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## A REVIEW OF COORDINATION STUDIES IN THE CONTEXT OF SUPPLY CHAIN DYNAMICS

H. K. CHAN<sup>#1</sup> and Felix T. S. CHAN<sup>2</sup>

<sup>1</sup>Norwich Business School,  
University of East Anglia,  
UK.

<sup>2</sup>Department of Industrial & Manufacturing Systems Engineering,  
The University of Hong Kong,  
Pokfulam Road, Hong Kong.  
<sup>#</sup>e-mail: h.chan@uea.ac.uk

### ABSTRACT

Supply chain management is a popular research topic in recent years. Among the reported studies, coordination is an important ingredient to improve the performance of supply chains subject to the presence of system dynamics. This paper sets out to review some recent supply chain studies in the last decades that are related to coordination among supply chain members regarding supply chain dynamics. Focus is put on inventory management problems. More than a hundred research papers are reviewed and they are broadly categorised into analytical approaches and simulations approaches. They are further divided into sub-categorises. Observations of each category are summarised in this paper so that characteristics of each of which could be comprehended. In addition, the concluding section reveals some insights that could be considered for future research regarding coordination in supply chains and supply chain systems dynamics.

**Keywords:** Supply chain management; coordination, analytical approach, simulation approach, system dynamics.

## 1. INTRODUCTION

Supply chain management (SCM) is not a new topic in production and operations management, despite the fact that its origin is not quite well documented (Chen and Paulraj, 2004). This implies that there is no single origin for the study of SCM. Nevertheless, SCM is a popular topic that has still been researched extensively over the last two decades. Although the definition of supply chain or SCM is not unique, a supply chain can be viewed as a network of organisations that are connected from the ultimate suppliers(s) to the ultimate customer(s). In this connection, coordination, which is the management of dependencies between activities (Malone and Crowston, 1994), among supply chain members plays an imperative role in SCM. It is a means to optimise supply chain activities due to improvements in information flow with the recent advance in information technology in the last decade (Yu *et al.*, 2001; Boyaci and Gallego, 2002; Lewis and Talalayevsky, 2004; Sirias and Mehra, 2005; Li and Liu, 2006). Poor coordination, however, could be easily found in the industry (e.g. De Souza *et al.*, 2000).

On the other hand, system dynamics of industrial systems had also been studied long time ago (e.g. Forrester, 1961), and it has been revisited by some researchers in recent years (e.g. Sterman, 1989; Towill, 1991; Lee *et al.*, 1997; Holweg and Bicheno, 2002, etc.). Among them, Lee *et al.* (1997) conducted a seminal work that analysed, statistically, the effects of demand amplification along a supply chain, which is also the increasing trend in variability in the ordering patterns along the chain towards the suppliers (Dejonckheere *et al.*, 2004). This phenomenon is called the “Bullwhip Effect” (Lee *et al.*, 1997). In an attempt to counteract this phenomenon, many companies, however, increase their buffer inventory, which is known as safety stock. If this is not done in a coordinated manner, the whole supply chain could end up with excessive inventories and holding expensive levels of stock (Riddalls *et al.*, 2000).

System dynamics is in fact an approach for “studying and understanding the evolution and behaviour of real-world systems” (Rabelo *et al.*, 2005). Otto and Kotzab (2003) defined supply chain, from the systems dynamics perspective, as “a chain of consecutive, sequentially interdependent local transaction systems”. From this definition, the purpose of SCM is thus to manage trade-offs among supply chain members (Min and Zhou, 2002; Sahin and Robinson, 2002; Otto and Kotzab, 2003; Li and Liu, 2006). If trade-offs exist, coordination may be a means to improve supply chain performance in the sense that in some situations all parties who get involved could gain benefits as a consequent of the compromise through coordination (Sirias and Mehra, 2005). The major objective of supply chain coordination is thus to “devise a mechanism that will induce the retailer to order the right quantity of product and set the right retail price so that the total profit of the supply chain is maximised” (Qi *et al.*, 2004).

In this connection, this paper aims at reviewing related literature with respect to coordination in supply chains and supply chain systems dynamics. The rest of the paper is organised as follows: Section 2 provides a discussion on previous review studies regarding supply chains, and to contrast them with the scope of this study. Criteria for selecting papers for review will be discussed in Section 2 as well. The papers under review were divided into two categories: analytical approaches and simulation approaches, which will be reviewed in Section 3 and Section 4 respectively. At the end of these two sections, a brief summary regarding the

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3 observations of the respective category will be presented. Finally, Section 5 provides  
4 a concluding remark on the review so that some insights could be gained for future  
5 research regarding coordination in supply chains and supply chain systems dynamics.  
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## 8 **2. SCOPE OF THIS REVIEW STUDY**

### 9 **2.1 General Review on Supply Chain Studies**

10 Many researchers tried to review supply chain studies and attempted to develop some  
11 generic frameworks or research directions for further research (e.g. Harland, 1996;  
12 Thomas and Griffin, 1996; Beamon, 1998; Min and Zhou, 2002; Chen and Paulraj,  
13 2004). Thomas and Griffin (1996) conducted a review on traditional mathematical  
14 programming for coordinated supply chain. They broadly classified supply chain  
15 models to support two planning decisions, namely operational planning and strategic  
16 planning. Operational planning model can be further broken down into buyer-vendor  
17 coordination, production-distribution coordination, and inventory-distribution  
18 coordination. They found that most of the principles behind strategic planning models  
19 had been discussed in business related journals (e.g. Simatupang *et al.*, 2002). Finally,  
20 they concluded that “independently managing facility can result in poor overall  
21 behaviour”. They also claimed that there is a deficient in the literature addressing  
22 supply chain coordination at an operational level, which is the main area for review in  
23 this paper.  
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28 With respect to multi-stage supply chain studies, Beamon (1998) reviewed and  
29 classified four types of models in the literature, namely, deterministic analytical (all  
30 variables are known), stochastic analytical (at least one of the variables is unknown  
31 and is assumed to follow a known probability distribution), economic, and simulation.  
32 The categorisation in this study is similar to Beamon’s study (1998). However, our  
33 focus is on those studies concerning supply chains with coordination or system  
34 dynamics. Similar to Beamon’s approach (1998), Min and Zhou (2002) reviewed  
35 integrated supply chains models and classified four types of supply chains, namely,  
36 deterministic models, stochastic models, hybrid models (e.g. simulation models that  
37 are capable to handle both deterministic and stochastic variables), and IT-driven  
38 models (e.g. real-time collaborative planning and forecasting replenishment which  
39 aims to integrate and coordinate different phases of supply chain planning so that  
40 visibility can be enhanced throughout the supply chain). However, IT-driven models  
41 are usually limited to those with specific application software. In addition, Chen and  
42 Paulraj (2004) reviewed a wide range of supply chain studies and analysed those  
43 studies from two perspectives, namely, critical elements of SCM and supply chain  
44 performance. According to their classification, there are four critical elements of SCM,  
45 which are strategic purchasing, supply management, logistics management, and  
46 supply network coordination. They also reviewed supply chain performance measures  
47 in terms of financial and operational perspectives.  
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53 Research that analysing decision models for integrated production or distribution  
54 planning in supply chains has been done by a number of researchers. One good  
55 review were conducted by Erengüç *et al.* (1999) who emphasised the operational  
56 aspects of supply chains and noted that most network design models in the literature  
57 do not consider operational issues such as lead times in making decisions. They  
58 suggested that applying hybrid analytical and simulation models to integrate all the  
59 procurement, production and distribution stages of supply chains could be utilised in  
60 future research. Riddalls *et al.* (2000) also reviewed various mathematical methods

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3 that used to model and analyse supply chains. They concluded that these models  
4 failed to cope with dynamic behaviour of supply chains as a whole because their  
5 approaches provide no insight into how system parameters affect the solution. They  
6 claimed that “the impact of these solutions on the global behaviour of the whole  
7 supply chain can only be assessed using dynamic simulation”.

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10 With the advanced development of information technology, information sharing  
11 becomes possible in order to make some valuable information become visible among  
12 supply chain members so that better decisions (e.g. on ordering, capacity allocation  
13 and production planning, etc.) could be made to alleviate the effects of supply chain  
14 dynamics (e.g. bullwhip effect). In fact, information sharing is generally regarded as  
15 one of the solutions to reduce the bullwhip effect (Lee *et al.*, 1997, Cachon and Fisher,  
16 2000). From another point of view, Sahin and Robinson (2002) reviewed those  
17 literature with two dimensions which are information sharing and physical flow  
18 coordination at the operational level, with focus on the interfaces between them. They  
19 concluded that although both dimensions could be viewed as pre-requisites for  
20 integrating supply chain effectively, this may require substantial investment in  
21 information technology infrastructure. Huang *et al.* (2003) conducted a review on  
22 sharing production information with respect to supply chain dynamics. Based on the  
23 review findings, they proposed a reference framework to reflect major elements that  
24 commonly involved in this direction of research.

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26 From above summary, simulation seems to be a better technique in analysing the  
27 behaviour of dynamic supply chain. Nevertheless, analytical approaches in relation to  
28 coordination in supply chains are also invaluable in supply chain studies. Therefore,  
29 they will be reviewed as well so that a more complete picture with respect to  
30 coordination in supply chains could be delivered in this paper.

## 31 32 33 34 35 36 **2.2 Scope of This Study and Criteria for Review**

37 As reflected from the above review studies in supply chains, the scope of supply  
38 chains is really broad (e.g. inventory management, product design, information  
39 system, etc.). Although some researchers attempted to formulate a framework for  
40 supply chains, it is not surprising that no universally accepted framework for supply  
41 chains can be found. One of the reasons is that there are too many articles under  
42 review in the above review studies (e.g. over 400 articles in Chen and Paulraj (2004)).  
43 Therefore, it may be too ambitious to generalise a unique framework for supply  
44 chains. In this connection, this study takes another approach as compared with the  
45 above reviews.

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49 First of all, supply chains studies under review in this paper are those highly related to  
50 coordination studies with regard to inventory management or materials flow, and the  
51 studies may probably subject to supply chain dynamics. Within this scope,  
52 uncertainties are usually the main issue to be tackled in the reported research.  
53 Secondly, the papers under review in this study are limited to those being published in  
54 the last decade, and focus would be put on those being published in the most recent  
55 five years, so that a recent trend of related studies, if any, could be observed. As a  
56 matter of fact, the scope of this paper usually belongs to one of the sub-topics in the  
57 above review studies. However, as mentioned above, their focus had been put on a  
58 general supply chain studies, rather than on the topic of this study.  
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It is a convenient point to define what coordination is. In this study, the definition from Malone (1987), who defined coordination as “the pattern of decision making and communication among a set of actors who perform tasks to achieve goals”, is adopted. Obvious, when decision makers have incomplete information, coordination is easily to be failed. Based on these criteria, over 150 research papers had been selected at the early stage, and some of them were then screened out due to their diverse scope of study. The remaining papers (about 100) form the basis in the following review. They are first classified under two broad categories, namely analytical approaches and simulation approaches, according to the methodology being applied to solve the supply chain problem of each study. Then, they are further divided into different groups with respect to the similarities of the studies, as summarised in Section 3 and Section 4.

### 3. ANALYTICAL APPROACHES

#### 3.1 Introduction

Although traditional analytical models usually deal with deterministic parameters only, there are still some modified versions of them to cope with supply chain dynamics. Taking the study of Escudero *et al.* (1999) as an example, they took uncertainties into consideration in a manufacturing, assembly and distribution supply chain such that they were modelled via a set of scenarios so that optimal solution could be obtained under different scenarios. In other word, non-deterministic parameters became deterministic in a particular scenario. In reality, however, it is not easy to obtain a set of such possible scenarios because uncertainty is something that you cannot predict, and the set of scenarios may be too large. Even if a problem could be modelled through analytical techniques, solution may not be obtained easily and sometimes heuristic is employed to obtain the solution. For example, Lakhali *et al.* (2001) developed a mixed-integer model for optimising supply chain networking decisions with regard to allocate different internal and external resources in a supply chain. However, they still needed to apply a heuristic to obtain a solution of the said problem. They said “mixed integer programming is difficult to solve optimally for realistic problems”.

It could be concluded from the above examples that analytical or mathematical modelling approaches, such as linear and integer programming or mixed integer programming, etc., are certainly excellent in understanding well-defined supply chains, which involve few decision variables and restrictive assumptions (Chen and Paulraj, 2004). When more complex settings are involved, like supply chain dynamics with demand and supply uncertainties, this approach may not be satisfactory in providing good results (Riddalls *et al.*, 2000; Van Der Vorst *et al.*, 2000). Therefore, the strength of traditional mathematical modelling techniques, which is to obtain robust optimal solution, may not be easily achieved in solving supply chain problems. However, there is still a rich body of literature that attempted to apply such techniques in coordinated supply chain problems. They will be reviewed in the following sub-sections.

#### 3.2 Control Theoretic Approach

Control Theoretic Approach is a formal approach which views supply chain as an input-output systems, and tries to model supply chain from control theory (mainly with Laplace transform or z-transform). In this school of thought, the transfer function of a system represents the relationship describing the dynamics of the system under

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consideration (i.e. supply chains in our concerns) by relating its output to its input. Earlier research could be traced back to Towill (1991), or even earlier. Riddalls and Bennett (2002) replicated the MIT beer game from control theoretical perspective. In other words, they attempted to analyse the MIT beer game analytically. For a general review of applications of control theory to production inventory problem, please refer to Ortega and Lin (2004). By adopting control theoretical approach, Disney and Towill (2002) analysed the dynamic behaviour of Vendor Management Inventory (VMI) system. They derived closed form condition to ensure that the VMI system is stable and robust. Subject to different forecasting models for the mean and variance of Normal demand function, Dejonckheere *et al.* (2003) modelled order-up-to inventory replenishment policy from control theoretic approach. An insightful comment was drawn from their study: order-up-to policy will result in variance amplification, i.e. bullwhip effect, for every possible forecasting method.

Like most of the mathematical programming approaches, control theoretical approach could provide conditions for systems to operate stably and robustly. It can also transform some uncertain variables to manageable parameters in the z-domain. However, the reported research from control theoretical perspective does not allow flexibility due to the fact that it is still a sort of analytical approach. Therefore, if the system configuration is changing from time to time, the transfer functions have to be updated accordingly. On one hand this is certainly a drawback of this approach; on the other hand it could be a new direction for future research regarding control theoretical approach if this shortcoming could be managed well.

### 3.3 Channel Coordination Approach

#### 3.3.1 Discount Policy

In supply chain studies, the relationship between product demand and product price are usually assumed to be linear, i.e. price is not a function of demand or vice versa. However, under the discount policy approach, demand and price are related to each other such that either price is a variable for discount subject to different order quantity, or order quantity is a variable for discount. For example, a supplier may be able to reduce its ordering costs by providing an incentive in the form of price discounts to buyers, provided that the order quantity exceeds a certain amount. In other words, discount policy is in fact a kind of incentive system (Sirias and Mehra, 2005). In this research direction, the optimal solution is found subject to a variety of supply chain settings.

Some reported studies (Viswanathan and Piplani, 2001, Chen *et al.* 2001, Boyacı and Gallego 2002, Klastorin *et al.*, 2002, Mishra, 2004) support the argument that there is little research regarding quantity discount that takes either the demand or the lead-time as a random variable, i.e. stochastic parameters as advocated by Sirias and Mehra (2005). Nevertheless, there are still some researchers who took stochastic variables into consideration. For example, Weng (1999) showed that when a manufacturer and a distributor coordinate together, the order quantity and joint profits would increase and the selling price would decrease. Li and Liu (2006) showed that quantity discount policy is a possible way to achieve coordination so that all parties in the supply chain could be better off by sharing of profit. In another study, Cachon (1999) investigated the effect of demand variability in a supply chain with one supplier, many retailers that face non-deterministic demand. The author advocated that a flexibility in quantity strategy that is able to compensate this problem: to lengthen the ordering interval and

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3 to increase the ordering batch size, which forms a flexible quantity strategy, is the  
4 most effective way to reduce the supplier's demand variability. Although demand  
5 variability is the most commonly considered uncertainty, there are still other types of  
6 uncertainties which could be considered. Since most of the coordination schemes as  
7 discussed above are static in nature, they are not able to face disruptions. By making  
8 use of wholesale quantity discount policy, Qi *et al.* (2004) studied a single-supplier,  
9 single-retailer supply chain that is experiencing demand disruptions.  
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13 It could be observed that most of the models of the abovementioned studies are two-  
14 stage supply chains. On the other hand, Munson and Rosenblatt (2001) considered the  
15 quantity discount in a three-tier supply chain with supplier, manufacturer and retailer.  
16 Their work provides further evidence for the value of supply chain coordination by  
17 extending two-stage study to three-stage study.  
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### 19 20 **3.3.2 Return Policy**

21 A return policy (sometimes known as buyback policy) is a commitment made by a  
22 manufacturer, or any upstream supply chain members in general, who accept products  
23 from a downstream partner to be returned for some reasons and credit will be given to  
24 the downstream partner subject to the agreement. Return policy could encourage a  
25 buyer to order more. This could be done because the supplier will share certain risk  
26 with the buyer by offering a credit for each of his returned units, be it due to unsold,  
27 or whatever reasons (Wang and Benaroch, 2004). In general, there are two kinds of  
28 return policies: full return and partial return. The former one refunds full wholesale  
29 price for all returned products, while the latter one only refunds a portion of a unit  
30 price for the returned products. For example, Lau and Lau (1999) studied return  
31 policy of a single-period problem for a monopolistic manufacturer and a retailer. In  
32 another study, Yao *et al.* (2005) studied the case that a manufacturer provides a return  
33 policy for unsold goods to two competing retailers, who face uncertain demand.  
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38 From the reviewed studies, it could be observed that channel coordination is in fact  
39 governed by a set of rules such as price or quantity discount between the parties who  
40 get involved. However, it could be observed that the studies under review in this  
41 section are more static in nature so that the main objective is to, say, find the optimal  
42 discount policy which could not be altered in later stage. Therefore, some of them just  
43 assume deterministic demand in their models and some of them considered single- or  
44 two-period problems for simplicity. In contrast, a flexible supply contract allows the  
45 retailer to change her orders dynamically. The next section is dedicated to review  
46 related literature with respect to contract approach.  
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### 49 50 **3.4 Contract Approach**

51 In fact, all channel coordination could be shaped as contract approach so that a set of  
52 rules for the interactions, such as price or quantity discount, return policies, the  
53 common replenished epochs as discussed above, etc., between the different parties  
54 who get involved is specified in the contract. On the contrary, contract approach  
55 usually permits the retailer to change her orders dynamically in different periods.  
56 Giannoccaro and Pontrandolfo (2004) advocated that contracts are a useful tool to  
57 make several supply chain members of a decentralised setting "behave coherently  
58 among each other". Blomqvist *et al.* (2005) found that, from a case study, a good  
59 flexible contract prevents disagreements in asymmetric R&D collaboration. In short,  
60 contracting enables joint rules for the collaboration to be established because a

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3 contract restricts the participating members to carry out the actions, if they are all  
4 coordination oriented in obeying the rules. However, as suggested by Anupindi and  
5 Bassok (1998), research on the analysis of supply contracts with commitments when  
6 the buyer faces stochastic demands is a relatively new research direction.  
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### 9 **3.4.1 Quantity flexibility**

10 In contrast to traditional channel coordination approach, quantity flexibility exists in  
11 the form of contract which could be altered once it has been setup. The major  
12 rationale of any kind of flexibility of a system is to pick up the most recent  
13 information, and then to make adjustments accordingly if needed so that the system  
14 could be improved as compared with the situation without such flexibility. Taking  
15 supply chains as example, it is impossible to provide accurate forecast subject to  
16 unknown demand. No matter how good is the forecasting technique, the forecasted  
17 demand is still only an estimation which could deviate from the actual demand.  
18 Therefore, if flexibility could be provided in order to alleviate this problem, it is  
19 possible that supply chain members could gain benefits from such policy. In a  
20 quantity flexibility contract, the buyer usually places an order earlier, or makes a  
21 commitment for minimum quantity to be purchased, depending on different settings  
22 of a contract and the supplier, in return, provides the buyer with flexibility to adjust  
23 the order quantity later, subject to the most updated and accurate demand information  
24 (Wang and Tsao, 2006). Tibben-Lembke (2004) found that flexibility becomes more  
25 important as demand becomes more uncertain and finally, they concluded that  
26 “flexibility in contracts has proven to be a fertile area for research”. Schneeweiss *et al.*  
27 (2004) concluded that it is worthwhile to choose the contract parameters in the best  
28 possible way by considering, in particular, the specific information situation between  
29 the partners of a supply chain.  
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### 35 **3.4.2 Real Options**

36 Real options approach is a special case of the above flexibility contracts. For example,  
37 Nembhard *et al.* (2005) developed a real-options-based contract with flexibility to  
38 select different suppliers, plant locations, and market regions. Although it is  
39 commonly believed that flexibility could allow firms to compete more effectively,  
40 flexibility is not costless (Nembhard *et al.*, 2005). Along this line of research direction,  
41 any adjustment arises from the given flexibility would incur cost. This practice is  
42 similar to exercise a financial option. Spinler and Huchzermeier (2006) advocated that  
43 such contracts could provide supply chain members with flexibility to respond to  
44 uncertain market conditions. Cachon and Lariviere (2001) developed an option  
45 contract and concluded that “supply chain should maintain the flexibility to defer the  
46 final production decision until after the manufacturer observes demand”.  
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### 51 **3.4.3 Revenue Sharing**

52 Revenue sharing is another form of contract approach in order to achieve coordinated  
53 planning. Usually, the overall “extra” revenue obtained from the contract is shared  
54 among the parties who get involved, as governed by the contract. By conducting a  
55 series of numerical studies in a two-stage single buyer single supplier chemical supply  
56 chain, Corbett and DeCroix (2001) showed that such contracts could be able to  
57 increase supply-chain profits, but not necessarily lead to reduction in the consumption  
58 of indirect materials involved. They also concluded that the goals of maximizing joint  
59 profits and minimizing consumption are generally not aligned. Cachon and Lariviere  
60 (2005) demonstrated that a revenue sharing contract could coordinate a supply chain

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3 with a single retailer situation and could allocate the supply chain's profit. However,  
4 they also identified the most critical limitation of using revenue sharing contract: the  
5 supplier must monitor the retailer's revenues to verify that they are shared accordingly.  
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#### 8 **3.4.4 Miscellaneous**

9 There are also other forms of contract that could not be classified under above  
10 categories because their scopes are too diversified. For example, Cheung and Leung  
11 (2000) studied a coordinated joint replenishment scheme between a supplier and  
12 buyer with two product types. The buyer will impose quality control procedures to  
13 decide if a lot of product received should be accepted, or rejected with corrective  
14 action. By coordinating the order quantity of both items, it was found that cost saving  
15 could be achieved because an optimal sample plan could be derived under the  
16 coordinated model. Chen and Xu (2001) studied the coordination of a manufacturer  
17 and a retailer in a supply chain for single-period products by a two-stage ordering and  
18 production system. The initial time of the first ordering and production remains  
19 unchanged as in the traditional single-stage ordering system counterpart. However,  
20 the retailer is allowed to reorder later in order to let the retailer to collect more  
21 information to reduce forecast error. Result showed that the manufacturer may not be  
22 better off or well off, although the retailer's performance is improved. They suggested  
23 that some profit compensation plans (i.e. revenue sharing as discussed above) should  
24 be incorporated so as to make both parties could be better off. Zimmer (2002)  
25 developed a coordination mechanism that allocates the cost of a two-stage supply  
26 chain through bonus and penalty cost. Zimmer (2002) found that the coordinated  
27 system could perform as well as a centralised counterpart. In a two-stage supply chain,  
28 Wang *et al.* (2004) employed continuous incentive contracts, which is a profit-  
29 sharing-based contract instead of quantity discount contract, and analysed the  
30 behaviour of the supply chain. Subject to normal demand, they tested their model  
31 through a numerical study and found that the costs of supplier, retailer, and the system  
32 could be reduced as compared with the case without coordination.  
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#### 39 **3.5 Information Sharing Approach**

40 Information sharing is regarded as a tool to reduce the effect of bullwhip effects (Lee  
41 *et al.*, 1997, Cachon and Fisher, 2000). Information technology is certainly an enabler  
42 for supply chain members to share information quickly, accurately and inexpensively  
43 (but not at zero cost). Therefore, information exchange among supply chain members  
44 could certainly facilitate the coordination of supply chain activities. Since the scope of  
45 information sharing is also quite broad, the review in this section focuses on  
46 information sharing only in the context of coordination studies (recall that they are the  
47 two different dimensions as reviewed by Sahin and Robinson (2002)), in order to  
48 match with the overall scope of this paper. In other words, the literature that only  
49 investigated the values or benefits of information sharing will be excluded (e.g. Chen  
50 *et al.*, 2000, Cachon and Fisher, 2000, etc.), despite the fact that even information  
51 sharing alone is highly related to coordinating supply chains. For example, Chen  
52 (1999) developed a model to find the optimal policy subject to delay in material and  
53 information flows. Yu *et al.* (2001) showed that how the supply chain members could  
54 form a partnership in order to achieve a pareto improvement by sharing demand  
55 information. Karaesmen *et al.* (2002) investigated when demand information should  
56 be released in order to coordinate production planning in a make-to-stock production  
57 system. For a general review of the impacts of sharing production information with  
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3 respect to supply chain dynamics, please refer to Sahin and Robinson (2002) and  
4 Huang *et al.* (2003).  
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### 7 **3.6 Market Economics Approach**

8 This approach based on microeconomics' view of market which consists of  
9 independent buyers and sellers in a perfect competitive market environment (Kaihara,  
10 2003). The interaction between price, demand and production of a product in order to  
11 maximise a firm's expected profit is studied. Although this is not a dominating  
12 research direction in SCM from the operations management perspective, there are still  
13 a number of reported research in this area. To name a few, Ugarte and Oren (2000)  
14 studied a coordination mechanism regarding production and allocation decisions of a  
15 two-stage supply chain from market economics perspective with private information.  
16 They showed that decentralisation is less efficient than centralisation if private  
17 information affects operational decisions. Kaihara (2003) analysed supply chain in  
18 economic terms. Both studies aimed at finding the Pareto optimal solution of the  
19 market economics based supply chains. This is the equilibrium solution of the system  
20 so that resources are allocated in the most efficient manner. Babaioff and Walsh (2005)  
21 developed a negotiation mechanism to coordinate the buying and selling of goods  
22 across a supply chain, based on incentive auctions to encourage supply chain  
23 members to report their private information truthfully.  
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### 28 **3.7 Observations**

29 Above reviews summarised some recent development which employed analytical  
30 approaches to study the impacts of coordination in supply chains. This section serves  
31 to investigate and to summarise the characteristics of the quoted literature in this  
32 respect. Major attributes of the above papers are summarised in Table 1. It is not our  
33 intention to criticise the approaches being employed in these papers. The objective is  
34 to observe the current research pattern which may be helpful for researchers to  
35 conduct further research in this area.  
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39 From Table 1, it could be easily observed that most papers concern dyadic supply  
40 chain, probably due to the simplicity of this structure in analytical analysis. It is  
41 logical to ask whether future research in this domain could extend the dyadic structure  
42 for analysis or not. Secondly, demand uncertainty is still the most frequently quoted  
43 parameter accounted for system dynamics. In this connection, it is insightful to  
44 include, if possible, more stochastic variables (like suppliers' capacity) in the analysis,  
45 although it may be difficult in various mathematical approaches. As a matter of fact,  
46 other types of uncertainty may also present in any supply chains. For example,  
47 uncertainty is inherent in the market at supply side (e.g. delivered from an external  
48 supplier may differ from those requested) (Petrovic *et al.*, 1998). It is desired to  
49 consider both supply and demand uncertainty into consideration.  
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53 However, the main drawback of these studies is on the inflexible coordination  
54 mechanism (that's why some studies consider only single- or two-period problem).  
55 The major objective of these studies is still to derive an optimal solution (in terms of  
56 expected value if uncertainties are involved) subject to the distribution of the  
57 stochastic variables. Even though some studies consider system dynamics, the impacts  
58 of uncertainty has not been studied. It is desired that some flexible coordination  
59 mechanism, which will be taking the most updated situation into consideration, could  
60 be developed. Finally, one may observe from Table 1 that some papers did not take

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3 uncertainty into considerations. As discussed before, a major weakness of some  
4 analytical approaches is that it is not easy to model such uncertainty mathematically.  
5 To be fair, coordination among supply chain members does not imply the presence of  
6 uncertainty. However, it is certainly worth considering the effect of coordination  
7 subject to uncertain environment. It is interesting to note that analytical approaches  
8 could not be employed to find the absolute optimal solution, because uncertainties are  
9 always unpredictable. In other words, future events could not be forecasted without  
10 error. However, the above studies could find the optimal value in expected values,  
11 like expected cost, when the system subject to a certain probabilistic distribution.  
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#### 15 **4. SIMULATION APPROACHES**

16 With advanced development in computing technology in the last few decades,  
17 simulation has become a very important tool to analyse complicated problems. It is a  
18 highly flexible tool that can be used effectively for analyzing complex systems, like  
19 supply chains, and enables us to model such systems in details (Van Der Vorst *et al.*,  
20 2000; Jansen *et al.* 2001). One of the advantages of simulation is the ability to study  
21 hypothetical models as close to the real situations as possible (Sirias and Mehra,  
22 2005). Parameters in simulation programs, i.e. dependent variables or systems'  
23 parameters, could be varied easily so that analysis of different combinations of the  
24 systems under study is affordable, and hence the cost to make decision could be  
25 reduced, and response to such modifications could be obtained very fast (Manzini *et*  
26 *al.*, 2005). Unlike traditional mathematical optimisation techniques, results in  
27 intermediate stages could be captured during simulation process so that system  
28 dynamics could be analysed in different perspectives. In this connection, it is not  
29 surprising that simulation has been widely utilised in supply chain studies with respect  
30 to systems dynamics. For example, Hung *et al.* (2006) presented a simulation study of  
31 a supply chain in which inventory replenishment systems and production planning  
32 had been modelled. They tested their model in a two-product divergent supply chain  
33 with uncertain demand, which was modelled by Normal distribution. The simulation  
34 model was built based on object-oriented approach for studying the dynamic  
35 behaviour of supply chain. In fact, object-oriented approach is highly related to the  
36 multi-agent approach, which will be discussed in the later section. One benefit of  
37 using such approach is that user can easily modify the simulation model to reflect  
38 changes in the supply chain.  
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45 Simulation is not only applicable to new system design. Manzini *et al.* (2005) made  
46 use of simulation to study five industrial cases in different sectors, but all are  
47 concerning material flows within the supply chain, in order to demonstrate how  
48 simulation could be employed to improve existing systems. Rabelo *et al.* (2005)  
49 employed simulation to evaluate system dynamics of a semiconductor enterprise.  
50 Their study demonstrated that how simulation could help top management to select  
51 the most appropriate options from various production decisions. As discussed  
52 previously, the scope of the papers under review is related to coordination or system  
53 dynamics in supply chains. For a general review of supply chain simulation study,  
54 please refer to Terzi and Cavalieri (2004). For a general review of simulation  
55 optimisation, please refer to Tekin and Sabuncuoglu (2004).  
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#### 59 **4.1 General Simulation Studies**

60 By making use of controlled partial shipment in a two-stage supply chain, Banerjee *et*  
*al.* (2001) conducted a series of simulation runs to prove that such scheme could

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3 improve customer service at the retail level. Also in a two-stage supply chain,  
4 Banerjee *et al.* (2003) studied the effects of lateral (i.e. intra-echelon) shipments  
5 through simulation. Inventory replenishment decisions were made based on a  
6 coordinated common review period. Based on order-up-to policy, Ng *et al.* (2001)  
7 studied two coordinated inventory models with alternative supply possibilities  
8 between two suppliers and two retailers. They found that higher level of coordination  
9 leads to significant savings in the average total cost of supply chain. In another study,  
10 Jansen *et al.* (2001) analysed the performance of several scenarios in a multi-  
11 compartment distribution system in order to satisfy customer demands for shorter lead  
12 times. This study illustrates an advantage of simulation – the ability to analyse  
13 different configurations and to record different performance measures easily.  
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18 By considering different supply chain configurations, Garavelli *et al.* (2003)  
19 investigated the effects of flexibility in supply chain configurations. Heuristics had  
20 been developed for product assignment and the authors found that even limited  
21 flexibility could provide better performance than the case with full flexibility. Zhao *et al.*  
22 (2002) analysed the effect of forecasting model, and employed early order  
23 commitment as a coordination method in a decentralised supply chain with a  
24 capacitated manufacturer and retailers under demand uncertainty. Simulation results  
25 showed that the manufacturer would gain the maximum benefit when retailers made  
26 early order commitments. On the other hand, selection of forecasting models is less  
27 important than selection of early order commitment in determining the benefits for the  
28 supply chain members.  
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32 Facing uncertain environment, it is logical to change a decision by adapting real time  
33 information after it has been realised. Pontrandolfo *et al.* (2002) developed a  
34 reinforcement learning approach to coordinate different supply chain members for  
35 decision making in global SCM. The performance of an action in a state is used to  
36 update the knowledge base until the system encounters another decision-making state.  
37 Their study showed another distinctive feature of simulation which allows iteration of  
38 some flexible algorithms. Regarding flexibility, Ferdows and Carabetta (2006)  
39 conducted a study to evaluate the impact of flexibility on inter-factory supply chain  
40 with uncertain demand. They found that flexibility in the inter-factory linkages can  
41 reduce the impact of this perturbation substantially.  
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45 As discussed in Section 3, most analytical approaches focus on two-stage supply  
46 chain. On the contrary, simulation may be employed to study multi-stage supply  
47 chains. For example, Beamon and Chen (2001) simulated a four-stage supply chain  
48 and then attempted to find out, statistically, the relationship among a number of  
49 independent variables with a number of performance measures. Also discussed in  
50 Section 3, contracting is a useful approach to achieve coordination. However,  
51 cancellation of contracts may be beneficial to supply chain members as well. Xu  
52 (2005) investigated how the supplier could choose cancellation costs that minimise  
53 her expected cost during the planning horizon. With the aids of simulation, Sirias and  
54 Mehra (2005) compared two incentive systems: quantity and lead time-dependent  
55 discounts in a two distributors and single supplier supply chain. They found that, not  
56 surprisingly, both discount policies could improve the performance of the whole  
57 supply chain.  
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#### 4.2 MIT Beer Game

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As discussed in the beginning of this paper, the most famous simulation study in this respect originates from Forrester's study in Industrial Dynamics (1961). Another seminal work was conducted by Sterman (1989), which is now known as "MIT beer game". These studies showed that there is a possibility that small fluctuation in end-customer demand will be amplified along a supply chain so that excessive inventory may be held in upstream members. As discussed before, Lee *et al.* (1997) coined this phenomenon as the bullwhip effect. By introducing the "time compression" concept, Mason-Jones and Towill (1997) found that stock levels could be reduced in the beer game. This could be done by transferring demand information as quickly as possible along the chain through the use of information technology. Owens and Levary (2002) supported the argument of Mason-Jones Towill (1997) by conducting another study of a food supply chain. These studies are highly related to information sharing, which will be discussed in Section 4.3.

By adopting the beer game approach, De Souza *et al.* (2000) analysed the performance of coordination by synchronising the inventory and work in process levels of each supply chain player under centralised and decentralised configurations. In a later study, Hieber and Hartel (2003) revisited the beer game and investigated the impacts of different ordering strategies on the system. They found that regardless of the ordering strategies, the last member of the chain will bear the greatest cost. By employing agent-based simulation approach, Kimbrough *et al.* (2002) proved that agent simulation could reproduce the Bullwhip Effect. They also concluded that agents do better than humans when playing the "MIT Beer Game" by using genetic algorithm to capture real world information. The major contribution of their paper is to demonstrate that agent-based modelling is able to mimic supply chain dynamics. More on agent-based studies will be presented later.

### 4.3 Information Sharing

With advanced information technology, information could be more visible than a decade before (Chan and Chan, 2009). Benefits of information sharing have been discussed in previous section. Undoubtedly, simulation is an effective tool for analysing the effects of information sharing. This is because some of the reported contributions could not be quantified analytically in nature. In this connection, simulation plays a vital role in this line of research. For example, Van Donselaar *et al.* (2001) analysed how to utilise advanced uncertain demand information reduce inventory level in a multi-period simulation study. In a divergent supply chain with a capacitated supplier, Zhao *et al.* (2002) and Zhao and Xie (2002) conducted simulation studies to show how forecasting models could affect the value of sharing information of the supply chain subject to uncertain demand. Reddy and Rajendran (2005) developed a heuristic approach to find out the dynamic order-up-to level, subject to different levels of information sharing.

Visibility in inventory information, or inventory accuracy in another sense, could improve supply chain performance in terms of reducing the chance of stock out or cost. Fleisch and Tellkamp (2005) simulated a three-stage supply chain with single product by aligning physical inventory information of the supply chain members. Fleisch and Tellkamp (2005) identified three factors, which are theft, unsaleables, and process quality, in their simulation model. They found that elimination of inventory inaccuracy by periodic inventory information alignment could reduce supply chain costs as well as the out-of-stock level. Apart from sharing inventory information, Yee

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3 (2005) analysed the impact of sharing demand mix information on various supply  
4 chain performance indicators, subject to both demand and capacity uncertainty.  
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#### 7 **4.4 Multi-Agent Simulation**

8 Multi-agent systems, a branch of distributed artificial intelligence, consist of more  
9 than one agent, which is defined as a “computer system, situated in some environment,  
10 that is capable of flexible autonomous action in order to meet its design objectives”  
11 (Jennings *et al.* 1998). This is a relatively new yet popular technique in analysing  
12 supply chain dynamics (e.g. Brandolese *et al.*, 2000; Sadeh *et al.*, 2001; Lin *et al.*,  
13 2002). In supply chain, each supply chain member could be represented as an agent  
14 and hence a group of enterprises form a multi-agent system (Lau *et al.*, 2004).  
15 Kaihara (2001) stated that it is natural to model supply chains through multi-agent  
16 approach. One of the rationales behind using multi-agent system approach to model  
17 supply chains is that multi-agent system provides a communication platform for  
18 information exchange through coordination or negotiation protocol. For example,  
19 Swaminathan *et al.* (1998) developed a modelling framework using multi-agent  
20 systems for simulating dynamics supply chain. The model consists of a reusable  
21 software library which contains functional agents (such as plants, suppliers, etc.),  
22 control agents (like inventory management or demand planning), and their interaction  
23 protocols (like message types). Lin and Shaw (1998) proposed a multi-agent  
24 information approach for modelling the order fulfilment process in supply chains, and  
25 discussed how the model could apply to three different demand strategies (make to  
26 order, make to stock, assemble to order) under different configurations. In a supply  
27 chain with uncertain demand, Brandolese *et al.* (2000) showed that supply chain  
28 members are able to coordinate with each other through a pre-defined communication  
29 protocol to bid for extra capacity in the production system. Sadeh *et al.* (2001)  
30 presented an agent-based architecture for dynamic supply chain called MASCOT  
31 (Multi-Agent Supply Chain cOordination Tool). MASCOT is a re-configurable,  
32 multi-level, agent-based architecture for coordinated supply chain. Agents in  
33 MASCOT serve as wrappers for planning and scheduling modules. By modelling a  
34 supply chain network with agent-based approach, Gjerdrum *et al.* (2001) simulated  
35 how the agent system could determine the inventory control policy in order to reduce  
36 the operating cost of the system while a high level of customer order fulfilment could  
37 be maintained. In another study, Umeda and Zhang (2006) developed an agent-based  
38 simulation model to study three different operation models (reorder-point, centralised,  
39 and pull). A negotiation (or coordination) protocol was developed in finding next  
40 order volumes between operational managers and parts suppliers of the distributed  
41 supply chain. Readers can refer to Lee and Kim’s review (2008) for a general review  
42 of applications of multi-agent systems in manufacturing and supply chain applications.  
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#### 51 **4.5 Fuzzy Logic**

52 Apart from using probability distribution to model stochastic variables, fuzzy logic is  
53 an alternative and is a useful tool to handle variables with imprecise information.  
54 There variables in supply chain could be described by vague linguistic language, and  
55 be modelled by fuzzy membership functions (Petrovic *et al.*, 1998; Grabot *et al.*,  
56 2005). Taking demand as an example, it could be described as “demand is *high* in this  
57 week”. For example, Petrovic *et al.* (1998, 1999) made use of fuzzy logic to interpret  
58 and represent vague and imprecise information in a serial supply chain with unlimited  
59 production capacity, while the objective was to determine the stock levels and order  
60 quantities for each inventory locations at the lowest cost. System dynamics was

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3 analysed with respect to uncertain demand and uncertain supply, which were  
4 expressed in linguistic phrase. In their simulation studies, supply chain members were  
5 coordinated by sharing inventory information with adjacent members. Hu *et al.* (2001)  
6 developed a fuzzy logic based bid calculation model to determine the set of product  
7 quantity that will be stored to inventory. Hojati (2004) investigated how fuzzy logic  
8 could be employed to model non-deterministic parameters in traditional EOQ-based  
9 model, and a probabilistic-based EOQ model. Grabot *et al.* (2005) modelled the  
10 uncertainty and imprecision of the demand by fuzzy membership function before they  
11 are allowed to pass through each step of the material requirement planning cycle.  
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#### 14 **4.6 Observations**

15 From the preceding review on simulation studies, it could be observed that majority of  
16 them, unlike analytical approach, are multi-period in nature and more performance  
17 indicators could be recorded for discussion. This is due to the capability of simulation  
18 study which can capture a variety of data during the course of simulation study, and  
19 could be employed to analyse iterative algorithm. Some other attributes are  
20 summarised in Table 2.  
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24 Regarding supply chain structures, Table 2 reveals that dyadic structure is not the  
25 most dominating structure being employed under most simulation studies. In other  
26 words, the attribute is more diversified as compared with the cases in analytical  
27 approaches. This observation is also a direct consequent of the benefits of simulation  
28 study that more complicated model could be coded and the computational time is  
29 reducing while computing power is improving over the years. Therefore, network  
30 model is more feasible in simulation study.  
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33 Nevertheless, demand uncertainty is still the major source regarding system dynamics.  
34 It could be beneficial to include more than one aspect of uncertainty into  
35 considerations as discussed in Section 3.7. However, this is not the only drawback  
36 regarding uncertainties. Most of the simulation studies only modelled them by a  
37 certain kind of probability distributions. There is a lack of study on varying the  
38 uncertainty level in order to get some insights on the impacts of them on various  
39 proposed methodologies.  
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43 In addition, probability distributions other than Normal distribution (e.g. exponential)  
44 are employed in some simulation studies to model some stochastic variables. This is a  
45 good practice and is encouraging to conduct such sensitivity analysis. Nevertheless, it  
46 is relatively easier to change the probability function of a particular parameter in a  
47 simulation study than in an analytical study. This could result in more robust  
48 simulation results, which can compensate the deficiency of simulation studies in terms  
49 of their ability to produce robust analytical solutions.  
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#### 53 **5. CONCLUDING REMARKS**

54 This paper aims at reviewing recent literature regarding coordination and system  
55 dynamics in supply chains. Section 3 and Section 4 provide a summary of the studies  
56 under two categories: analytical approach and simulation approach, respectively.  
57 Attributes of each category had been presented at the end of each section. Although  
58 both approaches are equally popular in solving supply chain coordination problems,  
59 there are some more interesting observations that could be shared as below. Table 3  
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3 summarises some key different aspects regarding the two approaches in this field of  
4 study. Some of them are elaborated in the subsequent sections.  
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### 7 **5.1 Analytical Approach or Simulation Approach?**

8 The main contrast between analytical models and simulation models is that the latter  
9 normally do not aim at optimising the problems under study. Instead, behaviour of the  
10 supply chains under study is the main focal point for investigation. In addition,  
11 simulation studies tend to include more performance indicators for discussion. This is  
12 certainly a benefit as a result of the simulation capability. However, this is also the  
13 weakness of simulation study that a robust optimal solution could not be guaranteed.  
14 In other words, simulation studies are more focusing on whether the developed  
15 algorithm could deliver a good result (rather than the optimal result), and the trend of  
16 the simulation results. It is quite unfair to say this is the shortcoming of simulation  
17 study, but, as a matter of fact, this is a limitation of simulation study. However, if the  
18 focus of a study is put on system dynamics, and stochastic variables are presented so  
19 that the optimal solution seems non-existent. Under this situation, it is straight  
20 forward to consider simulation study as a promising tool in relation to such study.  
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25 In this review, the number of simulation studies under review is slightly less than that  
26 number of analytical studies under review. It could be concluded that even though  
27 simulation is useful in many facets of supply chain studies, analytical approaches are  
28 still a widely accepted tool, especially for well-defined problems. It is not the  
29 intention of this study to judge which approach is the best methodology in supply  
30 chain research. From the attributes of the two sections, it could be concluded that they  
31 attract different pools of study and could be complementary to each other. Insights or  
32 algorithms observed in analytical studies could be modified as more sophisticated,  
33 and / or iterative, and / or even interactive algorithms to be studied by simulation.  
34 When system dynamics is the main concern, however, it seems that simulation could  
35 be more powerful in analysing the problem subject to different sources of  
36 uncertainties.  
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40 One important issue is noticed in the reported simulation studies, it is not uncommon  
41 that output analysis is omitted. Some of the reported literature only report the trend of  
42 the simulation results and this is, to a certain extent, inadequate. Simulation output  
43 data by employing statistical techniques (like paired-t test for testing the output of two  
44 or more different systems, subject to the same conditions) could be imperative in  
45 analysing, interpreting, and using the simulation results (Law and Kelton, 1991). Law  
46 and Kelton (1991) also advocated that some variance-reduction techniques should be  
47 considered to reduce the variances of the output random variables of interest, which is  
48 overlooked in some simulation studies.  
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### 52 **5.2 Flexibility in Coordination**

53 In fact, there is a drawback which could be observed from the review. Most of the  
54 proposed methodologies do not take flexibility in the coordination methodologies into  
55 considerations while system dynamics presents. Although some authors have  
56 attempted to add flexibility into their study (e.g. Tsay (1999) for quantity flexibility,  
57 Barnes-Shuster *et al.* (2002) for real options, Cachon and Lariviere (2005) for revenue  
58 sharing, etc.), they are restricted to single- or two-period problems. It is believed that  
59 flexibility in general provides a competitive advantage to firms, and allows them to  
60 compete more effectively when demand and / or price are uncertain (Nembhard *et al.*

2005). If production is inflexible such that production quantities are varied frequently, significant costs will be incurred and this will degrade any inventory policies (Dejonckheere *et al.*, 2004). In addition, flexibility seems decoupled from information sharing and adaptability characteristic. Interaction of them could be a new research direction in the future, especially if simulation approach is adopted (e.g. Chan and Chan, 2009).

### 5.3 Uncertainties

As discussed at the end of Section 4, there is a lack of study on varying the uncertainty level in order to gain insights on the impacts of such stochastic variables. This is also a focus of system dynamics, especially if simulation is adopted as the optimal solution could not be found. No matter how good a coordination mechanism could be developed, if it is only useful under certain situations, effort is required to further refine the model subject to different level of uncertainties.

Unsurprisingly, Normal distribution is popular choice for modelling stochastic variables (e.g. demand), which is still the main stream of research pattern. Apart from its simplicity, researchers have conducted some sensitivity analysis on using normal distribution to represent stochastic demand and concluded that this is a robust approximation (Tyworth and O'Neil, 1997). In fact, the Central Limit Theorem is widely quoted as a proof in approximating stochastic parameter by Normal distribution (Dekker *et al.*, 2000; Brandolese, *et al.*, 2001; Chou *et al.*, 2001; Chen and Lin, 2002; Kim *et al.*, 2003). Therefore, using Normal approximation is still a reasonable approach to modelling stochastic variables. However, as discussed above, sensitivity analysis could be carried out on different levels of uncertainties.

### 5.4 Research Gap

By reviewing the two observations (Section 3.7 and Section 4.6) and Table 1, the authors found that related research are polarised into two extremes. Nowadays supply chain practitioners are competing in a turbulent environment in which flexibility and fast response is a pre-requisite for survival. They witnessed the increasing complexity of coordination problems in supply chains. Although analytical approaches could provide us with a robust and closed form mathematical solution, there is a need to fill the research gap by studying agile (with flexibility) and networked supply chains. The authors advocate research with mixed-mode study in gaining the benefits from both approaches. That is, to develop an analytical based simulation modelling so that a robust analytical solution, with the ability to response to changes fast. In so doing, a proper sensitivity analysis has to be carried out in order to maintain a high level of robustness of the study.

To conclude, this is not an exhaustive review regarding SCM ss addressed in the beginning of this paper. The focus is put on coordination and system dynamics of supply chains. Nevertheless, the authors hope that readers of this study could gain insights from this paper in carrying out their research in the related areas in the future, especially when they are struggling in selecting a proper methodology for solving their problems.

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Table 1. Attributes of analytical studies under review

Approaches		Attributes	Uncertainty		Distribution				Structure				
			U1	U2	D1	D2	D3	D4	S1	S2	S3	S4	
<b>Control Theoretic</b>		Dejonckheere <i>et al.</i> (2003)	√		√				√				
		Dejonckheere <i>et al.</i> (2004)	√		√				√				
		Disney and Towill (2002)	√		√					√			
		Riddalls and Bennett (2002)	√			√				√			
		Sourirajan <i>et al.</i> (2008)	√	√	√					√			
<b>Channel Coordination</b>	<i>Discount Policy</i>	Boyacı and Gallego (2002)										√	
		Cachon (1999)	√		√				√			√	
		Chen <i>et al.</i> (2001)										√	
		Karabatı and Sayın (2008)										√	
		Klastorin <i>et al.</i> (2002)	√					√				√	
		Li and Liu (2006)	√		√					√			
		Mishra (2004)										√	
		Munson and Rosenblatt (2001)								√			
		Qi <i>et al.</i> (2004)	√						√		√		
		Shin and Benton (2007)	√		√						√		
	Viswanathan and Piplani (2001)										√		
	Weng (1999)	√				√							
	<i>Return Policy</i>	Lau and Lau (1999)	√		√						√		
		Lau <i>et al.</i> (2000)	√		√						√		
		Lee and Rhee (2007)	√				√				√		
Wang and Benaroch (2004)		√					√			√			
Yao <i>et al.</i> (2005)		√		√							√		
<b>Contract Approach</b>	<i>Quantity Flexibility</i>	Anupindi and Bassok (1998)	√		√					√			
		Bassok and Anupindi (1997)	√		√					√			
		Jung <i>et al.</i> (2008)									√		
		Schneeweiss <i>et al.</i> (2004)	√				√				√		
		Tibben-Lembke (2004)	√		√						√		
	Tsay (1999)	√		√						√			
	<i>Real Options</i>	Barnes-Shuster <i>et al.</i> (2002)	√		√						√		
		Cachon and Lariviere (2001)	√			√					√		
		Lee and Kumara (2007)											√
		Nembhard <i>et al.</i> (2005)		√		√							√
		Spinler and Huchzermeier (2006)	√		√						√		
		Wang and Tsao (2006)	√					√			√		
	<i>Revenue Sharing</i>	Cachon and Lariviere (2005)	√				√				√		
		Chiou <i>et al.</i> (2007)										√	
		Corbett and DeCroix (2001)	√					√			√		
		Giannoccaro and Pontrandolfo (2004)	√		√				√				
		Jaber and Goyal (2008)											√
		Zhang <i>et al.</i> (2008)	√		√						√		
	<i>Others</i>	Chen and Xu (2001)	√		√						√		
		Chen and Liu (2008)										√	
Cheung and Leung (2000)		√						√		√			
Mathur and Shah (2007)		√					√			√			
Wang <i>et al.</i> (2004)		√		√							√		
Zimmer (2002)										√			
<b>Information Sharing</b>		Chen (1999)	√			√			√				
		Karaesmen <i>et al.</i> (2002)	√			√				√			
		Lee (2001)	√			√				√			
		Weng and McClurg (2003)	√				√			√			
		Yu <i>et al.</i> (2001)	√		√					√			
<b>Market Economics Approach</b>		Babaioff and Walsh (2005)		√				√				√	
		Kaihara (2003)										√	
		Ugarte and Oren (2000)	√			√					√		

Notes:

1. "U1" is marked if demand is the only uncertainty; "U2" is marked if there is uncertainty other than demand, unmarked if no uncertainty exists, i.e. all parameters are all deterministic;

2. "D1" is marked if uncertainty is modelled by Normal distribution, "D2" is marked if uncertainty is modelled by non-specified Stochastic distribution, "D3" is marked if the uncertainty is modelled by uniform distribution, "D4" is marked if uncertainty is modelled by other distributions, unmarked if no uncertainty exists;
3. "S1" is marked if the supply chain structure is serial, "S2" is marked if the supply chain structure is dyadic (i.e. one to one), "S3" is marked if the supply chain structure is divergent (one supplier to many retailers), "S4" is marked if the supply chain structure is network.

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Table 2. Attributes of simulation studies under review

Approaches	Attributes	Uncertainty		Distribution				Structure			
		U1	U2	D1	D2	D3	D4	S1	S2	S3	S4
General Studies	Banerjee <i>et al.</i> (2001)	√		√						√	
	Banerjee <i>et al.</i> (2003)	√				√				√	
	Beamon and Chen (2001)	√	√				√				√
	Ferdows and Carabetta (2006)	√		√							√
	Garavelli <i>et al.</i> (2003)	√					√				√
	Hung <i>et al.</i> (2006)	√		√						√	
	Jansen <i>et al.</i> (2001)	√					√		√		
	Ng <i>et al.</i> (2001)		√				√				√
	Pontrandolfo <i>et al.</i> (2002)	√		√							√
	Rabelo <i>et al.</i> (2005)	√					√	√			
	Rabelo <i>et al.</i> (2008)	√	√				√				√
	Sirias and Mehra (2005)	√		√							√
	Van Der Vorst <i>et al.</i> (2000)	√					√				√
	Xu (2005)	√		√					√		
Zhao <i>et al.</i> (2001)	√		√							√	
MIT Beer Game	De Souza <i>et al.</i> (2000)	√					√	√			
	Helo (2000)	√		√				√			
	Hieber and Hartel (2003)	√		√				√			
	Holweg and Bicheno (2002)	√					√	√			
	Kimbrough <i>et al.</i> (2002)	√	√	√			√	√			
	Li <i>et al.</i> (2005)	√		√				√			
	Mason-Jones and Towill (1997)	√					√	√			
	Owens and Levary (2002)	√					√	√			
Information Sharing	Chiang and Feng (2007)	√	√	√						√	
	Elofson and Robinson (2007)	√	√	√							√
	Fleisch and Tellkamp (2005)	√	√	√				√			
	Reddy and Rajendran (2005)	√		√				√			
	Van Donselaar <i>et al.</i> (2001)	√					√		√		
	Yee (2005)	√	√	√							√
	Zhao and Xie (2002)	√		√						√	
Zhao <i>et al.</i> (2002)	√		√						√		
Multi-Agent Simulation	Allwood and Lee (2005)	√					√	√			
	Brandolese <i>et al.</i> (2000)	√					√				√
	Chan and Chan (2009)	√	√	√							√
	Gjerdrum <i>et al.</i> (2001)	√		√							√
	Lau <i>et al.</i> (2004)	√		√						√	
	Lin <i>et al.</i> (2002)	√					√				√
	Sadeh <i>et al.</i> (2001)										√
	Umeda and Zhang (2006)	√		√							√
Fuzzy Logic	Hojati (2004)		√				√		√		
	Hu <i>et al.</i> (2001)	√					√				√
	Grabot <i>et al.</i> (2005)	√					√	√			
	Petrovic <i>et al.</i> (1998)	√	√				√	√			
	Petrovic <i>et al.</i> (1999)	√	√				√	√			
	Yazgı Tütüncü <i>et al.</i> (2008)	√					√		√		

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**Table 3. Key Differences between Analytic Approach and Simulation Approach in Coordination Studies**

<b>Key Aspects</b>	<b>Analytic Studies</b>	<b>Simulation Studies</b>
Main objective	To find the optimal solution	To study the supply chain behaviour
Coordination Algorithm	Statics	Dynamic and iterative
Supply chain structure	Dyadic in most cases	Network
Parameters and Decision Variables	Deterministic in most cases	Can be uncertain
Time span of study	Single period in most cases	Multi-period
Flexibility attribute	Limited	Enabled
Performance indicators	Limited (single in most cases)	Multiple