Supply chain integration: A modelling classification

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Abstract
Previous literature reviews indicate that the efficiencies of supply chain management are often impaired by inconsistency among supply chain partners that have been managed independently in most of cases, whilst companies recognise the importance of an integrated supply chain as a key fact of their success. This fact has pushed researchers to use various models as an essential way of supporting the integration process of supply chain management. However, one element that has not been widely explored is the advent of supply chain modelling classification that helps practitioners and academics to select an appropriate tool for experiencing the real world before execution of any plan. To address this issue this paper presents a supply chain modelling classification.

Keywords: supply chain management, integration, modelling

1. Introduction

National and international corporations are focusing on the performance improvement of their supply chain to gain a competitive advantage in the world markets [16]. Whilst managing the supply chain cannot be left to chance, executives are striving to interpret and determine how to manage the company's supply chain network, and thereby achieve the potential of supply chain management [25]. Supply chain management is an integration philosophy to manage the total flow of materials, information and finance from the suppliers to the customers. The goal of supply chain is to meet the needs of the final customer by supplying the right product at the right place, time and price. Companies use the supply chain as a way to meet these goals in today's business environment [19]. Most supply chains are composed of independent agents with individual preferences. It is expected that no single agent have the power to optimise the whole supply chain whilst the overall business environment is becoming increasingly dynamic in both demand and supply sides [18]. Given the nature of supply chain environments, they are always unpredictable situations, which necessitates structured [2, 11, 33, 44].
Firms have responded to such uncertainties in different ways such as lean production in order to eliminate waste from all possible sources or agility via emphasis on faster response to unpredictable demand [38]. In some cases the focus of supply chain management has shifted from engineering efficient functional process to the co-ordination of activities in a supply chain network [19]. The traditional way of coping with uncertainties (i.e. quality variation, supplier unreliability, unpredictable customer demand in each stage of the supply chain and etc.) has been based on building inventories or providing excess capacities that lead to demand amplification making it costly and inefficient. It is also evident that improvement in individual organisations does not necessarily mean a chain-wide improvement [9, 17, 25, 27, 44].
Managing a supply chain requires certain co-ordination among partners that should be translated into process and function integration within and along the entire supply chain [7,13]. Consequently by analysing a company's supply chain as a single, interconnected structure, companies can make decisions that will minimise costs while maximising customer satisfaction [14]. To he achieve supply chain management objective (i.e. meet customer demand for guaranteed delivery of high quality; low cost product with minimal lead-time) and increase supply chain performance, companies need to have better visibility into the entire supply chain in both upstream and downstream [7, 46]. Traditional

concepts and methods for business management focused on the optimisation of internal activities of the company such as Material Requirements Planning (MRP) that address operation improvement and cost reduction through better planning and execution of internal activities [16]. These methods have limitations in dealing with uncertainties from the external business environments and therefore, entail the need for decision support tools that can help managers to understand the costs, benefits and risks associated with various alternatives respectively [46]. A better understanding of the dynamic characteristics of supply chains would enable managers to capture, reduce or eliminate inconsistencies within nodes and efficiently manage them. They have to be familiar with characteristics of supply chain to be able to consider all the effective elements of a successful supply chain into account for a better prediction of future.

The remainder of the paper is organised as follows: section 2 discusses existing problems of current modelling classifications. The importance of the research and modelling in study of supply chain is illustrated in section 3. The proposed framework is presented in section 4. Finally, section 5 is the conclusion.

2. Research Issue

Growing interest in supply chain importance has highlighted the need to adopt appropriate approaches such as modelling that ensure the efficient management of their complexity, enormity and broadness of the scope. Modelling is a way of solving problems that occur in the real world [8]. There are numerous sets of tools and approaches for supply chain modelling. Several algorithms and tools have been applied in supply chain modelling and problem solving [6]. The most common assumptions are demand backlogging, linear cost function, infinite capacity; constant lead-times and a stationary stochastic demand with common goal of minimise the inventory-holding costs [2]. The significance of supply chain modelling lies in two aspects: first, in order to manage the supply chain effectively, it should be properly modeled; second, processes to be integrated and coordinated. Supply chain modelling is a prerequisite for supply chain integration [29]. Different decision problems in supply chains entail different approaches to be used for modelling and problem solving. While there is a need for a unified approach to modelling supply chains [6], literature suffer from a clear supply chain modelling classification to justify which approach is proper for modelling a specific problem [1,14, 23, 24, 32, 36, 41]. Hence, there is a need for the development of a comprehensive taxonomy that provides supply chain decision makers with a proper framework to choose and then effectively integrate different components of a chain as a whole.

This paper aims to address this issue and presents a critical literature review of the field. The following systematic steps were taken: first, combination of six key terms (i.e. supply chain management, supply chain networks, value chain, collaboration, sustainability and competitive advantage) were used for browsing different online services (i.e. Scopus, Emerald and Google scholar), databases (i.e. Ebsco, ProQuest), thesis, journals, books, conference papers and etc. As a result, the first two hundred highly cited papers among top ranked journal presented by the Association of Business Schools (ABS) index were comprehensively reviewed. This stage leads to narrow down the scope and repeat the above-mentioned process for newly identified keywords: supply chain management, integration, modelling. In this stage three hundred additional papers were studied which consequently identified the literature' gaps and framed a supply chain modelling taxonomy consequently.

3. Importance of Modelling in Supply Chain

Modelling methodology is defined by Penlope [36] as ''an explicit representation of some portions of reality as perceived by some actors.'' Modelling in various forms is essential in supporting complex human design activities. Simon [43: p198] notes that due to bounded rationality, the human mind is not capable of solving complex problems in the real world. Instead, successful companies find their competitive advantage by making informed decisions to optimise the balanced and holistic view of all the elements that affect the planning, design, production and delivery of their product. Modelling and analysis to gain a better understanding of the system complexity and to predict system performance are critical and often valuable for system management [36].

A typical supply chain faces uncertainty and frequent changes in terms of supply, demand and process. In fact, the greatest constant of modern time is change that struggled companies to comprehend its consequences [45]. Due to this dynamic nature, managers often do not have insight into the ripple effects of their decisions. Effects also can easily get lost in the overwhelming flood of data that crosses the supply chain managers' desk. These elements make supply chain more complicated to model due to the presence of heterogeneous entities, multiple performance measures and complex interaction effects [46]. Due to the lack of a universal definition of supply chain management, its concept has been considered from different points of view in different bodies of literature ([15]. This has led almost all of the supply chain modelling research being an extension of the traditional problems of: production planning and inventory control and, distribution and logistics [28, 12, 31, 34] rather than focusing on integrating of whole the chain. Ozbayrak et al. [35] refer to a gap in the relevant literature where only a few attempts have been made in the direction of developing appropriate models for integrated supply chains. Indeed, there exist only a few accurate operationalisation model and related concept in integrated supply chain that forcing the necessity of more research for better understanding of supply chain integration through modelling.

4. Supply Chain Modelling Classification

Despite the importance of the topic, supply chain modelling methodology often is lacking in literature of a comprehensive taxonomy that aid researchers to evaluate various models when analysing the supply chain [14]. Also, there is no systematic way of defining the scope of a specific supply chain problem [16]. This may stem from nature of supply chain, which includes different functions that need to be modeled and/or overlap among different sets of models. In fact, there is a similarity between supply chain definition and modelling methodology as different researchers have classified and represented different sets of modelling approaches for analysing the supply chain where most of these classifications do have some common elements [29].

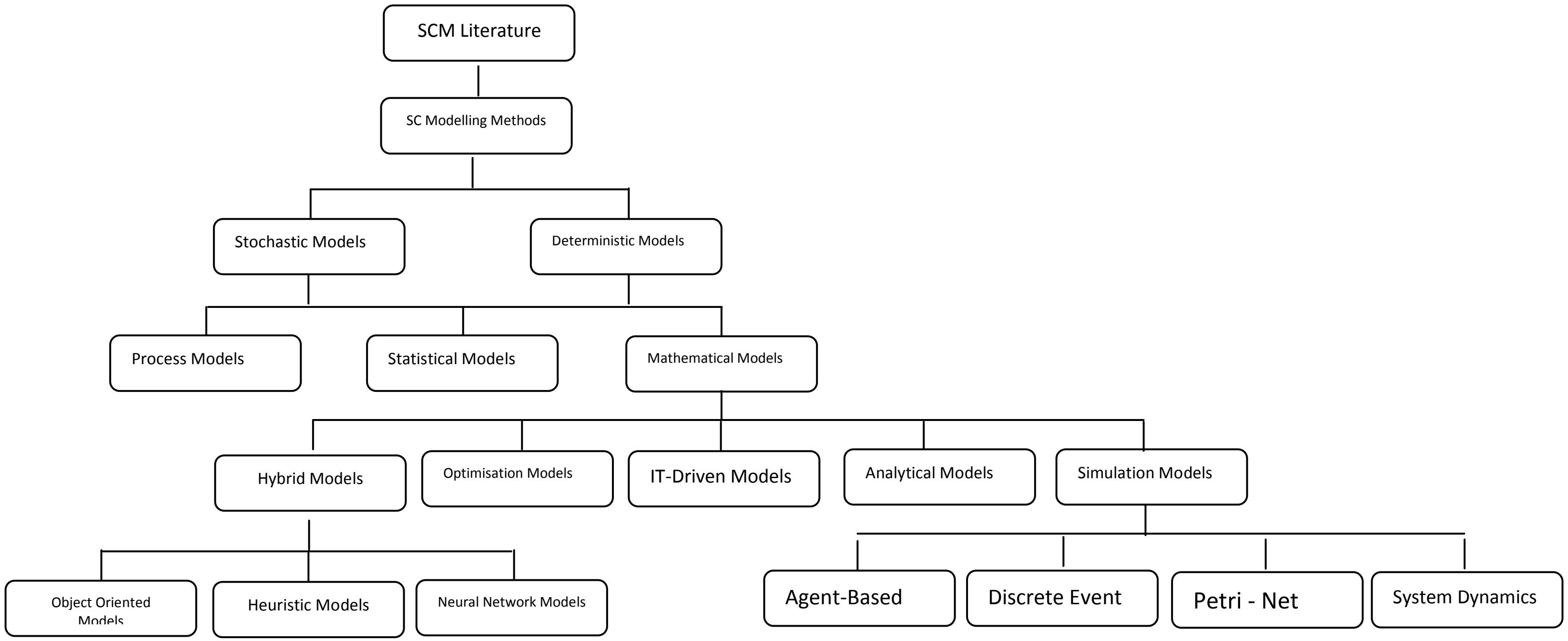
For example Vidal and Goetschalckx [47] to present a strategic production-distribution model, reviewed past literature on operation research techniques and mathematical programming (linear programming), analytical models and optimization models. The authors refer to importance of heuristic methods and deterministic models. A prominent classification presented by Beamon [5] and Sabri and Beamon [39] who classify supply chain modelling into four groups of deterministic analytical models, stochastic analytical models, economic models and simulation models. Indeed, many supply chain models have been classified in this basis. Shapiro [41] divides mathematical models into two parts: descriptive models including forecasting models, cost relationships, resource utilisation relationships, simulation models and normative models. Dong [17] took a broader approach and represents models into stochastic programming, optimisation models and heuristic models. Min and Zhou [32] classifies supply chain modelling into IT-driven models, hybrid models, stochastic models and deterministic models. Kim et al. [24] study present four techniques for supply chain modelling: linear programming, mixes-integer programming, network models and simulation modelling. Authors sub-classify simulation models based on static or dynamic; discrete or continuous; and deterministic or stochastic. Hung et al. [23] allow two broad classes: analytical and simulation models. Penlope [36] categorises models into process modelling, statistical modelling, neural networks, discrete-event modelling, mathematical modelling and system dynamics modelling. Cope [14] classifies supply chain methodologies into two classes of physical and analytical models. The author accordingly divides analytical models into four sub-divisions of hybrid models, spreadsheet process maps, simulation models and mathematical models. Acar et al. [1] sub-divide the analytical models into deterministic, stochastic or hybrid models.

Clearly, a modeler should consider a number of criteria before choosing a tool to construct the conceptual model. Different issues such as optimaisation, decision analysis, diagnostic evaluation, risk management, project planning [3] as well as different levels to manage and to model such as strategic, tactical and operational [26] exist that a modeler should pay attention before attempts to address the problem. According to Cope [14] supply chain environments are complex environments requiring a comprehensive methodology to adapt to a distributed environment where pieces of information are distributed along the different supply chain elements. It should be adaptive to the dynamic stochastic environment prevalent in supply chains, driven from a shared, common definition of the supply chain being modeled to encourage a thorough and common model of the system under study. Finally, it should be with minimal input from the user in a fast, easy to use and scalable format in diverse field at varying levels of fidelity.

In this paper the supply chain-modelling methodology has been classified on the following basis as shown in Figure 1:

A comprehensive review of the literature highlights that many researchers supports the idea that supply chain models at its highest level are stochastic or deterministic. Stochastic models take the uncertain and random parameters into account. The models are sub-classified into optimal control theoretic and dynamic programming models [32]. Deterministic models assume that all the model parameters are known and fixed with certainty. The models are categorised as single objective and multiple objective models. This category was developed to reflect the increasing needs to harmonise reflecting objectives of different supply chain partners [32]. Considering this broad classification we are able to sub-classify the supply chain models into three more specific types of process models; statistical models and mathematical models, each represents as follows:

Figure 1: Supply Chain Modelling classification.



4.1. Process Models

Process modelling refers to logically capturing and abstracting the systems components, relationships and behaviour, with respect to modelling objectives. Process models can be descriptive, prescriptive, iconic or symbolic. These models all try to capture the business tasks that are going to be automated, where the automating system deploys who will use it, and how it will integrate with other systems [36]. These models are static, a deterministic tool that do not account for changes in the system over time and neglect variability [14].

The SCOR model is a good example of process models. Supply Chain Operations Reference (SCOR) was developed by supply chain council to review supply chain as a process [29]. According to Cope [14], the SCOR model integrated the concepts of business process reengineering, benchmarking, and process measurement into a cross-functional framework. It describes the business activities associated with all phases of satisfying a customer's demand. The model is organised around five-management process: plan, source, make, deliver, and return. The model can be used to describe supply chains that are very simple or very complex using a common set of definitions. The SCOR model has been able to successfully describe and provide a basis for supply chain improvement for global projects as well as site-specific projects. The model is the most widely used tool for defining supply chains.

4.2. Statistical Models

A statistical model is a set of probability distributions on the sample space [30]. It is a form of modelling that explicitly recognises the existence of uncertainty in a set of data. It is conventionally seen as having two possible roles-descriptive and inferential. Descriptive statistics is simply concerned with summarising the main characteristics of a data set, particularly highlighting any patterns (and anomalies) that may not be immediately obvious. The implicit philosophy of statistical modelling is inherently empiricist. This model largely restricts itself to analysing empirically available quantitative data rather than going beneath the surface to explain the mechanisms that give rise to empirically observable events [36]. Structural Equation Modelling (SEM) is a famous statistical technique for testing and estimating casual relationships [42, 49].

4.3. Mathematical Models

Mathematical modelling is defined as the art of translating problems from an application area into tractable mathematical formulations whose theoretical and numerical analysis provides insight, answers, and guidance useful for the originating application [36]. The models are an equation or set of equations, which attempt to give a mathematical description of some real phenomenon. Mathematical modelling presents the easiest and fastest solutions for simple problems, giving exact and optimum solutions. The Petri-Net model is a famous mathematical model where Blackhurst [7] includes its limitations such as the inability to model the decision making; lack of ability to model uncertainty within the supply chain; the inability to extend the model to illustrate how the changes propagate through the network model and how these changes affect the attributes within the supply chain system. Finally, the model cannot encompass a full-scale supply chain from raw material to end-user.

4.3.1. Hybrid Models

These models are defined by on-line dictionary as a polygonal model that uses rapid surfacing and traditional solid modelling techniques. Object oriented models, heuristics models, and neural network models are some examples of hybrid models:

4.3.1.1. Object oriented Models

According to the www.webopedia.com object oriented model is a type of programming in which programmers define not only the type of a data structure, but also the types of operations (functions) that can be applied to the data structure. In this way, the data structure becomes an object that includes both data and functions. In addition, programmers can create relationships between one object and another. Chao [10] states that one of the principal advantages of object-oriented programming techniques over procedural programming techniques is that they enable programmers to create modules that do not need to be changed when a new type of object is added. A programmer can simply create a new object that inherits many of its features from existing objects. This makes object-oriented programs easier to modify. The major effort of the object-oriented approach is to map the corporate business process with IT in terms of a series of reusable business objects that encapsulate complex business rules. The advantages of this approach are (1) the tedious redesign efforts of the information system can be avoided and corporate information systems can become vary adaptive (2) applications can run on different platforms through internet/intranet connectivity, and (3) this schematic blueprint not only fits a given enterprise, but it can also be viewed as an open architecture [10].

4.3.1.2. Heuristic Models

Heuristic models integrate the simulation approach and optimisation method to find a feasible solution for a complex logistic network design problem [28]. A heuristic model is simply any intelligent approach that attempts to find good or plausible solutions. Generally, mathematical programming methods are used to solve strategic and higher levels of tactical supply chain planning. This method generally works only for solving linear- and some integer-based models, commonly used in strategic levels of planning. Tactical and operational models are usually not linear and are much too complex to solve using mathematical programming methods. For this reason, heuristic methods are generally used in tactical and operational planning level solvers. Heuristic methods used in supply chain planning and scheduling include the general random search approaches such as simulated annealing and genetic algorithms [19].

4.3.1.3. Neural Network Models

According to Penlope [36] neural network models are computational paradigms based on mathematical models that unlike traditional computing have a structure and operation that resembles that of the mammal brain. Neural network analysis is used to detect changes in the supply chain behaviour and map these changes into the future. It can be encapsulated in a software agent that can in turn use the company’s Enterprise Resource Planning (ERP) records and business intelligence data to perform this task routinely in real time in an actual system. Using the model to detect changes in the supply chain will empower companies to detect any changes occurring in the business environment that can affect their supply chain and hence give the company enough time to adjust its business strategies in order to counteract the impact of these changes. However, today a great deal of effort is focused on the development of neural networks for applications such as pattern recognition and classification, data compression and optimisation.

4.3.2. Optimisation Models

Britannica Concise Encyclopedia defines optimisation models as an application of mathematical and computer programming techniques to the construction of deterministic models, principally for business and economics. For models that only require linear algebraic equations, the techniques are called linear programming; for models that require more complex equations, it is called nonlinear programming. In either case, models frequently involve hundreds or thousands of equations. The discipline emerged during World War II to solve large-scale military logistics problems. Mathematical programming is also used in planning civilian production and transportation schedules and in calculating economic growth.

4.3.3. IT-Driven Models

According to Min and Zhou [33], IT-driven models aim to integrate and coordinate various phases of supply chain planning on real-time basis using application software so that they can enhance visibility throughout the supply chain. These models include transportation management systems (TMS), integrated transportation tracking, collaborative planning and forecasting replenishment (CPFR), material requirement planning (MRP), distribution resource planning (DRP), ERP, and geographic information systems (GIS).

4.3.4. Analytical Models

Analytical models are mathematical models that have a closed form solution directly with the differential equation. Many of the influential characteristics of modelling a supply chain can be succinctly expressed in different equation forms. But as these models produce smooth outputs, they are not suited for modelling all supply chains. The system must usually be analysed at aggregate level, in-which individual entities in the system are not considered. Rather they are aggregated into levels and flow rates. Therefore, these methods are not suited for a modelling process where each individual entity has an impact on the fundamental state of the system [7].

4.3.5 Simulation Models

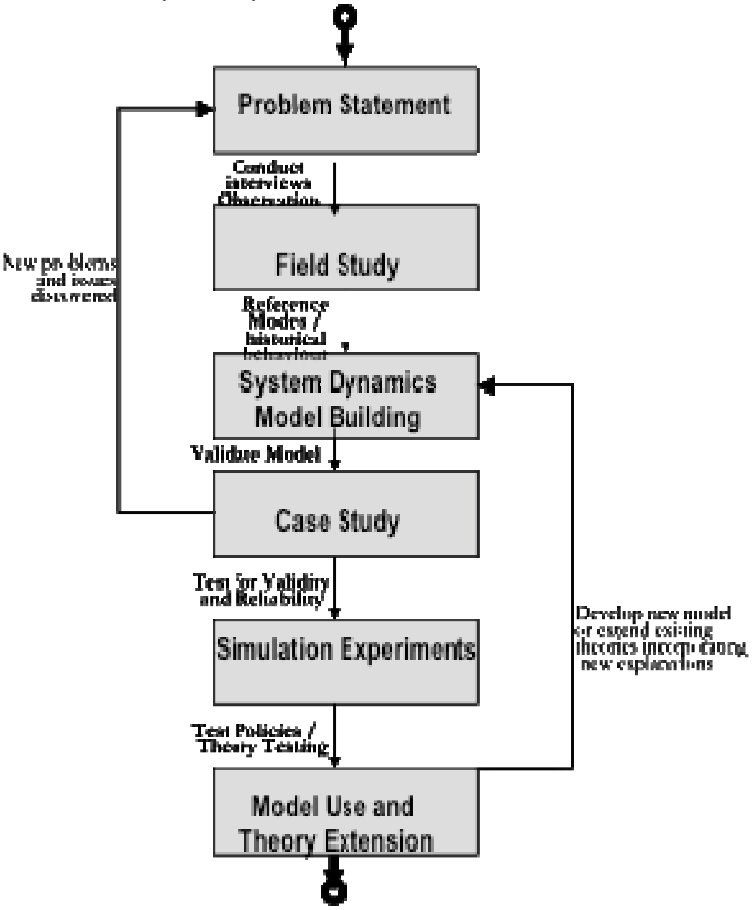
Simulation modelling is the only reliable way to test hypotheses and evaluate the likely effects of policies [46]. It is "the practice of building models to represent existing real world systems, or hypothetical future systems, and of experimenting with these models to explain system behaviour, improve system performance, or design new systems with desirable performances." Simulation modelling provides the flexibility to model processes and events to the desired level of complexity, in a risk free, dynamic and stochastic environment [14].

Banks et al., [4] recognise ten opportunities for simulation in supply chain as ''(1) Identify the shortcomings and opportunities for redesign (2) Measure the impact of changes in demand on supply chain components (3) Measure the impact of new ways of setting up and operating a large supply chain (4) Investigate the impact of eliminating an existing or adding a new infrastructure component to an existing supply chain (5) Investigate the impact of changing operational strategies within a supply chain (6) Investigate the impact of making in house, outsourcing, developing a new supply base and the combination of these (7) Investigate the impact of merging two supply chains or impact of separating a portion of the existing components of a supply chain (8) Investigate the relationships between suppliers and other critical components of a supply chain (9) Investigate the opportunities for postponement and standardization and (10) Investigate the impact of current inventory strategies on the overall performance of a supply chain''.

Without simulation, even the best conceptual models can only be tested and improved by relying on the learning feedback through the real world that is very slow and often rendered ineffective by dynamic complexity, time delays, inadequate and ambiguous feedback, poor reasoning skills, defensive reaction, and the costs of experimentation.

Dynamic simulations are necessary to analyse the supply chain because of its interactive and incorporates hierarchical feedback processes [22]. According to Forrester [20] only simulation methods are capable of revealing the behaviour implicit in the structure that can be built from knowledge about the many local decision-making individuals and how they are connected. Simulation models can be very thorough and provide high level of details about the system and are able to model uncertainty in a system [7]. It provides an effective pragmatic approach to detailed analysis and evaluation of supply chain design and management alternatives [46]. It is abstract of the real world-view of a

Figure 2: Business Process Improvement by using the System Dynamics



Adopted from Williams [49].

system or problem that can be an effective, powerful and universal approach to problem solving in different areas of application or to extend existing theories or identify new problem as shown in Figure 2.
There are number of simulation techniques for different purposes. This section explores application of Agent Based modelling, Discrete-event models, Petri-Nets and System Dynamics:

4.3.5.1. Agent Based
Wikipedia defines the agent-based model as a class of computational models for simulating the actions and interactions of autonomous agents (both individual and collective entities such as organisations or groups) with a view to assessing their effects on the system as a whole. The model consists of a set of agents that encapsulate the behaviours of the various individuals that make up the system, and execution consists of emulating these behaviours [35].
Literature suggests the combination of agent based modelling with system dynamics [40] that inspires the model solely is not a suitable tool for modelling the supply chain.

4.3.5.2. Discrete-Event Models
The discrete-event model is built based on the actual system to focus on productivity improvement. It is used widely for planning e.g. for evaluating design alternatives in a production process. In many dynamic processes particularly in industrial contexts (e.g. manufacturing, transportation and inventory management) the system states change at discrete points in time (i.e. at events), rather than through a continuous state of fluctuation. In such, a discrete event simulation is often desirable or even necessary to treat many model components as individuals, each with their own properties and processing history [36]. The advantage of these models lay in its ability to capture the discrete nature of event-based processes while retaining a continuous time framework. The barrier of this model is the absence of a succinct descriptive language for their formulation [37].

4.3.5.3. Petri-Net
According to Blackhurst [7], the Petri-Net model offers a number of features that make it an attractive methodology for modelling supply chains. The model was introduced in the early 1960s and its simplicity allows for a powerful method for modelling and analysing complex systems. It is a mathematical and graphical tool that enables user to monitor, preserve or check important behavioural system properties. Blackhurst [7] refers to usefulness of the model because of the following abilities/characteristics:

- Concurrency and parallelism: where most of operations take place simultaneously.
- Asynchronous operations: machines complete their operations in variable amounts of time and therefore, the model must maintain the ordering of events.
- Deadlock: where none of the processes can continue, which can happen when two processes share two resources.
- Conflict: it occurs when two or more processes require common resources at the same time such as when workstations might share a common transport system.
- Event driven: the system can be reviewed as a sequence of discrete events.

Although, model has some limitations including the inability to model the decision making; lack of ability to model uncertainty within the supply chain; the inability to extend the model to illustrate how the changes propagate through the network model and how these changes affect the attributes within the supply chain system. Finally, the model cannot encompass a full-scale supply chain from raw material to the end-user. These shortcomings, make Petri Net models an inappropriate tool for implementing this research.

4.3.5.4. System Dynamics

System dynamic over time has developed as a method for modelling the behaviour of complex social economic systems and it can enhance understanding the nature of organisational issues. Over several decades it has useful guides for working towards a better understanding of the world [20]. Today, various computer softwares such as i-think, Stella, Vensim, and Powersim identify the behaviour of the system elements/components over time mainly in a trial and error method to demonstrate the likely effects of various decisions in the model. A high-level graphical simulation programs support the analysis and study of these systems [21]. Sterman [45] points out that system dynamic can enhance the intuition about complex situations. Moreover, when experimentation in real systems is feasible, simulation becomes the main and perhaps the only way that can discover how complex system work [37]. Forrester in Industrial Dynamics (1961) states ‘‘system dynamics from the beginning specifically stressed the development of useful models, models unconstrained by the demands of analytic traceability, based on realistic assumptions about human behaviour, grounded in field study of decision making, and utulising the full range of available data not only numerical data to specify and estimates relationships.’’

5. Conclusion and limitations

Study of supply chain through modelling is a broad, complex and multidisciplinary field. Through a comprehensive review of previous research, both academics and practitioners suggest enhancing the performance of companies is in pledge of a broad viewing of the total chain. Successful supply chain integration involves using a proper model to illustrate outcomes of any plan before its execution and to find a best-tailored match [combination] of different components of a chain.

A careful systematic review indicates that academics and practitioners consensually recognise the importance of supply chain modelling. The literature is rich with research and development efforts that use modelling to aid decision makers in supply chain systems. However, much of the research did not clarify in-which basis certain models have been applied to solve various problems.

To help practitioners and researchers find an appropriate model for their research, they should be aware of various models and its applications, as well as understand the limitations of each model. Analysing each model in depth can be a difficult and confining process. Such in depth analysis may hinder further application of different models. The goal should be to strive for more creative ideas, which help academics, and practitioners develop critical thinking skills and continually challenge the selection and application of suitable models. Therefore, the new supply chain modelling classification presented in this paper can be used as a base to select an appropriate model for modelling supply chains. It is my hope that researchers use this classification herein to generate a much needed conceptual and empirical work in the study of a supply chain, thereby creating a body of literature that is more heavily influenced by a deeper analysis of the field. Certainly, there is ample opportunity for a wide range of models in the study of supply chain phenomenon. An advance in supply chain research is best through longitudinal studies. This research shows a need for continued study to enhance the presented framework applications.

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