HIGHWAY WASTE DISPOSAL: AN APPLICATION OF GEOGRAPHICAL INFORMATION SYSTEMS TECHNIQUES FOR DETERMINING AN OPTIMAL SET OF LOCATIONS FOR IN-TRANSIT LIVESTOCK TRUCK EFFLUENT DISPOSAL FACILITIES IN THE SOUTH ISLAND OF NEW ZEALAND.

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Abstract: This paper focuses on the problem of determining an optimal network of effluent dump-sites for stock cartage along State Highways in the South Island of New Zealand using geographical information system tools. The modeling formed part of a comprehensive analysis by Dr Thull for his PhD on the problems caused by environmentally unacceptable spillage of stock effluent from trucks used in the transfer of livestock by road. Special GIS macros were written by Dean Ashby. Professor Kissling supervised the study. It was used to inform the National Stock Effluent Working Party convened by Transit New Zealand, the national state highway authority. Construction of dump-sites commenced in year 2000.

Key words: Facility Location, Waste Disposal, Livestock Transport

1. BACKGROUND

New Zealand has a strong livestock production component in its economy that contributes significantly to Gross Domestic Product and to export earnings. New Zealand is a big player in the international trade in dairy products. Meat exports (cattle and sheep) are likewise big income earners within the agriculture sector. Livestock graze and are fed in the field year-round, not requiring in-doors accommodation in winter.

As a consequence, livestock are frequently being moved from place to place by commercial road transport operators and by farmers using their own vehicles. This may be from farm-to-farm, farm to saleyard and back to farm, or farm to meat processing works. The distances involved can be relatively short (<25kms) or extensive (400+kms) and may involve crossing Cook Strait by ferry between the two main islands of New Zealand.

1.1 Best Practice in Livestock Transport

Animals can be prepared for transport in a manner that reduces but will not eliminate the volume of effluent they produce whilst in transit. They can be brought into holding pens and stood for at least four hours to empty out and to become accustomed to close confinement in the company of other animals. They can be fed hay rather than lush pasture grass for several days prior to transport and that too will reduce the effluent volumes that have to be dealt with somehow.

Stock that are unstressed, travel better, tend not to bruise. When slaughtered at a meat works, they have a Ph factor that results in high quality cuts of meat. These command premium prices as they can be shipped chilled even to the other side of the world and still have excellent shelf-life in supermarkets.

Even so, livestock will still produce effluent while they are being transported. It is possible to contain that effluent in holding tanks on the vehicle units to avoid spillage onto the roads. If spillage does occur, not only is it a nuisance to other road users and a hazard that can cause accidents, it calls into question New Zealand's clean green image that attracts many tourists to visit the country.

There is still a limit of how far the livestock transport units can travel before they must empty the effluent from holding tanks, else they will overflow. That calls for places where they can legally dump the effluent with minimal time delays.

Best practice in the livestock supply chain would see farmers, stock agents, transport operators, meat processors and road controlling authorities all doing the right thing according to an industry agreed code of practice. They would communicate with each other in a timely fashion to ensure movements of livestock took place in a coordinated manner using the best possible equipment. There would exist strategically located dump-sites for the transport operators to off-load effluent in the course of long journeys.

Such an ideal world does not yet exist. We report here one facet of a major research effort that is leading to the adoption of better practice in the livestock movement industry. Specifically, we outline the model used to identify the vicinities where dump-sites should be constructed in the South Island of New Zealand. Such is the confidence in the simulation model we developed, that several of the locations we identified have or are shortly to have dump-sites installed. Furthermore, a similar exercise is to be conducted for the North Island of New Zealand during 2001-2002.

Our model is based on Environmental Systems Research Institute (ESRI)'s Arc-Info Geographical Information System (GIS). The determination of the "ideal" set of dump-sites is a form of location-allocation modeling.

1.2 Data Collection and Calibration

It was imperative that we could assemble a realistic data set of livestock movement patterns involving the South Island of New Zealand. This involved detailed surveys and comprehensive reconciliation between confidential information supplied by different stakeholder groups (farmers, transport operators, meat processors). Only with a data set that all concerned could feel was an accurate reflection of their industry, could we gain their confidence to accept the outcomes of the model. We could have generated random origin-destination data and a set of dump-site locations that would have minimised spillage for those movements. By repeating the process a sufficient number of times we would have converged upon a set of dump-sites that appeared robust., Some sites, however, would not be cost-effective as they would never collect much effluent being located just to catch sparse movements of livestock.

Knowledge of the rates of effluent production by cattle or sheep stock whilst in transit needed to be calculated. This was achieved empirically by sampling the amount of effluent collected in the holding tanks of transport crates on a variety of journeys at set distance and time intervals. It was necessary to derive charts for stock types that had been stood in yards prior to transport and emptied out, as well as charts for stock that had been taken directly off pasture.

Persistent rainfall during transport can speed up the rate of filling of stock truck effluent holding tanks. This required consideration of the climatic patterns in the South Island. There is considerably higher rainfall intensity on the West Coast in contrast with the East Coast. Also, less rain penetrates the cover provided by closely packed sheep in several layers in the transport crates particularly for the first few hours of travel, than gets through to holding tanks for dairy cows under the same rainfall conditions.

2. DATA REQUIREMENTS FOR THE MODEL

There are several data sources that make up the inputs into the simulation model. In the spatial context there is the road network for the study area, this consists of the major highways of the South Island of New Zealand and all source and destination locations contained in the sample trip data. The road network is stored as a network coverage in Arc/Info. It was obtained from a local government council and some minor modifications were applied to add additional locations that were not on the original network.

Because the simulation is split into a series of steps the stock movement data and the effluent output model data must be transformed into several files for use by each processing stage. Inputs are text files containing comma-separated values. These files are generated from data contained in spreadsheets using macros. As the data is split over several spreadsheets the macros also perform some basic validation to ensure that trip data matches the locations used for sources and destinations. Three different inputs were generated from the spreadsheets: trip data, trip parameters, and the effluent output rate model.

The trip data consists of a series of rows in a text file. Each row represents a single trip. A row is made up of the following columns: trip identifier number, source location identifier, and destination location identifier. This file is used to generate the spatial representation of the sample trips. The source and destination identifiers correspond to the node IDs contained in the Arc/Info transportation network. These are used to generate a set of shortest path routes for each of the trips in the sample data. The trip ID is used to relate each trip back to it's trip parameters that are contained in a separate file. The reason for the separation is due to the limitations on the formats that Arc/Info can import.

The trip parameters are used to specify values for the variables for each trip. This allows parameters to be controlled on a per trip basis. The input file has a single row for each trip which consists of: trip identifier, stock type, trip preparation, weather conditions, and vehicle tank size. The trip identifier is used to relate back to the route data contained in the trip data input file. The stock type variable is set to either sheep or cattle. Trip preparation is a boolean variable that indicates whether the stock have been stood in holding paddocks for four hours before being loaded onto transportation vehicles. The weather conditions variable is a boolean to indicate if it was raining during the trip. The final parameter is the size in litres off the effluent holding tank fitted to the vehicle.

The effluent output rate model is implemented as a lookup table. For a given set of input parameters (stock type, trip preparation, weather conditions, tank size, and the distance already travelled) the model calculates the distance a vehicle can travel before the tank becomes full. This distance is divided by the tank size and used to calculate a fill rate. If spilling occurs then the volume of spillage can be estimated, or if a vehicle makes it to a destination or effluent processing station without spilling then the volume of effluent in the tank can be estimated.

There is considerable uniformity in the carrying capacity of commercial stock trucks and trailers in New Zealand as they are designed to the limits of the legislation for dimensions and weight. This means we can assume that stock carrying capacity of all vehicles for each type of stock is equal.

3. THE SIMULATION MODEL

3.1 Overview of the multi-stage process

The simulation model was developed with two major goals in mind, the first was to build a perception of where effluent spills were occurring during trips, the second was to provide a tool to observe and visualise the impact of adding effluent processing facilities to the transportation network. Within the scope of this project there were too many external variables, both political and technical, to completely automate the process of determining optimal locations for effluent processing facilities. The simulation model was used interactively by the researchers to help identify key locations for processing facilities, and to validate the impacts of adding processing facilities at those locations.

Stage 1 - Generating the shortest path network of trips

The simulation model is split into two parts. In the first, generation of the shortest path routes for each trip is entirely automated as this operation can be performed using built-in functionality within Arc/Info. The second part of the simulation is more complex in that it is specific to the application of the stock effluent output model. There is no built-in functionality within Arc/Info to implement this model so it has been coded entirely on top of Arc/Info using the Arc/Info Macro Language (AML).

Stage 2 - Simulating each trip

Once the shortest path for each trip has been identified the model then uses the trip parameters and the effluent output model to determine where spills occur during each trip, how much effluent is spilled, and how much effluent is in the tank at the end of the trip. Determining where spills occur helps in the identification of suitable locations for processing facilities, while estimating the amount of effluent left in tanks and/or spilled helps determine what processing capacity is required at collecting facilities at both destinations and in transit.

The following terms are used when describing how the simulation processes each trip. The first two are related directly to the transportation network topology, while the second two are related to how the process of transporting stock from location A to location B is described:

Node: a location within the transportation network representing either a start point or destination point, or some other location such as a township, city, or intersection of several roads. Each node can be flagged to indicate that there is an effluent processing facility at that location.

Trip: a vehicle transporting stock from a source node to a destination node, with a given set of weather conditions, tank size, stock type, and stock preparation. Note that there may be several intermediate nodes in the route between the source and destination nodes of the trip. Nodes can occur at the end of a road, or where two or more roads join.

Section: a piece of road between two nodes in the network. A trip can be broken into sections, the first section starts at the source node and the final section ends at the destination node. If there are nodes in the route between the source and destination nodes that are flagged as providing effluent-processing facilities then these act as section breaks. For example, if a trip consists of a source, and one node flagged as having a processing facility that is not a destination then there will be two sections within the trip. The ends of sections can be potential locations where effluent processing facilities are provided. They do not necessarily correspond to locations where a vehicle stops, but vehicles will pass through the section ends. These sections should not be confused with Arc/Info sections that are simply arcs between any two nodes in the network.

Leg: a trip is made up of one or more legs, a leg being how far the vehicle can travel before the tank becomes full, or the final destination is reached. Legs therefore have only minimal relationship to sections, the source and destination nodes will be common to the first and last legs and sections of the trip, however a trip may involve a single leg that travels over several sections in the road network. A leg can never be shorter than a single section.

With the main terms used within the simulation model defined we now describe the algorithm used to establish where spills occur and how much effluent is output.

The simulation model consists of an AML that iterates over each trip read from the trip parameters input file. The processing carried out for each trip is identical.

3.2 The Algorithm

The simulation begins by building a list of the sections that make up the trip. This is done within the AML by selecting the route and opening a cursor on it. The cursor is used to step through each node in the route. Each node is checked to see if the effluent processing facility flag is set, if it is then the node marks a section break and we therefore store the node ID of the end of the section, the processing facility name, and the length of this section. If there is no plant at the node then nothing is recorded. Once the node is processed the cursor is stepped to the next node and same check is performed. This process is repeated until the end of the route is reached.

At this point for a given trip the simulation knows where the start point and end point is, and has a list of zero or more effluent processing facilities in between, ordered in the sequence through which they would be reached when travelling the route.

The next stage is the most complex and involves calculating where tanks should be emptied during a trip, and where spills occur along the route if a truck cannot reach a processing facility before its holding tanks become full.

Starting at the source node the simulation model uses the fill rate model combined with the trip parameters to determine what distance can be traveled on this leg before the tank becomes full. This is referred to as the range of the truck.

A check is performed to see if there are any remaining sections, as this is the source node and there is always at least one section in a trip. Therefore this check will be true. In future iterations this check may be false and if so then this marks the end of the route so the simulation would move on to the next trip.

We next check to see if the end of the section is within range of the truck. If it is within range then we remember the end of this section but continue testing the next section to see if we can reach the end of that one. We keep checking in this manner until the truck runs out of range.

At this point we know the node that we can reach without spilling. That node may be the node that the truck is currently at, in which case this means that even starting at this point with an empty holding tank it will fill before the truck reaches the next processing facility, therefore spillage will occur. If this is the case then we calculate how far the truck can travel down the section before the tank becomes full and it begins to spill. From here the simulation jumps to the end of the section.

The truck has now reached the end of the next section. If the truck was spilling as it reached the node then we calculate the amount of spillage by passing the start and stop distances of the spill and the trip parameters into a function that calculates the amount of spillage. The amount of spillage is added to the total spillage, and the tank volume is added to the total volume of effluent processed at this node. If the truck was not spilling then we call the same function to determine how much effluent is contained in the holding tank, and this value is then added to the total volume of effluent processed at this node.

At this point the simulation checks to see if there are any remaining sections. If there are sections remaining, then the procedure is repeated from the point where the end of the next reachable section is identified. If there are no remaining sections then an output routine is called to produce a summary of how much effluent was generated and how much was spilled.

Throughout the simulation spill points are recorded and total volumes deposited at each processing facility are recorded. Once the simulation is completed another AML is used to generate a map showing where spills occur on the network and listing the volume of effluent processed at each plant in the network.

3.3 Other Tools

There is an explorative trip tool that allows a specific trip to be analysed using different trip parameters. This is most useful for checking unusual trips or it could be used by transport companies to pre-check where their drivers should plan to dump effluent for a particular journey. It could involve specific livestock that have been prepared or not prepared for the journey by truck units with a specific holding capacity and transported in either fine or wet weather conditions.

4. OUTCOMES

The following two maps illustrate the mapped output from selected simulations. The first (Figure 1) indicates where spillage commences on the state highway system in the South Island of New Zealand. The simulation parameters are for 1999 conditions where there are no in transit dump-sites available, transport units have only 200 litres of holding capacity and 80 per cent of stock have not

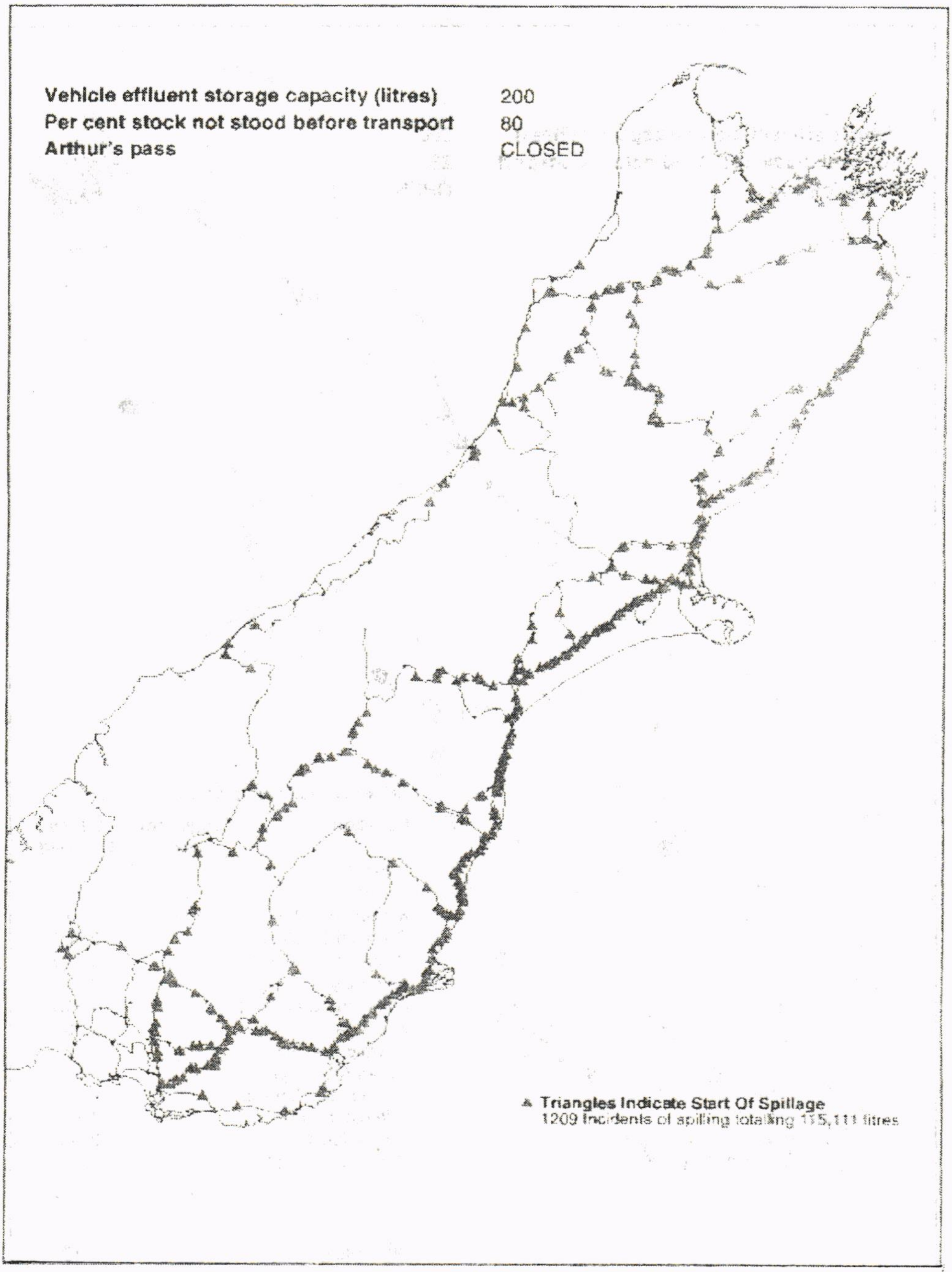
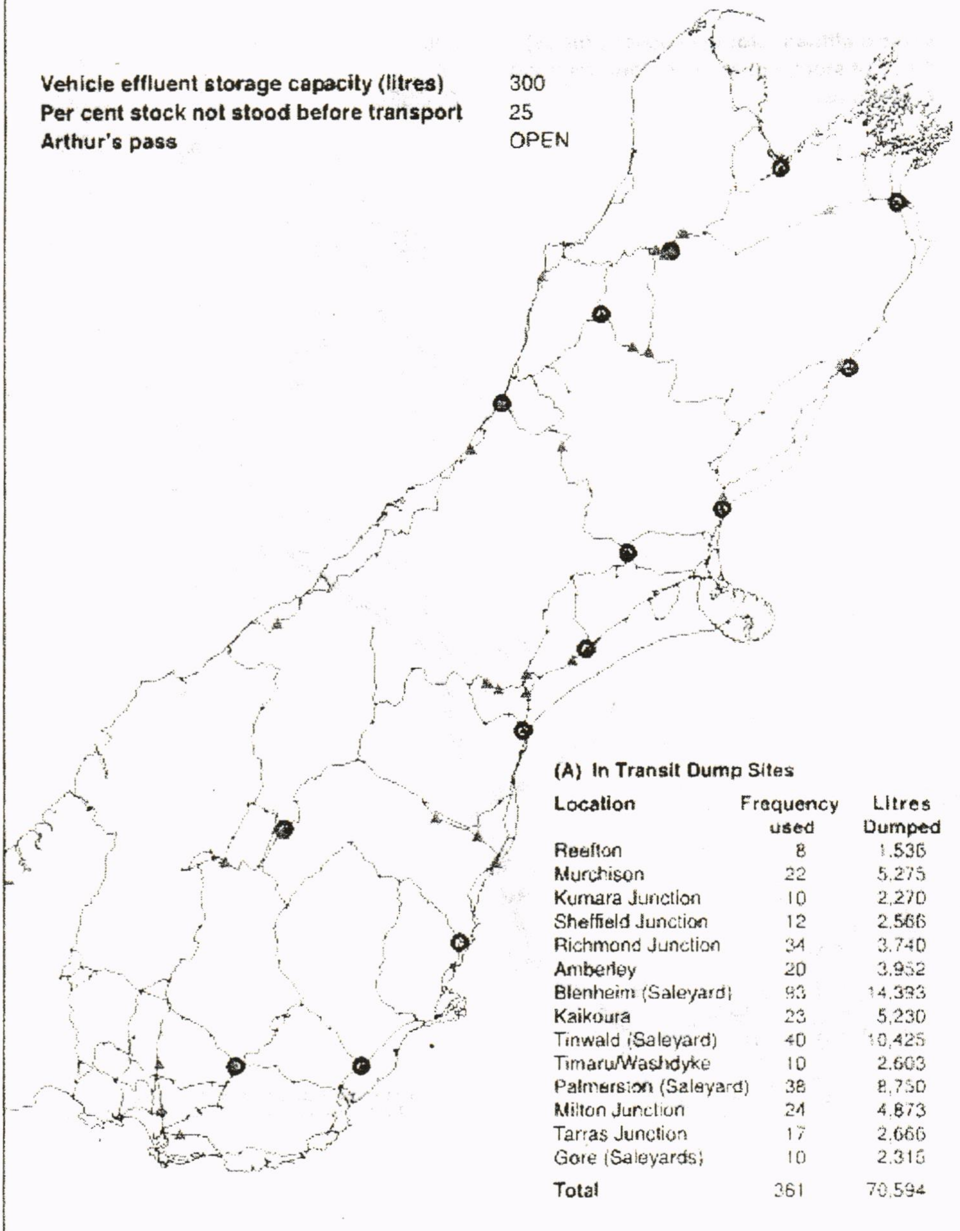


Figure 1 Effluent Spillage From Stock Trucks



(A) In Transit Dump Sites

Location	Frequency used	Litres Dumped
Reefton	8	1.536
Murchison	22	5.275
Kumara Junction	10	2,270
Sheffield Junction	12	2.566
Richmond Junction	34	3.740
Amberley	20	3.952
Blenheim (Saleyard)	93	14,393
Kaikoura	23	5,230
Tinwald (Saleyard)	40	10,425
Timaru/Washdyke	10	2.603
Palmerston (Saleyard)	38	8,750
Milton Junction	24	4.873
Tarras Junction	17	2.666
Gore (Saleyards)	10	2.315
Total	361	70,594
(B) Spillages	37	3.181
(C) Destination Dumps	4,460	443,740

Figure 2 Effluent Dump Site Network Model - 14 Sites

been stood off-feed for four hours prior to loading into the transport crates. The Arthur's Pass cross-island route is not available for stock trucks. Clearly the density of spillage start-points are greatest on State Highway 1 along the east coast of the South Island and provides strong evidence to support the call by communities located along that highway for something to be done about the spillage problem.

Figure 2 depicts the proposed network of dump-sites for the South Island taking into account that the cross-island route via Arthur's Pass will soon be open to stock carriers following extensive road reconstruction projects. Dump-sites in some instances have been positioned in conjunction with major stock saleyards as in the towns of Blenheim and Ashburton even though the simulation exercise may have indicated other nearby locations. The ports of Nelson and Picton that are involved in inter-island shipping of livestock were deemed not to have dump-sites.

It quickly became apparent that the size of holding tanks on the stock transport units was most critical in reducing the number of in-transit sites required. Preparing stock was important, but capacity of holding tanks even more so. Given the need for the construction costs and on-going operating costs of dump-sites to be kept as low as possible, it was important to derive the minimal set needed. We found that we could go as low as 12 sites but that assumed adoption of best practice by all concerned. That may never become a reality. We settled on the 14 sites that almost eliminated spillage, and certainly provided protection for the main urban areas.

Funding the sites produced much argument as to responsibility. Some of the sites are located in situations wherein the local farming community has little need for them but long-haul inter-regional cartage certainly needs them. This lent weight to the argument that the overall system needed to be funded centrally at least for construction and any associated road works. That has been agreed. It still leaves moot the responsibility for maintenance and disposal. Some local authorities with dump-sites in their territory may seek involvement from private enterprise to take the collected effluent which can be a useful ingredient in composting operations. Some will be able to tanker the effluent a short distance for diluting and input into local sewage treatment systems. Others may look to spread the effluent into exotic forest plantations as a fertiliser. All these options are better than having the effluent spill on the roads or being dumped illegally at secluded locations.

The modelling approach has provided the platform upon which politically sensitive decisions can be taken in confidence. All the stakeholders in the livestock movement system acknowledge that the exercise helped remove the doubts concerning the magnitude of the problem and who was responsible. The best testimony as to the value of the exercise is that it has led to the funding and construction of dump-sites at locations identified by the model.