ABSTRACT
The involvement of key suppliers is essential to new ventures introducing radical innovations, especially in manufacturing supply chains. However, due to the presence of interactive dynamics of a number of factors in supply chain systems, integrative product development is a complex task. As such, manufacturers should have in place a well-designed set of policies, robust enough to accommodate the dynamics of product development across the entire supply chain. In this research, we utilize system dynamics modelling to study the complex interrelationships among various players in a collaborative product development environment. Several "what-if" experiments are conducted in order to bring forward useful managerial insights in regards to manufacturing supply chain systems incorporating radical new product development.

KEY WORDS
New product development, innovation, supplier involvement, system dynamics

1. Introduction

For competitive and efficient new product development (NPD) in the manufacturing sector, most firms are increasingly turning to suppliers, researchers, and other stakeholders to access their product technologies with the aim of establishing stakeholder involvement [1]. The goal is to improve the new product development process, especially when radical innovations are expected. Radical innovations, as opposed to incremental changes, are normally associated with substantial shifts from the current or original product design. As such, considerable research has recently examined the role of suppliers in new product development [2] [3] [4]. A number of studies in the literature argue that the greater the supplier involvement, the greater the product innovation and the greater the manufacturer’s performance in the long run [1] [5]. Supplier involvement is critical for the success of radical innovations, especially in the manufacturing industry.

Radical new product development (RNPD) defines fundamental new product innovations that involve revolutionary changes in the product and/or related process technology. This view is consistent with definitions found in [1] and [7]. In this vein, several other researchers have studied the radical innovation process [8] [6]. Simply put, radical product innovations pertain to major departures from the current innovation status in terms of product and process performance, process technology. Therefore, RNPD entails higher levels of new knowledge, risk and uncertainty [7]. Despite the fact that RNPD is associated with high risk and uncertainty, firms continually engage themselves in radical innovations in order to outperform their competitors. In most cases, managers that engage in the risky RNPD process considerably enhance their corporate growth when their innovations succeed in the marketplace [9]. As such, both RNPD and supplier involvement are viable competitive tools that can positively influence the success of new productive development innovations, especially in the manufacturing industry.

The involvement of suppliers in the RNPD process is a competitive weapon for the present day manufacturing industry. Supplier involvement offers a key contribution to enhancing the success of RNPD [10]. In most cases, a firm that are only involved with incremental innovations end up losing competitive advantage over time as its competencies become obsolete [5]. In order to regain and sustain an acceptable level competitive edge, firms have to involve suppliers as partners in their RNPD processes. However, the level of involvement and the stage at which the supplier is involved may play a significant role on the success of the whole process. Thus, one most important factor that determines the success of the RNPD process is the understanding of the dynamics of the RNPD and supplier involvement; it is important that firms gain a deeper understanding of the dynamics of supplier involvement so that managers can come up with sound decisions in this regard.

In this respect of the above issues, the purpose of this research is to investigate, from a systems point of view via system dynamics simulation, the overall system behaviour of a typical RNPD process concerned with supplier involvement. Most important of all is the fact that the influence of the key factors on the RNPD process is investigated.
In pursuing the above-mentioned research purpose, the specific objectives of this research include the following:

1. to investigate the key factors behind the efficiency of the NPD process in a collaborative environment;
2. to develop a systems simulation model that captures the dynamics interactions of the key factors identified in (a); and,
3. to carry simulation sensitivity and “what-if” analyses, deriving useful managerial implications.

In light of the above objectives, we view RNPD as a process consisting of a number of stages at which the supplier can possibly be involved with varying levels of involvement.

The rest of the paper is as follows. The next section introduces system dynamics as a systems tool for modelling complex systems. Section 3 presents the proposed system dynamics model. This is followed by illustrative simulation experiments in Section 4. Results and discussion are provided in Section 5. Finally, conclusions and further research prospects are provided in Section 6.

2. System Dynamics

System Dynamics (SD), originated by Jay Forrester [11], is a computer-based simulation methodology based on information feedback and delays, for simulating and analysing complex problems with a focus on policy analysis and design. SD essentially consists of causal loop and stock flow diagrams. A causal loop diagram depicts the causal hypotheses of a system in an aggregate form. A flow diagram represents the system flow structure. Stock variables depict the state of the system, while flow variables describe the rates of change of the stocks. In a mathematical form, the net flow is equivalent to the rate of change of stocks. The approach has been applied to a number of problems such as corporate planning and policy design, supply chain management, public management and policy evaluation, economic behaviour, and healthcare modelling, new product development [9] [12] [13] [14] [15] [16]. In light of its widespread applications, SD is a viable tool for modelling the dynamics of RNPD and supplier involvement. We propose a system dynamics model in the next section.

3. Proposed System Dynamics Model

In this section, we present the proposed SD model for in-depth understanding of the behaviour of a RNPD process over time.

3.1 RNPD and supplier involvement

To facilitate the development of our model in this study, we assume that a typical RNPD process in manufacturing industry comprises the following stages or steps:

1. Concept development
2. Designing
3. Prototyping
4. Production and assembly

Figure 1 shows the sequence of stages or phases of a typical NPD process. The points at which a supplier can be involved are also indicated as SI1, SI2, SI3, and SI4.

![Figure 1. Possible stages of supplier involvement](image)

The consequences of supplier involvement at each stage are important. In addition, the extent and depth of involvement are critical to the performance of the RNPD. Our general hypothesis is that it is more beneficial to involve the supplier at upstream stages since upstream stages normally take more time than downstream stages. For instance, supplier involvement in the concept development stage will minimize possibilities of design errors and changes in the long run. Likewise, the involvement of the supplier at the design and prototyping stage will assist the firm in gaining information for necessary changes to be made. By working collaboratively in the early stages of the RNPD process, information regarding technical changes and improvements to be made is gained on time. Consequently, the development cycle time is expected to be reduced.

While higher supplier involvement is crucial in all stages, the dynamics of the involvement and its effects on the performance of the RNPD process need further investigation. The behaviour of the process, in terms of development lead time or cycle time, is influenced by (a) the overlap, that is, the number of stages in which the supplier is involved, and (b) the level of involvement, that is, the percentage of involvement at each particular stage of the RNPD process.
3.2 System Dynamics Model Structure

Figure 2 shows the model structure of radical NPD in terms of stocks and flows. Stocks of Design Concepts, Design, Prototype, Parts and Finished Product, are assumed to be composed of the smallest components of work that can flow through the stages of the RNPD process. Thus, stocks are accumulations of net inflows and are mathematically calculated as the integration of the net inflows as follows:

\[ S(t) = \int_{t_0}^{t} (\text{inflow}(s) - \text{outflow}(s)) ds + S(t_0) \]  

where, \( S(t) \) depicts the stock at time \( t \), \( \text{inflow}(s) \) and \( \text{outflow}(s) \) denote the values of the inflow and outflow at any time \( s \), respectively, between the initial time \( t_0 \) and the current time \( t \).

The stocks are transformed from one stage to the other along the chain from design concept, down to finished product. Flow rates at any time define the rate of change of stocks as shown by the following expression:

\[ \frac{d}{dt}(S) = \text{inflow}(t) - \text{outflow}(t) \]  

The initial design work to be done, Design Concept, of magnitude radical change is transformed into actual design components Design at a rate designing. Subsequently, the design components are translated to prototypes Prototype at a rate prototyping. Components that fail at the Design and Prototype stages are fed back for rework at their respective stages. The stocks of parts, Parts, are positively influenced by production rate by which prototypes are translated to parts. Parts are subsequently assembled at a rate assembling and transformed into finished product Finished_Product.

The magnitude of overall work done by the firm is determined by the level of supplier involvement at various possible stages. We assume in this study that supplier involvement, SI, can possibly be engaged at designing, prototyping, production or assembling stages. In addition, the coverage of these stages, determines the percentage of overlap. For instance, SI at a single stage designing implies 25% overlap. In the same token, SI covering all stages would be represented by 100% overlap.

4. Illustrative Experiments

The simulation experiments were performed in three stages. First, base simulation experiments were run assuming initial conditions as follows. The radical change is set at 50%, while supplier involvement SI is set at 0%. Design, prototyping, production and assembly times are assumed to be 10, 8, 6, 4 and 2 weeks, respectively. The model is run for 50 weeks. The expected completion time is 35 weeks. Second, sensitivity analysis experiments were carried out by varying the SI parameter from 0 to 75%. The goal was to illustrate the sensitivity of the model behaviour in respect of the level of supplier involvement SI at the design stage. Thirdly and finally, further “what-if” experiments were set up so as to investigate the combined influence of variations of SI and overlap on the performance of the model. The parameter SI is varied from 0 to 50% in steps of 5%, while the overlap is varied from 0 to 100% in steps of 25%. The radical change percentage is set to 100%, and the measure of performance was percentage completion. The next section presents the simulation results and discussion.
5. Simulations Results and Discussions

5.1 Base Simulation Results

Figure 3 provides the results of base simulation experiments. Curve 1 shows the RNDP work completed at each point in time, while curve 2 shows the percentage completion over the planning horizon. At time 35, only 75% of the project was completed, according to Curve 2. In addition, it can be seen that the project could not be completed in time 50. Supplier involvement offers a possible solution for the improvement of product development processes.

The next section presents the results of sensitivity analysis based on overlap and the level of supplier involvement.

5.2 Sensitivity analysis results

Figure 4 demonstrates the simulation results of the sensitivity analysis experiments. Curves 1, 2, 3 and 4 show the behaviour of the model corresponding to SI values of 0, 15, 30, and 45 %, respectively. As SI increases towards 45%, the value of percent completion tends to approach a limiting value. This illustrates that increasing the supplier involvement at one stage will improve the performance of the product development
process, however, with a limiting value as SI continues to increase. Thus, the extent of the overlap by the supplier plays an important role in the performance of the radical product development process.

5.3 Further “what-if” simulation results

Figure 5 presents a graphical analysis of the performance of the system based on product development completion. Both SI and overlap have significant influence on system response. As can be seen from the graphical illustration, the higher the overlap, the quicker the product development project runs to completion. Similarly, the higher the SI, the faster the project is completed. It can be observed that SI has a more pronounced influence on system response. Performance values of 100% can be achieved with SI values less than 25%. Moreover, it can be seen that over 90% performance can easily be obtained with overlap as low as 25%. Overall, the combined effect of SI and overlap bears a strong influence on the overall performance of the RNPD process. Performance values of 100% can be achieved easily. Therefore, supplier integration together with the extent of overlap along the RNPD process chain play a significant role in expediting and improving the radical product development process.

6. Conclusion

Supplier involvement in new product development is a potential competitive weapon in the manufacturing sector. However, the dynamics of the collaborative involvement is complex due to interaction of time delays and dynamic factors related to the manufacturer and supplier. The objective of this study was to investigate the impact of development process. We developed a system dynamics model to abstract and simulate the dynamic behaviour of the new product development process. Our simulation results unequivocally support our hypotheses that supplier involvement in new product development can improve the performance of the efficiency of the process, however, with diminishing returns as the involvement increases continually.

6.1 Contributions to theory

Our model contributes to the body of knowledge in the field of new product development as well as supplier collaboration (Song and Benedetto, 2008). However, we argue in this study that consideration of the dynamic interactions involving the manufacturing firm and the supplier is essential for deriving managerial insights leading to improved policy formulation. Factors such as level of involvement and overlap need careful consideration in order to obtain in-depth understanding of the whole process.

6.2 Implications for management

Our simulation results have implications for decision makers in new product development and supply chain management. By understanding the impact of overlap, the policy maker involved with new product development obtains the requisite knowledge for informed decisions on the extent to which the supplier should be involved in the process, from concept development down to production and assembly. In the same token, managers can anticipate the impact of the level of supplier involvement at each specific point of supplier involvement.
Supply chain managers can determine from a systems perspective, the effects of their involvement in the new product development process. At the same time, the managers can anticipate the ideal level of overlap for improved collaborative involvement. Such decisions are crucial for the product development managers as well. The system dynamics model offers an interactive decision support tool for the policy makers concerned with product development and supplier involvement. Overall, suppliers and manufacturers can have a systems tool by which they can make collectively reach the best trade-offs in regards to level of collaboration and overlap. Therefore, the proposed systems approach to new product development and supplier involvement is crucial in a collaborative manufacturing environment.

References