is increasing [1]. According to the findings, the total cost spent in reverse logistics is huge. In order to minimize the total reverse logistics cost and high utilization rate of collection points, selecting appropriate locations for collection points is critical issues in RSC/reverse logistics. Reverse logistics receive increasing attention from both the academic world and industries in recent years. There are a number of reasons for its attention. According to the findings of Rogers and Tibben-Lembke (1998), the total logistics cost amounted to $862 billion in 1997 and the total cost spent in reverse logistics is enormous that amounted to approximately $35 billion which is around 4% of the total logistics cost in the same year. The concerns about energy saving, green legislation and the rise of electronic retaining are increasing. Also, the emergence of e-bay advocates product reuse. Online shoppers typically return items such as papers, aluminum cans, and plastic bottles whose consumption and return rates are high. Although most companies realize that the total processing cost of returned products is higher than the total manufacturing cost, it is found that strategic collections of returned products can lead to repetitive purchases and reduce the risk of fluctuating the material demand and cost.

Research on reverse supply chain has been growing since the Sixties and research on strategies and models on RL can be seen in the publications in and after the Eighties. However, efforts to synthesize the research in an integrated broad-based body of knowledge have been limited [9]. Most research focuses only on a small area of RL systems, such as network design, production planning or environmental issues. Fleischmann et al. [2] studied RL from the perspectives of distribution planning, inventory control and production planning. Carter and Ellram [3] focused on the transportation and packaging, purchasing and environmental aspects in their review of RL literature. Linton et al. [4] studied the interactions between sustainability and supply chains by considering environmental issues regarding product design, product life extension and product recovery at end-of-life. Realff et al. [5] have also reviewed the literature on RL published between 1995 and 2005 by focusing on management of the recovery, distribution of end-of-life products, production planning and inventory management, and supply chain management issues. To consider the stock of the past

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research, Fleischmann et al. [6] and Fleischmann [7] their literature review suggested seven opportunities for further research. First, they proposed the use of closed-loop network design and the integration of facilities between forward and backward flow. Second, they suggested including more comprehensive facility location models to examine the impact of uncertainty on reverse logistics network design via scenario and parametric analysis. Third, they suggested the development of stochastic model for reverse logistics network on real time basis. Fourth, they recommended the assessment of the impact of product recovery network on transportation. Fifth, they also suggested the analysis of multi-agent characters in a reverse logistics network by revealing the underlying incentives of collectors, intermediaries and processors. Sixth, they proposed to investigate the impact of inventory management techniques such as risk-pooling and postponement on reverse logistics network design. Finally, they suggested investigating the impact of global supply chain issues such as taxation and cross-border waste transportation on the design of product recovery network. The need for more complex objective functions; reverse logistics network and robust stochastic models have also been suggested in the literature by many authors.

The review presented in this paper extends the review to consider important features of reverse logistics such as product acquisition, pricing, collection of used products, RL network structure vis-à-vis the integration of manufacturing, and remanufacturing facilities of location of facilities for inspection and consolidation activity. The literature review covers published research until 2009. A further literature review of the recent research papers focuses mainly on reverse logistics design will provide an overview of the overall progress of the research and identify further research opportunities. The main objective of this paper is to review literature addressing various issues related to reverse logistics/closed loop supply chain during the period 1990-2009 and then to identify future research opportunities. This paper specifically identifies and reviews papers which addressed the research opportunities suggested by Fleischmann et al. [6] and [7]. Chanintrakul et al, [8] and Pokharel and Mutha [9]. Altogether we found more than 100 papers published during the period 1990-2009. For each paper we identify the applied modeling method and assumptions, i.e., time period, commodity-product flow, network level, open or close-loop structure, objective function, uncertainty type and other model constraints. With this systematic approach we are able to review the progress and contribution of the recent research papers and identify new issues for further research. The rest of the paper is organized as follows. In the next section research methodology is discussed. In Section 3 on ward, the results of review are presented section wise with research directions for the future research. Each section is divided further into subsections to highlight various factors that are important to this research. The paper ends with conclusions and some thoughts on further research.

2. Review Methodology

We have adopted content analysis method for literature review [9]. Content analysis is an observational research method that is used to systematically evaluate the symbolic content of all forms of recorded communication. This method also helps to identify the literature in terms of various, thereby creating a realm of research opportunities. Al-Mashari and Zairi [10] used content analysis to analyze the implementation of SAP R/3 for re-engineering the supply chain using enterprise resource systems. Gallivan [11] adopted content analysis methodology to examine case studies of open source software projects in the research on balance between trust and control in a virtual organization. Content analysis was also used by Byrd and Davidson [12] to examine the impact of information technology on supply chain; and by Ellinger et al. [13] in their research on the transportation industry in the US. Recently, Marasco [14] also used a similar method for review of literature on third party logistics. The review is limited to the published literature including white papers and literature obtained from electronic sources. Search engines were used to explore Science Direct, Emerald Insight, Springer and Inderscience databases for literature. Keywords such as 'green supply chain', 'product returns', 'product recovery', 'reverse logistics', 'end-of-life products', 'closed-loop supply chains', 'recycling', 'remanufacturing' were used to find related literature. The publications were found in the areas of logistics management, production and operations management and business logistics. The references cited in each relevant literature were examined to find out additional sources of information. In this research, 7 reports and 113 journal publications have been reviewed.

3. Research on Reverse Supply Chain Network Design

Recently, a considerable number of case studies have been reported which address the reverse supply chain network design in the product recovery and remanufacturing context. Table 1 is given in appendix 1 and table 1 summarizes the papers related to design of reverse supply chain networks and relevant issues and a details of abbreviation used in the table 1 are given in table 2. Several researchers have studied the design of RL network focusing on their cost effectiveness. Studies have concluded that for recycling of the returned products, logistics costs account for a large share of the total costs [15]. RL requires high investment and a high portion of logistics costs. The RL cost can vary from 4% (Rogers, 2001) to 9.49% [15-16] of the total logistics cost. In the retail and manufacturing sectors, it is estimated that RL accounts for about 5–6% of the total logistics cost. Transportation of used products is the most challenging issue in RL as smaller return quantities and variability in product types Increase the transportation costs. Biehl, Prater, and Realff [18] emphasize on the need for collection centers in a reverse production system to help in maximizing collection of returned products. Reimer, Sodhi, and Jayaraman [19] have developed truck sizing models for collection of wastes and transporting them to recovery centers. Min, Ko, and Ko [20] have developed a mixed integer non-linear programming model to determine the exact length of holding time for spatial and temporal consolidation at the initial collection points to minimize the total RL costs.

A review on various quantitative models for RL networks is given by Fleischmann et al. [21]. The location of collection points in a RL system has been examined by Bloemhof-Ruwaard, Fleischmann, and van Nunen [22]. Fleischmann, Beullens, Bloemhof-Ruwaard, and van Wassenhove [23] have presented a generic MILP model considering a single product flow between incapacitated facilities and reprocessing as a product-recovery option.

Table 3: Literature Based on Various Issues of RL Design.

Contents	Literature
Modeling of uncertainty	Pati et al. (2008) (Shih, 2001; Krikke et al., 2003). (Fleischmann et al., 2001), (Shih, 2001), refrigerator (Krikke et al., 2003), (Schultmann et al., 2003), LPG-tanks (le Blanc et al., 2004), (Salema et al., 2006), (Salema et al., 2007), (Pati et al., 2008), carpet recycling (Realff et al., 2000, 2004), Krikke et al. (2003), Du and Evans (2008) (Srivastava, 2008), (Lee and Dong, 2008).
Reverse supply chain network with stochastic model	Pohlen and Farris (1992), Kolbin (1977), (Listes, 2002, 2007) (Listes and Dekker, 2005), Wojanowski, Verter, and Boyaci (2007), Gupta, and Kamarthi (2004)
Impact of transportation on RL design	Ferrer & Whybark, 2000, Nagurney and Toyasaki, 2005; Chen et al., 2007, Hammond and Beullens, 2007. (Min et al., 2006a), (Min et al., 2006b) (Min and Ko, 2008). De Brito and Dekker (2004, Nagurney and Toyasaki (2005), Chen et al. (2007), Hammond and Beullens (2007)
Simulation model for RSC	Frank et. Al.(2006), Kara et al. (2007), Biehl et al. (2007)

Jayaraman, Patterson, and Rolland [24] have proposed a MILP model by considering the reverse flow of goods. Pochampally, Gupta, and Kamarthi [25] have proposed a physical programming approach to identify potential recovery facilities in a region where reverse supply chain is to be established. Savaskan, Bhattacharya, and van Wassenhove (2004) have proposed a product-recovery strategy depending on who collects the used products.

Table 2: Abbreviation.

S.No.	Parameters	Abbreviation
1.	Model	SIM=Simulation ,LP = linear programming model, MILP = mixed integer linear programming model, MINLP = mixed integer non-linear programming model, NE = network equilibrium model, ST = stochastic model, SM = simulation model, OT = other models)
2.	Solution method	GA=Genetic Algorithum,EX = exact solution method, HE = heuristics method, MHE=Multi-heuristics method
3.	Period	S = single-period, M = multi-period
4.	Product commodity	S = single, M = multiple
5.	Levels	S = single, T = two, M = multiple
6.	Recovery Option:	S = single recovery option, M = multiple recovery options
7.	Issue	MI=Multiple Issues SI=Single Issue
8.	Constraints	MC=multi-Constraints ,SC=Single Constraint
9.	Network structure	(OL = open-loop, CL = closed-loop)
10.	Model objectives	S = single, M = multiple, CM = cost minimisation,PM = profit maximization, RM = risk minimization, OT = others such as environmental impact minimization, total tardiness of cycle time minimization, etc.

namely the manufacturer; the retailer; or a designated third party. The findings suggest that optimal results are achieved when the retailer collects the returned products. However, the authors consider the flow of goods in only a two echelon system i.e. retailer and manufacturer. De Koster, de Brito, and van de Vendel [26] have investigated the factors contributing to RL network decisions by considering inbound and outbound flows, the transport routes, the return volume, choice of receiving warehouse and the market location for returned products. The authors recommend that retailers that supply to stores should collect the returned material to the distribution centre using the same truck which delivered the products. Also, retailers that handle a high volume of returns should unload and sort returns in a separate area in the distribution centre.

Lu and Bostel [27] have also developed an incapacitated model for RL. Pohlen and Farris [28] have investigated the reverse distribution channel structure in plastics recycling and analyzed the compaction and routing issues related to transportation in the RL process. Spengler, Puchert, Penkuhn, and Rentz [29] have developed a model based on linear activity analysis to determine locations and capacities of recycling facilities for reprocessing byproducts of steel industries. Barros, Dekker, and Scholten [30] have proposed a logistics network for recycling of polluted sand by using MILP to determine the optimum number, capacities, and locations of the depots and cleaning facilities in the network. Louwers, Kip, Peters, Souren, and Flapper [31] have proposed a RL network model to determine appropriate locations and capacities for collection, preprocessing and redistribution facilities of carpet wastes. Realff, Ammons, and Newton [32] have proposed a multi-period MILP model for carpet recycling. Their model analyzes a set of alternative scenarios identified by the decision maker and provides a near optimal solution for network design. Schultmann, Zumkeller, and Rentz [33] have developed a recycling network for the German automotive industry by minimizing the travel routes between dismantling centres and reprocessing facilities. The authors solve their network model by using linear programming and meta-heuristics methods. Beamon and Fernandes [34] have developed an integer programming model for a four echelon reverse supply chain by assuming infinite storage capacities and same holding costs for recovered and new products. The authors assume that the remanufactured products are of the same quality as that of the new products. Therefore remanufactured products can be sold in the same condition as new ones to meet the market demand. Kusumastuti, Piplani, and Lim [35] have presented a multi-objective and multi-period MILP model for RL network design for modularized products. The model determines the number of existing forward flow facilities to be used and the number of dedicated facilities to be setup for handling return flows. The authors have not considered the use of new modules in remanufactured products. Salema, Povoa, and Novais [36] have proposed a MILP model to analyze the problem of closed loop supply chains. They consider multi-product returns with uncertain behavior but limit their consideration of demand for returned products to factories and not to secondary markets or spare markets. Thus a supplier network which may be required to remanufacture a new product to meet the market demand is not considered. Also, this model is not suitable for modular products.

Wojanowski, Verter, and Boyaci [37] have developed a stochastic model to analyze the network structure for product returns under a refundable-deposit scheme. They show that the success of the profitability of the network depends on the accessibility of the customers to the collection centers. Zhou, Naim, and Wang [38] analyzed the battery recycling practices in China and identified its obstacles and weaknesses. They recommend legislative actions, technical guidance and administrative resources, and cost-effective recycling and RL infrastructure to improve the system. Kroon and Vrijens [39] have considered the design of a logistics system for used plastic containers. They propose a MILP model to determine the number of containers required to run a five echelon system under consideration, the appropriate service, and distribution and collection fee per shipment for empty containers and location of depots for empty containers. Berger and Debaillie [40] have proposed a model for extending a production/distribution network with disassembly centers to allow the recovery of used products. The authors consider each plant and distribution centers with fixed locations and capacities, but determine the location and capacity of the disassembly centers based on a multi-level capacitated MILP model.

Few researchers discussed the aspect of supply planning in RL considering modular structure of products and address the problem of scheduling supplies of new modules from suppliers to meet the demand after a certain recovery of modules from the returned products. The authors present a MILP model for maximizing the cost savings by optimally deciding which quantity of products/ modules are to be refurbished and which are to be outsourced from the suppliers. Min, Ko, and Ko [41] have proposed a single objective, nonlinear, mixed integer programming model to provide a minimum cost solution for network design of product-recovery systems. Their proposed model considers trade-offs between freight rate discounts and inventory cost savings due to consolidation and transshipment. The authors perform sensitivity analysis on the holding period to determine the optimal length of holding time for consolidation and the collection centers. The model indicates that as the maximum holding period increases the RL costs decreases, but the overall network structure remains stable. The authors noticed dramatic cost saving in total RL costs after setting the maximum holding period at three days. Research is also done in areas of product disassembly planning (Guide, Jayaraman, & Srivastava, 1999; Gungor & Gupta, 1998; Lambert, 2002; Mok, Kim, & Moon, 1998), vehicle routing and planning in reverse logistics (Alshamrani, Mathur, & Ballou, 2007; Dethloff, 2001) and the pricing of a ‘‘remanufactured” product (Heese, Cattani, Ferrer, Gilland, & Roth, 2005).

Teunter, Van der Laan, and Inderfurth [42] have compared the performances of different methods for setting the holding cost rates in average cost inventory models with reverse logistics. Jayaraman et al. [43] have also proposed a model for location of remanufacturing and distribution facilities by optimizing the quantities for remanufacturing, transshipment and stocking. Pati, Vrat, and Kumar [44] have formulated a mixed integer goal programming model for analyzing paper recycling network. The model assumes five echelons and studies the inter-relationship between cost reduction, product quality improvement through increased segregation at the source, and environmental benefits through waste paper recovery. The model also assists in determining the facility location, and route and flow of different varieties of recyclable wastes. Shih [45] have proposed a MILP model to determine the optimal collection and recycling system for end-of-life computers and home appliances. The model helps to determine the location for storage and treatment facilities. Walther and Spengler [45] have developed a model for the treatment of electrical and electronic wastes in Germany. This model optimizes the allocation of discarded products, disassembly activities and disassembly fractions to participants of the treatment system. Ravi, Ravi, and Tiwari [46] presented an ANP based decision model to analyze the options in RL for end-of-life computers and link them to the determinants, dimensions and enablers of RL. Kara, Rugrungruang, and Kaebernick [47] have modeled the collection of end-of-life electrical appliances with high degree of uncertainty in quality and quantity of the returned products. The authors suggest that low costs can be achieved when local councils act as collectors. Fernandez and Kekale [48] have studied the implications of modular product architecture on RL strategies. They discuss that modular structure of a product affects the decision making in terms of destination for returned products or its modules. Krikke, van Harten, and

Schuur [49] analyzed a RL network for photocopiers with a fixed supplying processes and disassembly. The authors propose a MILP model to determine optimal locations for the preparation and reassembly operations. The modular nature of computer monitors is considered in RL by Krikke, van Harten, and Schuur [50] to find a profit-optimal product recovery and disposal strategy for each of the six types of monitors considered in the study. Their strategy includes options of partial disassembly, mixed and separate recycling. Frank, Basdere, Ciupek, and Seliger [51] have developed an optimization model for planning of capacities and production programs for remanufacturing of mobile phones. Their model considers modular nature of the product and considers reuse; component retrieval; material recycling; and disposal as the four possible options for recovery of products or its modules. The authors have also included an external procurement activity (suppliers) to satisfy the market demand. The process capacities and the remanufacturing program are determined by the optimization model. They have developed a simulation model to help in determining the required transport and storage capacities, and the performance of the remanufacturing system.

3.1. Contributions, Applications and Limitations:

After investigating more than 50 papers the review shows that the design of RL network is an important research problem as the circumstances leading to the model development could be unique. The research emphasizes on the reduction of RL costs through the choice of locations and capacities. The research also shows that remanufacturing of products and their sale in secondary markets are important considerations being studied for different types of returned products. While some researchers have focused mainly of used products only, others have recognized that used products do contain modules with different qualities. Kusumastuti et al. [35] and Franke et al. [51] have considered modular architecture of the returned products for remanufacturing operations. While Franke et al. [51] have considered new module suppliers for the remanufacturing of new products; Kusumastuti et al. [35] have considered multi-product configurations of returned products. In table 3 papers related to parameters investigation on reverse logistics has been listed.

3.1.1. Modeling of Uncertainty:

Furthermore, several authors began to investigate the impact of uncertainty on reverse logistics network design for large-scale problems solved by robust MILP models with exact algorithms, decomposition algorithms and heuristics algorithms and large-scale and dynamic problems solved by MINLP model with heuristics algorithms. Notably, Kirk et al. [49], Du and Evans [51] and Patti et al. [44] have started to investigate multi-objective MILP models. In addition, two papers have begun to take environmental regulation and technological issues into account. Furthermore, many of the proposed models were applied in different industrial and product sectors, i.e., copier remanufacturing and paper recycling [52], end-of-life home appliances and computer (Shih, 2001), refrigerator (Krikke et al., 2003), spent batteries (Schultmann et al., 2003), LPG-tanks (le Blanc et al., 2004), copier remanufacturing (Salema et al., 2006), office document company (Salema et al., 2007), paper recycling[44], carpet recycling (Realff et al., 2000, 2004), home appliances, computer, mobile phone and car (Srivastava, 2008), and end-of-lease computer products [1].

3.1.2. Modeling of Dynamic systems:

There are very few papers which use stochastic models to solve reverse logistics network design problems. Theoretically, a stochastic model is more flexible in dealing with uncertainty compared with an MINLP model via sensitivity and parametric analysis. However, Kolbin [53] argued that a stochastic model has a number of disadvantages including unstable outputs due to random values of parameters, huge computational effort and computational intractability. This may explain why we found only three papers which established comprehensive models to cope with return and demand uncertainty in terms of quantity. These models assumed a single-commodity flow and two-level reverse logistics network. The proposed models were further applied for electronic equipment remanufacturing industry [54-55] and sand (from demolition waste) recycling industry [56].

3.1.3. Impact of Transportation on Product Recovery:

Though there are only three papers, they laid the foundations for the research of the impact of the transportation issues in terms of consolidation and channel selection decisions (direct and indirect shipment). Particularly, the proposed models have coped with products returned from online sales [57], products returned from online and retail sales [58] and mail catalog or online sales business via third-party logistics company [59]. De Brito and Dekker [60] mentioned that there are three main classifications of agents in reverse logistics and closed-loop supply chain as follows; forward supply chain actors (as supplier, manufacturer, wholesaler and retailer), specialized reverse chain actors (such as jobbers, recycling specialists, etc.) and opportunistic actors (such as charity organizations). Each of players within forward and/or reverse channels may have particular operations objectives and constraints. Moreover, each of them may have different competition and/or collaboration behaviors with other agents in the same or different tiers.

To analyze the behavior of agents in reverse logistics network, Nagurney and Toyasaki [61], Chen et al. [62] and Hammond and Beullens [63] proposed a network equilibrium model for reverse logistics recycling network by using the variational inequality (VI) approach. All proposed models addressed single-period and single-commodity flow problem for the recycling waste of electric and electronic equipment (WEE). The proposed models consider an open-loop system with four-tiered network comprised of four agents including the sources of electronic waste, the recyclers, the processors and demand markets (Nagurney and Toyasaki,[61]; Chen et al.,[62]) and a closed-loop system with a two-tiered network and

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two agents including manufacturers and consumer markets[63].

3.1.4. Application of Simulation for RL Network Design:

A very few authors presents the overview of the simulation models for reverse logistics network design appeared in literature during the last two decades. Overall, few simulation models were proposed to analyze the impact of various network design parameters on the operational performance of reverse logistics systems. The objective of the simulation models was to investigate which possible design variables are important for a reverse logistics network design. For example, Biehl et al. [64] took potential design variables such as the number of collection centres, collection rates, type and set up of information technology for forecasting and control systems, recycling rates and return rates into account in order to assess how the US carpet industry would able to meet a 40% diversion from landfills by 2012. In addition, Kara et al.[65] considered design variables including the number and type of participants in the system, number and location of the disassembly centre, collection points, return rate and characteristics of the material flow and product characteristics in order to design a cost effective reverse logistics networks for taking back end-of-life white goods. It can be seen that both papers considered many realistic characteristic of reverse logistics network and return uncertainty into account. In summary, both papers addressed a single-item flow with multi-period. Biehl et al. [64] investigated closed-loop and two-level network structure while Kara et al. [65] considered open-loop and multi-level network structure. Regarding the model results, both simulation models were able to provide several crucial managerial recommendations for the improvement of reverse logistics network.

3.2. Research Gaps in Reverse Logistics Network Design & Development:

Despite many profound contributions of the researchers, these papers (models) are still faced with some limitations:

- All of the proposed models considered few elements of return and/or demand uncertainty left out other elements of risk and uncertainty in terms of quantity, quality and timing
- All of the proposed papers have not included more realistic assumptions, i.e., multi-objective, multi-period, multi-commodity flow, capacitated, closed-loop network structure into a single model
- Though a number of the heuristics solution methods were proposed, there is no computational time performance comparison between the proposed models and other heuristics solution methods.
- The models only investigated the element of return uncertainty in terms of quantity but ignored the risk and uncertainty in terms of quantity, quality and timing.
- All of the proposed models did not consider reverse logistics capacities and basic operations requirement
- All of the proposed models only considered single-commodity flow while only Hammond and Beullens [63] addressed closed-loop system and the two-tiered network.
- The authors took only return and demand uncertainty in terms of quantity into account but they have not included other elements of return and/or demand uncertainty in terms of quantity, quality and timing into account
- The authors employed only genetic algorithms to calculate outputs; however, there are several heuristic algorithms that might provide the same results with better computation time
- All of the models though applied two-level network structure only considered single objective instead of multiple objectives.
- The proposed models only considered return and demand uncertainty in terms of quantity but there are other elements of return and/or demand uncertainty in terms of quantity, quality and timing to be included.

4. Remanufacturing Issues in Reverse Supply Chain

In this section, we identify the problems with current descriptions of remanufacturing and their planning and control issues. As observed by Volmann et al. [66], an aggregate production plan should provide as close a match as possible between the model and the real world. Management must clearly define key objectives in order to develop advanced manufacturing systems. The development of formal production planning and control systems for remanufacturing is still in its infancy. Many firms simply use tools and techniques designed for traditional manufacturing operations. Previous research has shown that the production planning and control requirements for remanufacturing are unique [67]. Consequently, planners must consider a variety of complicating factors. Examples of the research addressing various aspects of remanufacturing are shown in Table 4. A complete review of this research stream is offered in both Fleischmann [52] and Guide and Jayaraman [67]. Currently, there is a relatively small but growing body of literature devoted to production planning and control for remanufacturing. Many of the models developed are based on a specific product type or a hypothetical scenario. In Table 4, we can see that much of the research has been grounded in actual remanufacturing systems. However, with the exception of Thierry et al. [68], the past research addresses a single aspect of remanufacturing using a single example, e.g. models for inventory control based on automotive parts remanufacturing. Further, the past work has been focused on producing operations research models and there have been a very limited number of attempts to structure the field.

Table 4: Recent Remanufacturing Researches.

Author	Product Type	Research Focus
Kara et al., 2007	Automotive parts	Recovery strategy
Kim et al. (2006)	------------	Remanufacturing cost
Seitz and Peattie, 2004	Automobile	Product take back
Guide et al(2003)	-------	Demand forecasting
Guide and Jayaraman, 2000	Mobile phone	Uncertainty
Krikke et al., 2001	Toner cartridges	Distribution issues
Toktay et al. (2000)	Single-use cameras	Inventory control policies
Krikke et al. (1999)	Photocopiers	Facility location and network design
Jayaraman et al. (1999)	Cellular telephones	Product returns management
Guide and Srivastava (1998)	Jet engine components	Short-term scheduling policies
van der Laan (1997)	Automotive parts	Inventory control policies
Thierry et al. (1995)	Photocopiers	Case study
Kelle and Silver (1989)	Refillable containers	Forecasting returns

Our purpose in Table 4 is to show that the research efforts to date have been focused primarily on analytical modeling. van der Laan [69] discusses independent demand inventory control policies as it relates to automotive parts. The independent demand inventory models can be classified as periodic and continuous review models. Kelle and Silver [70-71] considered the forecasting of returns of reusable containers in which the planner must forecast the core availability (a core is an item available for repair or remanufacture) that depends on the product's stage in its life cycle. van der Laan et al. [69] discusses a number of options for independent demand inventory control models using automobile part and photocopiers for examples. Guide and Srivastava [72] report on scheduling policies for remanufacturing shops using information from turbine jet engine remanufacturing. Jayaraman et al. [73] develop a location model for remanufacturable products and ground the model with information provided by a mobile telephone remanufacture. Krikke et al. [49] consider a number of alternatives for the design of a reverse logistics network for photocopiers in Western Europe. Toktay et al. [73] consider the problem of predicting return flows for single-use cameras. As the previous research shows, many studies have considered specific portions of the remanufacturing processes to support the development of a detailed operations research model. There is a clear gap in rich descriptive reports of remanufacturing systems from a planning and control standpoint. The work by Thierry et al. [68] examines several examples of product reuse and provides a series of managerial insights. Their research examines the operations of a number of firms engaged in product recovery management. One of the key managerial implications identified by Thierry et al. [68] is that product recovery management has the potential for large influences on production and operations management activities.

Previous research has reported different systems and techniques for gathering cores for remanufacturing. A common observation is that off-lease and off-rent products are an important source of used products for remanufacturing. Thierry et al. [68] have come to the conclusion that this type of return is more predictable than other types of returns due to the additional information that is available to the remanufacturing company. In the automotive industry, there is widespread use of ''exchange cycles'' where products are only sold if a core is given back [74]. In this scenario you first have to act as a supplier of a core in order to become a customer of a remanufactured product. Other reported systems are voluntary systems where the supplier freely returns the used products/cores to a remanufacturer, or where the cores are bought from core brokers or end customers. The company Lexmark uses a ''prebate'' program giving a discount on a product if the customer agrees to return the product after use; this program prohibits the customers from returning or selling their used products to other companies.

Guide et al [74] present a number of management propositions on what to focus on when trying to balance the supply and demand for remanufacturing. Regarding core acquisition, one of the most important issues is to focus on identifying different sources of cores and rating them according to their characteristics. Forecasting core availability is critical in order to balance supply and demand. This reduces the need to purge the system of excess cores and reduces stock-outs of unavailable units. Managers should also try to synchronise return rates with demand rates, since doing so will lower the overall uncertainties in the system and lead to lower overall operating costs [75]. According to Jayaraman et al [76], there are three crucial limitations that a remanufacturing firm needs to overcome: limited access of cores leaving the use phase, limited feasibility of product remanufacturing, and limited market demand for the secondary output from remanufacturing. Furthermore, a challenge that remanufactures need to tackle is the fact that market demands for remanufactured products and the disposal of used products does not always overlap. This is often referred to as, the problem of balancing supply of cores suitable for remanufacturing and the demand for remanufactured products. The reasons for returning used products are many. In theory, there are four basic types of returns:

- End-of-Life Returns. These are returns that are taken back from the market to avoid environmental or commercial damage. These used products are often returned as a result of take back laws.
- End-of-Use Returns. These are used products or components that have been returned after customer use. These used products are normally traded on an aftermarket or being remanufactured.
- Commercial Returns. These returns are linked to the sales process. Other reasons for the returns include problems with products under warranty, damage during transport or Product recalls.
- Re-Usable Components. These returns are related to consumption, use or distribution of the main product. The common characteristic is that they are not part of the product itself, but contain and/or carry the actual product; an example for this kind of return is remanufactured toner cartridges (Krikke et al., 2001).

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4.1. Contributions, Applications and Limitations:

The issue of forecasting for used product returns has proven to be a difficult challenge for the remanufacturing industry. The return of mainly mechanical products is dependent on factors such as age and use of the product, whereas electrical products tend to have a more random pattern of failure. Vacone et al. [77] report that different IT-based systems are used for keeping control over the products during use; two examples of these technologies are remote monitoring devices that communicate usage data and Radio Frequency Identification tracking systems used for keeping track of the installed base. Rogers and Tibben-Lembke [78] characterize good gate keeping as ''the first critical factor in making the entire reverse flow manageable and profitable''. Another important characteristic in the closed-loop supply chain is the need for a well-functioning reversed logistic network [67]. For example, reversed logistic networks for product recovery have been modeled by Kara et al. [65], with the aim to calculate the total collecting costs in a predictable manner. Kim et al. [79] also present a closed-loop supply chain model for remanufacturing to minimize the total cost of remanufacturing. Furthermore, the reverse supply chain and remanufacturing processes are dependent on what type of relationship the remanufacturer has with the original equipment manufacturer (OEM).Remanufacturers are often categorized into three categories: original equipment remanufacturers, contracted remanufacturers and independent remanufacturers (IRs). OEMs are in fact manufacturers that perform their own remanufacturing as a part of their company group, whereas CRs have a contract with OEMs to perform remanufacturing for them. In the last category, remanufactures work independently from the manufacturers, and often as competitors in the same market. The type of remanufacturing category has a major impact on the supply of spare parts and cores. The relationship perspective has the starting point that the important issue is the mutual exchange of value that occurs during an existing relationship between different parties.

4.2. Research Gaps in the Literature Related to Remanufacturing Strategies:

Despite many profound contributions, literature in the segment having many gaps that needs to be addressed by the researchers and models are still faced with some limitations:

- Although there are a lot of studies on various specific areas of remanufacturing, only a few research studies have focused on the development of a general framework and mathematical model about remanufacturing system
- Absolute shortage of integrated models which includes remanufacturing with OEM. More research needed on integrated modes which include reverse and forward channels simultaneously.
- Performance measurement system for the integrated manufacturing models which includes reverse and forward channels is still awaited.

5. Inventory Control and Coordination Issues in RSCC

Another important element of the supply chain design, besides the geographical location of the various processes, is their inter-temporal coordination. This relates to the location of inventory buffers, which decouple the individual processing steps. Traditional supply chain management commonly distinguishes inventories according to their supply chain function, such as cycle stock, seasonal stock, and safety stock. All of these functions also play a role in the extended supply chain [80]. Moreover, inventories assume an additional role in this context, which is driven by the mismatch between exogenous supply and demand. Since, in general, customers do not return products exactly at the moment that these can be resold, companies build up inventories of re-marketable products, which we denote as 'opportunity stock'. The effect is similar to that of forward buying in response to a temporary price discount. An important choice in any supply chain design concerns the location of the customer order decoupling point, i.e. the borderline between make-to-stock and make-to-order processes. In the extended supply chain, each usage cycle contains an additional such decoupling point on the supply side (see Figure1).

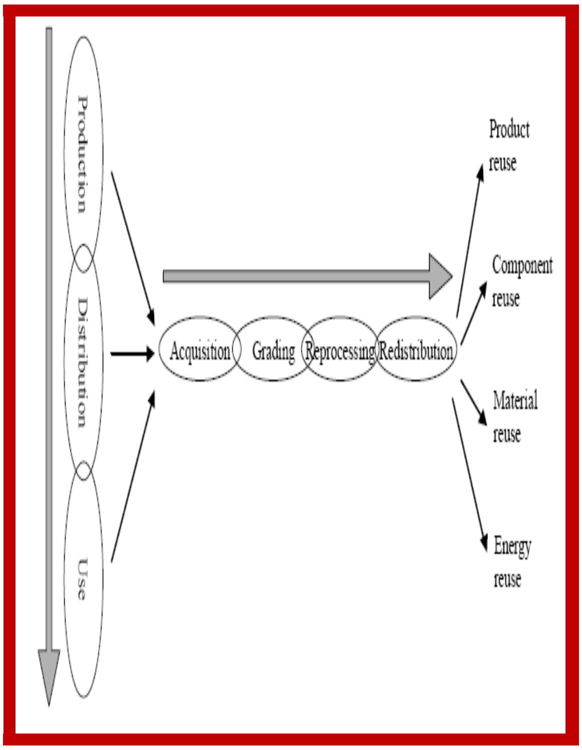

Figure1: Extended Supply Chain Generic Model [80].

This point indicates how far in the process chain a returned product moves upon its arrival. Analogous with traditional terminology one might denote the processes after and before this point as 'make-from stock' and 'make-from-supply' processes, respectively. Needless to say, both decoupling points may coincide in a single inventory buffer. A related, but not identical, supply chain characteristic concerns the border between supply-push and demand-pull processes. In particular, it is important to decide whether the re-processing stage, which typically represents the main value-adding activity of the extended chain, is to be push or pull-driven. In the former case, one processes returned products as they become available, whereas in the latter case one postpones value-adding activities until demand materializes. In a study on IBM's component-dismantling operation we highlighted that the appropriate choice depends primarily on how certain one is of future demand for the product in question (Fleischmann et al. 2003). In case of a serious risk of not finding a demand, and thus of wasting the reprocessing expenses, it is advisable to postpone any costly re-processing until more demand information becomes available. In all other cases, postponing the re-processing operation comes down to trading higher safety stock levels against lower holding costs per unit, which in sum leads to slight inventory cost savings at best.

The management of seasonal stocks and cycle stocks in the extended chain does not appear to differ essentially from traditional environments. The literature provides several variants of economic-order-quantity (EOQ) models for lot-sizing decisions in product recovery operations [81]. In contrast, choosing appropriate levels of safety stock and opportunity stock is more challenging. A significant body of literature addresses this issue. What complicates the matter in the first place is the additional uncertainty on the supply side of the extended chain. Higher overall uncertainty typically implies the need for higher safety stock buffers. A second complicating factor concerns the fact that returned product content and new products and components often serve as substitutes, as for example in IBM's service operations. In this situation, one needs to coordinate multiple alternative supply sources with different characteristics in terms of cost, reliability, and lead times, in such a way as to minimize overall costs. One can distinguish two approaches for integrating market returns into the planning of such a supply system. Most commonly in current practice we found a conservative, reactive approach, which only takes returns into account after they have actually occurred. The downside of this 'safe' approach is that it may create excessive inventories of unneeded returns. The alternative is to proactively incorporate expected future return flows into the current planning, for example when ordering new components. We have illustrated that such a proactive planning can significantly reduce inventories, even though it requires additional safety buffers to protect against supply uncertainty [82].

5.1. Contributions, Applications and Limitations:

Inventory management critically depends on the available information about future supply and demand, and thus in particular on forecasting. Just as in traditional supply chains, managing the extended chain requires projections of future demand. Expert assessments and statistical tools provide a basis for such estimates. What is more particular is the forecasting requirement on the supply side of the reverse logistics chain. In the literature, different methods have been proposed for estimating future product returns, which form the basic resource of the extended chain [83]. Simple methods treat the return flow as an autonomous process and apply the same statistical techniques as in demand forecasting. More advanced methods explicitly capture returns as a consequence of a previous supply chain cycle (see Figure 2).

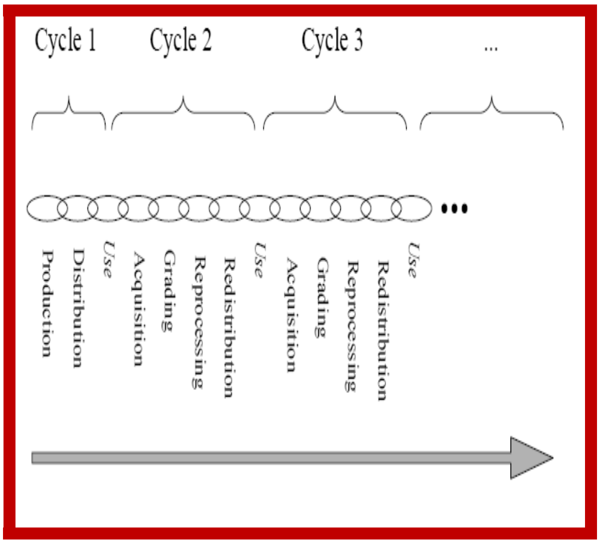

Figure2: Extended Supply Chain [80].

From this perspective, the key is to estimate the time a product spends in the market. Since this approach requires demand information from the previous supply chain cycle it is particularly appealing to OEMs that collect and recover their own products. Yet, even if historical demand information is available it may be non-trivial to determine the actual time that a product spent in the market. While the sales history of a high-end product in the business market may be well documented, this is not the case, in general, for commodities such as PCs, disposable cameras, or even soft drink bottles. However, as discussed previously, advances in information technology are about to change this picture. The ever more widespread and cheaper availability of digital storage devices, such as RFID-tags, provides the basis for tracking detailed product data even for simple commodities. Heineken's 'Chip-in-crate' project nicely illustrates this development. In this pilot project, the Dutch brewer equipped a set of its reusable beer crates with an electronic chip that is read whenever the crate passes through the bottling line [85].

These quickly expanding possibilities raise the question which type of information is the most critical for enhancing the extended supply chain and how to quantify its actual benefits. A stream of literature on the 'value of information' focuses mainly on inventory cost savings through the reduction of uncertainty [84]. Yet it appears that other benefits of advanced product information are even much larger. In particular, information helps identify potential supply and demand and thereby enables valuable transactions that otherwise would not have been realized at all. Pricing decisions are another issue that is closely related to this type of information. Finally, supply and demand information is key to supply chain design decisions such as capacity investments. In our opinion, a systematic and detailed analysis of the factors that determine this broader 'value of information' is one of the primary current research mandates in this field.

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6. Reverse Supply Chain/Reverse Logistics out Puts

Pricing the remanufactured product for sale is a complex and challenging issue [85] due to stochastic returns and demands. This makes it difficult to determine the price of a remanufactured product vis-à-vis new products. The groupings of literature under RL outputs are given in Table 4.

6.1. Pricing and Competition:

Researchers have studied the relationship between markets for new and remanufactured products and developed models to determine the optimum selling price for remanufactured products and parts. The competition between original equipment manufacturers (OEMs) and local remanufacturers not only affect the supply of used products but also the price of the remanufactured product [86-87-88-89]. They found that OEMs are in a better position to offer remanufactured. Products at a lower price than those offered by local remanufacture. Ferguson and Toktay [90] have discussed strategies used by OEMs to deter the entry of independent remanufactures. Substitution of new products by remanufactured products is discussed by Bayindir et al. 91]. Researchers have also recommended early entry of OEMs in RL to gain first mover advantages and to learn significant engineering capabilities and product disassembly knowledge [92].

6.2. Coordination Support:

Coordination in RL is also discussed by the authors. Some authors have discussed the importance of communication to help in quick and early disposition of returned products and also assisting in remanufacturing planning [93-95]. Some authors have suggested the use of information support systems to assist in coordination [96-97].

6.3. Customer Relation:

The benefits of RL on customer relationship such as improved customer retention and customer satisfaction through liberalized returns policies is analyzed by Fuller et al.[98], Turner et al.[99], Wise and Baumgartner [100], Sarkis et al.[101], and Mollenkopf et al.[102]. Amini and Retzalff-Roberts [103] suggest reduction in cycle time of providing refunds and exchanges to customers as a way of enhancing customer service quality. Daugherty et al. [97] suggest the use of information technology for better customer relations and enhanced service.

Table 4: Literature on Reverse Logistics Out Puts (Pokharel & Murtha, 2009).

Contents	Literature
Product pricing	Ferrer and Swaminathan (2006), Vorasayan and Ryan (2006), Karakayali et al. (2007), Mitra (2007), Vadde et al. (2007)Purohit (1992), Purohit and Staelin (1994), Majumder and Groenevelt (2001), Guide et al. (2003), Choi et al. (2004), Bayindir et al. (2005), Ferguson and Toktay (2005), Debo et al. (2005), Yalabik et al. (2005), Yao et al. (2005), Bhattacharya et al. (2006),
Competition	Goldsby and Stank (2000), Majumder and Groenevelt (2001), Sahay et al. (2003), Richey et al. (2004), Ferguson and Toktay (2005), Heese et al. (2005), Ferrer and Swaminathan (2006), Savaskan and vanWassenhove (2006),Webster and Mitra (2007)Porter and van der Linde (1995), Shrivastava (1995), Newman and Hanna (1996), Russo and Fouts (1997), Marien (1998),
Coordination	Fleischmann et al. (2000, 2001), Fleischmann (2003), Hess and Meyhew (1997), Chouinard et al. (2005), Daugherty et al. (2005), Yalabik et al. (2005), Aras et al. (2006), Atasu and Cetinkaya (2006), Ketzenberg et al. (2006), Kongar and Gupta (2006)
Customer relation	Sarkis et al. (2004), Daugherty et al. (2005), Mollenkopf et al. (2007), Srivastava (2007)Fuller et al. (1993), Turner et al. (1994), Amini and Retzalff-Roberts (1999), Wise and Baumgartner (1999), Daugherty et al. (2003),
Reverse Supply chain	Choi et al. (2004), Kim et al. (2006), Reimer et al. (2006), Bakal and Akcali (2006), Debo et al. (2006), Georgiadis et al. (2006), Tang and Teunter (2006)Guide et al. (1997a,b), Bras and McIntosh (1999), Guide (2000), Veerakamolmal and Gupta (2000), Inderfurth and Teunter (2001),

6.4. Reverse Supply Chain:

An understanding of reverse supply chain is also explored by the authors. Scheduling arrivals of new modules, storing or disposing excess recovered modules are some of the factors analyzed by researchers [104-105]. Research is also carried to analyze capacity planning techniques and material planning systems in a remanufacturing environment [104]; Ferrer and Whybark [106]. A few authors have also discussed the aspect of supply planning by considering the modular structure of products [107].

7. Concluding Remarks and Future Research Directions

This paper presents a comprehensive literature review of the journal papers on reverse logistics/closed loop supply chain published in last two decades. We have used a holistic perspectives approach to study the research on the various issues related to design and development of reverse logistics system/reverse supply chain systems. After surveying more than 100 papers, we have to come on this conclusion that the research in RL is multifaceted and distinguishes itself from forward logistics. The review also shows that research publications on RL are increasing specially after 2004 and therefore it shows the growing recognition of RL as a driver of supply chain and logistics. We have used content analysis approach [108] in this paper to study the research in reverse logistics and its impact on forward supply chain unctioning. Overall, the reviewed papers applied models such as linear programming, non-linear programming, MILP, MILNP, network equilibrium model, stochastic model and simulation model to deal with the above research issues.

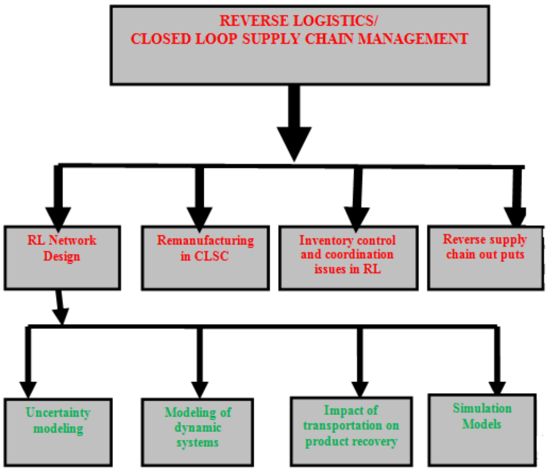

Figure 3: Shows The Eight Major Streams Covered by our Literature Review.

Figure 3 shows the eight major streams covered by our literature review with regards to the issues being addressed during the review period 1990-2009, the impact of design of reverse logistics network channel functions in isolation was most popular issue among the academician and practice , while the rest of the research issues received relatively less attentions. Particularly, we found a lot of contributions to the understanding of the impact of uncertainty on reverse logistics network design because return and demand uncertainty in terms of quantity, quality and timing have now been investigated [109]. The rest of the research issues, though received relatively less attention, have already given the foundations for future research.

The review presents reverse supply chain from a systems perspective. It can assist the decision maker in key operational and strategic decision making, for example, integrating manufacturing, distributors, remanufacturing operations and 3PL providers, evaluating end-of-life options for returned products, or setting up a returns policy. RL involves a paradigm shift in terms of product, that is, from "cradle-to-grave" to "cradle to cradle". Arising from the above, we propose some important directions in RL research. We have found that the research can be strengthened in assessing the stochastic nature of supply and demand and the yield from a remanufacturing process. More generic models have to be developed to tackle this type of situation so that better networks can be designed to facilitate RL [108].

The objective of this study was to encourage and provide researchers with future research directions in RSCM for which empirical research methods are appropriate. In addition, the research directions suggested in the paper address several opportunities and challenges that currently face business managers operating in RSCs. Studies using survey-based research methods are complementary to existing research in that they are used to develop generalizations about a representative group of firms, to clarify predominant and critical issues in the RSC and to explain the current business environment and managerial behavior [110]. In addition, most studies have focused on the retailer (with consumer product returns) or the remanufacturer (with process concerns). We believe there are several opportunities to conduct survey-based research along all tiers of the RSC. There are many opportunities for future research using empirical-based research methods in RSCs.

Arising from the above, we propose some important directions in RL research

Future research could measure organizational commitment as it has been defined in social exchange theory and test its relationship to operational performance Although the relationship between organizational commitment and RSC performance is implied in several studies [9,23,65,66], research has not addressed how organizational commitment and the form of the investments influence operational performance.

The second direction of research should be development of performance measurement mechanism to investigate remanufacturing influences on production, planning & control in the RSC. We are only beginning to develop an understanding of the constraints in remanufacturing that challenge our traditional PP&C systems. Previous work on traditional PP&C systems, recent PP&C case studies in RSCs and normative research on remanufacturing systems provide a good foundation for future work. To extend our current understanding of the difficulties of using PP&C systems with both remanufacturing and new products, empirical research can be used to audit the applicability of PP&C systems in different remanufacturing environments and the PP&C system's influence on performance.

The third direction of research should be in terms of pricing of products based on quality of the returned products. Good quality products require less number of processes in terms of inspection, and less number of new parts for remanufacturing; this can possibly lead to higher value extraction to the remanufacturer. Therefore, designing a good pricing policy for the acquisition of used products should be strengthened. Liang et al. [85] have proposed an option theory method for acquisition pricing based on anticipated demand. However, the authors do not explicitly consider network design and the remanufacturing process [108]. Therefore, integration of models from acquisition of used products to the sale of remanufactured products should be considered.

The fourth area of research could be selection of return facility like, 3PL provider, in-house or centralized returns center with cost effective manners. The results of a study by Autry et al. indicated that managers perceived higher levels of environmental regulatory compliance when reverse logistics was carried out in-house rather than being outsourced. In Lieb et al., the results suggested that Western European managers outsourced to third-party logistics (3PL) providers because they perceived flexibility as a primary benefit, whereas U.S. manufacturers outsourced to 3PL providers to reduce and control costs, as well as to improve productivity and service. Both parties perceived that using third-party providers reduced costs, although Western European companies perceived this improvement to be more significant. The alignment of competitive priorities with the returns facility selection decision should be further developed and explored.

The fifth area of research could be in terms of management of collection centers. These centers should be attracted to work with the OEM and remanufacturers on a long term basis. This requires multi-period transactions between the OEM and the remanufacturers.The challenge would be to use similar concepts by incorporating obsolescence and fluctuating lead times in a RSC situation.

The sixth area of research could be research on the impact of uncertainty on reverse logistics network design, though investigated many different elements of uncertainty, lacks considerations of the element of risk and multiple objectives. Also, the comparison of heuristics algorithms solution methods is often ignored. There is a need of future models should consider a multi-objective model which takes multi-period, multi-commodity flow, capacitated and closed-loop network structure problem into account and there is a need for comparison of the proposed solution method with other heuristics, e.g., GA, ANN, Lagrangrian relaxation, tabu search and scatter search.

The seventh area of research could be development of stochastic models for reverse supply chain network applied more comprehensive models to cope with return and demand uncertainty in terms of quantity but they lack considerations of multi-level or multi-commodity models and other elements of uncertainty. Despite the call for more stochastic modeling by Sasikumar and Kannan [111], there is still limited research in this area.

To sum up, the development of closed loop supply chain conceptual and quantitative models is one of the most imperative research areas of reverse logistics research because of the need to address the uncertainty of supply and the dynamic interactions between forward and reverse flows. Our literature review updates and complements the literature reviews by Fleischmann et al. [112], Fleischmann [113], Carol et al. [110], Pokharel et al. [108] and Chanintrakul et al. [109]. Our review concludes that there have been a gradual increased of efforts in modeling of reverse supply chain/closed loop supply chain network but there is a need for incorporating more realistic and complicated assumptions in terms of time period, commodity-product flow, network level, open or close-loop structure, objective function, uncertainty type and other model constraints.

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Appendix 1

Table 1 Summary of Reviewed Papers Based on Reverse Supply Chain Design.

References	Model	Solution methodology	Period	Commodity flow	Level	RL Structure	Model objectives	Constraints	issues	Recovery option
Mutha et al. (2009)	MILP	Sim	M	M	M	OL	M	MC	MI	M
Lee and Dong (2008)	MILP	HE	S	S	T	CL	M	SC	MI	S
Pati et al. (2008)	MILP	EX	S	M	M	OL	M	SC	MI	S
Srivastva (2008)	MILP	EX	M	M	M	OL	M	SC	MI	S
Biehl et al. (2007)	MILP	HE	S	S	T	CL	M	SC	MI	S
Lieckens and Vandaele (2007)	MINLP	HE	S	S	S	OL	M	SC	MI	S
Ko and Evans (2007)	MINLP	HE	M	M	T	CL	M	SC	MI	S
Lu and Bostal (2007)	MILP	HE	S	S	T	CL	M	SC	MI	S
Salema et al. (2007)	MILP	EX	S	M	M	CL	M	SC	MI	S
Lieckens and Vandaele (2007)	MINLP	HE	S	S	S	OL	M	SC	MI	S
Boyaci et al. (2007)	MILP	HE	S	S	T	CL	M	SC	MI	S
Wang et al. (2007)	MINLP	HE	S	S	S	OL	M	SC	MI	S
Salema et al. (2006)	MILP	EX	S	M	T	CL	M	SC	MI	S
Jayaraman et al. (2006)	MILP	EX	S	M	M	CL	M	SC	MI	S
Min, et al.(2006b)	MINLP	HE	S	S	S	OL	M	SC	MI	S
Rentz et al. (2006)	MILP	HE	S	S	T	CL	M	SC	MI	S
Seliger et al.(2006)	MILP	Sim	M	M	M	OL	M	MC	MI	M
Hwang, et al. (2005)	MILP	EX	S	M	M	CL	M	SC	MI	S
Fernandez and Kekale (2005)	MILP	EX	S	M	M	CL	M	SC	MI	S
Piplani et al(2004)	MILP	EX	S	M	M	CL	M	SC	MI	S
Beamon and Fernandes (2004)	MILP	EX	S	M	M	CL	M	SC	MI	S
Jayaramanet al(2003)	MILP	HE	S	S					MI	S
Bloemhof et al (2001)	MILP	EX	S	M					MI	S
Fleischmann et al (2001)	MILP	EX	S	S					SI	

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An Application of Customized Lean Six Sigma to Enhance Productivity at a Paper Manufacturing Company

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Abstract

This article presents a process improvement study applied at a local paper manufacturing company based on customized Lean Six Sigma methodologies. More specifically, the DMAIC (Define, Measure, Analyze, Improve, and Control) project management methodology and various lean tools are utilized to streamline processes and enhance productivity. Two performance measures namely production rate and Overall Equipment Effectiveness (OEE) are employed to evaluate the performance of the cutting and the printing machines before and after the DMAIC cycle. Obtained results indicate that the production rate increment for printing machines by 5% and for the cutting machines by 10%. Moreover, the OEE for the printing and cutting machines has increased by 21.6% and 48.45% respectively

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Keywords: Six Sigma; DMAIC; Lean manufacturing; Overall Equipment Effectiveness; Paper manufacturing

1. Introduction and Background

Organizations look for ways to improve their production and management processes in order to remain competitive in the market. This calls for ways to reduce production cost, enhance productivity and improve product quality. Therefore, organizations must utilize all the available resources efficiently and effectively in order to cater their customers with high quality products at a low price. For these reasons, researchers all over the world proposed several improvement strategies and tools to satisfy organizations needs. Such initiatives include Total Quality Management, Quality Awards, Total Preventive Maintenance (TPM), Lean and Six Sigma.

The lean concept, which was initially referred to as the Toyota Production system, concentrates on the flow of the entire processes rather than on the optimization of individual operations [13]. Womack (2002) specified the main components of lean management system as follows:

1. Identify process value from the customer perspective.
2. Identify the value stream for each product and eliminate all types of wastes currently imbedded within the production process.
3. Try to develop a continuous production process.
4. Develop the pull management technique within the production lines.
5. Manage toward perfection.

Six Sigma, on the other hand, is a data driven methodology used to identify root causes for variations in a production processes in order to achieve organizational excellence. Six Sigma management strategies require process improvement through identifying problem, root causes, process redesign and reengineering, and process management. Six Sigma follows a model known as DMAIC (Define, Measure, Analyze, Improve, and Control). Therefore, Six Sigma starts by analyzing defects and lean initial focus is on customer, process flow, and waste identifications [23]. However, using one of these tools has limitations. Since lean eliminates the use of Six Sigma's DMAIC cycle as a management structure to define required process capabilities to be truly lean. On the other hand, Six Sigma eliminates defects but does not address how to optimize the process flow. Hence, applying both Six Sigma and Lean tools sets results in far better improvements than could be achieved with either one method alone [16].

DMAIC is a systematic six-sigma project management practice inspired by Deming's PDCA (Plan, Do, Check, and Act) Cycle. The process consists of the five phases called Define, Measure, Analyze, Improve, and control. The Define phase concentrates on forming the team, defining the project's goals, mapping the process, identifying customers, and identifying the high impact characteristics or the CTQs (Critical to Quality). The Measure phase consists of defining and executing a systematic data collection plan for the key measures (CTQs) for the targeted process. Data collected in the Measure phase are analyzed in the Analyze phase to identify the root causes behind the gap between the current performance and the goals identified in the first phase by defining the main type of wastes embedded within the production processes and the root causes for these wastes. The Improve phase focuses on identifying expected solutions, suggest set of alternative solutions to enhance

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performance, and implement some of these solutions according to the available budget and the expected cost for each alternative. The Control phase concentrates on creating and implementing monitoring and response plans for sustaining improvements, spread out the outcome and the methodology for the whole organization, insure the establishment of a new culture within the organization. Moreover, operating standards and procedures are documented and published in the Control phase.

Lean and Six Sigma have been implemented successfully in the manufacturing and service sectors to optimize different performance measures. Both lean and Six Sigma methodologies have proven over that last twenty years that it is possible to achieve dramatic improvements in cost, quality, and production time by focusing on process performance. Linderman et al. (2003) pointed out that Six Sigma could be implemented to the processes of producing manufacturing goods, business trade, executive management, and services. Recent research papers include improving operational safety [5], reducing amount of waste [8], improving quality for surveillance cameras to diminish related excess costs [10], enhancing the assembly efficiency of military products [4], increasing customer loyalty in the banking sector for Bank of America and Citigroup [21, 22], reducing patients' waiting time and length of stay [3, 17, 29], reducing length of stay for Ophthalmology Day Case Surgery [16], reducing lead-time [1], enhancing staff satisfaction [7], reducing clinical errors [20], process improvement for both the radiology department and medication administration process [15], and process design of compressor-housing machining process [25]. Others include [2, 6, 11, 12, 18, 19, 24, 26, 28, 29].

As a summary, both lean and six sigma methodologies have proven over that last twenty years that it is possible to achieve dramatic improvements in cost, quality, and production time by focusing on process performance. In this paper, a customized lean Six Sigma methodology is deployed at a local paper manufacturing company to increase production rate, minimize waste and increase Overall Equipment Effectiveness (OEE). The two tools have been used as complementary to each other, wherein DMAIC's roadmap has been used as a general framework for process improvement and lean tools have been embedded within these phases. Furthermore, the research focuses on employee involvement and motivation that are imperative to advance a new culture [9].

2. Problem Statement

The environment for most of the manufacturing companies is very challenging these days under the massive global market competition, therefore companies are looking for systematic ways to cut production cost, improving production rate, and increasing production quality. Managers at the local paper manufacturing company under investigation expect that they could improve their current production rate without increasing the existing resources. Moreover, managers noticed that their production processes are not running efficiently; in the first quarter of 2009, only 77% of customer orders were delivered on time. Furthermore, they decided that employees should be involved in improvement projects to build up a new culture and guarantee sustainability. The reason behind this attitude is that many manufacturing companies have implemented different process improvement tools without creating the underlying culture, so they end up with poor follow-up, lack of interest, diminishing productivity, and no ownership of improvements. So few years after the termination of their projects, company returns to the previous status and in some cases to a poorer state.

3. Research Methodology

The improvement team starts to recognize in broad scope the major problems that the company currently have. The scanning approach took different perspectives through direct observations, interview, and data analysis. The direct observations show that the operation process currently contains different types of wastes, which has not been identified and classified correctly. Afterward, different set of general interviews have been carried out with the plant manager, operation manager, quality manager, and maintenance manager. These interviews emphasized that the production processes could run more effectively if all types of wastes have been identified and eliminated. The last technique is data analysis, in this technique the production reports have been reviewed for the year 2008 in addition to the first quarter of 2009. The results confirmed that the average Overall Equipment Effectiveness (OEE) for the whole production line is lower than 33.5% where it should be around 85% as indicated by the top managers based upon the best practice for similar manufacturing companies. These results could explain the reason behind the incapability of the company to meet customer requirements. So there is a need to identify these wastes, analyze it, and develop action plans to lean them. The following subsections illustrate how the DMAIC cycle is used to increase the Overall Equipment Effectiveness in the paper manufacturing company.

3.1. Define Phase:

In the define phase, the project outlines, metrics, and objectives must be clearly identified. The project charter is a helpful tool in this context; it describes the project scope, goals, performance measures, significant risk, and anticipated benefits. Project charter is typically one of the most challenging steps in the DMAIC cycle, as it defines the expected delivery for the project and it may help to complete the project as proper as possible. To identify the scope of the project, a high-level process map is used as shown in Figure 1. The map shows that the main production operations that affect the performance of the production process. The operations are printing, cutting, window, and the gluing. The study was then limited to bottleneck operations of printing and cutting. Hence, a team is formed for the corresponding production processes including the authors (project champion), operators, quality personnel, production engineers, and management. Afterward, a set of brainstorming sessions are held to identify the main components of the project charter.

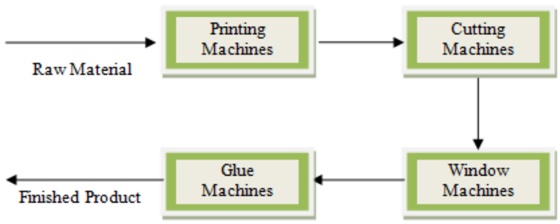

Figure 1: High-level Process Map.

To identify the project scope, ABC analysis is performed using historical data and revealed that four main products are the most frequent products manufactured at the company, these four products contributed to more than 80% from the total production rate. Performance measures are identified as production volume (ton), production rate (sheets/hour), percentage of wastes, and Overall Equipment Effectiveness (OEE). Targets are set to increase the production rate for the cutting machines from 4400 sheets/hour to 4700sheets/hour, to minimize cutting wastes from 0.25% to 0.15%, to increase the production rate for the printing machines from 6500 sheets/hour to 6750 sheets/hour, and to minimize printing wastes from 3.07% to 2.00%. The significant risks have also been identified as machine accident stoppage and shortage in the raw material required to produce the above four products. The project charter was reviewed and approved by top management team. This approval gives full support to the team to achieve the required goal and offers a clear and well-organized vision.

To develop a new culture, the project champion spread a good baseline about lean manufacturing and Six Sigma through two extensive awareness and training sessions. Moreover, the eight types of wastes are explained clearly to the team members to insure collecting the correct data during the measurement phase. Furthermore, posters were distributed within the whole organization in order to deepen the understanding of how to approach a lean and Six Sigma culture.

3.2. Measure Phase:

To start the measurement phase a standard form has been designed and distributed to the DMAIC team, the from contains the necessary information that should be gathered to be analyzed at the next phase, these information comprise from product type, raw materials type, machine parameters, type of wastes combined with general comments. Afterward, a set of pilot runs are carried out under the supervision of the project champion. During these experiments, the team starts to understand clearly how the data should be collected. Furthermore, a uniform team is formed to minimize personal errors (repeatability) and the error within the team (reproducibility). Machine operators are advised about the reasons behind collected data to enhance collaboration and to spread out the knowledge further. Data are collected over a period of three months; a sample from the collected data for the printing machine is shown in Table 1.

Table 1: Sample from the Waste Time for the Printing Machine.

Machine Name	Printing	Area	Printing	Date	16-June-09
Number of Operators	2	Product Type	XXX	Day	Thursday
Raw Materials Used					
Type	Supplier Name	Storage Day	General Comments		
Carton: A	MM	27-March-09	None		
Ink	MMM	1-March-09	None		
Machine Parameters					
Time	Number of Operators	Speed Parameters	General Comments		
8:30	2	4616	The operators don’t try to reach to the maximum speed since there is a problem in the gearbox for unit number five.		
9:20	2	4500			
10:30	2	4570			
Types of Wastes					
Stoppage			Transportation		
Activity Type	Time (Minutes)	Comments	Activity Type	Time (Minutes)	Comments
Carton stoppage	00:30	This problem has been repeated five times during five hours and a half	Internal shortage on carton	00:40	
Feeder problem	2:10	Feeder problems include: 1- Feeder adjustment. 2- Evacuate stoppage. 3- Sheet guide problem.	Internal shortage on carton	00:50	
Feeder problem	1:30		Insert alcohol	1:00	
Feeder problem	7:40				
Carton jam	00:30				
Clean and adjust blanket varnish	4:57				

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Cut blanket varnish side	3:40				
Varnish roller bearing problem	120:30				
Waiting Time (Minutes)			Moving Time (Minutes)		
Waiting until the carton rearranged and fed to the main Feeder	1:30	The carton came from the warehouse not in a proper way, so the operator have to rearrange it to minimize the time	Bring tools to cut parts from the varnish blankets	3:40	
Waiting until the carton rearranged and fed to the main Feeder	1:00				
Waiting until the carton rearranged and fed to the main Feeder	4:00				
General Observations					
1- There is no homogeneity between the ink, water, and alcohol so from time to time there is an accumulation in the varnish roll.					

3.3. Analysis Phase:

The analysis phase deals with identifying the critical factors embedded in the current operation that could be improved to minimize waste. Prior to starting this phase, the project champion reviewed the collected data to filter out any type of noise and disturbance. Data mining is then used to identify main types of wastes for each machine to perform the corrective actions. Data reveal that there are seven types of wastes at the cutting machines with jamming during sheet feeding, jamming at mold, adjust press and knife, and adjusting feeder contribute to more than 90% of the total waste. Table (2) presents times for each type of waste per 5.5 hours during 9 working days. Similarly, for the printing machine the main types of wastes include carton jam, feeder problems, and clean and adjust plate, and blanket for color and varnish.

Table 2: Main Types of Wastes for the Cutting Machine.

Report No.	Jam problem during sheet feeding	Feeder adjustment	Adjust side and front lays	Jam at mold	Adjust pressure at the pressing and cutting knifes	Motor problem	Adjust flagstone	Total Time	Percentage of waste in time (%)
1	25:00	11:30	5:02	7:00	4:12	0	0	53:44	13.3
2	19:17	7:14	0	5:55	0:00	3:20	0	35:56	8.9
3	18:35	3:20	0	15:45	21:09	0	0	58:49	14.5
4	24:40	2:22	0	5:04	4:32	0	0	36:38	9.1
5	16:12	0:00	0	0:00	9:23	0	0	25:35	6.3
6	27:50	3:09	0	4:30	0:00	0	2:30	35:29	9.4
7	17:20	10:30	0	0:00	45:25	0	0	73:15	18.1
8	20:30	0:00	0	32:53	2:00	0	0	55:23	13.7
9	19:40	0:00	0:45	6:54	0:00	0	0	27:19	6.8

Once the team has identified the main types of wastes for each machine a set of brainstorm meetings have been carried out to find the root causes for each problem, these sessions are organized after a training course conducted for the DMAIC team on problem solving and decision making tools. Figure (2) shows the main causes for the jamming problem in the cutting machine.

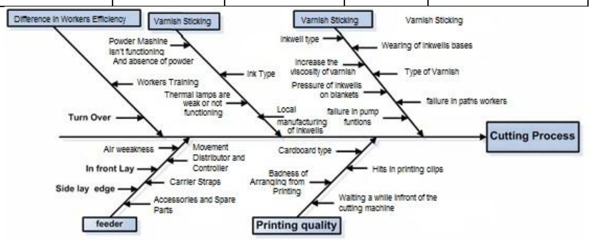

Figure 2: Cause and Effect Diagram for the Jamming Problem in the Cutting Machine.

3.4. Improve Phase:

Having identified and verified main types of wastes, the team proposed actions to minimize the probability of reoccurrence for these problems. Brainstorming sessions are held to generate solution alternatives. Each solution is evaluated with respect to cost, ease of implementation, and probability of accomplishment upon implementation. Sample from the proposed solutions for the cutting machine are summarized in Table (3).

At this stage, the DMAIC team has recognized clearly the main causes for each type of wastes, expected solutions, required actions, time interval, and others. Corrective actions are started immediately as requested by management. For example, investigations show that one of the main causes for the carton sticking problem is the wearing out for roller base, the action plan was to adjust the roller base instead of buying a new base because of the high cost of the roller base; by working on finishing surface, specify the wear parts, and fix.

To evaluate gains, data are collected over the three months period following the implementation of suggested solutions. Tables 4 and 5 summarize results for both the printing and the cutting machines respectively. Results confirm the achievements: production volume (ton) for printing and cutting machines increased by 24%. The production rate increment for printing machines by 5% and for the cutting machines by 10%. In addition, the OEE value is has increased by 21.5% and 48.44% for the printing and cutting machine respectively. Moreover, the order fulfillment rate increased by 11.43%.

Table 3: Sample from the Summarized Corrective Actions for the Cutting Machine.

No	Machine	Stoppage	Action	Required time	Notes
2	Cutting	Varnished carton sheets sticking			
2.1		Wearing out roller base	Fixing the roller	4 hr	Monthly maintenance
2.2		Varnish Type	Perform more test on varnish to check the conformance to the specification	Acknowledgment of receiving committee comment	checked once samples are received
2.3		Lack of accuracy of the adjustment works	The adjustment should be done by the most skilled operator or printing supervisor	1 hr	Monitoring
2.4		Roller type and manufacturing accuracy	Stop buying from local supplier		Regularly
2.5		High varnish viscosity	Adjust the viscosity sensor	0.5 hr	Circularly
2.6		Roller pressure on blanket	Continuous checking on roller rotating accuracy	0.5 hr	During assembly of rollers
2.7		Low efficiency of the pumps because of impure dirty varnish	Installing filters for dust and rotating brush to homogenize varnish	2 hr	Monthly maintenance

Table 4: Summarized Performance Measures for the Printing Machine.

Printing Department	Before	After	Financial
Production (ton)	672 ton	1143 ton	147894 JD
Production Rate	6500 sheets/hr	6850 sheets/hr	-
Waste%	3.45%	2.67%	4500 JD
OEE	27.70	33.67	-
Total			152394 JD

Table 5: Summarized Performance Measures for the Cutting Machine.

Cutting Department	Before	After	Financial
Production (ton)	638 ton	1086 ton	-
Production Rate	4550 sheets/hr	4850 sheets/hr	3265.92 JD
Waste%	2.50%	2.50%	-
OEE	29.27	43.45	-
Total			3265.92 JD

3.5. Control Phase:

In order to sustain the achieved results and to prevent degradation in the machines' performance, a sustainability plan is formed including checklists. A sample from the sustain plan for the cutting machine is presented in Table (6).

Before the termination of this project and during the control phase, the outcomes of this research are spread out for the whole organization using posters and seminars. In addition, operating standards and procedures are documented and published. Moreover, the study helped the organization build a new culture of continuous improvement. They decided to start a 5-S project for the whole organization. 5-S is a strategy for creating and maintaining an exceptionally clean, orderly, and safe work environment. 5-S creates a clean environment, eliminates many types of wastes, creates a tone of enthusiasm, and prepares workplace for further improvements.

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Table 6: Sustain Plan for the Cutting Machine.

Machine name: Cutting Machine operation Name:			**Date** / /				
	Description	Task	Period	checked by	fixed by	Approved By	Action Plan
1	Ink Roller Varnish	Cleaning	Each Sunday				
		Change bearing	Each Sunday				
		Lubrication	Monthly				
2	General Situation	Cleaning	Each Sunday				
		Lubrication	monthly				
4	Foundation and Bearing	Cleaning	Each Sunday				
		General Status	Each Sunday				
5	Varnish	Cleaning	Each Sunday				
		Lubrication	monthly				
		Check bearing	Each Sunday				
6	Roller Provision	Availability	Each two month				

4. Conclusions

The paper presents a lean Six Sigma procedure to enhance the performance of the cutting and printing machines at a local paper manufacturing company. The scope of the study is to identify, analyze, and minimize all types of wastes, based upon customer and management request. Thorough investigations revealed various causes that contributed largely to minimize production rate, increase wastes, and minimize Overall Equipment Effectiveness (OEE). Following a DMAIC procedure, various improvement opportunities are suggested and implemented. As a result, the OEE for the printing and cutting machines has increased by 21.6% and 48.45% respectively. Furthermore, to ensure the control of the achieved results a sustain plan has been prepared in addition to a new working procedure. To achieve long-term benefits of the lean Six Sigma approach, awareness and training sessions are carried out to start a culture change focusing on individuals rather than only results. This target has also been achieved once management decided to start a 5-S project for the whole organization.

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المجلة الأردنية
للهندسة الميكانيكية والصناعية

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