Group Technology (GT) and Lean Production: A Conceptual Model for Enhancing Productivity

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Abstract

While Group Technology (GT) has considerable effects on important dimensions of lean production such as production wastes, set up time, quality and inventory management, the relationship between the two subjects has been not been sufficiently addressed in the literature. In this paper, a conceptual model has been proposed for enhancing productivity through the application of Group Technology (GT) in lean production systems. The model includes dimensions of GT and its relationship with lean production goals. Statistical analysis has been conducted and the links in the proposed model have been examined based on a questionnaire. The statistical population included managers of two industrial companies. The results confirm the high correlation between the elements of the proposed model in both companies. Also, the results of the variance analysis imply that except two items of the questionnaire, there is no difference in other items between the two companies.

Keywords: Group technology, Lean production, Productivity, Relationship, Model

1. Introduction

In the intensive competitive environment of the global economy, the survival of even the most well-established world class manufacturers depends on the ability to continuously improve quality while reducing costs. The resulting higher productivity is the key to market leadership and gaining sustainable competitive advantage. In this respect, changing production methods from mass-production with high inventory to a leaner operation with low inventory has become an essential practice for successful manufacturers such as General Electric and United Technology Corporation among others (Sim and Rogers, 2009).

Lean manufacturing is a leading manufacturing paradigm in many sectors of world economy where improving product quality, reducing production costs and being first to market and quick respond to customers' needs are critical to competitiveness and business success. In its most basic form, lean manufacturing is the systematic elimination of waste from all aspects of an organization to optimize manufacturing process. The basic underlying idea of 'lean' is to minimize the consumption of resources that add no value to a product (Shahin and Alinavaz, 2008). This concept originated in the Japanese manufacturers systems after World War II. When Japanese manufacturers realized that they could not afford the huge investments of the required building facilities similar to those in USA, They tried an unconventional path to reach greater heights. The Japanese started questioning some of the basic manufacturing assumptions then began the long process of developing and refining manufacturing process in order to minimize waste in operation processes. Lean manufacturing initiatives, which are also known as the Toyota production system, were originated by Ohno (1978) and Shingo at Toyota (Shingo, 1989). They used the Japanese word, 'muda', which they defined as any human activity that absorbs resources but creates no value (Dettmer, 2008). Womack et al. (1990) coined the term 'lean production' in their book entitled 'The machine that changed the world'. The systematic attack on waste is also a systematic assault on the elements underlying poor quality and fundamental management problems (Childerhouse and Towill, 2002). In the internal manufacturing context, another major contribution was made by Monden (1998); he suggested a novel scheme of classifying operations in to three generic categories as non-value adding, necessary but non-value adding and value adding operations. This scheme proved to be more generic and was extended to different areas. Value stream and lean initiatives researchers have also been exploring other ways such as using the theory of constraints, system dynamics and simulation, mathematical and expert system-based approaches. The major focus of their work is the same, i.e. how to minimize inventory and to insure its visibility in the pipeline in different industrial scenarios. In this context, the work of Towill (1997) regarding the principles of

good practice for material flow engineering and system design methodologies seems important. Another important work by Towill (1997) regarding the design principles of supply chains is also considerable (Seth and Gupta, 2005). Decades ago, the lean production concept (Womack et al., 1990; Shingo, 1989) was viewed as a counter-intuitive alternative to traditional manufacturing models (Hayes and Pisano, 1994). Today it is arguably the paradigm for operations and its influence can be found in a wide range of manufacturing and service strategies (Womack and Jones, 1996). Yet, despite its pre-eminence, the lean production model and the research that informed it, raised a number of theoretical and methodological concerns (Williams et al., 1992). Some authors have made attempts to define the concept (e.g. Lewis, 2000; Hines et al., 2004), while others have risen the question of whether the concept is clearly defined (Petersen, 2009). Forza in 1996 highlighted the differences of work organization in lean production and traditional plants. Lewis (2000) suggested that being 'lean' can curtail the firm's ability to achieve long-term flexibility and sustainable competitive advantage. Spithoven (2001) discussed the relation between lean production and disability and he claimed that the lean production appears to be more stressful than production in a traditional firm. This possibly influenced the rise of disability in the 1980s and 1990s. In 2003, the environmental protection agency had a research on lean manufacturing and the environment and had recommendations for leverage of better environmental performance. Seth and Gupa (2005) noticed the application of value stream mapping for lean operations and cycle time reduction. Black (2007) suggested four design rules for implementing the Toyota production system or what is now known worldwide as lean production. Shewchuk (2007) described the characteristics of lean production and proposed worker allocation algorithm in lean U-shaped production line to provide optimal solution. Fullerton and Wempe (2009) examined how utilization of non-financial manufacturing performance measures impacts the lean manufacturing/financial performance relationship. The results provided substantial evidence that utilization of this method mediates the relationship between lean manufacturing and financial performance. Riezebos et al. (2009) reviewed the role of IT in achieving the principles of Lean Production, which included the use of IT in production logistics, computer-aided production management systems and advanced plant maintenance. Petersen (2009) investigated the definition of lean production and the methods and goals associated with the subject as well as how it differs from other popular management concepts.

Recently, manufacturer problems (stagnation, energy crisis, pollution, skillful labors, rapid changes in product design and technical innovation) lead the production systems to eliminate redundancies, reduce waste and increase productivity and enhance their manufacturing performance. The development of manufacturing systems and changes and variety of customers' interests, push companies to produce various products with high capacities. Therefore, manufacturing systems must be changed from job shop and mass production systems to new systems. In this respect, many manufacturing companies have noticed the effectiveness of 'Group Technology (GT)'. It is the best production system to produce various products in large amounts with high productivity (Ham et al., 1985). This subject is a process based philosophy with the principle of similar processing of similar products (Askin and Standridge, 1993). In 1925, Flanders described the application of product oriented department in manufacturing standard product with less transportation and Snead (1989) assumed it was the beginning of GT application. Burbridge (1975) developed a systematic approach on the basis of classifying work pieces and similar pieces in standard similar processes (Askin and Standridge, 1993). Several examples of applying GT to production scheduling can be found in the literature. Oliff and Burch (1985) attempted to reduce product changeover costs that were highly sequence dependent by grouping products into families. Using these groups they successfully reduced changeovers between product families and machine set-up costs. Miller (1991) used it in developing an aggregate production and distribution planning model. Hubbard et al. (1992) incorporated GT into the process flow scheduling technique to guide production of a high-volume repetitive manufacturing system. Additionally, Prasad and Bhadury (1993) applied GT to grouping jobs into families based on the jobs' tool requirements. They reported that the implementation of GT would result in a 16.5 percent improvement in the utilization of the machining centre Al-Salti and Statham (1994) investigated an effective procedure for estimating the process parameters, using historical data from similar components and based on the GT principle. The methodology involved the determination of component code number, family formation, retrieving data, and estimating process parameters. Cheng et al. (1995) formulated a 0-1 quadratic model for producing machine cells and a criterion for forming corresponding part families for GT. Their methodology allows for multiple copies of machine types for which a two-stage procedure was proposed and computational experience of the procedure was reported.

Zhu et al. (1997) described the application of GT in scheduling industrial bag production in a woven products division of a bag manufacturer. This study addressed a new application area of GT which led to a better solution of labor assignments and provided management with valuable information essential to the development of a strategic competitive advantage. Santos and Arauojr (2003) proposed a computational implementation of the

production flow analysis for GT, called 'GroupTech'. Nomden and Van der Zee (2008) proposed Cellular manufacturing (CM) as an application of Group Technology (GT), and assumed physical groupings of machines, each grouping or cell being dedicated to the manufacturing of a product family. The similarities in manufacturing requirements for members of a product family lead to reduced set-ups, less material handling, and more (Burbidge,1975). It is important to add that clarified Virtual Cellular manufacturing (VCM), for functional layout settings where a conversion to Cellular manufacturing (CM). However, instead of a physical re-allocation of machines, CM-VCM aims to reduce set-up times by grouping similar jobs in production planning and control.

Considering the literature review, it is concluded that it seems most of investigations assume GT and CM as synonyms. Although in such resources, CM is addressed as a technique of lean manufacturing, it also seems to be one of the principles of GT is described as physical groupings of machines, each grouping or cell being dedicated to the manufacturing of a product family (Nomden and Van der Zee, 2008).

The aim of this paper is to address how GT can assist managers to achieve lean production goals. For this purpose, in the following, the dimensions of GT and its relationship with lean production goals are demonstrated. A new model is then proposed in which the interrelationships between the elements of the two subjects are addressed. The proposed model is also examined in two companies using a questionnaire and finally the results are discussed and final remarks and future research opportunities are addressed.

2. Lean production

There is no agreement upon definition of lean that could be found in the reviewed literature, and the formulations of the overall purpose of the subject are divergent. Discomforting as this may seem for lean proponents, there seems to be quite good agreement on the characteristics that define the concept, leading to the conclusion that the concept is defined in operational terms alone. However, formulating a definition that captures all the dimensions of lean is a formidable challenge (Pettersen, 2009). Inspiring by waste elimination concepts developed by Henry Ford in the early 1900s, Toyota created an organizational culture focused on the systematic identification and elimination of all waste from the manufacturing process. In the lean context, waste was viewed as any activity that does not lead directly to creating the product or service a customer wants. It is important to note that in many industrial processes, such "non-value added" activity can comprise more than ninety percent of the total activity as a result of time spent waiting, unnecessary "touches" of the product, overproduction, wasted movement, inefficient use of material, energy and other factors. The terms "lean production" or "minimum workshop", as Ohno (1978) states, are inspired by the fact that the lean model requires less stock, less space, less movement of material, less time to set up the machinery, a smaller workforce, fewer computer systems and more frugal technology. As well as responding to the need to be cost effective, this characteristic also constitutes a general principle that inspires a philosophy of essentiality and makes every superfluous element seem wasteful.

2.1. Lean production objectives and benefits

The most frequently mentioned characteristics of lean in the literature review are stated as setup time reduction; continuous improvement; failure prevention (Poka Yoke); and production leveling or heijunka (Shahin and Alinavaz, 2008). According to Seth and Gupta (2005), "The goal of lean manufacturing is to reduce waste in human effort, inventory, time to market and manufacturing space to become highly responsive to customer demand while producing quality products in the most efficient and economical manner". Lean manufacturing results could include reduced inventory level (raw material, work in progress, finished product); decreased material usage (product inputs, including energy, water, metals, etc.); optimized equipment (capital equipment for direct production and support purposes); reduced need for factory facilities (physical infrastructure primarily in the form of building and associated material demands); increased production velocity (the time required to process a product from initial raw material to delivery to a consumer); enhanced production flexibility (the ability to alter or reconfigure products and processes rapidly to adjust to customer needs and changing market circumstances); and reduced complexity (complicated products and processes that increase opportunities for variation and error). Also, lean implementation consistently fosters changes in organizational culture through characteristics such as a continual improvement culture focused on identifying and eliminating waste throughout the production process; employee involvement in continual improvement and problem-solving; operations-based focus of activity and involvement; a metrics-driven operational setting that emphasizes rapid performance feedback and leading indicators; supply chain investment to improve enterprise-wide performance; and a whole systems view and thinking for optimizing performance. Lean methods typically target eight types of waste (Muda). These include defects; waiting; unnecessary processing; over production; movement; Inventory; unused employee creativity; and complexity.

2.2. Lean production principles

The lean production model relates manufacturing performance advantage to adherence to three key principles

(Womack et al., 1990; Womack and Jones, 1996):

- i) Improving flow of material and information across business functions;
- ii) An emphasis on customer pull rather than organization push (enabled on the shop floor with Kanban); and
- iii) A commitment to continuous improvement enabled by people development.

As an evidence of the paradigmatic nature of lean production, it is interesting to note how these originally counter-intuitive principles have become main stream managerial concerns. Yet, beyond these general rules, the definition of lean production is actually rather vague and confused. Attempts to empirically assess progress toward lean production have been forced to develop metrics linking together a wide variety of tools and techniques, many based on opposing principles. For example, Karlsson and Alsthrom (1996) describe 18 different elements (each with their own sub-elements) of lean production and the Andersen Consulting (1993) Lean Enterprise Research required firms to fill in a questionnaire that typically took five-and-a-half-days of managerial time to complete (Oliver et al., 1996). If no improvement technique is excluded, then defining what actually constitutes the lean production process becomes extremely difficult.

3. Group Technology (GT)

Group Technology (GT) is a processing philosophy based on the principle that similar products should be processed similarly (Askin and Standridge, 1993). The basic idea of GT is to decompose a manufacturing system into subsystems. It reduces (Kusiak, 1990) production lead time; work-in process; labor; tooling; rework; scrap material; set-up time; delivery time; and paper work. The idea behind GT is to improve efficiencies by exploiting similarities. The application of GT influences time power of operation, WIP inventory, material handling, job satisfaction, jig and fixture, set up time, required space, quality, finished product and labor cost (Wemmer and Hyer, 1998). This concept has been successfully employed in cellular manufacturing in which, parts with similar processing requirements are identified and grouped into part families, and then machines with different processing capacities are placed within a cell (Kusiak, 1990).

3.1. Principles of GT

GT principles can be applied to a number of different areas. For example, Shafer and Ernst (1993) applied GT principles to warehousing operations. In warehousing operations, efficiency can be improved by locating closer together those stock-keeping units which have a higher probability of being picked simultaneously in the warehouse, thereby reducing the amount of time required to fill a customer order (Ham et al., 1985). In the following, some of the principles of GT are addressed.

3.1.1. Constitute groups of products (part family) and GT cells

Groups of product are the number of products that have the similar design characteristics or similar manufacturing processes. Grouping the products is an important step in the use of this technique. Four main methods for grouping products include manual/visual search; nomenclatures/functions; production flow analysis and classification and coding system.

3.1.2. Design conformance

One of the important and practicable benefits of GT based on proper coding system and classification is refining design information and design justification. Design conformance helps to standardize process plan; group scheduling; group tooling setup; and improve inventory purchasing requirements.

3.1.3. Group production

In order to constitute group production, the following steps should be taken:

- i) Machine group/cell: GT allocates machines for one or more product family in order to produce similar production. The machine group layout base on the similarity of components and production process can be categorized in the following three types:
- Group Technology (GT) flow line: in this layout each of part families has almost the same production line or needs the same machines. Group Technology (GT) flow line is the most logical layout and uses the benefits of product-layout.
- Group Technology (GT) cell: in this layout the production process path for one or some part families is not similar, so it is impossible to use GT flow line. In this layout all equipment, tools and machines that are needed are gathered in a cell. The sequence of process is determined by the required operation.
- Group Technology (GT) center: this layout is similar to process layout. The design of work center is proper to

produce the part family.

- ii) Group tooling: For producing a part family, design group of jig and fixtures are required because of similar tools and similar setups.
- iii) Numerical control and part programming: The concept of GT is related to numerical control machine and it is used in part programming. In numerical control planning, the central computer is used for coordinating between similar programming elements of one part family.

3.1.4. GT and production management

The integration of operation management and GT is necessary to enhance productivity and efficiency. Recently computer-aided design and computer-aided manufacturing (CAD/CAM) are noticed and the use of computer is developed and consequently, the role of GT in CIM is more identified. Thus, operation managers are interested in the implementation of GT in computer-aided process planning and computer-aided group scheduling. Computer-aided process planning is one of the key requirements for implementing CIM successfully. Also, GT simplifies the scheduling problems on the base of grouping products.

4. New methodology: A Conceptual Model for the relationship between GT and lean production

As it was illustrated earlier, lean production as a management philosophy tries to eliminate waste (muda) and preserves value added processes in order to enhance productivity. In previous studies, researcher focused on lean production and they address the GT synonym of cellular manufacturing, but it seems that the two subjects are not similar. This paper tries to demonstrate how GT concept and its processes can lead to lean production (eliminate waste) and finally to productivity improvement.

For this purpose, a conceptual model is proposed. This model consists of four sections:

- i) GT processes: Constitute groups of products (part family), Coding system and classification, Design conformance, Group production, GT production management, and automated factory system.
- ii) Intermediate variables: Identifying part family, standardize process plan, group scheduling, group tooling set up, improve inventory purchasing requirement, cellular manufacturing, use of CAD-CAM, and use of DNC-CNC. The secondary intermediate variables are power of operation, WIP inventory, material handling, use of jig and fixtures, set up time, required space and quality.
- iii) Lean production wastes: power of operation, inventory, movement, complexity, waiting, unnecessary process and defect.
- iv) Lean production goals: in lean production systems the main aim is to reduce the wastes and costs to achieve higher productivity.

The new methodology is developed based on the reviewed literature and according to the following three impacts of GT on lean production.

i) The role of part family (grouping, classifying and coding) in lean manufacturing system

Constituting groups of products and GT cells according to similar characteristics of design such as shape, dimension, material and process of production, classifying and coding provides the basis for identifying the products rapidly in systems and this grouping reduces the time of preparing, storing, takt time, lead time and empowers the operation process to decrease over production. Reduction of over production in turn influences waste in lean production and enhances productivity as it is illustrated in Figure 1 (+ and – denote increase and decrease, respectively).

ii) The role of design conformance in lean manufacturing system

After grouping the products and constituting part families, an important step is reviewing the design and refining the design information and justifying the design. Design conformance includes standardizing process plan, scheduling for groups of products, grouping tools, equipments and improving inventory purchasing requirements. These tasks can decrease time, work in process inventories, material handling and increase the power of operation. Group scheduling can reduce the time of process (lead time and takt time) by grouping tools; and equipments and applying proper jig and fixtures to part family can reduce set up time. These two events can diminish and eliminate extra movements, redundancies or unnecessary process and finally leads to designing jig and fixtures in a way that makes the work easy for labor and avoids complexity in the system, improve inventory purchasing requirements, decrease the size of batch material and required space in system, which in turn reduce further inventories, complexity, extra movement and redundancies as wastes in a lean production systems. However, if the addressed elements could be reduced, the productivity of system will increase. This is illustrated

in Figure 2.

iii) The role of GT management and automated factory in lean manufacturing system

Computers could be utilized in production systems for designing, producing and managing the process which are called computer aided design (CAD) and computer aided manufacturing (CAM) or totally, computer integrated manufacturing (CIM), which is a bank of computerized information that consists of design, production and management information. CIM systems integrate computer technology and manufacturing to gain the organization's goals. Automated factory systems are increasingly using new technologies such as direct numerical control systems, computer numerical control machines that control the production processes by a central computer. These mechanisms can improve quality because of reducing defects and errors and eliminating waste in a lean production system. Figure 3 illustrates the context.

5. Case study

In order to validate the proposed model, a questionnaire is designed to measure the viewpoint of industrial managers about the model (Appendix 1). The questionnaire is designed using the five point Likert scale (1: very low, 5: very high). The first 10 questions measure the relationships between GT process dimensions and intermediate factors of GT and lean production; the next four questions measure the interrelationships of intermediate factors; and finally the remaining nine questions measure the relationships between intermediate factors and lean production wastes. The validity of questionnaire is approved by a number of experts. Its reliability is calculated as 0.857 using Cronbach alpha coefficient, which is satisfactory. The questionnaire was filled by two company's managers, i.e. Gaze Seke Co. and Ghetehkaran Co. GazeSeke is a company that produces Gaz, which is a kind of sweet and has a flow shop operation and six of its managers filled the questionnaires; Ghetehkaran produces automobile pieces and has cellular manufacturing and nine of its managers filled the questionnaires. For analyzing the questionnaires, Mean values of each of the relationships are tested by one sample T-test with a t-value of 3.00. It is interesting to note that the significant value of all of the questions derived as zero, implying that all of the answers have a mean value different from 3 and more than 3 (with respect to the mean values). Table 1 presents the mean values and standard deviations with a confidence level of 95 percent.

6. Discussion

According to the theoretical and empirical results of this research, it is argued that productivity of lean manufacturing systems will be improved if the system reduces its waste and none added value processes. On the other hand, in GT, the philosophy is to divide systems in to subsystems. The conceptual model emphasizes on the fact that in manufacturing systems, GT constitutes groups of products in to part families, classifying and coding the part families, designing the process of similar part families and consequently classifying tools, machines, equipments that lead to designing and preparing the customized jig and fixtures for similar part families. Cellular manufacturing is a kind of layout that may be used in GT systems and as it is stated before, this kind of layout is one of the tools and methods of lean production systems. Recently, the use of computers in production systems has become prevalent and the role of GT in computer aided process planning (CIM) is more recognized, so production managers are interested in using it in CIM. The last step of GT is to developing and extending the use of industrial robots, center machining, CNC, DNC, micro processors and etc. to lead the production systems into integrated computerized systems. On the other hand, the foundation of automated factory systems is on cellular manufacturing and grouping the systems.

The proposed model tries to illustrate the relationship of GT and lean production systems with the fact in mind that such synergy will diminish wastes and redundancies. The model was validated using a questionnaire and the results were presented in Tables 1 and 2. The results imply that all of the mean values are higher than the median (i.e., 3) considering 0.95 level of confidence, denoting a high relationship between the two subjects. The derived values are highlighted in Figure 4.

According to Figure 5, the highest Mean-value is 4.46, which is related to the second question, i.e. coding system and classification on fast identifying if part family. Also, the lowest mean value is 3.46, which is related to question 15, i.e. increasing the power of operation to decrease over production and it declares the fact that managers believe the effect of increasing the power of operation to decrease over production is less than other parts of proposed model. Another statistical analysis is related to variance analysis of two groups of managers in the two companies (Gaze Seke Co. and Ghetehkaran Co.). The results imply that for all of the questions except question 12 and question 15, there is not significant difference between two groups of managers. This fact may refer to their similarity in flow shop production, variety of product types and lot size of their production. As it is addressed, the significant value of question 12, i.e. use of cellular manufacturing to decrease set up time is less

than 0.05, which means there is a difference in the viewpoints of the two groups of respondents. This result may be due to the different processes of two companies; in Gaze Seke Co. the raw material of most types of products are the same and the process of production is similar, but in Ghetehkaran, the process of production is different from one product to another. The significant value of question 15 is also less than 0.05, which highlights a difference in viewpoint of the two groups of respondents. It may be due to limitations of the process of production in Gaze Seke Co. In this company, over production is inevitable, because of the special process of Gaz manufacturing. It is important to note that question 15 has the least mean value. Consequently, the relation of power of operation and over production needs more investigation and research.

However, this research may have some limitations. For instance, as it was mentioned in the literature review, GT is applied for operation systems with multi products and lot size. Therefore, the proposed model should be further examined in other companies with more than one product system, although the model seems to be applicable for multi product systems with lot size. Although the model emphasizes on the application of GT for enhancing productivity, it does not indicate the amount of productivity increase. The model does not offer any approach for measuring the production changes, while applying GT processes. In GT, the philosophy is to divide systems in to subsystems and it refers to all systems of the organization. The proposed model is concentrated on operational systems, but it can be extended into other parts and systems of organization such as financial, administration, research and development, information systems, etc.

7. Conclusions

This paper demonstrated the dimensions of GT and its relationship with lean production goals. In fact, an attempt was made to address how GT can help manufacturing systems to achieve lean production goals. A conceptual model was also proposed for the relationship between the two subjects. In order to examine the links of the model, a questionnaire was designed and filled by managers of two companies. The two companies were Gaze Seke and Ghetehkaran. Data analysis approved the high relationship between the dimensions of the proposed model. The variance analysis also addressed no difference between the two groups of respondents except for two questions.

Although researchers focused on lean production and they address the GT synonym of cellular manufacturing, it seems that the two subjects are not similar. The paper emphasized on GT and its processes to achieve lean production and productivity improvement. GT has many effects on production wastes; particularly it can improve set up time, quality, inventory management, jig and fixtures in order to decrease waiting time, defects, inventory and over production.

This paper focused on the two subjects of GT and lean production and their linkage to enhance productivity but it didn't indicate that how much GT can improve the productivity and lean production goals. It is important to note that the proposed model does not offer any measurement approach for measuring the effects of variables on productivity. The proposed model is applied for manufacturing systems and particularly for mass production. Since the model is applied for manufacturing systems, it is highly recommended to be customized and implemented in other organizations such as service companies. Identifying indicators for measuring the amount of increase in productivity is recommended for future studies. Also, the relationship of power of operation and over production which was indicated in the model needs more investigation.

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Table 1. Results of one sample t-test

Ouestion	Mean Std		Question	Mean	Std	
Question		Deviation			Deviation	
Constituting part family on fast identifying of part family	4.0667	0.4577	Use of CAD-CAM manufacturing on increasing quality	4.2000	0.8619	
Coding system and classification on fast identifying of part family	4.4667	0.5164	Use of CNC-DNC Robot on increasing quality	4.0667	0.8837	
Standardizing the process on decreasing WIP inventories	4.0000	0.8452	Increasing the power of operation on decreasing over production	3.4667	0.8338	
Group tooling set up on increasing use of jig and fixtures	3.7333	0.7037	Decreasing WIP inventories on decreasing inventories	3.8000	0.8619	
Group tooling set up on decreasing set up time	4.2000	0.6761	Material handling on decreasing inventories	4.2667	0.7037	
Improving inventories on decreasing required space	4.4667	0.8338	Reducing required space on decreasing inventories	3.6000	0.8281	
Improving inventories on better material handling	4.4000	0.6325	Increasing the use of Jig and Fixtures on reducing movement	3.9333	0.5936	
Group Technology production management on the use of cellular manufacturing	3.8000	0.6761	Increasing the use of Jig and Fixtures on reducing complexity in system	3.7333	0.7988	
Group Technology production management on the use of CAD-CAM manufacturing	3.6667	0.9759	Increasing the use of Jig and Fixtures on reducing unnecessary process	4.0000	0.6647	
Automated factory system on increasing the use of CNC-DNC, Robot	4.0714	0.6157	Reducing set up time on reducing waiting time	3.7333	0.8837	
Fast identifying of part family on increasing the power of operation	4.1333	0.7432	Increasing quality on reducing defects	4.3571	0.9288	
Use of cellular manufacturing on decreasing set up time	3.6667	0.4880				

Confidence level = 95 percent

Table 2. Results of the two independent sample test for comparing the responses of the two companies

Question	Asymp. Sig	Question	Asymp. Sig
Constituting part family on fast identifying	0.060	Use of CAD-CAM manufacturing on	0.479
of part family		increasing quality	
Coding system and classification on fast	0.838	Use of CNC-DNC Robot on increasing	0.183
identifying of part family		quality	
Standardizing the process on decreasing	0.533	Increasing the power of operation on	0.005
WIP inventories		decreasing over production	
Group tooling set up on increasing use of jig and fixtures	0.478	Decreasing WIP inventories on decreasing inventories	0.488
***************************************	0.601		0.071
Group tooling set up on decreasing set up time	0.001	Material handling on decreasing inventories	0.071
Improving inventories on decreasing	0.204	Reducing required space on decreasing	0.640
required space		inventories	
Improving inventories on better material	0.188	Increasing the use of Jig and Fixtures on	0.230
handling		reducing movement	
Group Technology production management	0.069	Increasing the use of Jig and Fixtures on	0.799
on the use of cellular manufacturing		reducing complexity in system	
Group Technology production management	0.666	Increasing the use of Jig and Fixtures on	0.421
on the use of CAD-CAM manufacturing		reducing unnecessary process	
Automated factory system on increasing the	0.172	Reducing set up time on reducing waiting	0.319
use of CNC-DNC, Robot		time	
Fast identifying of part family on increasing	0.127	Increasing quality on reducing defects	0.840
the power of operation			
Use of cellular manufacturing on decreasing	0.031		
set up time			

Confidence level = 95 percent

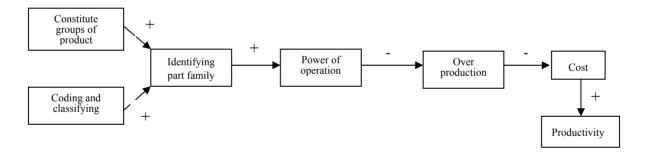


Figure 1. The impact of part family (grouping, classifying and coding) on lean manufacturing system -Extracted and modified from Ham et al. (1985)

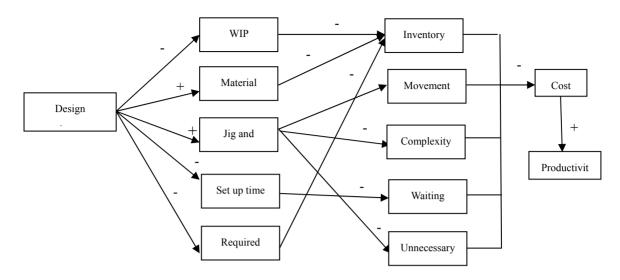


Figure 2. The impact of design conformance on lean manufacturing system-Extracted and modified from Ham et al. (1985)

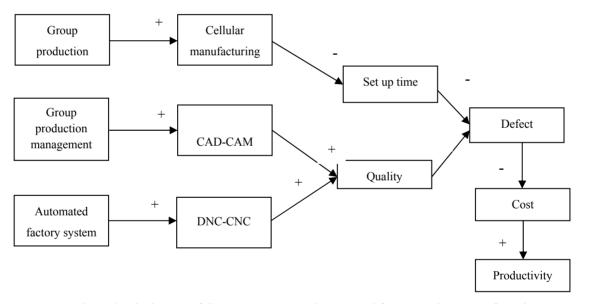
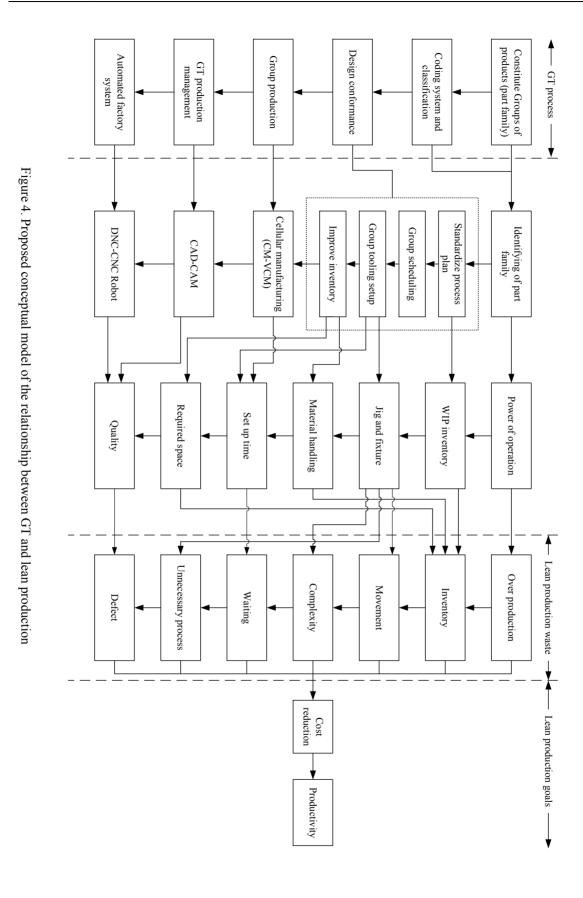
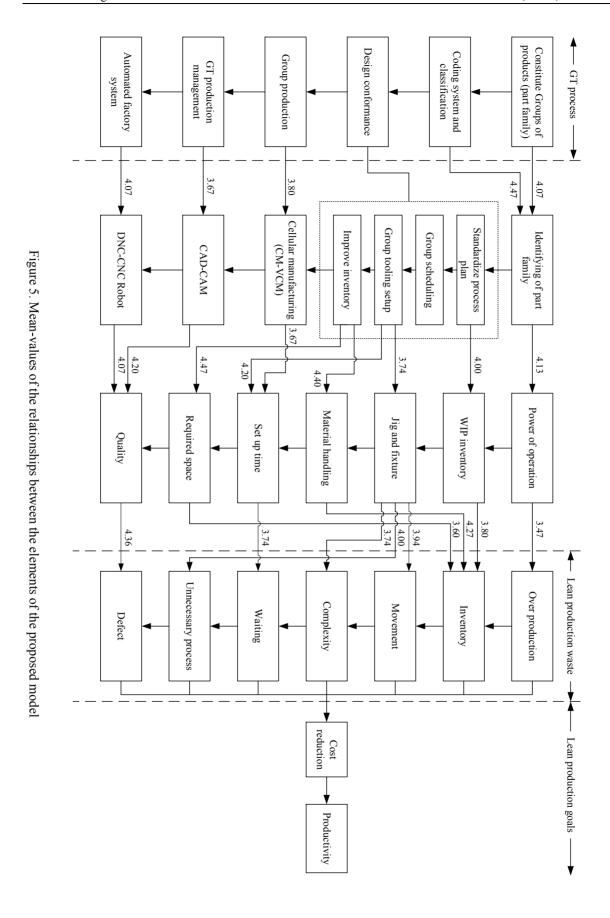


Figure 3. The impact of GT management and automated factory on lean manufacturing system - Extracted and modified from Ham et al. (1985)



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Appendix 1. Questionnaire

The aim of this investigation is to study the effects of Group Technology on lean production. Please mark the choices which are close to your idea. Thank you for your participation.

Demographic characteristics:

Gender:	male (female	\bigcirc		
Age:	20-30	30-40	Ŏ	40 or	over \bigcirc
Degree:	BS	MS	\bigcirc	P	h.D. 🔘
Years of expe	rience since e	mployment:			
Under 10 year	rs	to20	20to3	$0\bigcirc$	

		very				very
No	Question	high	high	medium	low	low
1	Constituting part family on fast identifying of part family					
2	Coding system and classification on fast identifying of part family					
3	Standardizing the process on decreasing WIP inventories					
4	Group tooling set up on increasing use of jig and fixtures					
5	Group tooling set up on decreasing set up time					
6	Improving inventories on decreasing required space					
7	Improving inventories on better material handling					
8	Group production on the use of cellular manufacturing					
9	Group Technology production management on the use of CAD-CAM manufacturing					
10	Automated factory system on increasing the use of CNC-DNC, Robot					
11	Fast identifying of part family on increasing the power of operation					
12	Use of cellular manufacturing on decreasing set up time					
13	Use of CAD-CAM manufacturing on increasing quality					
14	Use of CNC-DNC Robot on increasing quality					
15	Increasing the power of operation on decreasing over production					
16	Decreasing WIP inventories on decreasing inventories					
17	Material handling on decreasing inventories					
18	Reducing required space on decreasing inventories					
19	Increasing the use of Jig and Fixtures on reducing movement					
20	Increasing the use of Jig and Fixtures on reducing complexity in system					
21	Increasing the use of Jig and Fixtures on reducing unnecessary process					
22	Reducing set up time on reducing waiting time					
23	Increasing quality on reducing defects					