A SYSTEMS DYNAMICS APPROACH TO MODELLING IN THE AUSTRALIAN BEEF SUPPLY CHAIN

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Abstract:

This paper describes the Australian Beef supply chain and notes some of the major concerns expressed by agents in the supply chain. The paper then outlines the systems dynamics approach, its potential benefits and dangers and then discusses a simple model of the production process within the supply chain. We show how the systems modelling approach, utilizing the Vensim® software application can be used to develop insights into operations of the supply chain. The paper closes with a discussion of the research direction in supply chain modelling that will be followed by this group.

Australian beef supply chain

Beef supply chain management is the integration of beef producers, beef processors, retailers and end customers. The cattle move from feedlot/farms to processors who transform them into beef products and organise delivery into the hands of end customers. Smith (2001) indicates that this supply chain included: seedstock generators, cow/calf producers, stockers/backgrounders, feedlot operators, packers, processors, supermarket operators and food-service providers. In this paper we look at one section of the supply chain, the interaction between a generic supplier and the processor.

Further work following from this paper will however consider the full supply chain, and we briefly describe this in the following section and in Figure 1. There are four stages of Australian beef supply chain framework: Breeding, backgrounding, fattening and feedlot; Processing; Retailing; and Customer.

Stage 1: Breeding, backgrounding, Fattening Properties and Feedlots

This stage, cattle breeding, is the beginning section of the beef supply chain. There are around 76,600 beef enterprises in Australia. They produced around 25 million head of cattle in 2005 with a gross value of production of around $5.7 billion. Additionally, around 65% of production is typically exported. The contribution of the feedlot sector is around 27% of total beef production. According to the Australian Lot Feeders Association and Meat and Livestock Australia (2000), (National Accredited Feedlot survey), there are 680 accredited feedlots in Australia, representing a total capacity of around 850,000 cattle.

Stage 2: Processing

This stage transforms the cattle into carcass and primal beef and veal products. The most valuable product from beef cattle production is meat. There are around 240 to 300 abattoirs in Australia. An abattoir is the facility where cattle are processed into meat and other products such as offal and hides. About 25 large processors, located across Australia, process 61% of production. Bone out is done primarily at the abattoir where the animal was killed.

There are many internal operations in the beef processing facility:

- Holding yards
- Slaughter
- Hide removal
- Removing internal organs
- Trimming
- Weighing
- Chilling
- Boning
- Meat Inspection Service
- Packaging

We have illustrated the potential for Systems Dynamics (SD) modelling in this paper by developing a model of a simple three-stage process; slaughtering, hide removal and trimming. The techniques are readily scaleable to larger and, if required, more complex models.

Stage 3: Beef wholesaling and retailing

There are two types of distribution in beef retailing. The first is the domestic market. After processing beef or veal, those products may be distributed to the wholesaler or broker. They then might go to the food services sector, butchers' shops or supermarkets such as Coles, Woolworths, BILO, IGA, and Franklins. Transportation is a key element in this stage of the domestic and international supply chain. Red meat is transported in refrigerated trucks, and the surface temperature of the hanging carcass must not go above 7°C. There are several guidelines for the product receipt such as no delays, safe and still fresh.

The domestic beef market consumes about 30-35 % of the processed beef and veal. Around 68 percent by weight is sold through supermarket and retail butcher outlets, while 27 percent is marketed through the food service sector (92 percent of which is through commercial food service outlets and 8 percent is distributed through institutional food service providers). The remaining 5 percent is marketed to the processing sector to be further transformed into other food products.

Stage 4: End Customer

The end products (beef or veal) from food services, butchers' shops and supermarkets go to the end customers who consume them.

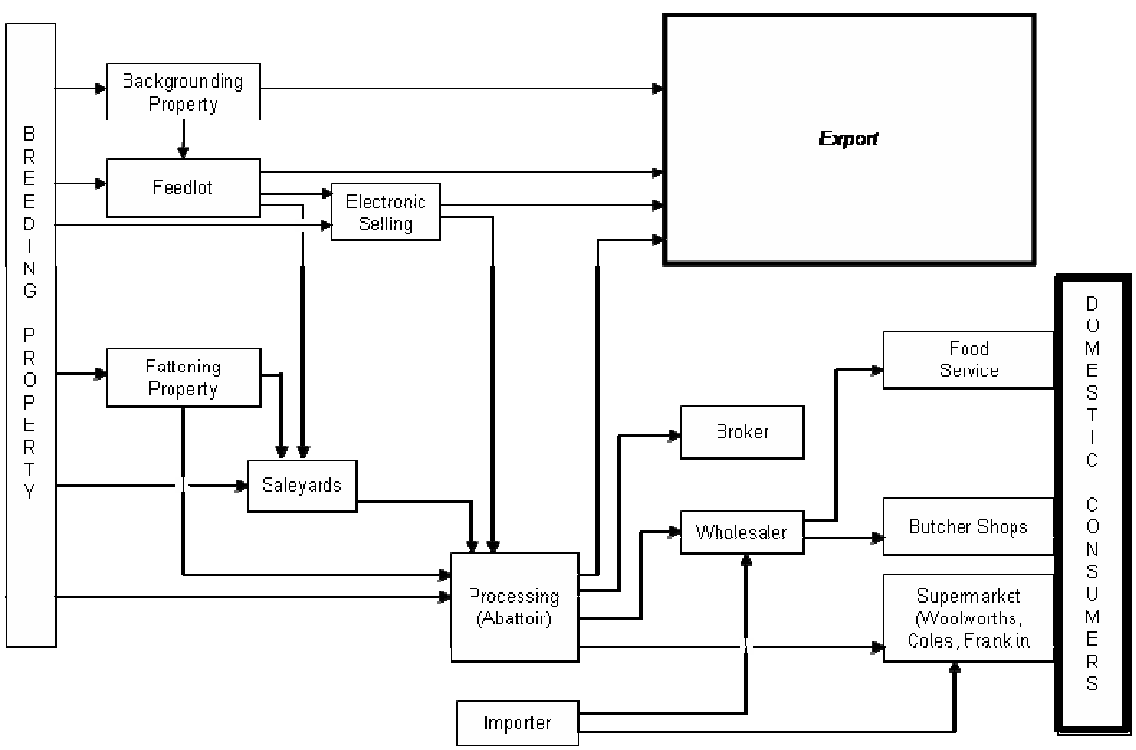

Figure 1 Australian Beef Supply Chain

Beef is the most popular meat in Australia. Most customers in Australia consume beef or lamb as a main meal around three times a week. Australia has the fourth highest beef consumption level in the world at 36 kg/capita/year.Overall the Meat and Livestock

Australia (MLA) has estimated that the Australian red meat industry has a value of more than $15 billion per year (Harris & Ryce 2005), with around 34,000 livestock producers. The supply chain is complex. There are many producers, many processors, and many customers. This complexity has two dimensions; there is combinatorial complexity, and dynamic complexity. The level of combinatorial complexity is indicated by the range of agents that can be found in the supply chain as shown in Figure 1. There have been some changes that will reduce the combinatorial complexity in the supply chain in that the MLA has sponsored some aggregation at producer level, and the continued expansion of key supermarket chains will lead to aggregation at the consumer level. Internally however there are still a large number of agents, each of which potentially has different perceptions and motivations towards their role in the supply chain.

In this paper we focus on complexity in the system that arises due to the impact of delays in the system. Sterman (2001) describes this complexity as dynamic complexity and he has, with others, argued that this type of complexity can be studied with a systems dynamics approach. In order to study these types of systems we need techniques that can model the behavior of feedback processes, of processes with time delays, and of processes that contain stocks and flows. These are the key structures in systems dynamics, and there are computer based modelling environments that can readily facilitate the incorporation of these elements in process simulation models. These models can be directed at many goals, but they are particularly useful when used to explore the interaction between policy choices and system performance (Sterman 2001).

Modelling

In this paper we discuss the use of a specific simulation tool as a means of developing useful models of part of the Australian beef supply chain. The specific tool used in this paper is Vensim® (see http://www.vensim.com/). The modeling approach embedded within this application is referred to as dynamic modelling or a systems dynamics approach. In this paper we will adopt the terminology used by Forrester (1962, 1992) and Sterman (2001) and refer to this modelling approach as systems dynamics (SD). The Vensim® application has been chosen as it is freely available in the basic form for research and educational use. Other applications such as iThink and Stella are available and embody essentially identical simulation paradigms.

Models built in this environment have been developed for systems ranging from management games such as the Beer Distribution Game (Sterman 1989), to material and information systems in single organisations (Alonso & Frasier 1991), performance metrics in supply chains (Kleinjnen & Smits, 2003), the impact of organisational design on supply chain performance (Zhang & Dilts 2004), the impact of supply chain structure on performance in the Indian grain supply chain (Sachan, Sahay & Sharma 2005), to a model of the global environmental system (Meadows, Meadows, Randers & Behrens 1972, Meadows, Meadows & Randers 1992). SD clearly has a wide range of application to the study of dynamic complexity. As a technique it is not without critics.

The dominant criticism of the technique relates to the basis for setting the assumptions within the model. Simon (1990) noted that the findings published by the Club of Rome within the ‘Limits to Growth’ (see Meadows, Meadows, Randers & Behrens 1972) were criticised by economists because the framework did not conform to established econometric descriptions of wide ranging economic systems. This criticism is clearly valid, but Simon considered this criticism to be irrelevant because in his view existing assumptions were also not robust indicators of real world behaviours. Simon then went on to argue that even if the model was of limited credibility it still served a useful purpose in serving to 'briefly attract and focus public attention upon the dangers of a world having unconstrained growth of population and energy use.' (Simon 1990)

Lilienfeld (1988) in a much less sympathetic tone asserted that Systems Dynamics had:

> 'a weakness for programmatic statements coupled with a scarcity of concrete results, a fondness for abstract schematic formula and diagrams having little practical reference; a fundamental begging of questions that take the form of an unstated and presumably invisible shift from concrete world "systems" in their fullness and complexity to closed formal models based on convenient "simplifying assumptions", a shift we are not expected to notice; and finally the absence of concrete work done beyond refinement of the system itself.'
> (Lilienfeld 1988, p. 227)

This criticism was relaxed somewhat if the modelling project was set with more constrained goals, with smaller and more closed systems. Lilienfeld’s argument is best contextualised as a caution against confusing the map with the terrain. Churchman (1979) was of the view that any representation both perceives and deceives. We must be prepared to allow managers to find in the model ways of thinking about their system that allows them to find workable solutions. Validity is not the issue; the model must allow a ‘continuing re-viewing of the world, of the whole system, and of its components. The essence of the systems approach, therefore, is confusion as well as enlightenment.’ (Churchman 1979, p. 231) Models are valuable when they challenge the entrenched and tacit models that influence the current policies and decisions in a system. They do not have to be valid models of the system in order to accomplish this outcome (Simon 1990, Alonso & Frasier 1991).

At this stage of the project discussed in this paper we have limited concrete work with which to set the parameters of the model. But the real question is in what way the model will be used. We argue that the real power of these models is not as some engineering design tool that will be used a blueprint for process change. This is an approach that is appropriate for a discrete event simulation of the flow of automatic guided vehicles in a steel mill. That type of simulation can show the impact in quantitative terms of different numbers of vehicles and of different maintenance policies. In our system we are modelling a social system. Here we wish to work with managers to develop and use a model to interactively discover aspects of the system that can enable managers to respond. This is the key finding of work done on the impact of product development (Alonso and Frasier 1991) and by the work of Winch (1995) and is a key part of the strength of the SD modelling framework. This is a strategy that depends on simplicity in the modelling technique and simplicity in the representation of the system being modelled. Simplicity in the use of the techniques is well established. Eden in 1993 was of the view that modelling techniques even then were simple enough to follow this interactive strategy. Models can be developed interactively with managers providing commentary on the assumptions, delays, policies, and causal structures embedded in the model. Simplicity in intent is however just as important, and this can be more difficult to maintain. The model is a vehicle for revealing structure in the reference system – the model should not be overly loaded with requirements for technical validity and verification. The model does not have to be tested against the null hypothesis that the model is the same as the reference system (Law & Kelton 1991). Close collaboration with managers will be essential to achieving this outcome.

In this paper we set out a simple model that shows the impact of delays in the management of staffing levels on overall performance of the system. We identify and weakly define a heat stress index, and show the relationship between the three variables of heat stress index, process stability and staffing level responsiveness. The model is a prototype and will be used to set the framework for our next stage of interaction with managers in the beef supply chain. The model is intended to illustrate how systems dynamic modelling can be used to explore the impact of policy choices on the key performance indicators for this industry of quality, responsiveness, and efficiency (Jie 2007).

Simulation Model

The model is developed in the Vensim® application. The modelling constructs are well described in the literature, two references that are particularly accessible are Forrester (1992) and Sterman (2001). (Full details of the model can be obtained from roger.jenkins@uts.edu.au)

We have modelled the process from the arrival of cattle in trucks at the meat processing plant, to the loading of the processed carcass into the processing plant chiller. We have a simple, purely sequential flow of the single entity (a single animal) from the truck, to the holding yard and then through a labour constrained process of slaughtering, hide removal, and finally triming and weighing. At the completion of this process the entity is loaded in a chiller where it simply accumulates without dispatch. In line with early results from our survey of agents in the industry (Jie 2007) the model is designed to illustrate interactions between quality, responsiveness, and efficiency. Our concept of quality is a simple index of heat stress that is a function of ambient temperature and time in the holding yard at that temperature. We emphasis that concept of quality is illustrative. More relevant constructs can be readily designed in conjunction with practitioners during the next stage of the project. Responsiveness is related to the responsiveness of the staffing levels within process to the rate of arrivals of cattle for processing. Efficiency is, for the purpose of this paper, considered as a function of the labour required to process one day's production. If efficiency were conceptualised as plant utilisation the model can be readily modified to include process capacity constraints. The model runs for one day, and always processes the complete set of arrivals. The model contains no stochastic or random elements. It is also sufficiently simple to avoid chaos related variation in the process outcomes. For these reasons it is not appropriate to run multiple simulations in order to estimate variability in the outcomes.

Arrivals

Cattle arrive over a 24 hour period according to the dimensionless rate shown in Figure 2. This plot establishes the relative rates of arrival over the simulation period; it can readily be scaled up or down to reflect seasonal variation. One of the more useful modelling constructs in Vensim®, as with other SD modeling applications, is the capability of modelling a variable that changes according to a user defined, irregular function. The arrival rate of cattle was modeled using this function, and the specific function is shown in Figure 2. The X-Axis is time of day, from 0000hrs to 24000hrs.

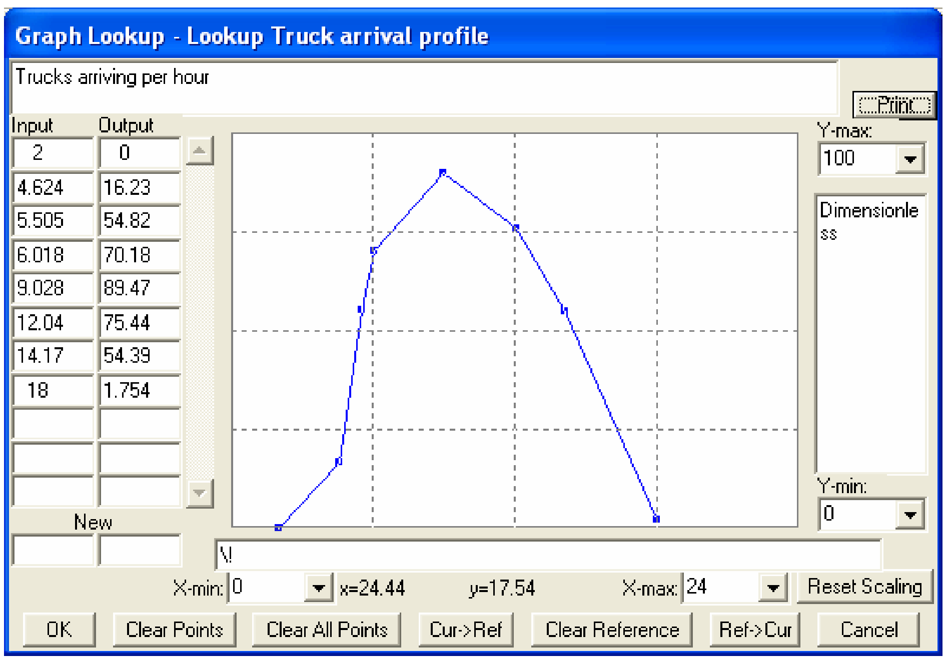

Figure 2 Cattle arrival rate

Quality

Quality is indicated by an accumulation of heat stress over the day's throughput. This is an integral function of the product of number of cattle and a lookup function of ambient temperature and the relationship between ambient temperature and heat stress.

Responsiveness

Flow of entities through the sequential process is constrained purely by labour levels in each operation. Labour levels can be modified according to the amount of work in the inbound accumulator. The critical dimension in SD modelling is often the delay between a stimulus and response, and in this system we have focused on the impact of the delay between a change in the amount of work in the inbound accumulator and the change to the level of staff in the processing stage responsible for that accumulator.

We examined the impact of responsiveness on quality by setting up three scenarios:

Base case – Level Scenario

Labour is set at a fixed level for each operation to provide for a level flow of production over a period of 12 hours. Processing starts once there is a sufficient accumulation of entities in the holding yard to provide for full utilisation of the labour. Start time for slaughtering was set at 0800 hours for this model.

High responsiveness - Fast Scenario

Labour is continually adjusted to a real time indicator or work level in the inbound accumulator. Labour levels across all operations continually vary.

Low responsiveness - Slow Scenario

Labour is continually adjusted to a delayed indicator of work level in the inbound accumulator. Labour is adjusted based on stimuli that have been delayed one hour. Labour levels vary continually across all operations.

Results of the simulation

Holding yard levels

There was little difference in holding yard levels between the Fast and Slow scenarios. The Level scenario however produced very high levels of cattle in holding yard, and this occurred during times of peak temperature (Figure 3).

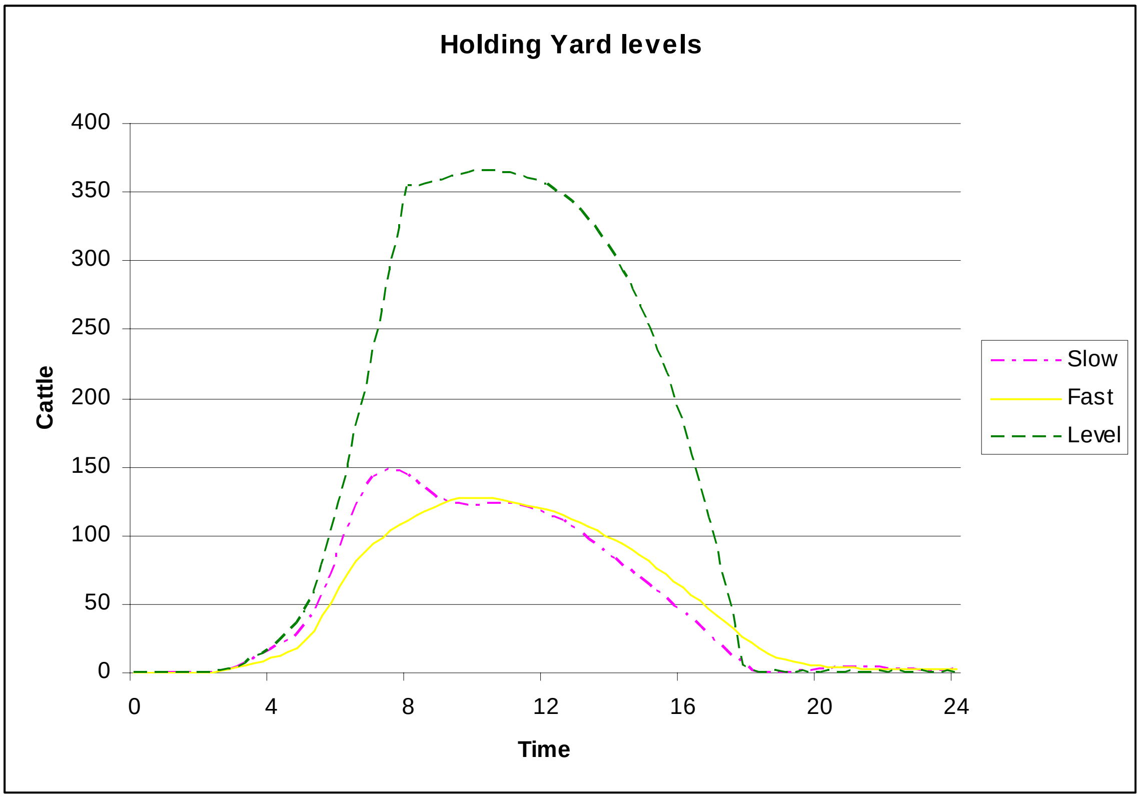

Figure 3 Holding Yard levels

Further runs could have readily established a more effective start time for the slaughtering operation and this would have brought peak levels down. As noted earlier the purpose of this simulation is not to optimize the process, it is to illustrate the use to which we will be putting the models with process managers.

Heat stress index

The results for Heat stress index (HSI) are dependent on the interaction between the daily temperature profile and amount of cattle in the holding yard.

The chart shown in Figure 4 shows the cumulative heat stress for the duration of the simulation. The final value could be used as a metric for different scenarios for crude comparison of different approaches to managing this process. The results are clearly dominated by the impact of the late start for the slaughtering operation in the Level scenario.

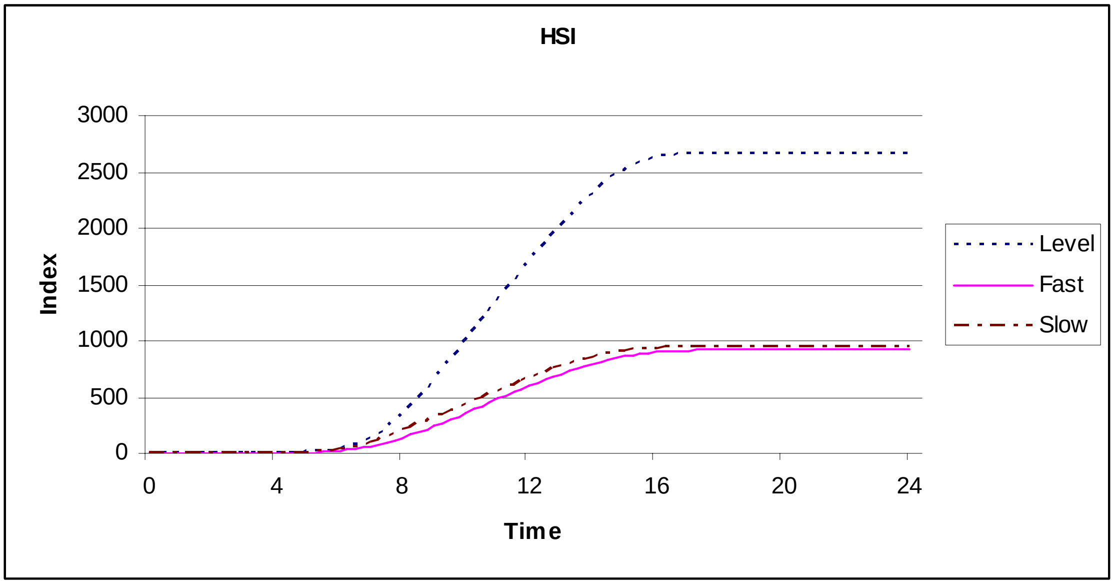

Figure 4 HSI for three scenarios

Staffing profile

The Level and Fast scenarios used dynamic logic to set the staffing levels throughout the day. Staffing levels in the Level scenario were set using the automatic *Simulate On Change* function within Vensim®. This function allows the user to change a value of a variable and immediately observe the impact of the change. The Level scenario staffing levels were found by increasing staff for the three operations of slaughtering, hide removal, and trim until all cattle were processed in one working day. Staffing levels were held at that fixed level until all entities were cleared from that process inbound workspace. Staffing levels were set at 50 units for Trim, and 25 for both Slaughtering and Hide removal.

Total hours worked

The model was set to export labour levels every 15 minutes. These values were summed to find overall labour consumption for one day's production. These values are shown in

Table 1.

There are minor differences and these are due to the granularity of the data record. If this factor was expected to be significant then data may need to be captured at one minute intervals.

Table 1 Total hours worked per day

	Process operation		
Scenario	Slaughtering	Hide Removal	Trim
Level	256	256	625
Slow	250	250	623
Fast	248	247	616

The staffing profiles for the all scenarios are shown in Figure 5, and these plots illustrate the normal behavior of systems with delays.

In the Level scenario staffing levels were set at a fixed level and assigned to process until that operation ran out of work. There is a spike of late assignment at 2200 hours due to a slow trailing input of cattle. For the Fast scenario the staffing levels rose in line with the arrival rate of cattle into the system. There was a minor offset on the time base due to the sequence of processing. This trace is stable and follows the load of work as it arrives to the process. Response time is fast enough to avoid cycling. The Slow scenario illustrates the impact of delays on the ability of systems to find stable control points. This is obviously made more challenging when there is variation in inputs, but as the Beer Distribution Game demonstrates, it is difficult to maintain stability in this type of system even when there is minimal variation in the system inputs.

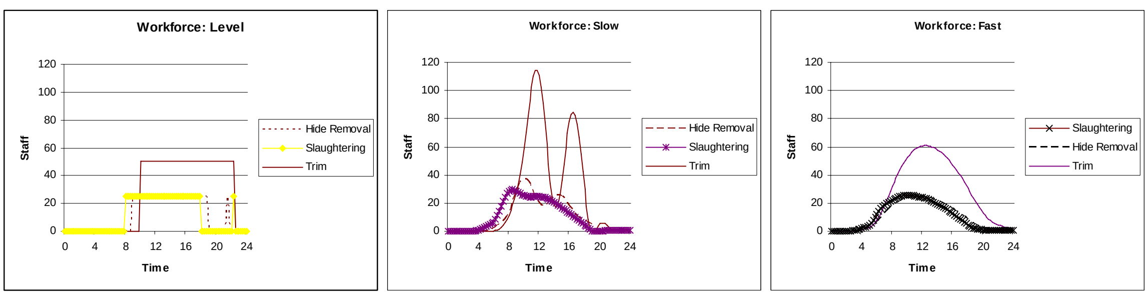

Figure 5 Staffing profiles for Fast and Slow scenarios

In each of the three scenarios labour was fully utilised and so labour costs were very similar, except for some minor differences due to data capture frequency. As an indicator of system efficiency we can conclude that the three scenarios are similar. The peak labour requirements are shown in Table 2, and these levels are quite different.

Table 2 Peak workforce

	Peak workforce in this Process operation		
Scenario	Slaughtering	Hide Removal	Trim
Level	25	25	50
Slow	30	37	115
Fast	26	25	60

Taking the Level scenario as a benchmark we can see that the Fast scenario requires a moderate increase in the maximum process labour capacity, most pronounced in the trimming operation. In the Slow scenario there is a very pronounced impact on peak process labour capacity. Peak workforce is 20% higher in the first operation (slaughtering), but due to process cycling the peak workforce in the second operation is almost 50% higher than the Level scenario, and the third operation (Trim) has a peak workforce that is 130% greater than the Level scenario. It is evident that although responsive strategies have limited impact, in this model, on labour costs, there could be very significant impact on process capacity requirements and thus fixed costs. If a responsive process is to be explored, then the system should be designed with a fast response.

Discussion

This paper presents our work on the development of a simple model within the Australian beef supply chain. The model has been developed as a means of illustrating to managers in the supply chain one way of analysing their supply chain. We can make some observations on the model.

First, the model is simple, and was developed in a short period of time. This is an important attribute if we are to apply the model interactively. It is our expectation that managers in this supply chain will behave similarly to the managers in the project analysed by Alonso & Frasier (1991). The managers will benefit from the process of developing the model as much as from any ‘answers’ the model can provide. If we are to capture these benefits then the managers must be involved in model development, and thus the model must be easy to build. Second, the model can simulate constructs that are of interest to the managers. The constructs of efficiency, quality and responsiveness are all readily simulated in the modelling environment. We do understand that this type of modelling has been criticised for the use of models that show ‘a fondness for abstract schematic formula and diagrams having little practical reference (Lilienfeld 1988, pg. 227). We therefore temper our belief in the applicability of this modelling approach with the strong assertion that this paper describes what we consider is a proof of concept; the work must now be followed up by work field with practicing managers. This work is expected to commence in the second half of 2007.

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Appendices

Screenshots of the four sections of the model are available. They have not been included in this copy of the paper due to page restrictions.

As noted in the text of the paper, full details of the model can be obtained from roger.jenkins@uts.edu.au