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Integrated Autonomy – A Modeling-based Investigation of Agrifood Supply Chain Performance

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Abstract

The success of supply chains, whether they are whole-of-industry chains or internal business chains, depends on integration, coordination, communication and cooperation. However, one of the key issues faced by enterprises within a supply chain is the tendency for each component in the supply chain to have different goals – particularly since each component is very often an autonomous business unit. This situation can, and very often does, result in a lack of integration, coordination, communication and thus cooperation.
This paper describes the use of agent based modeling techniques to investigate whether the distributed computing concept of Integrated Autonomy could also be promoted as a business strategy for managing agri-food supply chains in order to increase efficiencies and coordination across the chain.
The results of modeling two different supply chain scenarios in both an industry and in an enterprise environment indicate that IA as a concept can be translated into a practical management strategy with associated performance metrics aimed at increasing efficiencies, coordination and communication across supply chains.

1. Introduction

The operational management of staff in multi-unit or multi-enterprise organisations with distributed locations is complex. A particular concern in such situations is managing to ensure that the work undertaken adds value not only to the business unit or enterprise the staff are in physically, but that it also adds to the overall organisational viability and/or profitability [1]. Similarly, managing supply chains (that is, a network of activities and/or companies that are involved in satisfying an end-user demand for a product or service), is a multifaceted task combining operational and functional skills with key corporate knowledge, in order to effectively manage and enhance profitability and to provide better returns to shareholders [2, 3, 4].

According to Porter [5] developing strategies to enable successful management of both a business and it's associated internal or industry supply chain is critical to modern, competitive business practice. Tan et al. [6], Cayla [7], and Kulmala and Lonnqvist [8], all suggest that creating a tightly integrated and cohesive supply chain is an important value creation mechanism for a business – the more tightly the chain is integrated, the more cohesive it is and the greater the value created. Thus if goal incongruence (when individuals or groups within an entity may have only partly overlapping goals) amongst components of the supply chain develops, a risk to supply chain integration and thus to value creation for the business ensues [9].

Bryceson and Slaughter [10] investigated this problem using a case study approach to determine what performance metrics could be devised to reduce the risk of goal incongruence across the internal supply chain of a very large, successful, multienterprise grazing enterprise in Australia. The results showed that goal incongruence and a lack of cohesion can easily develop even in well managed supply chains and that this can be managed by using appropriately holistic performance metrics. In a multisectoral follow- up study [11] they proposed that a strategy of "Integrated Autonomy" (IA) – a term originally coming from the distributed computing literature and defined as: "*a paradoxical state where two or more agents within a distributed system transcend their individual identities (autonomy) to combine with other agents in the system to amplify their individual strengths, while at the same time enabling synergies associated with operating as an integrated whole, to create additional overall benefits to the system*" [12], should be strived for as a best practice supply chain management (SCM) strategy.

Achieving IA would mean that each component within either an internal business or whole of industry chain situation would have a level of autonomy and expertise to manage its own area of specialisation and product development, but could also benefit by integrating key functions and processes with other components to facilitate a multiplier effect of

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component expertise in order to achieve the broader strategic goals of the whole company/chain. I.e. a sum of the parts is greater than the individual components. The study outline in this paper investigated a modeling approach as a means of evaluating these claims through monitoring profitability across the chain...

1.1 Supply / Value Chains as Complex Systems

Supply chains have long been regarded as complicated systems [13, 14] involving both strategic and operational issues along with complex social and functional behaviors. Bonebeau, Dorrigo and Theraulaz [15], in their book 'Swarm Intelligence' likened a company's and/or an industry's many individual parts to ants in an ant colony. They postulated that by focusing on these distinct entities at 'ground' level, the answers to developing a coordinated overall management strategy could be developed from the 'bottom up' given that such ant colonies were superbly well organised despite having no centralised 'top down' control.

Bornebeau and Meyer [16] developed this theory further reiterating that supply chains are complex systems comprising many autonomous decision-making 'agents'. Indeed, Choi et al [17], Pathak et al [18] and more recently Surana et al [19] argue the case for them to be regarded as Complex Adaptive Systems (CAS) because individual components or agents within a supply chain can and do intervene at any point in a meaningful way to change the behavior of the whole. An agent under these circumstances may represent an individual, a project team, a division, or an entire organization, each agent having varying degrees of connectivity with other agents. The connectivity between agents is what allows information and resources to flow between them. Bonabeau [20] then argued that if management strategies were to be successfully developed for supply chain systems, the systems themselves should first be modeled using agent-based modeling (ABM) techniques.

1.2 Agent Based Modeling (ABM)

ABM is a modeling paradigm in which each "agent" in a system corresponds to an autonomous individual in a simulated domain. The idea is to construct the agents and their attributes and to link them through a set of dynamically interacting communication and behavioral rules to create complexity like that which we see in the real world. The process is one of emergence from the lower (micro) level of the system to the higher level (macro) [21, 22].

ABM is a deterministic rules-based approach and allows the modeling of the finer detail of the structure of each component's operation, the signals they pick up and the rules they use to process those signals when making a decision. When different situations are modeled the different ways in which information flows in the chain, and the different sensitivities to that information at each level within the chain, need to be taken into account.

In recent times there has been a plethora of studies and associated literature on multiagent based supply chain logistics handling modeling – mainly from a computational perspective [23]. However in this study the interest in a modeling approach is to evaluate the impact and effects of business decision making scenarios and related information flows across components in either a multienterprise business (internal business chain) or across an industry-wide chain in the agri-food sector.

2. The Agrifood Sector

The agri-food sector is a large, multifaceted industry sector that exists worldwide, and involves a range of businesses that create industry specific (e.g. Grains, Sugar Cane, Timber, Dairy, Cattle/Meat, Fruit and Vegetables, Cotton, Wool, to name a few) agri-industry chains that often exist across international boundaries. The businesses involved in such chains tend to deal in low margin commodities where competitive market forces have typically resulted in the cost of production being very close to the value created, thus leaving relatively thin profit margins [24]. Additionally, raw material production is directly affected by climate and the resulting uncertain weather conditions which very often results in a variable supply of the raw product. Ensuring constant volume, high quality product at the right time and price is thus a key business consideration and involves rigorous supply chain management both within the company and between businesses in the industry supply chain [25, 26, 27]. Analysis of agri-industry supply chains has thus become a valuable tool in determining where added competitive advantage can be generated for the companies and/or industries involved [28, 29].

2.1 Australian Beef Industry – Whole of Industry Supply Chain

In this study, the first supply chain modeled using ABM techniques was a whole of industry cattle/beef meat industry chain [30] with the most common components of this supply chain being shown in Figure 1. In this project, only one producer, a feedlot, an abattoir, a food processor and the market were defined as components.

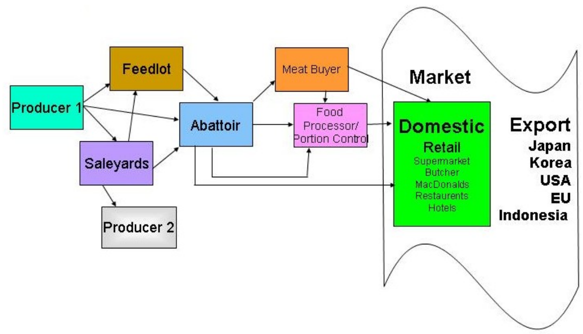

Figure 1. A Generic Beef Supply Chain in Australia

In the Australian beef meat supply chain the market specifications for the type and quality of animal and/or meat are clearly defined with associated prices attached and thus all components of the chain decide which particular market segment they are aiming for and adhere to delivering the specifications required – if they do not, they risk losing revenue and/or customer.

While the beef meat chain is a complicated one with many scenarios and decisions with associated information requirements being involved, the variables chosen for the model that were traced throughout were: animal age (days); weight of beast (kg); period of growth (days); price/unit liveweight (c/kg). The issue for the supply chain that was focused upon was information-based decision making and the impact those decisions might have both on the component of the supply chain involved and the other components in the chain. In agrifood chains where raw material production at source is involved, different producers with different production systems and different value and belief systems will make different decisions regarding managing their production and the selling of their product (managing a herd of cattle in our example and then selling that beast into the market), dependent on externalities such as drought or market fluctuations. These different decisions will create ripple effects across all the other components of the beef supply chain – effects which can only be well documented for long term sustainable management if seen many times – which is only possible using simulation techniques because of the long lag time associated with production in the 'real' chain.

2.2 Australian Beef Industry – Internal Supply Chain of Multienterprise business

In the second model the internal supply chain (Figure 2) of a multienterprise grazing enterprise was modeled. Like many of the larger agribusinesses within the cattle industry in Australia, the company is a multi-enterprise business. That is, the company comprises a number of different operational business units (Breeder, Backgrounder or Finishing properties) that are either supplied by, or supply, another component within the company to form an *internal* supply chain [31]. Each operational business unit is an independent property run by a property manager and associated staff. Each property has its own individual operational budget and is regarded as a profit centre - although all properties are expected to contribute to the overall profitability of the company as their first priority.

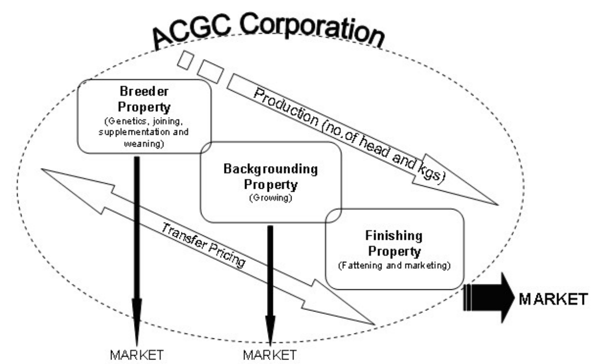

Figure 2. The internal supply chain of an integrated multienterprise beef producer (ACGC).

The internal supply chain includes the physical flow of goods and the associated management accounting information flows that are required for raw materials to be transformed into finished products within the overall company [32, 33, 34, 35, 36]. A major component of the accounting information flow in the company is that associated with transfer pricing between operational units (Figure 2) which is used within the organisation as a proxy for market prices of cattle when transferring product (cattle) from one part of the internal supply chain to the next.

3. Model Development

The software iThink^{TM} was used to set up "Agents" (e.g. Producer, Feedlot, Abattoir and Market in the whole of industry supply chain, and Breeder, Backgrounder, Finisher in the internal supply chain) each with their own independent decision-making rules. While only one Producer, Feedlot, Abattoir and Market component in the Australian beef supply chain was developed as agents in this project, the approach allows any number of agents to be added – each with its own decisions and rules. Thus there could be fifty producers, ten feedlots and five abattoirs involved in a real chain and all making their own decisions based on the same or similar information that can be modeled using this approach. Additionally, other supply chain components could also be added such as saleyards, animal feed companies, chemical suppliers, smallgoods processing companies, retail etc, each with their own linkages creating a supply network which is more realistic in its complexity [37].

Once the agents were determined, the information flow rules that were then created allowed information to pass from one component in the chain to another allowing, for example, a Feedlot to make a 'decision' to fatten a particular type of animal according to a demand signal from an Abattoir and a supply signal from a Producer. By changing these information flow rules the Integrated Autonomy (IA) or Non-Integrated Autonomy (Non-IA) scenarios for each chain being modeled could easily be created. Each component in the chain had up to 3 sub agent models. For example, each chain component had an associated economics model, and in the Producer component of the whole of industry supply chain and in each component in the Internal Supply chain, an associated 'sustainability model' (drought, pasture quality and stocking rate) was included as was a cattle growth rate model (including supplementary feeding). The producer economics model captured the time it takes to grow an animal, costs involved and sale price.

Once developed each scenario (IA or Non-IA) for each model was run 100 times over a 5000 day cycle and the outcomes in terms of a) the whole of industry supply chain and b) the internal supply chain of a business were compared and evaluated.

4. Results

Figure 1 shows an example of Producer, Feedlot and Abattoir profitability/head of cattle calculated over a 5000 day cycle. In this example, each component in the industry chain is looking out only for itself (i.e. a Non-IA scenario). It can be seen that profits vary substantially between chain components and the inter-component variability is also large. In particular Feedlot profitability is highly variable as it is dependent on animal numbers in the feedlot, market demand and the price of grain. Producer profitability is clearly the most affected by drought and is a result of reduced production and the additional costs of supplementary feeding requirements.

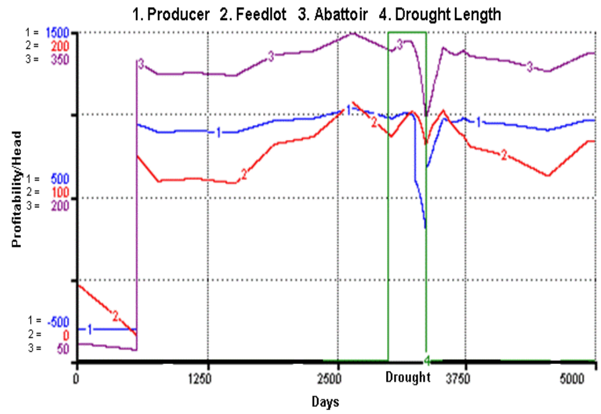

Figure 1. Producer, Feedlot, Abattoir profitability over time when working as independent players in a whole of industry supply chain (i.e. Non IA situation, grain price stable at A$400)

If, however the whole chain works in an IA scenario, this variability in profit is decreased because each component better coordinates their buying and selling activities relative to each other for any given market demand.

Table 1 below gives a comparison of a Non-IA and an IA scenario for the internal supply chain discussed in the text.

Table 1. Summary output of Model showing Non-IA (Table 1a) and IA (Table 1b) scenarios for a grazing enterprise's internal supply chain. *NB financial data supplied by company.*

Table 1a

Breeding		Backgrounding		Finishing		Enterprise	
Head produced	*14,875*	*Head produced*	*14,875*	*Head produced*	*14,875*	*Head produced*	*14,875*
Transfer Income	$ 4,899,825	Transfer income	$ 2,499,000	Sale Income	$ 10,376,800	Sale Income	$ 10,376,800
Costs of Production	$ 1,472,625	Costs of Production	$ 7,086,450	Costs of Production	$ 4,432,750	Costs of Production	$ 5,146,750
Profit	$ 3,427,200	Profit	-$ 4,587,450	Profit	$ 5,944,050	Profit	$ 5,230,050
Income per head	$ 329	Income per head	$ 168	Income per head	$ 697.60	Revenue per kg	$ 1.60
Cost per head	$ 99	Cost per head	$ 359	Cost per head	$ 298.00	Overall cost per kg	$ 0.79
Profit per head	$ 230	Profit per head	-$ 191	Profit per head	$ 399.60	Profit per kg	$ 0.81
Return on Assets	8.6%	Return on Assets	-15.3%	Return on Assets	18.6%	**Return on Total Assets**	**5.15%**

Table 1b

Breeding		Backgrounding		Finishing		Enterprise	
Head produced	*12,750*	*Head produced*	*14,750*	*Head produced*	*14,875*	*Head produced*	*14,875*
Transfer Income	$ 4,335,000	Transfer income	$ 10,336,800	Sale Income	$ 16,340,363	Sale Income	$ 16,340,363
Costs of Production	$ 1,402,500	Costs of Production	$ 8,182,000	Costs of Production	$ 12,299,300	Costs of Production	$ 6,662,625
Profit	$ 2,932,500	Profit	$ 2,154,800	Profit	$ 4,041,063	Profit	$ 9,677,738
Income per head	$ 340	Income per head	$ 701	Income per head	$ 1,098.51	Revenue per kg	$ 2.10
Cost per head	$ 110	Cost per head	$ 370	Cost per head	$ 826.84	Overall cost per kg	$ 0.86
Profit per head	$ 230	Profit per head	$ 331	Profit per head	$ 271.67	Profit per kg	$ 1.24
Return on Assets	7.4%	Return on Assets	7.2%	Return on Assets	12.7%	**Return on Total Assets**	**9.52%**

As can be seen, in the Non-IA scenario (Table 1a) when the internal supply chain components work towards maximising their own profitability, it is at the expense of overall company profitability. Compare this to the IA scenario (Table 1b) which shows overall company profitability increasing when each component in the internal supply chain works towards maximising the overall corporate profitability.

5. Discussion & Conclusion

The results of the modeling exercise indicate that when a group of businesses in an industry supply chain or a group of business units within a company, work together, a positive effect on profitability occurs compared to when the same entities work primarily for themselves. This supports the idea that while individual businesses in an industry chain or business units within the internal supply chain may be autonomous, key areas where integrated approaches are required should be strategically managed to promote a coherence of goals at all levels within the chain - i.e. a situation where a condition of Integrated Autonomy (IA) as defined in the introduction exists.

The results do speak more strongly to IA being more beneficial in an internal supply chain situation rather than across a whole of industry supply chain. While it was not a research point pursued in this study, the key issue involved in this finding is about collaboration and its benefits. The question is how can a collaborative supply chain strategy be successful when the individual chain components are self interested autonomous businesses in which the individual enterprise takes precedent over the supply chain as a whole? Practically it is far easier to establish such collaboration within an enterprise rather than between enterprises.

Recently, in an investigation that looked at a conceptual framework for supply chain collaboration Matopolos, et al [38] argued that collaborative relationships encourage greater vertical and horizontal coordination that go beyond normal commercial relationships. In these situations, two key elements of successful coordination are the design and governance of chain activities, and the maintenance of relationships within the chain.

However, determining what areas and at what level individual businesses within an industry supply chain and/or the autonomous organisational units within an enterprise's internal supply chain have to coordinate, can be a complex task. Fawcett and Magnan [39], and Fawcett et al [40] found that chain complexity can be a major problem and a barrier to collaboration. The primary reason for this problem is that most companies participate in multiple supply chains and thus multiple relationships can exist between the same two companies which complicates supply chain management and design. "*Therefore, considerable experimentation can be expected as managers attempt to build efficient, coordinated supply chains*"

Modeling generally and ABM in particular is a useful tool for experimenting and for investigating different scenarios such as the different vertical and horizontal relationships found in supply chains. A practical outcome from this study therefore has been not only to positively evaluate IA as a potential strategy to be strived for in the management of supply chains, but also to emphasise the benefits of modeling tools such as ABM. These tools can allow managers to work with different scenarios of their own making prior to launching into new supply chain ventures: they thus provide a means of reducing the risks involved in investing in resources associated with developing unrewarding relationships.

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