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Balancing the efficiency and effectiveness of new product development through implementation of Lean principles

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Introduction:

Economic crises, evolving market demand, and stiff global competition are kinds of challenges that engineering companies face nowadays, many of them just struggling for survival. Companies are constantly looking for new ways of guaranteeing their long term success and sustainability in a highly competitive global environment. Focusing on incremental improvement and innovation to their products, as well as enhanced product quality, shorter project lead times, and improved cost effectiveness have been the centre of attention of many companies during last two decades. However, despite considerable improvement there is still significant opposition to the 'better, faster and cheaper' paradigm. While reduction in R&D investment have reduced the innovative products, adhering to new regulations and standards have increased the projects lead time and inflation rate and intense global competition have hindered cost effectiveness. Facing these problems companies have tried to improve their process performance especially in new product development by incorporating novel management techniques, among them Lean thinking, which is an improvement philosophy based on the creation of value and the elimination of waste, is a potential solution in this regard (Womack and Jones 1996).

Lean thinking has been the subject of research since early 1990s, mainly on improving manufacturing processes (Womack, Jones and Roos 1990), as well as administration, management and the supply chain. However, applying Lean in new product development is still a very conceptual idea, with no detailed tools or methodologies and no detailed level of implementation available, possibly because of unstructured and iterative approach in traditional new product development (Khan 2012). It was first by industrial revolution that companies were forced to start developing new products for a particular market, making use of traditional product development processes. While the main principle remained the same, the complexity of development processes evolved over the years as a result of more sophisticated products and demanding customers, meaning that new products needed to be developed with different functions, phases and activities (Ulrich and Eppinger 2012). Improving the performance of new product development processes with Lean philosophy proves helpful in the progress of engineering, and opportunities for research in this field, including theory building, developing methodologies, as well as analytical and experimental research, are numerous because of the lack of academic research related to that.

Research aim and objectives:

The main aim of this research is to develop an innovative model to support manufacturing companies in implementing Lean in their new product development processes by focusing on improving both the efficiency and effectiveness of processes. This aim is in response to the overall research question: how different is Lean implementation for innovative and knowledge-intensive environments such as new product development? Combining Lean product development principles and practices the model is expected to help companies in developing more customer-focused and innovative new products with better quality, while reducing time-to-market and development costs.

To reach to the answer of the general research question it is divided into three sub-questions as shown in figure 1.

Figure 1: Research questions aligned with objectives

Research context:

Research is a systematic process, using scientific methods, to discover or investigate new facts. To develop a proper research methodology it is important first to elucidate the context of the research. The focus of this research is on the field of new product development (NPD) which can be defined as the complete process of transforming conceptual ideas into marketable products (Smith 2010). In addition, this research fall under the research area of systems engineering, which, based on the definition of Kapurch (in Khan 2012), is a disciplined and methodical approach to different stages of a system from design and realisation to technical management, operations, and finally retirement. It could also be defined as an interdisciplinary approach or a structured, disciplined, and documented technical effort to simultaneously design and develop systems products and processes to satisfy the needs of the customer (Belay, Welo and Helo 2014).

Contribution to the knowledge is the fundamental aim of this research, so justification of what is being regarded as knowledge, which is the subject of epistemology as a branch of philosophy, is important. Although it is difficult to classify most of researchers into the categories of any given typology, this research adopts a hybrid of social constructivism and pragmatism as its epistemological standpoint, as the contribution to knowledge will be both a result of the interaction between social phenomena (social constructivism) and also what the researcher will develop as a result of what is learnt from practice (pragmatism). Covering the study of human being in social settings and trying to develop a theory for real world settings put this study in the field of applied research in social science.

Three main types of research design which are largely applied by academic scholars are qualitative, quantitative and mixed design (Saunders, Lewis and Thornhill 2007), between them this research will adopt a qualitative approach. The main reason for this design is to develop a rich understanding of the social settings and the impact of the research on them, which is significant where the research needs to draw on multiple perspectives and be responsive to both primary and secondary data. Qualitative research supports studies related to detail explanation, exploration or empathy, so ideals of qualitative research involve rich description, meaning, reflection and connection to the investigated subject area.

Based on qualitative design, Saunders, Lewis and Thornhill (2007) suggested ethnography, grounded theory and case study as three main strategies for research. Case study comprises the investigation of a theory based on a single or a number of cases of an individual or group of participants. They can be used to describe what is learnt about a particular phenomenon within a contextual boundary, or propose some generalisations for similar contexts which may be tested in future (Yin 2014). Another advantage of adopting a case study approach is that it may benefit from prior development of theoretical propositions to guide data collection and analysis.

Research process:

After defining research type and strategy, the research process presents the phases, tasks and methods that will be adapted. The adopted research process could be divided into three interrelated phases. Each phase consists of some tasks for accomplishment using mentioned methods of data collection. These are literature review to establish a research gap, and case studies in manufacturing innovation-based companies, including interviewing the main informants, as well as reviewing archival data related to past projects and doing observations during their process of new product development, to take industrial perspectives, modelling base on system dynamics (discussed later) and finally, semi-structured validation (based on the work by Andersen, et al. 2012) to derive a conclusion from the research. The first phase is the exploratory phase wherein the first objective will be addressed. This will be followed by the modelling phase, in which a model will be developed thus satisfying second objective. The third and final phase is the test phase through which the final objective will be addressed (figure 2).

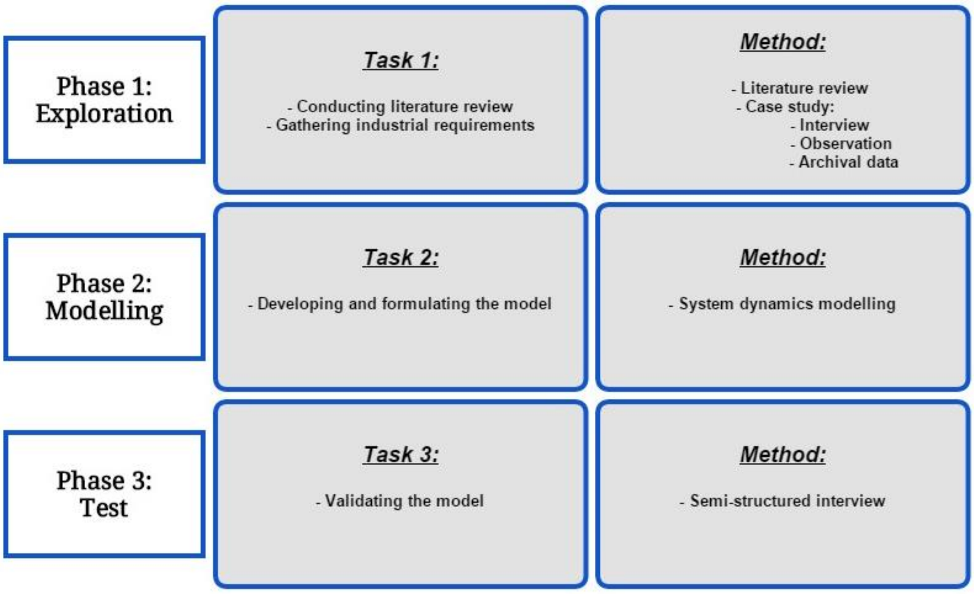

Figure 2: Phases of the research project

Current research directions in process-modelling area:

There are two general assumption which researchers in the field of process modelling relies on (Martínez León and Farris 2011): first, the execution of the process is positively affected by the information flow improvement, leading to the faster development of better products, with or without cost improvement ; and, second, process architecture affect the development cost, time and quality. In other words, as Senge (1993) mentioned "when placed in the same system, people, however different, tend to produce similar results" or "structure influences behaviour" which is the first principle of systems thinking (Martínez León and Farris 2011). Current research on process modelling has, therefore, focused on understanding Lean product development process structure, and its behaviour over time.

Browning (2003) argued that, in new product development processes, the flow of information is similar to the flow of deliverables, and is defined by the process structure which has great impact on value. This argument implicitly explains the aforementioned first system thinking principle in Lean product development terminology (Martínez León and Farris 2011). As a result, the structure of the activity network determines the value trajectory of the Lean product development process, and, thus, its efficiency and effectiveness (Browning 2003).
Traditional project schedule management techniques, such as Program Evaluation Review Technique (PERT), and Critical Path Method (CPM) have been more widely used in industry for new product development projects (Martínez León and Farris 2011). However, these techniques are typically cited in the new product development/Lean product development body of knowledge only to show the inadequacy of their assumptions development processes (Lin, et al. 2008, Wang and Lin 2009, Martínez

León and Farris 2011). Iteration, an inherent characteristic of new product development, is an important element for modelling Lean product development processes as well, and iteration-aware models are expected to better describe the time-based behaviour of the structure of Lean product development processes than the traditional project schedule management techniques, such as PERT and CPM, which do not account for iterations (Martínez León and Farris 2011). Ignoring iterations or implicitly incorporating them into duration estimates in traditional project management models limit the capability of these scheduling techniques in modelling new product development processes. Therefore, there is a need for another modelling techniques for iterative product development processes. For example, Browning and Eppinger (2002) developed the first simulation model based on Design structure matrix (DSM) technique for analysing new product development iterations in a generalized project network (Lin, et al. 2008). In addition, several researchers (Ford and Sterman 1998, Repenning and Sterman 2001, Ford and Sterman 2003, Lin, et al. 2008) tried to use system dynamics models for investigating the continuous progress of new product development projects.

Besides the iterative nature of the new product development processes, especially in Lean product development, the concept of overlapping the phases or stages of development (process concurrency) instead of sequential development is at the centre of attention of these researchers. For instance, Lin et al. (2008) developed a system dynamics model for overlapped and iterative new product development processes in that they incorporated the probability of discovering errors of upstream in downstream activities and giving feedback. In another work, Belay, Welo and Helo (2014) investigated the effects of front-loading using set-based concurrent engineering on cost and lead time using a system dynamics approach. All these attempts just focused on a part of the development process and some of performance measures, while still there is a need for a holistic modelling of new product development processes to investigate their influence on different parameters of performance.

System dynamics modelling:

Lean product development consists of interrelated components as elements of a coherent system (Karlsson and Åhlström 1996, Morgan and Liker 2006, Hoppmann, et al. 2011), each one have a different effect on the parameters of performance.

Some characteristics of Lean product development as defined by Liker and Morgan (2011) make research in this field challenging. Looking at Lean product development as a system of interwoven components which needs an integration between people, processes and tools in order to be effective makes it impractical to test hypotheses about the effectiveness of individual best practices. In other words, whereas a system’s view assumes complex interactions between variables, looking at system features in isolation will break the integrity of the system and result in misleading conclusions (Senge 1993). As a result, instead of conventional, cross-sectional surveys that look at collections of best practices as independent variables predicting outcomes greater vision can be gained by in-depth cases studies (Liker and Morgan 2011).

One way for companies to check these effects is by experimenting in the real world. This, however, may be very expensive, time consuming or even risky if the decision is proved wrong. A safer way for managers is to use virtual models to assist them in the logical analysis of a simulation in order to take a decision and in controlling business processes by identifying, up front, the consequences of an action. A model as defined by Pidd is an external and explicit representation of parts of reality as seen by the people who wish to use that model to understand, change, manage and control that part of reality (Galanakis 2002). Compared to real experimentation, modelling has lower cost, and is faster, safer and more legally compatible while it is also possible to replicate the same conditions in order to repeat the simulation with any combination of decisions (Pidd, 1998 in Galanakis 2002).

To have a good virtual model representing the reality it should be simple, concrete, and fully defined. While this simplification compared to the reality put some limitation on modelling, it is the actual reason of usefulness of models. However, it is important for a model to be validated within the framework of scenarios which are being examined. Model construction is a step by step process which its goal is to clarify the aspects of reality under study and creating an understanding of why reality reacts in such a way (Pidd, 1996 in Galanakis 2002). It this situation, the full definition of the problem may only emerge during the process of modelling. Because of below reasons, as Pidd mentioned, business models are difficult to be validated (Galanakis 2002), so, validation of the model, as Coyle and Exelby (2000) suggested, can be replaced by referring to the level of confidence of the conclusions derived from the output of the model.

1- The reason for building a model is often to help investigating the way something works or might work. So, the model is a theory about the operation of its reference system and so there is no understood reference to which the model can be compared.
2- Models may be built under known conditions and be used to study ways of improving these conditions. Thus the original reference system is not valid any more.
3- Models are often used to predict the future. The future however is uncertain and unknown, that is why it is modelled in the first place. Therefore, the future is the reference system.

System dynamics, an approach selected for modelling in this research, aims to describe the system, understand the effect of feedback loops on system's behaviour, and design vigorous information feedback structures and control policies through simulation and optimisation (Galanakis 2002). System dynamics modelling rooted in engineering, but is commonly used for business administration and public analysis. In this modelling approach connections between different system elements and their behaviour are at the centre of study, and the changes in policies are being designed based on the feedback structures and the system’s response to feedbacks (Pidd, 1996 in Galanakis 2002). Between different supportive computer-based modelling packages, such as DYNAMO, STELLA, VENSIM, and POWERSIM, The VENSIM package has been selected to develop and simulate the model because of its advanced and easy-to-use interface for modelling, writing the equations and presenting the results.

Sterman (2000) suggested a five-stage approach, which is used in System Dynamics modelling to understand, control and improve a system (Figure 3). It is important to mention that the modelling process is iterative, and results of each step can yield insights that lead to revision in any other earlier stage.

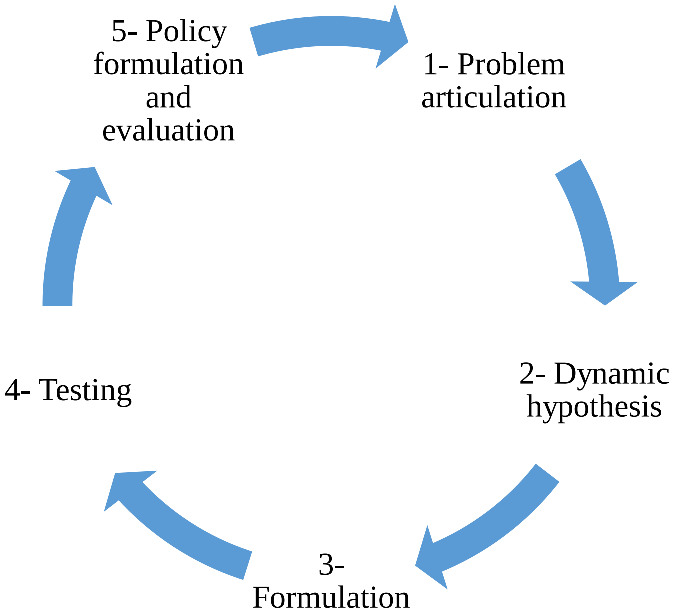

Figure (3): The process of system dynamics modelling

1- Problem articulation:

The most important step in modelling is problem articulation by asking question such as: what is the purpose of the model? And, what problem is it trying to address? Although a model with the clear purpose can still be difficult to understand, a clear purpose always helps revealing the usefulness of the model in addressing the problem. Every model is a representation of a system, a group of functionally interrelated elements forming a complex whole. But, to be useful, the model should simply address a specific problem rather that mirroring an entire system in detail. The usefulness of the models lies in the fact that they simplify reality, by creating a comprehensive representation of it. Actually, the model purpose is as a criteria for decision on what can be ignored and what are the essential features necessary to fulfil the purpose. Without the purpose the model would have a very wide boundary and should include an overwhelming array of variables.

2- Formulating a dynamic hypothesis:

After identifying the problem, developing a theory, called a dynamic hypothesis should be began. It is a hypothesis because it is always provisional, subject to revision or abandonment. Much of the reminder of the modelling process helps modeller to test the dynamic hypothesis, both with the simulation model and by experiments and data collection in the real world.

System dynamics includes a variety of tools, such as causal loop diagram and stock and flow maps, to help communicating the boundary of the model and representing its causal structure. A causal loop diagram is a flexible and useful tool for diagramming the feedback structure of a system in any domain. They are maps showing the causal links among variables with arrows from a cause to an effect. A stock and flow map emphasises its underlying physical structure. It tracks accumulation of material, money and information as they move through the system. Stocks characterize the state of the system and generate the information upon which decisions are based. The decisions then alter the rates of the flow, altering the stocks and closing the feedback loops in the system.

3- Formulating a simulation model:

Sometimes it is possible to directly test the dynamic hypothesis through data collection and experimentation in the real system. However, most of the time because of the complexity of the model, its dynamic implications are vague. In many situations, especially in human systems, it is difficult, unethical and even impossible to conduct a real world experiment to reveal the flaws in a dynamic hypothesis. So, doing that in a virtual world needs a fully specified formal model with equations, parameters and initial conditions. Formalization helps in recognizing unclear concepts and resolving unnoticed contradictions during conceptual phase. System dynamics practice includes a large variety of tests during the formalization stage for identifying flaws in proposed formulations and improving the understanding of the system.

4- Testing:

Testing includes comparing the simulated behaviour of the model to the actual behaviour of the system. Every variable must correspond to a meaningful concept in the real world. Every equation must be checked for dimension consistency, and finally the sensitivity of model behaviour must be assessed in light of the uncertainty in assumptions, both parametric and structural.

5- Policy design and evaluation:

After developing the confidence in the structure and behaviour of the model, it can be used to design and evaluate policies for improvement. Policy design includes the creation of entirely new strategies, structures and decision rules. Since the feedback structure of a system determines its dynamics, most of the time high leverage policies will involve hanging the dominant feedback loops by redesigning the stock and flow structure, eliminating time delay, changing the flow and the quality of information available at key decision points, or fundamentally reinventing the decision processes of the actors in the system. The robustness of policies and their sensitivity to uncertainties in model parameters must also be assessed, including their performance under a wide range of alternative scenarios.

Comparing with the 3 phases of research process designed for this project, it is possible to connect those phases with the 5-stage approach to system dynamics modelling proposed by Sterman (2000). Back to figure (2), phase 1 of research, exploration, cover the first two stages of modelling, which are problem articulation and dynamic hypothesis. Phase 2 and 3 of research process, Modelling and testing, are exactly the same as third and fourth stage proposed by Sterman, which are formulating a simulation model and testing. Finally, the fifth stage of system dynamics modelling, is out of the scope of this research.

Performance in new product development- Efficiency and effectiveness concepts:

Viewing the new product development as a transformation process which by using allocated resources produce a definite output, its performance can be translated as the efficiency and effectiveness of purposeful action (Neely, Gregory and Platts 2005). As Tangen (2005) mentioned most researchers agree that the main difference between these two concepts is that the efficiency is input oriented and relates to the internal performance of a process while the effectiveness is about the results and output oriented, so links to the external performance. Sink and Tuttle (from Tangen 2005) in simple words described efficiency as 'doing things right' and effectiveness as 'doing the right things'. Efficiency as defined by Neely, Gregory and Platts (2005) is the measure of economically utilization of a firm's resources in order to provide a certain level of customer satisfaction. It is the main standpoint of most practitioners when they look at the process improvements in terms of Lean implementation; They just see the short-term outcomes in order to produce more with less resources, or to become faster, cheaper and better, but in reality they scarify the effectiveness. Ironically, it is possible to develop a new product efficiently in smaller time and with lower cost and the results still be a complete failure for the company in the market. In other words, a firm can be efficient in introducing new products, but this efficiency will not guarantee a competitive advantage unless the firm produces customer value as a result of its effective new product development processes. There are several examples of problems originated from too much focusing by organizations on efficiency and neglecting effectiveness, for instance, failures in some of NASA's Mars missions as a result of emphasising on "faster and cheaper" products (Browning and Sanders 2012).

As the final goal of every new product development project is higher profitability, introducing a product to the market which match the customer expectations and target customers are willing to pay for it should be at the centre of consideration. Effectiveness of new product development process is very difficult to quantify in most cases because as Neely, Gregory and Platts (2005) argued it is about the extent to which customer requirements are being met. In spite of efficiency, effectiveness is about the outcomes, results and the ability of a firm to reach a desired objective or the degree to which a desired results are achieved (Tangen 2005). While it is possible for an efficient system to be ineffective, the opposite situation is also probable in that an effective system could be inefficient, so it is the combination of high values of efficiency and effectiveness in a transformation process such as new product development which leads to higher achievements.

As Lewis et al (2002) mentioned, whereas certain activities may foster one while impeding the other, reaching to both effectiveness and efficiency needs some trade-off between opposing demands in new product development efforts. They emphasised the ability to manage tensions between loosely and tightly coupled activities, bottom-up and top-down processes, and flexibility and formality, or as Brown and Eisenhardt (1995) highlighted, awareness of the need to balance opposing forces and integrate multiple factors, as a driving force for higher performance in new product development activities.

To be applicable form industrial perspective, performance measures should be dynamic (Yazdani 2000). Smith and Reinertsen (1998) mentioned that there are four objectives that should be measured in the management of new product development processes. Also, there are trade-offs between these objectives, development speed, product cost, product performance and development expense, which are modelled based on specific company conditions and the economic balance which allow managers to make dynamic decisions at project and company level. In other work, Clarks and Fujimoto (1991) identified three performance dimensions based on long term competitiveness of new product development processes. They put these performance dimensions in a simple framework as shown in figure (4).

1- Lead time which is the time passed between concept development and introduction of the product to the market and based on Clark and Fujimoto (1991), and Smith and Reinertsen (1998) plays a vital role in the success of new product development efforts.
2- Productivity which is defined based of the amount of resource consumption, have the engineering hours as its main measure, while the cost of the development process should also be a part of it (Yazdani 2000).
3- Total product quality (TPQ) in about the degree that customer requirements are being satisfied by the final product.

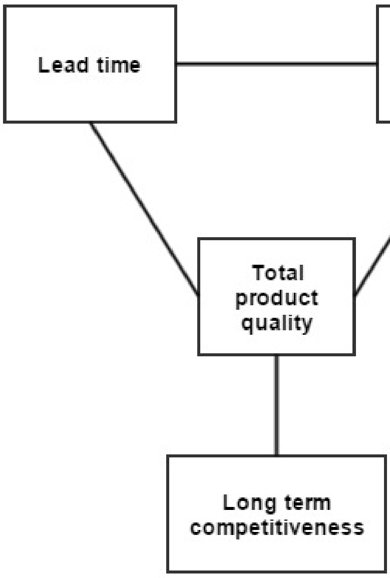

Figure 4: dimensions of new product development performance (from Clark and Fujimoto 1991)

For this research a combination of measures proposed by Clark and Fujimoto (1991), and Smith and Reinertsen (1998) will being used which form a basis for modelling the dynamics of the new product development system as shown in figure (5).

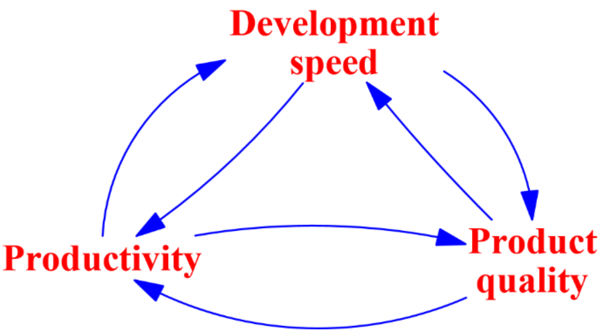

Figure (5): performance measure and their interrelation

Development speed is a key component of time-based strategy, which has become increasingly important for managing new product development processes in a fast-changing business environment (Chen, Damanpour and Reilly 2010). Productivity, as mentioned before, is the level of resources, including engineering hours worked, and the cost of equipment, services, and materials used mainly for prototype construction and testing, required to take the project from concept to commercial product. product quality is affected both by objective characteristics of the product such as the quality of design (design quality) which is the degree to which product designs are matched with customer expectations (Clark and Fujimoto 1991), especially from the performance perspective, as well as subjective evaluations such as the degree of match between final design and defines concept from the point of view of aesthetics, style and experience (perceived quality).

Lean product development:

Applying Lean concepts to technical and engineering operations, such as new product development, where work is less repetitive than the manufacturing and the product is less tangible, is not straightforward (Liker and Morgan 2006). Additionally, since components and structures that have been found to support an efficient and effective new product development process show only few similarities between manufacturing and product development (Haque and Moore 2004), most of the authors, instead of just adopting tools from the manufacturing, have taken the approach of investigating and identifying best practices in the field of new product development, mainly from Toyota, that leverage the benefits of Lean principles. In line with this view, this research employs seven common components of Lean product development, proposed in their models and frameworks by different researchers, including Karlsson and Åhlström (1996), Morgan and Liker (2006), Ward (2007), Cooper and Edgett (2008), Hoppmann, et al. (2011), and Khan et al. (2013) for modelling. Clarifying the relation between these Lean components and performance measures introduced in figure (4) is the first step of the process of modelling.

- **Concurrent (simultaneous) engineering**

Process concurrency as the result of concurrent (simultaneous) engineering as one of the common themes in Lean product development, emphasised by almost all researchers in the field. A direct outcome of process concurrency could be reducing the process lead time as a result of overlapping different phases of new product development processes. But there is an almost neglected negative effect of process concurrency which Lin et al. (2008) mentioned in their work. Corruption probability is the probability of the task in downstream phases to be corrupted because of the change of tasks in a relevant upstream phase and is highly affected by the dependency between overlapped phases. In corruption, the downstream tasks need to be reworked, whether they have been done correctly or not, because they have been based on incorrect information of upstream phases (Lin, et al. 2008). Increasing the degree of concurrency between phases will result in higher corruption probability, which increases the amount of rework and unplanned iteration between phases. The time of iteration and rework will be added to the planned time of doing the job, and thus increasing the actual lead time of the project as a result of reducing the process speed. It will also result in consuming more resources and decreasing the productivity of the process. On the other side, increasing the frequency of information transfer between the team members instead of batch transformation of information between functional groups in traditional sequential product development processes may increase the process complexity and as a result, have a negative effect on process speed. Front-loading is defined by Thomke and Fujimoto (2000) as ‘‘a strategy that seeks to improve development performance by shifting the identification and solving of problems to earlier phases of a product development process’’. Front-loading the process of new product development is one of the other outcomes of process concurrency where different functional groups are participating in the process from its outset. This will reduce the amount on expensive late design changes, as well as unplanned iteration and reworks, so have the positive effect on process lead time and process productivity.

- **Customer focus:**

One of the pillars of Lean philosophy is focusing of customer needs and aiming to satisfy the final customers (Womack, Jones and Roos 1990). This lean principle have been directly transferred to Lean product development and so, no product will be designed and developed unless there is a customer demand that could be satisfied. This will shows its result in increasing the quality, as well as the innovativeness of the final product. But, on the other side, because finding and extracting the actual customer needs is complicated and time-consuming, and customers' demands are ever-changing, focusing on the customer could result in too much late design changes that is a main source of rework and unplanned iteration during the process. These reworks and iterations will affect process speed and productivity in a negative way.

- **Chief engineer system:**

The chief engineer system based on Morgan and Liker (2006) is one of the characteristics of Toyota product development system (TPDS) which involves cross functional teams plus heavy-weight project managers who are leaders and technical systems integrators (Morgan and Liker 2006). Internal integration as a result of chief engineer system and cross functional teams can reduce misunderstandings between different functional groups. Misunderstandings are the main source of errors which if remain undetected would deteriorate the product quality, and in case of being detected would increase the amount of rework and unplanned iteration. Besides, it facilitates the information access across the cross functional teams which increases the speed of decision making and process speed, accordingly. Internal integration, also, is one of the prerequisites for process concurrency. Team autonomy is another outcome of chief engineer system, in which, the assigned heavy-weight project manager is in charge of the whole process of product development and have the unique authority to make vital decisions. Consequently, the waiting time for manager approval will reduced that have a positive effect on decision making speed. In addition, increasing the flexibility of the development process as a result of team autonomy will increase the team member's motivation and have a positive effect on their creativity which shows itself in the innovativeness of the final product. On the other side, process flexibility may increase the unplanned reworks and iterations, and thereupon, has negative effect on process productivity and lead time.

- **Process and product standardization:**

Standardization is a part of Lean philosophy which allows organizations to follow continuous improvements in their processes (Hoppmann, et al. 2011). Product standardization is about using common parts between different designs of new products and is based on incremental modular innovation. It could help reducing the design time which positively affects process speed and productivity. But, on the other hand, it could reduce the team autonomy as team members will not have enough flexibility in applying new designs. It mainly affects the innovativeness of the final product and may damage the customer perceived quality. Forcing team members to follow standardized rules and procedures in their work as a result of process standardization may also negatively affect the innovativeness of the final product as it can reduce the member's motivation, but at the same time, as it reduce the amount of deviation from the schedule, process speed and productivity would be increased.

- **Set-based design:**

Unlike point-based design which iterates only on a single solution, based on Ward, et al. (1995) and Sobek II, Ward and Liker (1999), set-based design is an approach of reasoning, developing, and communicating ambiguously about sets of solutions independently in parallel, making late decisions in the best ongoing converging solutions. It is the driver of front loading of the process of new product development, which may later deceases the amount of unplanned iteration and reworks, so increases the process speed and productivity. On the other side, as it is about working on different separated designs on the same time, it may consume more resources because of intense prototyping and iteration.

- **Supplier integration:**

The last but not the least of Lean product development components is the integration of suppliers in the design process (Karlsson and Åhlström 1996, Morgan and Liker 2006). It changes the role of supplier from the mere manufacturer of components based on the drawings and procedures sent by the client, to an active part of the new product development from its outset. Outsourcing parts of design process to the suppliers can be resulted in reducing the overall design time.

a basic feedback loop diagram based on aforementioned discussion about Lean components and their relation with different performance measures (figure 5) has been constructed which shown in figure (6).

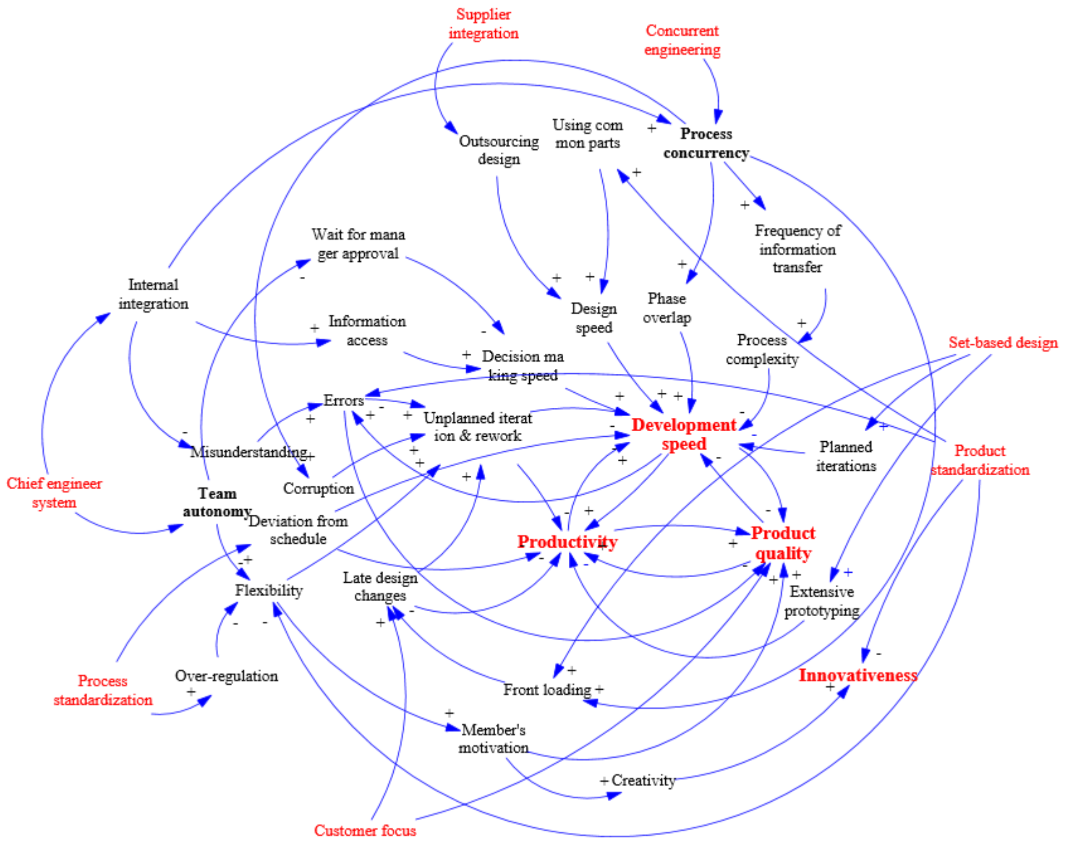

Figure (6): Feedback loop diagram of Lean product development

Summery:

Despite committed employees and innovative products, organizations always break down just because of their inability to pull their functions and talented individuals into a productive whole. System thinking is a discipline to see wholes rather than parts, and dynamic interrelations rather than static snapshots (Senge 1993). Seeing wholes will allow managers to understand the structures that underline complex situations. Improving quality, reducing costs and time, and satisfying customers in a sustainable way, through implementing innovative approaches, such as Lean thinking, in new product development processes is a dynamic problem which requires a holistic view on the system elements and their interrelationships. To answer the main research question, using system dynamics approach which requires the intense use of qualitative data and human judgment in all stages of model development, a model which relates different Lean components to performance metrics, such as process speed, cost and quality, will be constructed. Defining the relationships and estimating the dynamic behaviour of performance measures will guide the research towards finding the optimal balance between different performance measures. In the end, testing the simulated behaviour of the model will be done by comparing it against actual system behaviours. The model which will be provided in this research could be used by managers to predict the effect of different policies on different aspects of performance in new product development processes, and will help them to design improvement policies.

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