CSIRO PUBLISHING

The Rangeland Journal, 2013, **35**, 181–191
http://dx.doi.org/10.1071/RJ12090

A framework for optimising capital investment and operations in livestock logistics

Andrew Higgins[A,G], *Ian Watson*[B], *Chris Chilcott*[C], *Mingwei Zhou*[F], *Rodolfo García-Flores*[D], *Sandra Eady*[E], *Stephen McFallan*[A], *Di Prestwidge*[A] *and Luis Laredo*[A]

[A]CSIRO Ecosystem Sciences, GPO Box 2583, Brisbane, Qld 4001, Australia.
[B]CSIRO Ecosystem Sciences, PMB Aitkenvale, Townsville, Qld 4850, Australia.
[C]Queensland Government – Department of Agriculture, Forestry and Fisheries, 80 Anne Street, Brisbane, Qld 4001, Australia.
[D]CSIRO Mathematics, Informatics and Statistics, Normanby Road, Clayton, Vic. 3168, Australia.
[E]CSIRO Animal, Food and Health Sciences, Locked Bag, Armidale, NSW 2358, Australia.
[F]CSIRO Ecosystem Sciences, 37 Graham Road, Highett, Vic. 3190, Australia.
[G]Corresponding author. Email: Andrew.Higgins@csiro.au

Abstract. Despite the longevity, scale and importance of northern Australia's beef industry, recent disruptions to external markets have demonstrated a degree of vulnerability to shocks in the supply chain. Matching the industry's long-evident resilience to climatic variability with resilience to changes in markets and supply chains requires careful planning. One component of this is how investments in infrastructure will need to be planned to facilitate adaptive responses to market changes. This paper provides an outline of a modelling framework that links strategic and operational dynamic models of logistics along the supply chain from the property to the abattoir or port. A novelty of the methodology is that it takes into account the high granularity of individual livestock transport vehicle movements and the ability to scale up to an almost complete view of logistics costs across the entire beef industry of northern Australia. The paper illustrates how the methodology could be used to examine the effects of changes in logistics infrastructure on efficiency and costs using examples from the states of Northern Territory, Western Australia and Queensland.

Additional keywords: beef, infrastructure, northern Australia, simulation, transport.

Received 2 November 2012, accepted 2 May 2013, published online 27 May 2013

Introduction

The supply chains of the beef industry in northern Australia extend from the north-west of Western Australia to the Northern Territory and Queensland. The northern beef herd of 12.5 million cattle supplies nearly 90% of Australia's live export cattle, with 694 000 head exported in 2011 (Meat and Livestock Australia fast facts – www.mla.com.au, accessed 6 May 2013). While live cattle exports are a significant trade for beef producers in northern Australia, the bulk of the cattle move from northern breeding regions to southern and south-eastern feedlots and fattening properties, then onward to slaughter. Compared with the southern states of Australia and most beef-producing countries, the on-shore supply chains of beef industry in northern Australia have long transport distances. For example, nearly 50% of cattle in the Northern Territory travel upwards of 1000 km between breeding property and abattoir (or port), with the transport costs exceeding A\$150 head^{-1} (Economic Associates 2011). The industry is almost exclusively reliant on road for both business inputs and outputs, with most properties having very low stocking rates (10 head km^{-2} or less) compared with the southern states. Year-round supply to both live export and slaughtered meat markets is not possible in most of northern Australia due to the wet season. Mustering sufficient cattle to transport is difficult at this time while major transport routes are regularly inaccessible due to flooding or wet road conditions.

The complexity that the extensive spread of properties brings is further complicated by market dynamics. Recent short- to medium-term market challenges have arisen from the imposition of restrictions on the liveweight of livestock exported to Indonesia, and the suspension in the trade following examples of poor animal welfare in Indonesian abattoirs in June 2012. There have also been reductions in import quotas to Indonesia for both live cattle and boxed beef. Investigation of alternative paths to market is a clear priority for the northern beef industry. In time, alternative live export markets may be developed in south-east Asia, reducing the reliance on Indonesia as the primary market for live export cattle but, in the short-term, market alternatives for beef producers in northern Australia will come from the domestic beef supply chain and the possibility of new local abattoir investments. Investment to support the resilience of the northern beef industry must anticipate and capitalise on future challenges and opportunities, and future market conditions. In recent years, emerging markets have taken a larger share of Australia's beef exports. In 2004–05, 92% of beef exports were to Japan, the United States and the Republic of Korea. This share fell to 69% by 2010–11 (Department of Agriculture, Forestry and Fisheries, unpubl. data). The rapid diversification in markets has been driven by increased demand from Russia, the Middle East (Gleeson *et al.* 2012) and Asia. These changes in beef markets will have implication for the dynamics of the domestic supply chain.

A review of the northern Australian beef industry by McCosker *et al*. (2010) indicated that a significant increase in the costs of production has meant that many properties are economically marginal and struggle to produce adequate returns on investment during poor seasons. The lack of gains in productivity has meant that the beef industry in northern Australia is struggling to remain profitable. While the declining financial performance is largely a result of reduced beef prices, reduced turn-off and increased farm debt (Gleeson *et al.* 2012). McCosker *et al*. (2010) also identified rising overhead and direct costs, such as freight, as contributors. Goucher (2011) found that transport costs for beef cattle moved from the western Darling Downs, Queensland to Japan represented 13.1% of the effective farm-gate value. In contrast, transporting of live cattle from the Victoria River District (Northern Territory) to Indonesia represented 28.6% of the effective farm-gate value (Goucher 2011).

The northern Australian beef industry and related stakeholders (e.g. State and Commonwealth governments) require a range of holistically evaluated options for capital investment, e.g. road upgrades, bridges, holding yards, feedlots, abattoirs, cold stores and export facilities, along with policies, e.g. driver fatigue, animal welfare and heavy vehicle regulations, that best exploit and support the logistics of moving live cattle within the industry's existing structures. A capability is required to analyse the costs of the logistics of the supply chain, and to identify where future investments are required to support growth, changes in productivity and markets, and incorporate system redundancies to accommodate natural disasters. A linked set of models of the logistics of the beef supply chain at relevant temporal and spatial scales is needed to enable the iterative examination of how changes in infrastructure could catalyse changes in logistics under different market scenarios. Such a set of models would also allow assessment of the effectiveness of decisions on infrastructure investment and would assist businesses to optimise their freight tasks.

The literature contains examples of holistic analysis across multiple segments of the beef supply chain, though not focussed on logistics. These include static analyses that map existing chains to understand the performance of different segments of the chain, as well as identifying opportunities for increased efficiency and international competitiveness (Francis *et al*. 2008; Economic Associates 2011; Uddin *et al*. 2011). Compared with model-based approaches, such static analyses do not allow alternative scenarios to be evaluated or compared, and are not adaptable to a dynamic industry. McDermott *et al*. (2005) developed a model of the beef supply chain in New Zealand representing activities from breeding property to export. Its purpose was to simulate 'big picture' changes to farm practice, farm input prices, markets and industry structures, with the aim of maximising net value to the industry. Other past modelling approaches for beef supply chains include optimising contracts between producers and abattoirs given different market options and uncertainties (Boyabatli *et al*. 2011), and optimising the location of infrastructure such as abattoirs (Domingues Zucchi *et al*. 2011). Other than the latter paper, models for simulating and optimising livestock logistics are limited, despite being relatively common for other agricultural supply chains [see Higgins *et al*. (2010) and Ahumada and Villalobos (2009) for reviews].

Modelling livestock logistics, particularly between property and abattoir or port presents several challenges. These include the substantial within- and between-year differences in the number of cattle movements, loss in liveweight and body condition during transit, the unpredictable impact of inherently variable climates on cattle supply and the ability of the transport system to move them. Further complexity is added in northern Australia by the slow and staged movements through the supply chain, from extensive breeding properties in the north through more intensive finishing and feedlot enterprises particularly in the south and south-east of Australia. The industry comprises thousands of privately owned properties and utilises a vast network of roads under the control of multiple authorities, and a range of domestic- and export-accredited abattoirs. Availability of, and access to, the data needed to construct such a model may be limited by privacy issues and complicated by the numerous government agencies that manage particular parts of the data related to the supply chain (e.g. main roads and bio-security).

For simulation and optimisation, computational complexity is an issue particularly at an industry-wide scale, due to the thousands of variables created to represent movements of cattle between supply-chain enterprises throughout a single year. There have been few 'ground-up' attempts at modelling agri-food logistics that are scaled up to industry or national level. Higgins *et al*. (2011) undertook a state-of-logistics study, which aimed to develop and test a methodology for estimating the costs of logistics in Australian food industries, and apply this methodology to understand the structure, drivers and challenges of these logistics. Due to data availability, the analysis was limited to small regional case studies. Marquez *et al*. (2012) developed a model of freight flows for all fruit and vegetable movements within and in and out of the state of Victoria in Australia, with the goal of evaluating the costs of transport logistics under various scenarios of extreme weather events and price shocks. Available datasets of retail demand and geographical production were interpolated to estimate seasonal movements of fruit and vegetables between growing regions, distributers, processors and markets.

The range of alternative capital investment and operational scenarios, applicable to the beef industry in northern Australia, requires a much more multi-disciplinary and broader modelling methodology than has been attempted in the past. This paper outlines the modelling framework developed to meet these requirements along with individual elements of the framework and some initial results. Key questions and scenarios, formulated by stakeholder working groups that will be addressed using the modelling tools, are also outlined.

Data preparation and scope

There are several technical challenges to developing a model of transport logistics for the beef industry in northern Australia. In particular, such models typically require large volumes of data from multiple sources, which often have privacy or licence restrictions. Key requirements include:

- location of each cattle property, identified by a unique property identification code (PIC), the number of cattle, and expected turn-off (numbers and type of cattle);
- location and scale of downstream supply-chain enterprises (also identified by PIC), including sale yards, accredited European Union (EU) saleyards, feedlots, holding yards, export depots, abattoirs and ports;
- historical records of movements of cattle between livestock enterprises, which are provided by the National Livestock Identification System (NLIS) for the period 2007–11 and which were used to map past supply-chain pathways between PIC;
- costing models for livestock transport; by road, based on the Freight Metrics model (www.freightmetrics.com.au/, accessed 4 May 2013) and, by rail, with pricing data obtained from Queensland Rail;
- road and rail networks and their history of access restrictions due to seasonal conditions and extreme events (i.e. floods and cyclones); and
- scenarios of cattle turn-off under different market conditions.

The geographical scope required careful consideration. It could not be limited purely to northern Australia since cattle are extensively transported to southern regions. This is particularly the case for Queensland where large numbers of cattle are transported from the north to southern feedlots and abattoirs (e.g. Brisbane), and cattle are transported to and from New South Wales. To ensure key supply chains were captured without extending the analysis to all of Australia, the scope was limited to transport between enterprises (PIC), shown in Fig. 1, and which includes all of Queensland. Movements of cattle into Queensland from southern states were considered, but only the transport component from the Queensland border. Similarly, movements from the Northern Territory to South Australia were considered, but only to the state border. In Western Australia, the transport component to enterprises, e.g. abattoir, backgrounding or finishing properties and ports, was considered. However, transport to abattoirs were not considered in detail, as they are all located in southern Western Australia and outside the geographical scope of the analysis.

Table 1 summarises the supply-chain movements, using NLIS data for 2007–11, between the enterprises of Fig. 1. The largest volumes of cattle movements were between properties, (which included feedlots), or to saleyards (including EU-accredited

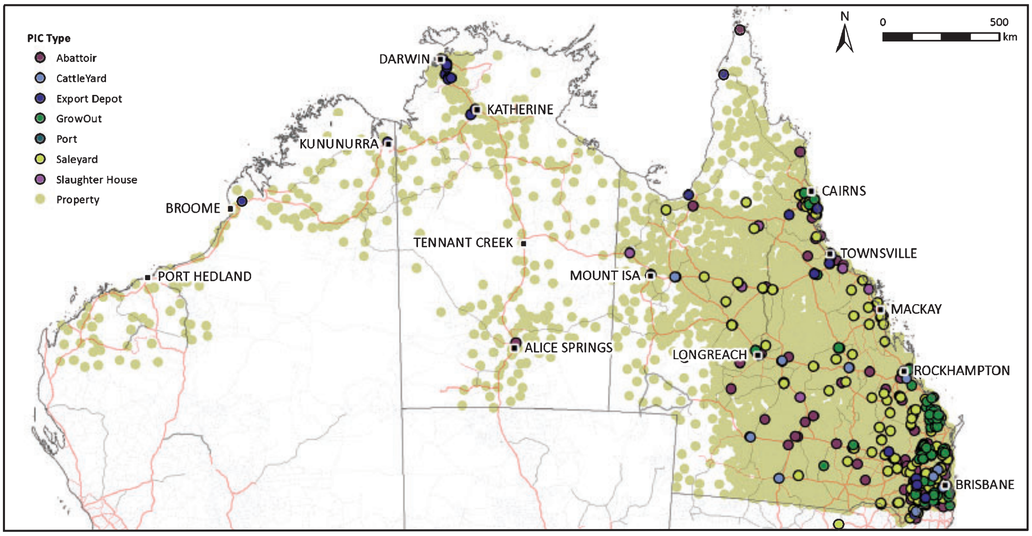


Fig. 1. Geographical scope of livestock logistics project. Some of the property identification codes shown did not have movements shown in the National Livestock Identification System in 2007–11, and may no longer be in use.

Table 1. Number of cattle moved between each type of enterprise for the northern beef industry, aggregated over 2007–11, based on data from the National Livestock Identification System

Only enterprises with a large number of cattle movements are shown. Compared with Fig. 1, Saleyard-EU were differentiated from Saleyard

To/from	Abattoir	Export depot	Port	Property	Saleyard	Saleyard-EU
Abattoir	1629	1589	–	48 417	370	5296
Export depot	27 188	327 996	1 480 557	265 615	3726	31 649
Port	–	1428	184 854	192	–	–
Property	9 650 681	2 049 392	41 734	18 434 783	205 763	8 570 573
Saleyard	3210	111 670	2908	120 966	258	34 688
Saleyard-EU	2 360 252	74 815	–	6 404 476	37 125	–

saleyards), abattoirs and export depots. Movements between properties were likely to be from breeding properties to feedlots or finishing properties; the PIC does not distinguish between property types.

The models, outlined in this paper, focus on the consequences of investment (and optimisation) in transportation infrastructure and improvements in the operational efficiency of the livestock industry. All of the variables affecting transport costs were considered, including loading/unloading and stoppages (e.g. rests, spelling and waiting time). On-farm activities, meat processing and marketing were outside the scope of the study. If a scenario of no live export or a new abattoir was to be considered, the models outlined here would consider the consequences for transport costs (versus a base case) from a changed herd structure (or turn-off) and re-direction of cattle along different pathways of the supply chain. If the full-value chain implications were to be analysed, the logistics analysis from the models of this paper could be incorporated into a broader analysis. The models can accommodate the impacts of market prices, for example in the price paid by abattoirs in different locations. It may be more profitable for some producers to send cattle to a large abattoir near Brisbane (due to higher prices paid from better economies of scale) at a higher transport cost than to a closer abattoir.

Large- and small-scale investment options, which can be either privately or publically funded, are considered. Road and bridge infrastructure is funded by the Commonwealth or State governments. The costs of such infrastructure developments or upgrades are high and could rarely be justified by livestock transport alone. In making these investments, the government would consider the benefits to the livestock industry in conjunction with other road users (e.g. mining, other agriculture commodities and tourism) and other benefits (e.g. safety, social benefits and capacity for growth). In contrast, investments, such as abattoirs, feedlots, and holding yards, are usually made by large pastoral or meatworks companies. Such companies would also use the models to improve their own operational efficiencies. The producer normally pays for the cost of transport to the saleyard, abattoir (if not via saleyard) or to export depot. Once the cattle change ownership at these points in the supply chains, the new owner is responsible for transport costs. A reduction in transport costs, resulting from an investment, will only be passed on to the producer if the contracted transport provider reduces the price, unless the infrastructure upgrade reduces the distance travelled. The transport operator charges a higher price per deck where a deck holds between 18 and ~35 cattle depending on the size of the cattle if smaller B-Double vehicles need to be used instead of road trains.

Model framework and initial results

A technical challenge was to develop a model capability that accommodates the range of spatial and temporal scales in livestock logistics but which can meet the requirement for analysis from the key stakeholders. These are diverse in terms of investment size, geographical location and operational approaches. As a result, three linked models were developed (Fig. 2), which are described in the following sections along with some initial results.

Operational simulation model

The operational model is used to provide real-time simulation of movements of individual transport vehicles (trucks and trains) between elements of individual supply chains. The model accommodates design features such as individual ports and holding yards, vehicle and yard capacities, loading/unloading times, queue times and other site-specific management issues. It provides a capability to analyse smaller-scale investments that improve operational efficiency, and help maximise operational efficiencies of existing and new infrastructure investments. Its design enables it to accommodate specific business-level

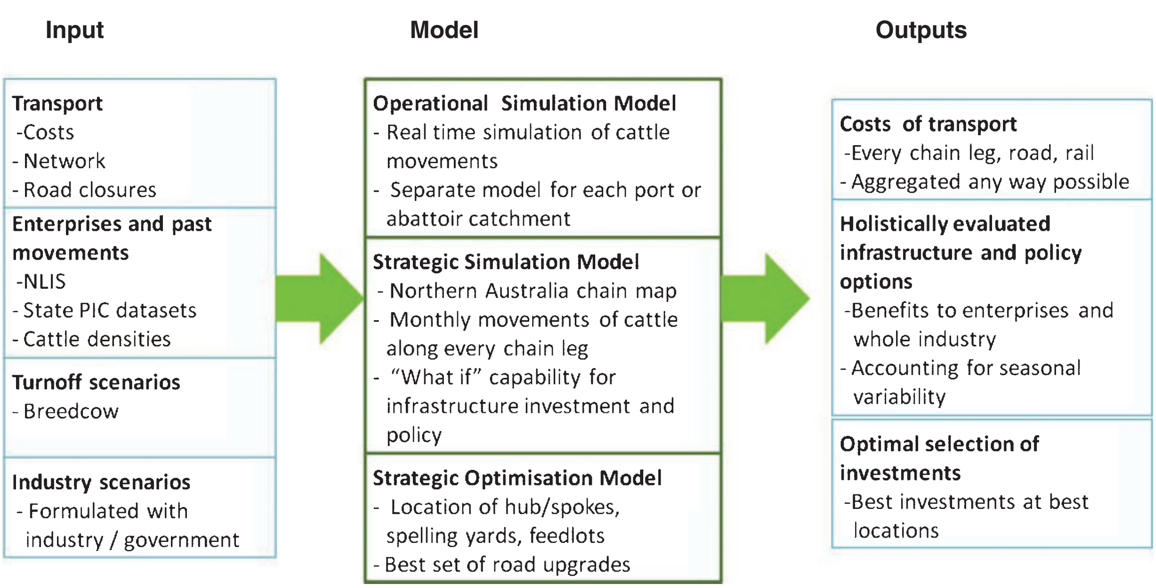


Fig. 2. Process map of the livestock logistics project showing relationships between inputs, main model components and outputs. (NLIS, National Livestock Identification System; PIC, Property Identification Code).

information and to undertake real-time simulations to assess different transport and logistics issues for individual supply chains. With the granularity of real-time movements, instead of aggregated monthly movements as in a strategic model, it can analyse smaller-scale investments, e.g. holding yard expansion and alternative operational scenarios. These types of models are commonly used in mining applications, particularly for mine-to-port logistics, but have hitherto been unavailable for beef supply chains. This model can also account for inputs into parts of the supply chain; the most obvious example being the transport of bulk feed grains into feedlots.

The operational model can be applied in two ways: the 'base case' that captures the current state of operations of the selected segments of the supply chain, and a 'what-if' scenario analysis. Figure 3 shows a snapshot of the operational model for the scenario of livestock exports from Townsville, Queensland. The model simulates the day-to-day, minute-by-minute operations of the supply chain, such as receiving orders, loading cattle, transporting through trains and different types of trucks, breakdown of road trains to accommodate trailer-combination limitations, as well as unloading to ship at the port. Uncertainties, such as road conditions, queuing delays, potential liability for shipping demurrages, can also be simulated and visualised.

The 'base case' application can help achieve a shared understanding among the stakeholders of their role and interactions in the supply chain through a real-time simulation and, therefore, facilitate the identification of operational issues such as bottlenecks and inefficiencies (e.g. spare abattoir and yard capacities and under-utilised transport paths). The model can also be used for scenario analysis, enabling stakeholders to identify opportunities for improving their operational efficiency and highlighting areas where cross-supply chain coordination needs to be enhanced. It will also provide a basis for developing a business case for investment in new infrastructure or new supply pathways, and encourage discussion of new industry scenarios.

The 'what if' application can be used to simulate the likely future state of operations under various alternative scenarios. It enables a quantitative analysis of the costs and benefits of proposed improvements to the existing practices or infrastructures before they are implemented. A comparison of the 'base case' and 'what if' scenarios would be critical to developing a business case for investments in infrastructure that would improve local supply-chain efficiency or reduce costs.

Instead of a single model for all of northern Australia, separate base models are required for individual port and/or abattoir catchments. The operational simulation model was written in AnyLogic (www.anylogic.com/, accessed 4 May 2013), so that 'licence-free' end-user versions can be provided to stakeholders. Any business in the northern Australian beef industry can thus explore their role in the beef supply chain and seek to optimise their operations through new infrastructure or by reducing work-flow inefficiencies.

Strategic simulation model

This model is used to evaluate the impact of investment in infrastructure on transport efficiencies, or to inform policy decisions that affect the mass flow of cattle across the north of Australia. It is based on simulating the number of cattle (or vehicle trips) per month moved between enterprises across northern Australia and the granularity of the logistics is thus considerably coarser than the operational model.

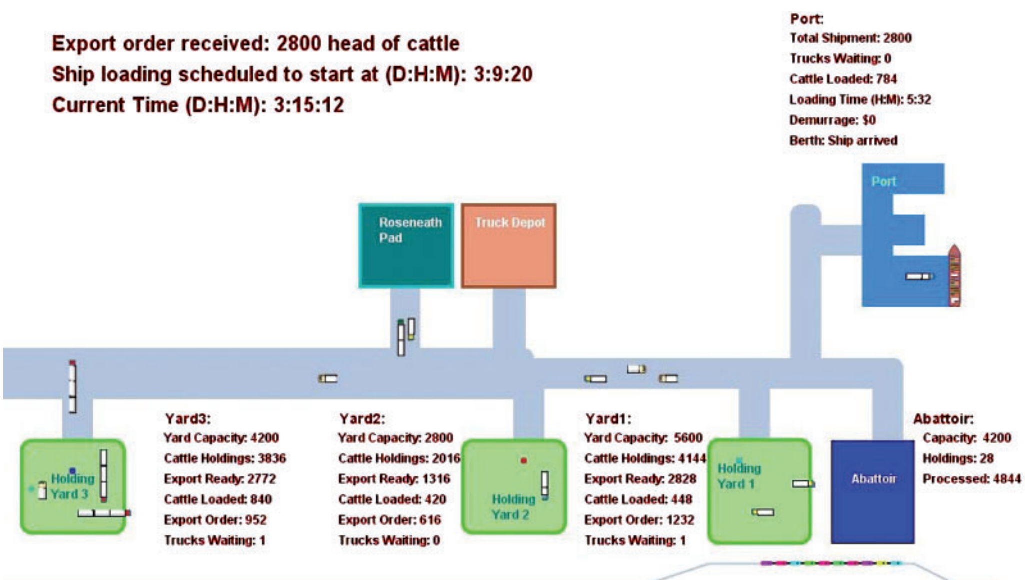


Fig. 3. A snapshot of the Townsville Livestock Export Scenario as an example of an Operational Simulation model. This example has three holding yards where cattle are rested and undergo veterinary checks before proceeding to the port for live export, an abattoir processing 800 cattle per day and a pad where large road trains are broken down into B-Doubles. The line at the bottom is the rail line transporting cattle to Holding Yard 1. The model dynamically shows the number of cattle in each yard, loaded on the ship and processed, as well as statistics about trucks and ships waiting, current time of the simulation and when further ships are expected to arrive. A ship is shown being loaded, with loading begun nearly 6 h previously.

The strategic model follows the path of livestock between enterprises, ultimately to the port or abattoir. Conceptually, cattle for a specific export shipment or abattoir arrive from dispersed locations across northern Australia along several possible paths. For each cattle movement recorded in the NLIS data for 2007 and 2011, an optimal 'least cost' trip path between the origin and destination PIC is generated, accommodating the road conditions. There were ~88 000 unique origin-to-destination movement records between PIC. A computer routine was written that used GIS software (ArcGIS), to define the route for each unique origin-to-destination record and produce an accompanying set of tabular data with details such as road segment lengths, speed limits, truck restrictions and travel time. The cost of cattle transport was then calculated for each of the 1.5 million trips, and these were aggregated to monthly or annual costs between enterprises.

Routeing of vehicle trips and calculation of costs accounted for road transport limitations, including access limits on Type 1 (total road train length >26 and <36.5 m) and Type 2 (total length >36.5 and <53.5 m) vehicles, along with seasonal road conditions that affect accessibility. Regulatory constraints in Australian Animal Welfare Standards and Guidelines – Land Transport of Livestock (Animal Health Australia 2012) were also considered. These require the vehicles to temporarily unload the cattle at spelling yards en-route if the total trip time exceeds the animal-welfare threshold for the type of cattle being transported. Drivers' fatigue laws require drivers to take minimum short and long breaks en-route. Such stoppages were built into the travel time and costs. The paths taken were assumed to be the most direct route given transportation limitations, e.g. road grade and weight restriction. The expectation, however, is that this path may be undertaken at a lower cost through a range of improvements to the network. The model will allow this expectation to be tested by including a scenario module where network improvements, such as road upgrades or alignment of regulatory requirements between jurisdictions, can be introduced. To undertake the analysis, data are imported from an MS Access database into a geo-database and connected to an ArcGIS network dataset. Results of the analysis are returned to the MS Access database for scenario assessment. The primary application of the model is to simulate infrastructure and policy options that provide maximum benefit at lowest cost. Individual scenarios are run across time to determine the net annual benefit given seasonal variability of road closures and cattle availability.

For this paper, a scenario of road blockages in Western Australia and Queensland due to flooding was examined. Supply chains of 25 locations (aggregation points on the main road) supplying a yard at Katherine (south of Darwin, Northern Territory) and 25 locations supplying an abattoir near Brisbane, Queensland were simulated. Figure 4 shows the base case where the thickness of the lines represents the number of cattle moving along that road route. Figure 5 shows the scenario where roads are cut by flooding (marked by X), and the vehicles need to be re-routed along detours. In this example, the average increase in transport costs was 21% for cattle supplied to Katherine and 11% for cattle supplied to the Brisbane abattoir. This example could easily be modified to test the transport cost savings if some roads, particularly unsealed beef routes, were upgraded.

Strategic optimisation model

To complement the strategic simulation model, an additional model was needed to help stakeholders choose the optimal investment decisions out of a large range of possible options. Policy makers, such as State and Commonwealth governments, and infrastructure users, such as beef producers, transportation and processing companies, normally list and analyse individually several potential and alternative investment projects in order to plan their medium- and long-term operations, possibly by commissioning feasibility studies. These investment projects comprise the construction and maintenance of roads, as well as

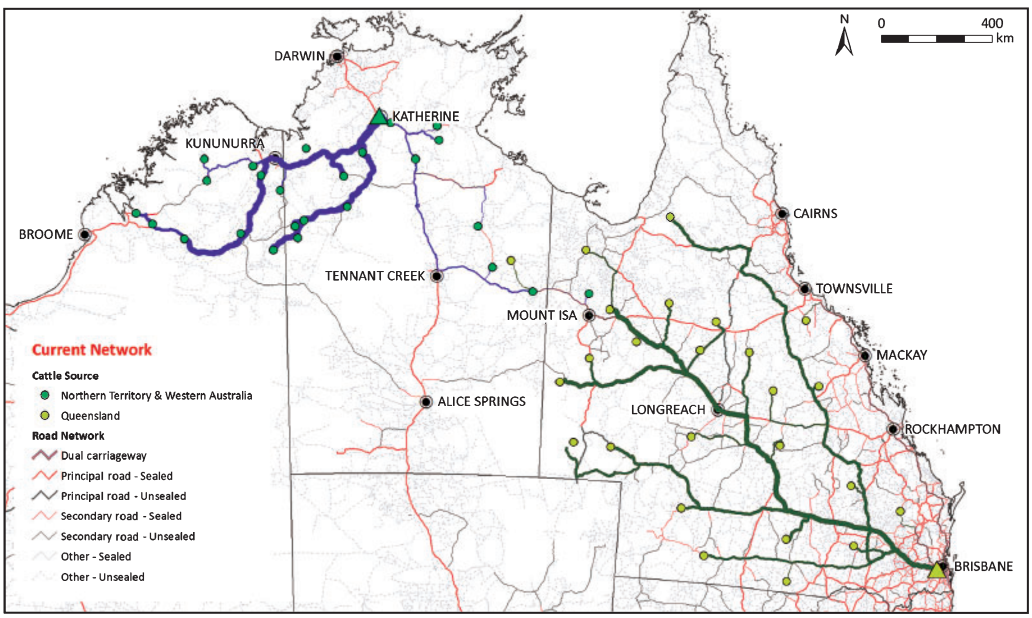


Fig. 4. Simulated base case movements of cattle from ~25 locations (each) to Katherine and Brisbane.

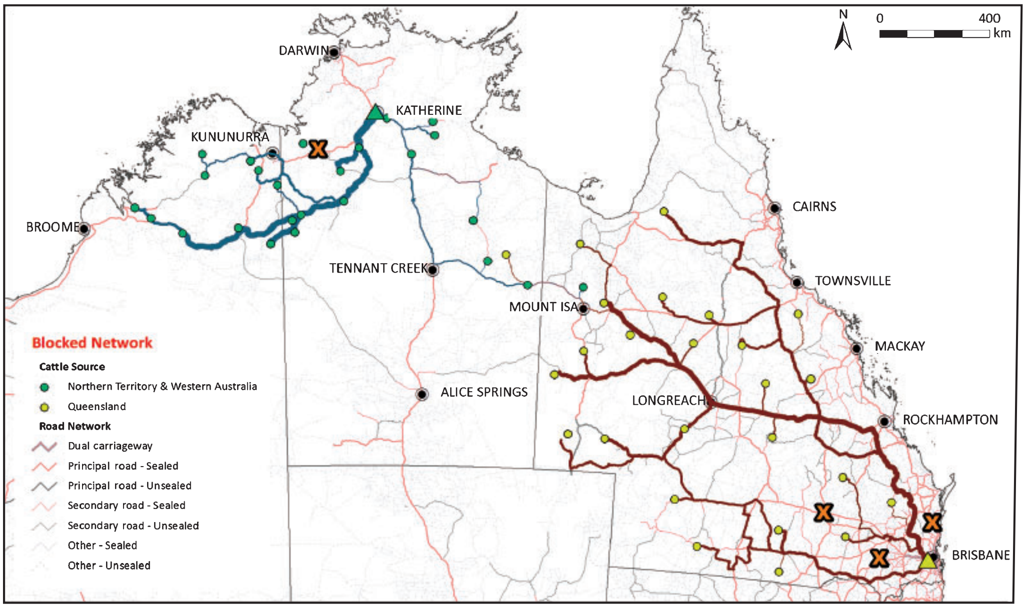


Fig. 5. Revised movements of cattle due to flooding at locations marked by X.

the establishment of finishing properties, and slaughter and processing facilities. Even when the number of alternative infrastructure improvements proposed by each single player may be small, the effect of the different investment proposals working together is difficult to assess. Furthermore, the very same investment proposals may perform completely differently in the system as a whole when the market or environmental conditions of the supply-chain change. This problem quickly becomes extremely complex as the number of proposals to be assessed increases and is made even more complex when decisions need to be made within the context of three different state jurisdictions.

To tackle this complexity, the strategic optimisation model selects the best combination of proposed roads and facilities by solving a mathematical programming problem. The solution is the best in the sense that it produces the combination of available investment proposals that maximises the revenue of cattle producers, subject to budget and operational constraints. The model adopts a systems view of the supply chain by combining capital and operational costs.

On one hand, the model incorporates infrastructure information, such as existing road segments, proposed road extensions, location and type of properties that participate in the supply chain, and building costs and locations of new facilities. On the other, it also uses operational data regarding cattle flows along the network, transportation costs and facility operating costs.

The optimisation model is formulated as a combined ‘facility location’ and ‘network design’ problem – the type of operational research problem that has been studied extensively in the literature in relation to optimising geographical locations of agricultural infrastructure (Melkote and Daskin 2001; Lucas and Chhajed 2004; Garcia-Flores and Higgins 2012). In contrast to the operational and strategic simulation models, this model is intended to inform selection among multiple investment options, such as new road links, road upgrades, spelling yard location, or investment in alternative transportation routes in case of disruptions. At present, the model considers two stages: the transportation from breeding to finishing properties (or feedlots), and the transportation from finishing properties to abattoirs. In the near future, it will be expanded to accommodate live exports and selection of optimal spelling yard locations.

During the initial development, hypothetical investments in abattoir sites and road construction were analysed using a simulated supply chain in the Pilbara region of Western Australia. The distribution network used in the preliminary study is shown in Fig. 6. In this example, properties turn-off ~280 000 head each year, with turn-off numbers from each location simulated from a normal distribution. All capital and operational costs are included in the model, but are not shown due to space limitations.

Figure 7 shows changes in the network design as a function of budget. Each figure shows the structure of the supply network and the selected abattoir sites. Designs in Fig. 7*a* and *b* recommend the construction of one abattoir (at Site 1), the design in Fig. 7*c* recommends the construction of two abattoirs (Sites 1 and 2) and the design in Fig. 7*d* recommends three abattoirs (Sites 1, 7 and 10). It is interesting to note that the three sites considered by the feasibility study (RIRDC 2010) as more likely to host an abattoir in the region, namely Karratha, Newman, and Port Hedland, are very close to sites selected by the optimiser. While this congruence does not validate the strategic optimisation model, it does enhance its credibility for broader application.

Development scenarios

As part of the developments reported here, several workshops were convened with stakeholders in the north Australian beef industry to identify scenarios that should be analysed using the modelling framework described above. These stakeholders included: State and Commonwealth government departments, livestock producers’ associations, transport providers, major

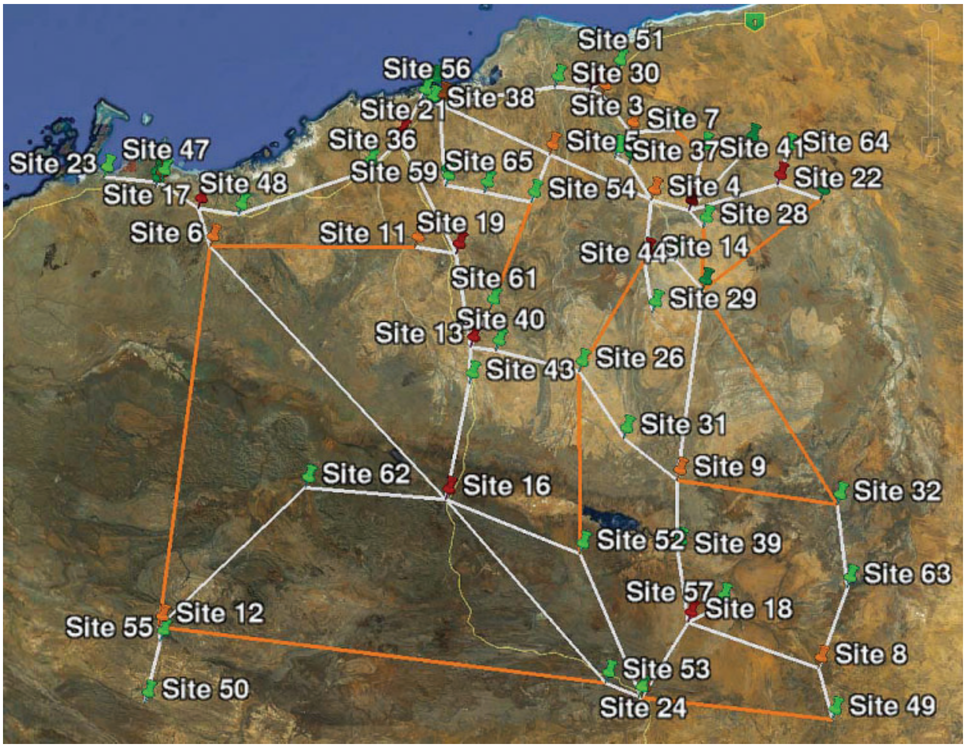
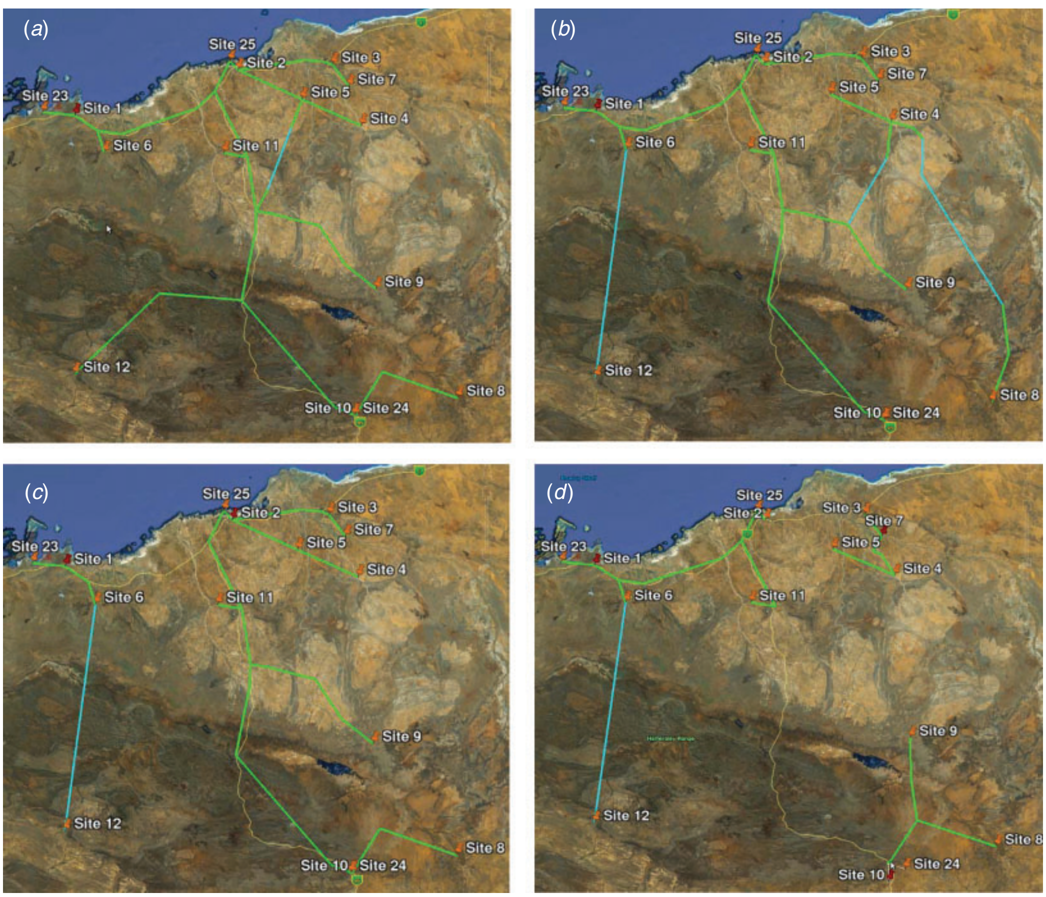


Fig. 6. Hypothetical supply chain using the Pilbara region. Breeding properties are marked in green, finishing properties in orange, and road junctions in red. Existing roads are shown in grey, proposed roads in orange.



feedlots and abattoir enterprises. Scenarios identified by these workshops were re-prioritised in the context of data availability and tractability for modelling. While many identified scenarios seem closely related, they collectively offer the opportunity to refine the model outputs for different end-users. Following these stakeholder workshops, a baseline scenario was formulated using cattle movements for the period 2007–11, current infrastructure and the existing live export market. This base line scenario profiles various zonal or regional supply-chain characteristics together with their current constraints and opportunities. The scenarios that will require comparison with these base lines are briefly outlined below.

New beef industry developments

A new abattoir at Darwin has been proposed by the Australian Agricultural Co. (www.aaco.com.au/, accessed 4 May 2013) to provide abattoir infrastructure in a region otherwise heavily reliant on live export markets. It would substantially alter existing supply-chain paths, particularly those moving store cattle from east to west Queensland, and then returning with cattle for export. There are opportunities to optimise transport schedules by maximising return loads. There will be a requirement for forage or hay close to the abattoir, to hold stock and potentially to finish them. This will create opportunities for irrigated agriculture or feedlots, and possibly for interaction with the expanded Ord River Irrigation Area. As throughput is increased, this may have implications for supply to other abattoirs which can be evaluated. Supply during the wet season will be a challenge and long-term feedlots 200–300 km south of Darwin will need to be established to accumulate cattle for processing when transport is restricted.

Several other initiatives are currently exploring the potential to produce forage using small-scale, or mosaic, irrigation. A reliable supply of well-priced hay or silage could make a substantial difference to beef supply-chain logistics. These feedstocks could be used to accumulate cattle in holding yards close to ports or new abattoirs, or to alter beef enterprises fundamentally by enabling them to turn off different classes of cattle, or to finish cattle for slaughter.

New transport infrastructure investment

Current issues with roads include: inaccessibility due to their poor quality or wet season flooding, the need for long detours, and availability of spelling yards. Several road links in the more remote parts of northern Australia have potential, via upgrade, to significantly reduce transport costs and increase wet season accessibility. These would allow easier movement of cattle between the Northern Territory and Queensland when existing highway routes are closed due to flooding. Road suitability for Type 1 and 2 vehicles is a problem in some areas due to gradients and sharp turns, requiring significantly longer travel distance than the direct route.

Investment in infrastructure to allow better utilisation of multi-modal transport would provide significant benefits. This might include hubs and depots, which would need to be optimally located to minimise handling costs and meet required standards with respect to animal welfare and driver fatigue.

Alternative supply-chain options – turn-off scenarios

A key input into all models is the number and class of cattle turned off from the breeding and finishing properties. Data for 2007–11 from NLIS were used to capture the recent annual variation in these movements. However, for future market scenarios, such as the loss of live export or the construction of a new abattoir, the beef production system will need to be re-modelled to identify likely cattle turn-off by class and time of year. Extensive consultation with industry stakeholders identified the following scenarios for cattle currently being exported to Indonesia from the Kimberley, Victoria River Downs, Katherine and Top End regions of Western Australia and the Northern Territory:

- turn-off of steers and heifers at 18 months of age to Longreach, Queensland for finishing, with mature cows going to slaughter in southern Western Australia; and
- turn-off of mature steers for slaughter in Townsville, Queensland with surplus heifers and mature cows going to markets in southern Western Australia.

Longreach and Townsville were chosen as the most appropriate destinations due to the acceptance of cattle with a high Brahman content in the northern Queensland market. For the Pilbara region of Western Australia, the primary scenario for cattle currently being exported to Indonesia is turn-off of mature steers for slaughter in southern Western Australia and of surplus heifers to southern Western Australian markets for finishing. Markets in southern Western Australia were chosen as the most likely destination for Pilbara cattle given the shorter travel distance and the complexities imposed by regulations of cattle tick control on interstate movements. In addition, cattle from the Pilbara region have a high Droughtmaster content, and are thus more acceptable in southern markets than cattle from Kimberley, Northern Territory with a high Brahman content.

For most of Queensland, the live export market to Indonesia is minor and the alternate scenarios identified involved changes to the production system, such as the introduction of leucaena, improved nutrition and management, and movement of young stock to central Queensland for finishing.

Each of the above scenarios was modelled in Breedcow (Holmes 2011; Holmes *et al*. 2011) with the templates produced in the Cooperative Research Centre for Beef Genetic Technologies representing 'business as usual' in each of the northern cattle regions. This gave a predicted turn-off of cattle of a certain age and liveweight range for each month of the year in each region defined by the Australian Bureau of Agricultural and Resource Economics and Sciences. The logistics model

Fig. 7. Sites selected as abattoirs (marked in red) and network design. Existing roads are marked in green and proposed roads are marked in blue. The total budget for each design is (*a*) \$50 million, (*b*) \$93.3 million, (*c*) \$100 million and (*d*) \$130 million, assuming a flat rate cost per km of new road. Designs (*a*) and (*b*) recommend the construction of one abattoir (Site 1), design (*c*) recommends the construction of two abattoirs (Sites 1 and 2) and design (*d*) suggests building three abattoirs (Sites 1, 7 and 10).

utilised this revised turn-off to estimate movements by property, to model the flow-on effects for transport and evaluate how infrastructure development could best support alternate market pathways.

Optimising existing transport infrastructure and utilisation

These scenarios particularly involve innovative ways of utilising existing infrastructure modes and improved transport scheduling. In Queensland and the Northern Territory, there are opportunities to increase rail utilisation, where accessible, as currently only 6% of cattle slaughtered are delivered to the Queensland abattoirs by rail (Economic Associates 2011). Trade-offs will occur between cost per km, (which is lower for rail), double handling of cattle, delays, animal welfare and availability of trains, all of which can be considered in the modelling. To utilise the Adelaide to Darwin rail link, cattle-loading facilities would be required in suitable locations with depots at Katherine (for movement to Darwin), and Alice Springs (for movement to southern Australian abattoirs). Also, a railway siding at any new abattoir development near Darwin could be considered.

Coastal shipping is a potential alternative to long-distance road transport, to move cattle from the north to the various abattoirs. Analysis will need to consider the trade-off in costs and other benefits such as animal welfare and liveweight loss.

Through transport and turn-off planning, there are opportunities to reduce the seasonal variability or other time-of-year pulses of supply to abattoirs and increase utilisation of vehicles on return trips.

Regulatory impacts

There is a need to define the impact of management rules on driver fatigue in relation to transport and freight tasks, especially around the rest rules that could be applied by the National Heavy Vehicle Regulator (www.nhvr.gov.au/, accessed 4 May 2013). The model can also determine options to better accommodate cattle that are adversely affected by long-distance travel, or are at risk due to wet weather. Road upgrades can reduce travel time and risk, thus making it possible to make additional trips within driver fatigue and animal welfare guidelines. This will require determining optimum location of rest areas for vehicles and spelling yards. There is also the opportunity to optimally coordinate driver rest and animal welfare requirements, given the uncertainty of travel times.

In many areas of Queensland restrictions on the use of Type 1 and Type 2 road trains can cause diversions of up to 300 km and additional road safety costs are incurred by the need to break down road-trains to get to an abattoir through urban areas. The model can be used to evaluate the cost of these constraints to the beef industry versus alternatives, e.g. new bridge, change in curfew for Type 1 and 2 access and better breakdown facilities.

Minor changes to the administration of cattle tick control regulations, e.g. allowing free movement direct to slaughter or feedlots, may interact with road-train regulations or vehicle load limits.

Fundamental supply-chain issues

In current planning of the live export of cattle, there is only a short time interval between the granting of export permits and the arrival of a ship. Quotas also dictate the supply of live cattle for each shipment. Identifying sources of cattle of the correct liveweight to ensure a reliable supply to the port is, therefore, difficult, particularly when weather conditions restrict access from some properties at different times of the year. More lead time would allow planning of supply from different properties, which would allow better account to be taken of weather-related transport disruptions and risks. The port of Darwin in the Northern Territory currently operates within capacity, although delays in the arrival of ships create a fluctuating demand and the risk of queuing for ship berths and loading/unloading facilities. The port of Wyndham in the north of Western Australia could be used as an alternative, though dredging would be needed to allow bigger ships. While it is currently expensive to export from Wyndham, analysis may reveal a supply-chain trade-off warranting investment in upgraded facilities and dredging.

Conclusions

The on-shore supply chains of the beef industry in northern Australia are characterised by very long transport distances, upwards of 1000 km between the breeding property and abattoir (or port) with transport cost often exceeding A\$150 head^{-1}. This makes the industry highly vulnerable to supply-chain shocks from markets and climate, with many cattle properties having no viable alternative markets. Through multiple working group meetings, the industry identified opportunities to reduce the transport and logistics costs, including upgrades of important beef routes, new abattoirs, increased use of rail transport, new spelling and feedlot facilities, and more consistent and reliable supply to abattoirs. A model framework incorporating three different models was constructed. These collectively address the strategic versus operational, and regional versus local aspects of these opportunities to reduce logistical costs. Initial results have demonstrated how the tools can be used to examine logistic efficiencies of individual facilities or businesses, evaluate options for new infrastructure investments, and test the sensitivity of transport costs to supply-chain blockages. Availability of, and access to, data were the biggest limitations to conducting these large-scale logistical analyses, particularly as the industry has a large number of supply-chain pathways geographically and complete datasets are not available. Further work is required, using GIS techniques, to identify road networks accommodating minor beef routes and the range of attributes, e.g. tick-dipping facilities, and accessibility of unsealed roads when wet, that affect the road transport of cattle. A further difficulty is that several properties are identified by a single PIC, and a more accurate transport analysis would consider movements between individual properties within a PIC. However, historical NLIS data are not available at this scale and data relating individual properties to PIC are not released by State governments.

Both the strategic models developed are very demanding in terms of memory and computational capacity. Applications to additional scenarios can require major technical refinement and manual calibration, thus automated platforms and interfaces are required before they can be used by government and industry.

When available, these will allow easy updating of inputs such as property boundaries, livestock numbers and supply-chain parameters, e.g. paths and costs.

Acknowledgements

The authors thank Scott Wauchope (Department of Resources, Northern Territory) for his effort in co-ordinating the workshop in Darwin, and Peter Stone (CSIRO) for input into the design of the project, and for reviewing a draft of this paper. This project is co-funded by the Commonwealth Government – Office of Northern Australia, as well as the Queensland, Western Australia and Northern Territory state governments. A large amount of industry and state government support was provided to the project team in the form of local expertise and data. While too numerous to list them all, the authors particularly acknowledge the following: Rick Dunn and Michael Lancaster (Queensland Department of Agriculture, Forestry and Fisheries); Rob Rankin and Ross Mensforth and colleagues (Queensland Department of Transport and Main Roads); Adele Kluth and Barb Littler (Northern Territory Government); Brad McCormick and Peter Cunningham (Western Australia Department of Agriculture and Food); Renee Clegg and Alice Gillam (Western Australia Department of Main Roads); Cameron Best (AACo); Liz Schmidt (Queensland Livestock Transport Association); Peter Quigley and colleagues (NLIS); and John Berry (JBS). The authors would also like to thank the Associate Editor and anonymous referees for helpful comments on an earlier version of this paper.

References

Ahumada, O., and Villalobos, J. R. (2009). Application of planning models in the agri-food supply chain: a review. *European Journal of Operational Research* **196**, 1–20. doi:10.1016/j.ejor.2008.02.014

Animal Health Australia (2012). 'Australian Animal Welfare Standards and Guidelines – Land Transport of Livestock.' (Animal Heath Australia: Canberra, ACT.)

Boyabatli, O., Kleindorfer, P., and Koontz, S. (2011). 'Integrating Long-term and Short-term Contracting in Beef Supply Chains.' Research Collection Lee Kong Chian School of Business, p.1801. (Singapore Management University: Singapore.)

Domingues Zucchi, J., Zeng, A. Z., and Caixeta-Filho, J. V. (2011). Optimum location for export-oriented slaughterhouses in Mato Grosso, Brazil: a dynamic mathematical model. *International Journal of Logistics: Research and Applications* **14**, 135–148. doi:10.1080/13675567.2011.608653

Economic Associates (2011). 'Development and Assessment of Options for the Efficient and Commercially Sustainable Transport of Cattle in Queensland.' Final report prepared for Queensland Department of Transport and Main Roads. (Queensland Department of Transport and Main Roads: Brisbane.)

Francis, M., Simons, D., and Bourlakis, M. (2008). Value chain analysis in the UK beef foodservice sector. *Supply Chain Management* **13**, 83–91. doi:10.1108/13598540810850346

Garcia-Flores, R., and Higgins, A. (2012). On the feasibility of establishing a northern-western Australian beef abattoir as a facility location problem. Handbook of Operational Research in Agriculture and the Agri-Food Industry, Unpublished report.

Gleeson, T., Martin, P., and Misfud, C. (2012). 'Northern Australian Beef Industry: Assessment of Risks and Opportunities.' Report prepared for the Northern Australian Ministerial Forum. (Australian Bureau of Agricultural and Resource Economics and Sciences: Canberra.)

Goucher, G. (2011). 'Transport Costs for Australian Agriculture.' Research Report. (Australian Farm Institute: Surry Hills, NSW.)

Higgins, A., Miller, C. J., Archer, A. A., Ton, T., Fletcher, C., and McAllister, R. R. J. (2010). Challenges of operations research practice in agricultural value chains. *The Journal of the Operational Research Society* **61**, 964–973. doi:10.1057/jors.2009.57

Higgins, A., Estrada-Flores, S., Singh, G., and Ton, T. (2011). The state of logistics in the Australian food industries. *ASOR Bulletin* **30**, 24–41.

Holmes, W. (2011). Breedcow and Dynama software, DEEDI. Available at: www.dpi.qld.gov.au/16_6886.htm

Holmes, W., Sullivan, M., Best, M., Telford, P., English, B., Hamlyn-Hill, F., Laing, A., Bertram, J., Oxley, T., Schatz, T., McCosker, K., Streeter, S., James, H., Jayawardhana, G., Allan, R., Smith, P., and Jeffery, M. (2011). Representative Herds Templates for Northern Australia V1.00 – data files for Breedcow and Dynama herd budgeting software, Beef CRC, DEEDI (Qld), DAFWA and DRDPIF&R (NT). Available at: www.dpi.qld.gov.au/16_20534.htm (accessed 8 October 2011).

Lucas, M. T., and Chhajed, D. (2004). Applications of location analysis in agriculture: a survey. *The Journal of the Operational Research Society* **55**, 561–578. doi:10.1057/palgrave.jors.2601731

Marquez, L., Higgins, A., and Estrada-Flores, S. (2012). Simulating vulnerability in Victoria's fruit and vegetable supply chain. Handbook of Operational Research in Agriculture and the Agri-Food Industry, Unpublished report.

McCosker, T., McLean, D., and Holmes, P. (2010). 'Northern Beef Situation Analysis 2009.' (Meat and Livestock Australia: Sydney, NSW.)

McDermott, A. K., Smeaton, D. C., Sheath, W., and Dooley, A. E. (2005). A model of the New Zealand beef value chain: evaluating opportunities. *Proceedings of the New Zealand Grassland Association* **67**, 81–86.

Melkote, S., and Daskin, M. S. (2001). An integrated model of facility location and transportation network design. *Transportation Research Part A, Policy and Practice* **35**, 515–538. doi:10.1016/S0965-8564(00)00005-7

RIRDC (2010). 'Feasibility of establishing a northern Western Australian beef abattoir.' Publication No. 10/214. (Rural Industries Research and Development Corporation: Kingston, ACT) Available at: https://rirdc.infoservices.com.au/downloads/10-214 (accessed 4 May 2013)

Uddin, M. N., Islam, N., and Quaddus, M. (2011). 'Supply Chain Performance of the Australian Beef Industry: Comparing the Industry Structure, Inter-firm Relationships and Knowledge Systems of Western Australia and Queensland.' (Western Australia Department of Agriculture and Food: Perth.)