Knowledge Management across a Supply Chain

Peter G. Higgins
School of Engineering and Science
Swinburne University of Technology

Abstract

This paper locates an area of research in Supply Chain Management to apply the findings from the author’s research into the decision-making behaviour of humans in production scheduling. The focus is on theoretical constructs for modelling the knowledge-based activities associated with persons managing a supply chain. The aim of this paper is to bring to a knowledge-management audience preliminary research activities in the endeavour to seek guidance on work that is across disciplines.

Introduction

Through a discursive study of manufacturing history, McKay (2001) argues that as organisations evolve from ‘early market entry’ to maturity, they eliminate waste or non-value adding activities. After they eliminating internal inefficiencies, their focus shifts to the reduction of inventory by tightening the coupling to their suppliers. As the coupling tightens, the control of production is affected by the timing of deliveries from suppliers. If production planners can use information on capabilities, capacities and availability of their suppliers, then production control may transform from the dynamic scheduling of stochastic arrivals to the scheduling of multiple resources of a virtual factory, which includes both the suppliers’ and the customers’ resources. To further increase the certainty of supply while minimising inventory, purchasers have extended their purview beyond their immediate suppliers to the suppliers of their suppliers. Likewise, suppliers in seeking to forecast demand have extended their sights to the customers of their customers. Thus a network of distributors, suppliers and retailers is formed. The simplest form of network is a chain. A supply chain consists of a set of firms that pass materials forward from raw materials to finished products — usually with several independent legal entities involved — to the end consumer (Mentzer et al., 2001). The term supply chain is not limited to a ‘chain’ but is also applies to more complex networks of organisations with upstream and downstream linkages. A network may extend beyond the suppliers and the customers to ancillary organisations providing legal, financial and marketing services or logistics service providers.

Managing the supply of materials along a supply chain, from raw materials to finish product, is the concern of Supply Chain Management (SCM). While supply chains exist as a phenomenon irrespective of them being recognised by anyone, SCM is manifestly a practice that occurs only when persons actively manage the interactions between more than two organisations within a supply chain. The management of a supply chain is a knowledge-based activity that occurs across organisational groups, which may be
separate legal entities. The strategic questions that Denning (2000) raises in regard to knowledge management are therefore especially germane:

- What knowledge to share?
- With whom to share knowledge?
- How will knowledge be shared?
- Why will knowledge be shared?
- Will knowledge be shared?

This set is similar to activities of knowledge acquisition, sharing and utilisation that Wiig (2003) associates with knowledge management.

Knowledge applied by each person in managing a supply chain depends upon their activity. The identification of the core activities on which to focus the research depends upon the processes associated with its management. However, there is considerable confusion regarding the meaning of supply chain management (Mentzer et al., 2001). There is no universal definition of SCM: a variety of definitions, varying in degree and scope, employ multifarious factors, relating to manufacturing technologies and processes, materials management and distribution strategies. They cover, *inter alia*, the planning and control of information flows, strategic inter-organisational issues, the forms of organisation or the identification and description of relationships between customers and suppliers. In classifying the types of literature that have an interest in SCM, Croom, Romano and Giannakis (2000) identify six principal component bodies to categorise over 60 factors:

- Strategic management
- Logistics
- Marketing
- Relationships/partnerships
- Best practices
- Organisational behaviour.

The broadest definition of SCM encompasses all the major business processes in managing supply, including logistics, shown in the list above (Lambert, Stick, and Ellram, 1998; Ross, 1998; Tan 2001; Mentzer et al., 2001; Skjoett-Larsen, 1999). Two streams of definitions correspond to their evolutionary roots: transportation and logistics functions; purchasing, and supply activities (Croom, Romano and Giannakis, 2000; Tan, 2001). Researchers focussing on transportation and logistics are interested in developing logistics systems in which processes, systems and organisations are integrated so that goods are moved from suppliers to satisfied customers with minimal inventory and without waste. Their goal is to replace inventory with perfect information. Tan (2001) identifies the second stream, purchasing and supply activities, with the formation of a virtual organisation composed of several independent entities that share the common goal of efficient and effective management of all entities and operations. It includes the integration of purchasing, demand management, new product design and manufacturing planning and control. Its focus is on manufacturing industry and has little to do with wholesaling and retailing. Primarily, its short-term objective is to increase productivity and reduce inventory and cycle time. The long-term strategic goal is to increase customer satisfaction, market share and profits for all members of the virtual organisation.

Instead of seeking the “holy grail” of a universal definition, Croom, Romano and Giannakis contend that researchers should advance theoretical models of supply chain phenomena should be advanced. Their contribution to model development is a taxonomy.
for mapping and evaluating supply chain research and a topology of the field of supply chain management that provides a means for delineating or defining the subject domain. Their framework has two epistemological dimensions — from theoretical to empirical and from prescriptive to descriptive. In their review of the literature, they found a paucity of theoretical work and a dominance of descriptive empirical studies. The theoretical works were restricted mainly to the dynamics of inventory systems (materials flow and stocks). To enable a rigorous and structured research of SCM, empirical studies need to be reflected against theoretical.

Extending the theoretical constructs that the author developed for representing decision behaviour in production scheduling may help to fill this gap in theory. These constructs apply to decision-making under dynamic production conditions. Corresponding conditions in SCM occur where persons have to respond to events as they arise — what Wiig (2003) calls “occurrences”. Typical situations entail persons making decisions with others under time pressure. Negotiating parties seek outcomes that satisfy multiple criteria.

### Knowledge Work

Decision makers within the supply chain (purchasers, suppliers, production controllers, logistics controllers etc.) handle situations as they arise. Situation handling is a process of identifying the situation and making decisions about what to do (Wiig, 2003). They have to make sense of situations as they evolve. Before they complete actions associated with a situation they may have to develop and execute new actions in response to new occurrences. They also have to assess results of actions often before their effects are known. Knowledge of the situation is usually incomplete. They therefore complement known facts with semantic relationships, which they find through inferences and induction (McKay, 1987). Their decision-making behaviour is goal directed (Higgins, 1999). Their goals, and the means they employ to assess performance in meeting the goals, are constrained by environmental factors, such as “production and information flow structure, organisational culture, and performance metrics” (Wäfler, 2003). Various cognitive factors also influence decision-making activities. Behaviour tends to be pragmatic. They do not generate alternative strategies and then compare their strengths and weaknesses. Instead, they recognise typical situations and the ways in which to respond. They are predisposed towards actions that require little expenditure of time and cognitive effort. Their behaviour is like Klein’s (1989) proficient decision maker, who evaluates possible responses one at a time. Klein argues that proficient decision makers try to anticipate what would happen if they carry out a specific action, by imagining its execution in the specific working environment. For simple cases, they easily recognise the situation and know straight away how to act. There is no analysis and deliberation in this type of behaviour, which Klein calls recognition-based reaction. It is similar to Rasmussen’s (1986) rule-based level of performance. For cases that are more complex, decision-makers consciously evaluate feasible choices. Such behaviour matches Rasmussen’s knowledge-based level of performance.

The making of decisions may range from automatic and tacit to deliberate and explicit (Wiig, 2003). Indeed, tacit knowledge is not complete “in the head” but is a behavioural response of situated action (Suchman, 1987). As decision making is situated activity that is embedded in the particular work environment; rules are unable to fully specify the required actions (Suchman, 1987). For any specific situation, a considerable amount of
implicit knowledge is required to transform a rule into action. In her terms, there is an “irremediable incompleteness” of instructions. Decision makers pick up this unrepresented knowledge from the context of the situation and from physical cues within the environment acting as external memory. Persons managing a supply chain need tools to help them seek patterns within data, recognise familiar work situations, and explore different decision-making strategies under novel circumstances.

Wiig (2003) sees the handling of these situations as an exercise in steering “very complicated and dynamic problems, often with insufficient information and understanding.” He divides situation-handling into four primary tasks: sense making; decision-making; problem solving; implementation; and monitoring. These tasks are similar to Sheridan’s (1976) human supervisory control model in which a person controlling a process has four modes of operating: planning, teaching, monitoring and intervening.

**Theories and methods**

Croom, Romano and Giannakis analyse the content of the literature using a two-dimensional matrix of level of analysis and elements of exchange. The levels of analysis are dyadic (party-to-party) relationships, chain of dyadic (party-to-party) relationships and a network of operations. The elements of exchange address the processes in managing the supply chain and split into “what” is exchanged (materials assets, financial assets, human resources assets, technological assets, information and knowledge) and “how” the exchange occurs (the relationship between actors). The formalisms developed by Higgins (1999, 2001) for representing the decision activities of production schedulers make use of theoretical constructs that are consistent with the elements of exchange.
Capturing the behaviour of human decision makers in a form that is suitable for formulating the requirements of software that can support situated activity is problematic. Ethnographic studies of situated behaviour of persons lead to rich descriptive models, full of meaning and nuance. However, they are difficult to verify and findings at a level of general abstraction are elusive. A method is needed that can realize generalised findings through abstraction, while providing the richness of descriptive models. There is a need for a formal language that describes human decision-making processes in a way that bridges the gap between descriptive and analytic models. Such a language for analysis is posited on a systems-thinking context. It encompasses both the engineering system and the problem-solving operations of the human decision-maker. It has a framework that acts as a template on which to plot the information used in the making of decisions.

In forming structural models of scheduling activities that software developers can use to set the requirements in designing human-computer scheduling systems, it is not necessary to detail the actual mental processes engaged by schedulers. The immediate aim is to develop systems that support the conceptual models held by domain experts, without necessarily preposing their mental models (Wilson and Rutherford, 1989).

The formal structure developed by Higgins for representing goal-oriented decision activities extends Cognitive Work Analysis (CWA), developed by Rasmussen (1986) and further elaborated by Sanderson (1998) and Vicente (1999). It provides a means for representing the cognitive factors that Crawford and Wiers (2001) found prevalent in
scheduling, in their review of existing knowledge on human factors of planning and scheduling. The *environmental factors* they identified in regard to planning and scheduling also apply to SCM. Their claim that the issues raised from an analysis of the cognitive behaviour of schedulers will be instrumental in laying the groundwork for better and more appropriate planning and scheduling aides, we argue is also applicable to SCM.

As with other forms of knowledge management, SCM is not the manipulation of disconnected facts without concern for the context that information was collected or applied. Knowledge work is not a solitary occupation, but “involves communication among loosely structured networks and communities of people, and that understanding it involves identifying the social practices and relationships that are operative in a particular context” (Thomas, Kellogg and Erickson, 2001). This is particular pertinent in the management of a supply chain.

Using Higgins’s formalisms we hope to address the development of “valid, reliable and practical methods to study, analyse and implement findings from detailed, ethnographic research” identified by Crawford and Wiers.

CWA incorporates two different types of analysis: Work Domain Analysis (WDA) and Control Task Analysis (CTA). Higgins added a goal structure as a third component to the analyses. WDA identifies the system constraints using a ‘ends-means’ abstraction hierarchy. It is an event independent analysis that is used to describe a system of resources in a way that distinguishes its purposive and physical aspects; it is concerned with “what” is being acted upon. Its elements form the constraints on possible decision choices. Figure 1 shows the particular ends associated with printing and their relationship to means: for example, a desired ‘end’ is the perforation of paper, which may be realised using a machine called AKIRA. In Figure 2, showing a very detailed abstraction hierarchy for various AKIRA machines that have different capabilities, the five levels of the abstraction hierarchy are depicted: physical device, physical function, purpose-related function, priority/values and functional purpose. The functional purpose is the objective met by the system and the priority/values are the criteria used to measure the performance of the system in regard to its functional purpose.
CTA is an event dependent analysis of activities that are directed towards specific goals. These control activities correspond to “how” relationships. For each specific goal, a ‘decision ladder’ is used as a template to represent the control activities associated with decision behaviour that is directed towards the goal. In Figure 3, for an ultimate goal, the minimisation of average tardiness and machine utilisation, there is a scheduling policy that meets this goal: a procedure that arranges jobs in a queue in the order of the earliest to latest due date.
Using a field study as an example, McKay and Wiers (2001) identified three different levels that software tools can assist schedulers: automatic, supporting and enabling functionality. Both automatic and supporting functionality are rule-based behaviour. Rule-based decisions relate to the shaded region in Figure 4 (Higgins, 1999). For automatic functionality, the scheduling tool carries out actions without intervention of the human scheduler. All the activity in the shaded region is automatic. Routine, basic activity fits this category: for example, sorting new orders in due-date order. Supporting functionality helps schedulers operate within the shaded region by automating some of the activity. It includes ways of presenting information to help schedulers perform periodic procedures: for example, menu choices for suitable automated procedures that are on the right side of the ladder.

To solve ill–defined problems, the focus of reactive scheduling in job shops, schedulers apply contextual knowledge. Enabling functionality provides the support for knowledge-based activity. It includes ways of presenting information to help schedulers recognise cues and to see patterns in the data during the analysis process on the left side of the ladder and the automation of procedures on the right. The tool highlights the type of information the decision makers commonly ask about and search out. Schedulers also draw on information from the environment and on relevant sources: patterns in current and historical data, their experiential knowledge and expert sources (books, consultants, etc.). Hence, computer support for knowledge-based decisions may include a depository of information on which the decision makers can make inferences. Enabling functionality also provides flexibility to operate in a decision space through the relaxation of
constraints, as Higgins (1999) represents with abstraction hierarchies. Using Higgins’s formalisms, this information is identified by links between nodes in the decision ladder and the abstraction hierarchy Figure 2.

The details in the goal structure and the decision ladders vary between decision makers, as the particular problem-solving technique a person applies depends on experiential familiarity with the task.

A structural relationship (Figure 5) exists between the various goals that may become activated at different times in decision-making activity. It is found by mapping the actual operational objectives, which form the ‘ultimate goals’ in the various decision ladders, to goals at higher levels of abstraction. The higher a goal is up the hierarchy, the less
directly it relates to immediate operational activity. High-level goals tend to be attained through satisfaction of low-level goals, rather than being directly linked to ‘ultimate goals’ of decision makers. The relationship between a decision ladder, the goal structure and the abstraction hierarchy is shown in Figure 6. There are links between the high-level goals and the functional purpose and the priority/values in the 'ends-means' abstraction hierarchy. The apex of the goal structure coincides with the functional purpose level of the abstraction hierarchy, and the level immediately below coincides with the highest-level priorities in the abstraction hierarchy.

Figure 6. The relationship between the goal structure, decision ladder and abstraction hierarchy
(Higgins, 2001)

The degrees of freedom in McKay and Wiers’ DSS can be represented as constraints in an abstraction hierarchy. In their display, the type of information the decision makers commonly ask about and search out are highlighted. Using Higgins’s formalisms, this information would be identified by links between nodes in the decision ladder to the abstraction hierarchy (see Figure 6). Higgins’s formalisms provide a structure on which to map the environmental cues used in deciding resource allocation. Its structural elements are used as a template on which to plot the information used in the making of decisions. A Cognitive Work Analysis requires the identification of the sources and forms of information used by the decision-makers. This entails an ethnographic study of schedulers in action, as the sources of information are generally diverse; they may include visual scanning of production areas, discussion with machine operators and a variety of informal ‘information networks’ (Crawford and Wiers, 2001; McKay et al., 1995).

Extending the method to the Supply Chain

Higgins (1999) contends that his methodology is not restricted to production scheduling, but can be applied generally to decision making in complex systems in which there are many competing and conflicting goals. The decision-making environment in SCM has similar features to production scheduling; an environment lean in resources, and subject to uncertain and incomplete information, is managed to meet specific objectives. Activities that are identifiably purchasing and supply activities are associated, in effect, with production control of a virtual factory extending through the links of the supply
chain. At the top of Higgins’s goal structure would be the long-term strategic goals, such as those identified by Tan (2001).

Using the principal components delineated by Croom, Romano and Giannakis (2000), our immediate concerns, per se, are neither the strategic-management issues in establishing a supply chain, the establishment of relationships/partnerships nor marketing. Nevertheless, the constraints that these components place on the structural form of the supply chain are significant, as they affect the ‘ends-means’ abstraction hierarchy. Also, the effects on the boundary constraints from control activities are perceived to be important factors. For example, organisations that initially share information only on a need to know basis may evolve over time to an open-book relationship as the level of trust increases through experiences of inter-organisational interactions (Lamming, Caldwell, Harrison and Phillips, 2001; Whipple and Frankel, 2000). Accordingly, the constraints associated with relationships between partners — identified during the WDA — change over time. If in this case, the decision behaviour of buyers towards their suppliers is directed by a partial goal, say, ‘to reinforce relationships’ (i.e., to increase the level of trust) then the model should depict the interaction between the control activities in a decision ladder, the goal structure and the abstraction hierarchy.

Control activities in a supply chain are associated with information flow. However, unlike logistics, the processes of interest go beyond technical factors but include cognitive and social factors. For example, the extent that information flows between organisations depends upon the degree of mutual trust. Where there is trust, organisations can work together to align their operations and processes. Alignment depends on relationships between organisations, which may or may not be formally specified. Cousins (2002) argues that trust is the certainty in the dependent relationship (with a set of constraints) that has been established from previous experience.

Control activities depend upon the objectives of the decision makers. The relative dominance of the parties influences which objectives are common between organisations. The more powerful organisation may have more say in defining the boundaries on the relationships in the alliance and also the common objectives. As each organisation is primarily concerned with maximising the benefits to itself, the formation of alliances depends on risk analysis (Cousins, 2002). The trade off is between the benefits of minimising the risks from uncertainties (e.g., inflation of order size to hedge against scarcity) and the additional risks from sharing sensitive information with other organisations. By reducing uncertainties across a chain, the dynamics of the processes in the system may become more stable.

Stadtler (2000) separates the control activities between customers and suppliers into three distinct modes: pre-transactional elements that precede the formation of a contract; transactional elements contributing to order fulfilment; Post-transactional elements that concern ‘after sales’ service. Pre-transactional elements concern customer access to information regarding the products and services a firm offers and the existence of an adequate link between organisations involved. Transactional elements include the availability of products (from stock), order cycle times and information on the current status and location of an order. Post-transactional elements include the repair or exchange of defective parts, maintenance and the way of dealing with customer complaints and warranties.

We intend to limit our study to the dynamics of managing a supply chain associated with the transactional mode of a supply chain. A well-managed supply chain would, ideally, operate in dynamic equilibrium, with decision makers responding to small disturbances in
the system. The control activities are routine and procedural in form. Using the decision ladder in Figure 3 as a template (ignore the scheduling labels), the decision maker on observing the state on the left ‘short cuts’ to procedural activities on the right of the ladder. The procedural steps may be performed manually or automated. Occasionally, large disturbances generate instabilities in the system. This may require a human agent to act innovatively in a non-procedural manner. The range of control activities is constrained by strategic level decisions of the relationship between organisations and the subsequent implementation of theses decisions at an operational level. Strategic-level decisions affect the information resources that are available and the legal relationships (e.g., the formality of contracts) between organisations. Responsiveness to disturbances may be affected by the degree of the formality of the relations between organisations.

To judge the performance of the system, managers of a supply chain need objective measures. Performance measures are depicted within Higgins’s formalisms at the priority/values level of the ‘ends-means’ abstraction hierarchy and are linked to high-level goals in the goal structure. A significant aspect of the proposed research is to identify the performance metrics that would support the formation of control activities that only meet the immediate objective (located at the top of the decision ladder) but the higher objectives associated with the functional purpose and strategic goals of the supply chain. This is critical, as there is a lack of consensus on valid measures of performance for SCM (Tan, 2002). Through a survey, Tan (2002) endeavoured to find a correlation between 25 different management practices in SCM and three performance measures. Although the results of this survey are not clear, it is rare attempt to ascertain actual industrial practices. Many organisations apply metrics for assessing the performance of internal logistics (e.g., fill-rate, lead-time and on-time performance) to relationships across the supply chain. Lambert and Pohlen (2001), in stating that these are inappropriate measures, ascribe the lack of definitive metrics to the absence of a widely accepted definition of SCM. Metrics are needed to guide behaviours that improve the performance of the overall chain. The correspondence of the overall chain and the internal performance of partners will be a issue covered by the research. For example, minimisation of the bullwhip effect, where amplification of orders increases up the chain due to buyers ordering more than they require from their direct suppliers, because of their past experience of only receiving part of their orders on time (Forrester, 1958). However, this behaviour may be difficult to discourage if buyers cannot see the forecast demands on their suppliers from other customers. That is, if the links between the immediate objectives of a buyer (for instance, ‘to ensure supply on time’ as the ‘ultimate goal’ in a buying decision-ladder) and the requisite knowledge of constraints in the abstraction hierarchy (observability of supplier’s availability) are not present, then there would be insufficient information to meet the higher-level priority/value of the supply chain, while meeting the immediate objective of the buyer.

**Research focus**

We have a similar objective to that of Wiers and McKay (1996) but applied to SCM: the understanding how information is obtained, structured and represented by decision makers. Their focus was on developing information systems that support rule-based reasoning. Our endeavour is to develop theoretical constructs that can be used to model both rule-based and knowledge-based behaviour of decision makers, thereby covering both procedural activities and activities associated with inductive reasoning.
We put forward the proposition that knowledge-based behaviour by decision makers in a supply chain is prevalent under the combined conditions of information changes being non-predictive (e.g., changes in order sizes, material availability and production capacity occurring with little warning) and the presence of tight coupling between organisational units. Under the second condition, variances (in a socio-technical sense) are exported between organisational units: both within and across legal entities. Where coupling is tight, humans acting with local autonomy cannot recover from uncertainty. The local resolution of uncertainty extends beyond the system boundary under the control of a local decision maker. Furthermore, the effects of control activities may ripple across the supply chain. In situations where there is much uncertainty that cannot be compensated through autonomous decisions made at the shop floor, the authority for decision-making has to be allocated to someone who has a broader organisational perspective.

From the above argument, we deduce that our research domain must be a commercial/industrial sector that has tight couplings between production, supply and purchasing activities within each organisation. Also, linkages between the supply and purchasing activities across the supply chain must have direct effects on production and material flows within the chain. All significant constraints within the supply chain that are to be represented in the ‘ends-means’ abstraction hierarchy have to be identified. This requires Work Domain Analyses of all organisations that are principal contributors to the constraints. Furthermore, ethnographic studies will be required of the decision makers both within and across organisations, with the aim of identifying the information they use and the control activities they apply to meet objectives that may often be tacitly held and therefore difficult to extract.

References


