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A GIS model for simulating infrastructure investments in livestock logistics: Application to the northern beef industry

Stephen McFallan [a], Andrew Higgins[a], Di Prestwidge[a], Luis Laredo[a]

[a] *CSIRO Ecosystem Sciences, GPO Box 2583, Brisbane Queensland, Australia*
Email: Stephen.McFallan@csiro.au

Abstract: Australia's northern beef industry of 12.5 million head is characterised by supply chains of long travel distances, and high vulnerability to variability in climate and external markets. With transport costs being up to 35% of farm gate price, infrastructure investments in roads, bridges and holding yards, have the potential to substantially improve viability and resilience of the expanding northern industry. However, there has been no tool available to holistically evaluate a range of such options and benefits across each enterprise. To address this issue a project was funded by the Commonwealth and State Governments to develop three logistics models in simulation and optimisation, each of which is designed to analysis a range of options. In this paper, we outline one such model, based on GIS, that is designed to simulate the transport cost implications to enterprises across the livestock supply chain from infrastructure investments and changes to driver/animal welfare policy. It does this by estimating the transport costs for all livestock movements between enterprises in the northern beef industry, accommodating road conditions, vehicle access restrictions and tick clearing. A feature of the methodology is that it accounts for high granularity of individual vehicle movements between property, abattoir and port, as well as the ability to scale up to an almost complete view of logistics costs across the entire beef industry of northern Australia. We demonstrate the model using case studies of: upgrading highways in Queensland; removing tick clearing requirements for cattle transported to abattoirs; and a new abattoir south of Darwin..

Keywords: *transport, infrastructure, simulation, beef, northern Australia*

1. INTRODUCTION

The northern Australian beef industry supply chains extend from the north-west of Western Australia (WA) through to the Northern Territory (NT) and Queensland (QLD). The northern beef herd of 12.5 million supplies nearly 90% of Australia's live export cattle, with 694,000 head exported in 2011. The northern Australian beef industry's on-shore supply chains have long transport distances with nearly 50% of cattle in the Northern Territory travel upwards of 1,000 km between breeding property and abattoir (or port). The industry is almost exclusively reliant on road for both business inputs and outputs. Year round supply to both live export and slaughtered meat markets is not possible in most of northern Australia due to the wet season.

A review of the northern Australian beef industry in terms of productivity and profitability (McCosker et al., 2010) indicated that a significant increase in the costs of production has meant many properties are marginal and struggle during poor seasons. While the declining financial performance is largely a result of reduced real beef prices, reduced turnoff and increased farm debt (Gleeson et al., 2012), McCosker et al. (2010) also identified rising overhead and direct costs such as freight as contributors. The extensive spread of properties and declining financial performance is further complicated by market dynamics. Recent short to medium term market challenges have arisen from the imposition of weight restrictions on 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. Investment to support the resilience of the northern beef industry must anticipate and capitalise on future challenges and opportunities, and future market conditions. Infrastructure investments in roads, bridges and holding yards, have the potential to substantially improve viability and resilience of the expanding northern industry.

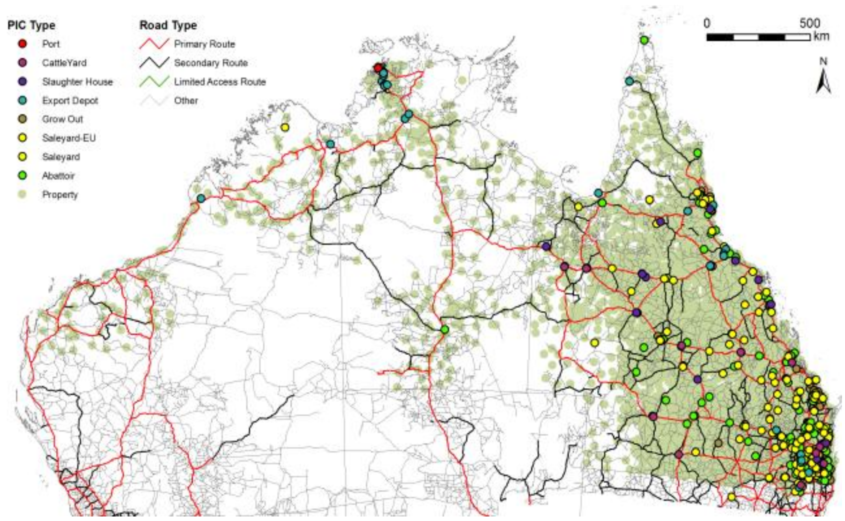

Figure 1. Geographical Scope of Livestock Logistics project

There have been some past studies that evaluate beef value chains in different countries. These include static analyses that map out existing chains to understand the performance of different segments of the chain, as well as identify opportunities for increased efficiency and international competitiveness (Francis et al. 2008; Uddin et al. 2011). Compared to model based approaches, such static analyses do not allow alternative scenarios to be evaluated/compared, and are not adaptable to a dynamic industry. Models for simulating and optimising livestock logistics are very limited, despite being more abundant in other agriculture value chains (see Higgins et al. 2010 for reviews). The "ground-up" approach to modelling beef logistics in this project considers the scale of every vehicle movement between individual enterprises. This provides the capability of a wide range of infrastructure or operational opportunities, whether small or large scale. There have been limited "ground-up" attempts at modelling agri-food logistics, let alone in livestock.

In this paper, we outline a model, based on GIS, that is designed to simulate the transport cost implications to enterprises across the livestock supply chain, from property gate through to export port or abattoir. Road and rail transport are considered, including intermodal transfers and different vehicle combinations as well as infrastructure investments and changes to driver/animal welfare policy. The first challenge was to determine the spatial extent for the study. 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 animals are transported from the north to southern feedlots and abattoirs (e.g. Dinmore), and cattle transported from New South Wales (NSW). To ensure key supply chains were captured without extending the analysis to all

Australia, the scope was limited to enterprises shown in **Figure 1**, which includes all Queensland. Movements of cattle into Queensland from southern states are considered, but only the transport component from the Queensland border. Similarly with NT, movements to South Australia (SA) are considered, but only to the state border. In WA, the transport component to enterprises (e.g. abattoir, finishing farm, port) are considered, but not beyond that.

2. DATA

For this project usable data was gathered from more than 20 government departments and companies over a 12 month period. Data was gathered for three primary reasons: mapping the supply chain pathways of the beef industry; constructing the transport networks and costing models; and developing the different herd structures and turn-off scenarios.

Mapping of the supply chain involved obtaining the location of each enterprise (breeding property, finishing farm, sale yards, feedlots, holding yards, abattoirs, ports, etc). This was made possible by obtaining the property identification code (PIC) from the Department of Primary Industries (or equivalent) from each state. Then data on the movement of stock between enterprises and over time was required which was obtained through the National Livestock Identification System (NLIS). The NLIS data contained a daily record of the number of cattle moved between every PIC, with a total of 1.5 million movements between 2007 and 2011 inclusive. The bulk of movements over this time were from sale yards to properties then either between properties (i.e. from feedlots to finishing farms) or from properties to the abattoirs or ports. The mapped supply chains only represented past scenarios (or baselines) though they show annual and seasonal variability.

Table 1. Road transport costs per vehicle

	Cost ($) / km for a given km / day						
Type	1200	1000	800	600	400	200	Idle cost ($/hr)
B-Double	2.16	2.35	2.64	3.13	4.10	7.03	141
Type 1	3.01	3.24	3.59	4.17	5.33	8.82	169
Type 2	3.19	3.43	3.78	4.36	5.52	9.02	177

Other data captured included transport costs. Here we use both road and rail costs. Where possible it was essential to use a "ground-up" approach to transport costs that accounts for all variables including labour, fuel, maintenance, depreciation etc. In the absence of access to a model used within the Australian beef industry, we calculated road transport costs using the Freight Metrics model (www.freightmetrics.com.au). We considered three vehicle classifications in this project; B-Doubles (3 decks), Type 1 road train (4 decks – two 40 foot trailers) and Type 2 road trains (6 decks – three 40 foot trailers). For road transport, we needed sensitivity of "cost-to-travel" speed, to accommodate the different grades of roads and speed restrictions in built up areas. Through running several scenarios of the Freight Metric model, a matrix of transport costs was produced (**Table 1**). These costs should be doubled to accommodate an empty return trip.

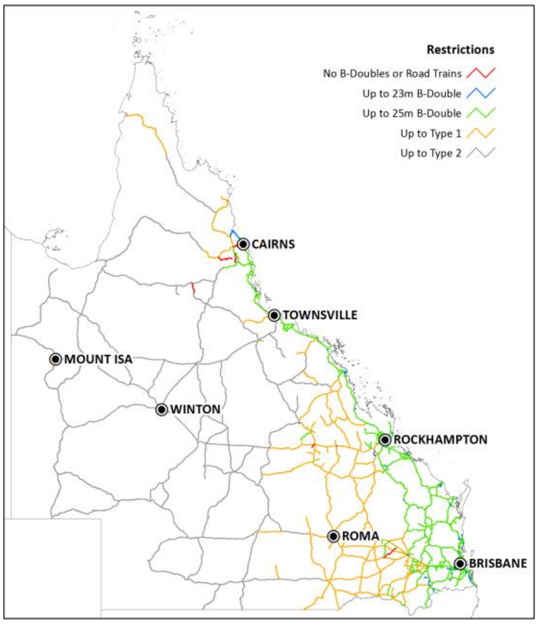

Figure 2. Accessibility of heavy vehicles in Queensland

Queensland Rail pricing was used for rail transport costs, with origin to destination costs per km captured for each station and averaging around $1.00 per km per deck. A train will carry 44 decks, with a deck being the same size for both road and rail. Cattle per deck are dependent on weight and range from 38 per deck for 250kg down to 18 for 650kg. Cattle arriving into a live export yard incur the following costs: loading and unloading, dipping, weighing, NLIS scanning, extra day feed, yard fee and botulism vaccine. Costs representing the Julago export yard were used for this project.

The road network data was critical for the model. Data for primary, secondary and other roads is contained in **Figure 1**. These road conditions affect average speed and transport cost per km. An additional feature included is the restrictions for B-Doubles, Type 1 and Type 2 road trains (**Figure 2**). The main restrictions are in moving cattle to east coast abattoirs and ports. Typically when transporting with a Type 2 (6 deck) combination the vehicle would drop the trailers off at vehicle trailer break down locations, where another company will transport them to the destination as a Type 1 or B-Double configuration. Not only is there a higher cost per head (**Table 1**) for transporting in smaller vehicle combinations, there is an additional cost for the double handling. Often the existing locations for vehicle breakdown (e.g. Clermont) require detours for road trains to reach these points. Accessibility restrictions for vehicle combinations (B-Double, Type 1, Type 2) are not an issue for transport of cattle in NT, Pilbara or Kimberley.

3. STRATEGIC SIMULATION MODEL

The intended purpose of this model is to simulate large scale investment decisions for infrastructure to support transport efficiencies, or to inform policy decisions that impact on the mass flow of cattle across the north of Australia. In terms of logistics granularity, it is based on simulating number of head of cattle (or vehicle trips) per month moved between enterprises across northern Australia.

The current route used to move cattle between enterprises may not be the most efficient route. Dependent on a range of constraints at the origin, along the route due to transport, transport network and/or other limitations more optimal routes may be available. Furthermore the movements for the industry can be difficult to optimise however with this modelling, aggregate estimates can be made allowing decisions for transportation investment to be tested and directed to targeted network locations maximising investment outcomes.

The hypothesis behind the development of this model was that industry wide efficiencies may be gained through a range of small changes and/or improvements to the network through strategic investment at critical locations. It is expected that the economic benefits would be accompanied by benefits to the animal welfare, driver safety and that of other road users as well as benefits to the environment through minimised transportation and the associated reduction in emissions. In this model, it is required that any network modifications will maintain or improve outcomes in terms of the animal welfare, driver safety and ultimately economic efficiencies for all parties including transport network owners. All aspects of the transportation of the stock related to the movement part of the task in this simulation model were designed to meet the Australian Animal Welfare Standards and Guidelines.

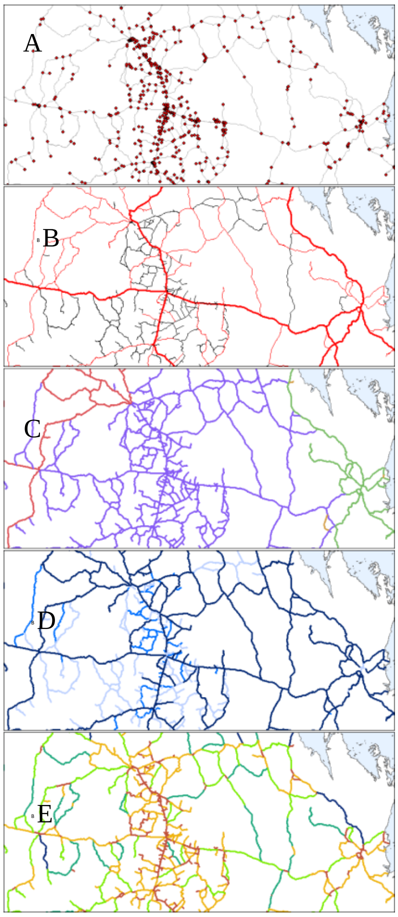

Figure 3. Components in a subset of the livestock logistics GIS network.

To develop the model a suitable platform was identified that would have the capacity to deliver on the concept but also be widely available for further use and development. A combination of Microsoft Access and Esri ArcGIS was chosen. The process required a digital map layer of the road infrastructure in the relevant region to be used as the base layer of the GIS network. Different road layers were then mixed to produce a single layer which satisfies the rules of a network element. **Figure 3A** shows the network element edges (lines) and junctions (vertices). Each of these contain information specific to that section of road, some of which are shown alongside the network. **Figure 3B** shows the network classified by road rank, with thicker lines representing major highways, down to local roads in black. **Figure 3C** shows the truck restrictions for each segment, where the size/capability of the maximum allowable truck size influences the overall cost of transporting livestock over a given segment or segments. **Figure 3D** shows a general schematic of the speed limits, with darker lines showing higher speed limits. This attribute is important to accurately model traversing through towns / urban areas and sometimes known geographical features, such as the Toowoomba range. **Figure 3E** shows an approximation of what a combination of attributes would produce as a weighted cost of travel, measured in hours.

To determine the optimal route, the analysis takes into account these parameters as costs, descriptions, restrictions or hierarchical value. It is essential for the solving of optimal routes, for all these to work together logically. Network segments should be relevant to the one next to it and carry attributes that will enable travel through, unless a restriction is in place. It is of high importance to apply rules and exceptions appropriately throughout the network.

A trip requiring a load of stock to be moved across the network to a destination is modelled to have travelled to the closest road/network segment from the origin, moving and accumulating costs along the way, finishing at the closest point on a road/network segment to the destination point. Bear in mind that most PICs are located somewhere in a property or abattoir grounds, for example. They are not always geographically attached to a road. This process is repeated for all routes, always searching for the minimum cost, including penalty costs, selecting it as the optimal route.

The model first assembles a base case which is an optimised route from origin to destination. For a given simulation, data on the trip origin, destination and stock to be moved are entered. The simulation process then obtains possible routes for the trip collecting 'road section travelled' information on all sections along the routes. These sections could be constrained by access constraints such as truck size/load limit which will determine the final set of routes. From these routes the optimal route is selected which may not necessarily be the route taken in the existing network but rather the route that would be taken should the planner be seeking an optimal direct route. Once these routes are captured, added constraints or improved conditions are included in the network and the simulation re-run with a new set of final routes as the outputs. The tool is particularly useful at identification of bottlenecks and or points of high costs and ultimately providing information to decision makes looking to optimise the supply chain.

In the future, the model will allow the flexibility of easily updating inputs on property boundaries, livestock numbers and supply chain parameters (e.g. paths, costs). In terms of scale, the model will enable consideration of all supply chain pathways from the farm gate through to ports and domestic wholesale. It will also assist with decisions on road closures, in northern Australia; the road network is regularly disrupted due to seasonal flooding events. This reduces the capacity of the industry to supply cattle to live export yards, finishing farms and abattoirs.

4. CASE STUDIES

Case studies were selected to best demonstrate, validate and test the models. It was necessary that a case study represents the range of logistics complexities in the industry, so that their further application beyond the life of this project is not technically inhibited. Scenarios were identified by stakeholder groups related to the industry - state and federal government departments, livestock associations, transport providers, major feedlots and abattoir enterprises.

4.1. Case Study 1 - Investing in Transport Infrastructure

In Queensland, it was hypothesised that a Type 2 road train corridor between Clermont and Roma with reduced tick clearing requirements for cattle transported to the abattoirs would be a major benefit. Currently the corridor allows Type 1 road trains, with Type 2 road trains usually broken down at Clermont. Cattle within tick infested areas are generally transported to the abattoirs via the Bruce highway (along east coast) in B-Doubles to avoid the expensive and time consuming tick clearing. This can lead to major detours, use of less efficient B-Doubles, and increased heavy traffic on the Bruce highway. This case study

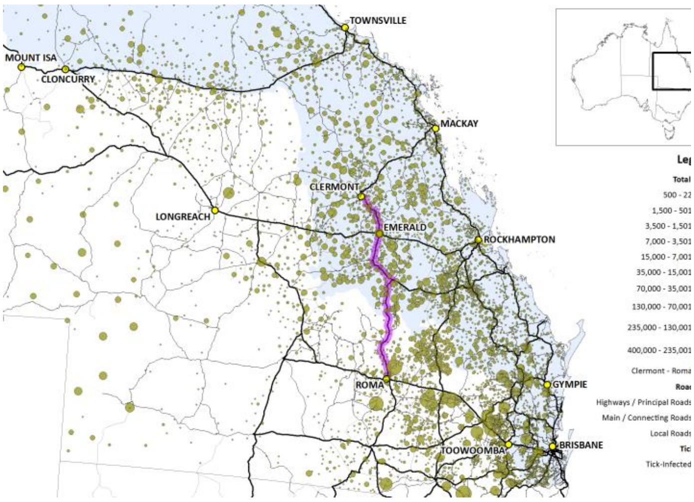

Figure 4. Livestock industry in Queensland showing the Bruce and Carnarvon/Gregory highways

proposed an upgrade of the 400 km Carnarvon highway between Roma and Emerald plus the 110km Gregory highway between Emerald and Clermont to allow Type 2 road trains (**Figure 4**). By upgrading the corridor for Type 2 road trains and implementing suitable tick clearing guidelines for cattle transported to the abattoirs, it is expected this would remove a large volume of north-south cattle traffic away from the Bruce highway and substantially reduce costs. It would also provide a flood resistant alternative to the Bruce highway reducing flood blockage situations. The model was used to estimate the transport cost savings per year, when considering all affected cattle movements between 2007 and 2011. The base case and the scenario are defined as follows:

Base case: Existing Roma to Clermont highway, limited to Type 1 vehicles. Cattle travelling between enterprises that are both in tick infested areas, must avoid travelling into tick free area.

Scenario: Upgrade of Roma to Clermont highway allowing Type 2 road trains. Cattle travelling to an abattoir can travel through a tick free area if it does not unload cattle.

The model produced both cases, where optimal routes are created for each PIC to PIC movement. For the estimated 1.6 million cattle moved along this route from 2007 to 2011 combined with an additional 0.6 million cattle that could have taken this route to the abattoir there were no tick clearing requirements, it was estimated this would have saved $75.6 million (or 19% reduction) in livestock transport costs alone. Such savings would be much higher by considering other heavy vehicle users, with cattle transport being an estimated 3-4% of the total transport usage between Clermont and Roma.

The scenario also led to an expected reduction in GHG emissions, due to fuel consumption efficiencies of using Type 2 road trains versus Type 1 and B-Doubles. To calculate the GHG savings, we used fuel consumptions of the vehicle options from the Freight Metrics transport cost model (www.freightmetrics.com.au) which were 0.625 litres per km for B-Doubles, 0.785 litres per km for Type 1 and 1.11 litres per km for Type 2 road trains. GHG emissions were calculated using the GHG calculator on the Australian Government sustainable transport web site (http://www.environment.gov.au/settlements/transport/fuelguide/environment.html), assuming a diesel fuel type. If the scenario was implemented, total GHG savings for 2007-2011 would have been 2177 tonnes. This is equivalent to the carbon sink capability of 500 hectares of native trees.

4.2. Case Study 2 –Potential Benefits of Infrastructure Investment

The strategic simulation model was also used to identify average transport savings if an abattoir was built south of Darwin. A pastoral company associated with the project provided seven typical properties in NT that currently provide cattle for slaughter in Queensland abattoirs. Existing transport costs were estimated based on the supply chain paths in 2007-2011 NLIS data and optimal transport routes to east coast enterprises. These transport costs accounted for the need to break down Type 2 road trains into Type 1 or B-doubles en-route to the abattoir. Stops to intermediate enterprises (e.g. fattening properties, feedlots) en-route to the abattoir were also considered. **Figure 5** shows the paths from these properties if they were re-routed to a new abattoir south of Darwin. Average distance to the new abattoir was estimated at 835km with an average cost of $1.39 per km per deck assuming an empty return trip. The average distance on existing supply chain paths is 2047km at an average cost of $1.46 per km per deck accounting for part of a trip being Type 1 or B-Double vehicles. If the abattoir processed 120,000 head per year, total transport savings to property owners would be $13.2 million per year. These transport cost savings do not account for differences between price paid between the Darwin and Queensland abattoirs, or the cost of transporting boxed meat to the port or market.

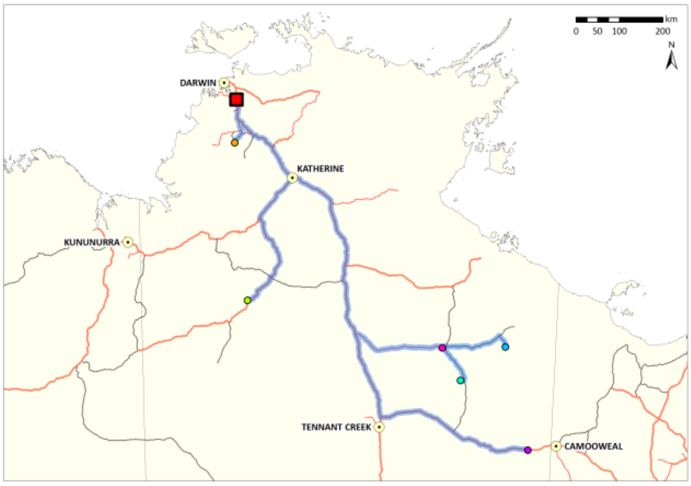

Figure 5. New routes taken between the seven properties and the proposed Darwin abattoir.

5. DISCUSSION AND CONCLUSIONS

The strategic simulation model has demonstrated a capacity to estimate benefits of changes in the logistics network. The model has the additional capacity to test the impacts for regulation changes, for example to map out the impact of driver fatigue management rules on transport and freight tasks, especially around the quality of rest rules that could come into place from the National Heavy Vehicle Regulator. The model can also map out options to better accommodate cattle that are adversely affected from long travel distances, or are at risk due to wet weather. Road upgrades will 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 co-ordinate driver rest with animal welfare, given uncertainty of travel times.

The model is heavily reliant on good quality data to provide decision makers with reliable analysis of investment options. 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 data sets 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. The model was 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 readily used by government and industry.

While the primary focus for this model development was the Northern Australia Beef Industry the concept presented could be developed to cater for other industries with significant complex logistical challenges.

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