

MANAGEMENT OF INTERSTATE RAIL ROLLINGSTOCK

Summary

The Centralised Wagon Control (CENWAG) Group of Railways of Australia is responsible for managing the interstate pool of rail rollingstock. They asked the Study Group to develop a methodology to allow more efficient and effective direction of empty wagon movements. The Study Group chose to develop two linear programming approaches. One was for allocating empty wagons, and the other modelled both empty and full wagons. Although large in size, the models were otherwise feasible, showing that, conceptually, the method would work. However, there is still a major amount of development work required to implement the system.

1. Introduction

The problem was presented to the Study Group by Max Michell, Assistant Director, Intersystem Traffic Control, Railways of Australia.

The continental Australian railway network comprises five individual railways mainly organised on State lines. These are Australian National, Queensland Railways, State Rail Authority of NSW, V/Line, and Westrail. Broad (1600 mm) or standard (1435 mm) gauge connects all mainland capitals (Figure 1). Bogie exchange depots at Melbourne, Adelaide and Albury take care of freight wagons requiring transit from one gauge to the other. Queensland and West Australia have narrow gauge railways, with only their intercapital links on standard gauge. These narrow gauge lines are not part of the Railways of Australia system.

Railways of Australia co-ordinates the intersystem traffic, most of which is intercapital. This traffic, which is mainly general (non bulk) freight, is highly competitive and very responsive to price and quality of service. Mr Michell's group, Cenwag, co-ordinates the 12,000 pool wagons involved in intersystem freight. These are sometimes also used for intrasystem freight.

The overriding objective of rollingstock management is to minimise the units of rolling stock required to undertake any given task. This implies wagons are kept on the move and the proportion of empty movements is minimised.

Cenwag has a computerised information system which depends on train load messages as its source data. These messages give details of wagons on trains,

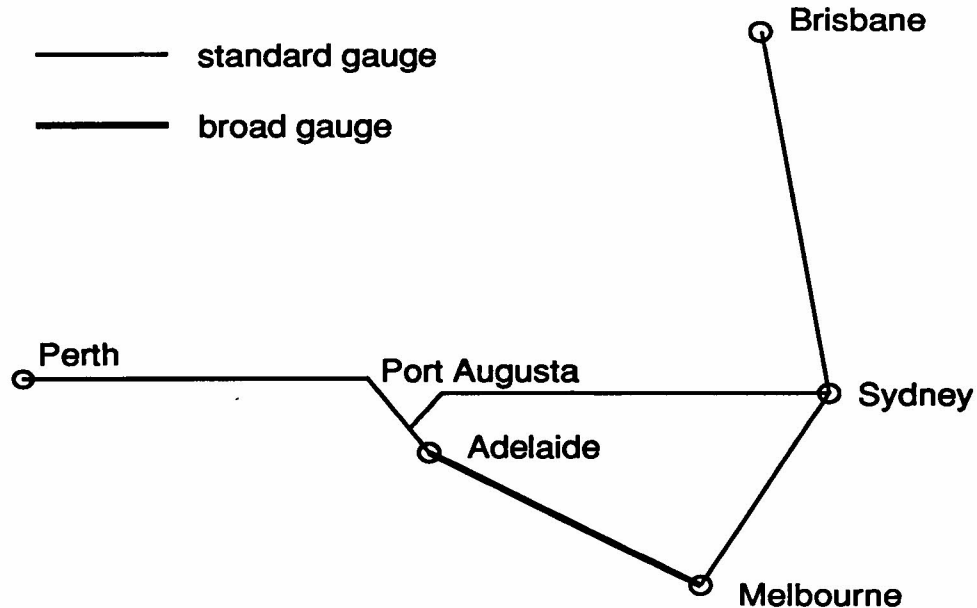


Figure 1: The Interstate Rail Network

status (empty or loaded), origin, destination, gross weight, consignee (receiver) and date of despatch. This information, suitably processed, can provide reasonably good loaded and empty wagon flow information, as well as providing information on train loads compared to train capacity.

The make-up of Railways of Australia as five co-operating state systems means that management is more by negotiation than by direct control. The database still depends largely on each state's system, although the format of the database, and speed of data supply is being reviewed. The present system does not lead readily to prediction, as each State system is responsible for its own sales. As well, empty wagon release is not always notified promptly.

We were asked to develop a methodology to allow a more efficient and effective direction of empty wagon movements. This is seen as an important step toward the broader objective of minimising rollingstock.

2. Wagon Characteristics

Wagons are subdivided into six groups for operating purposes:

- Motor car carriers

- Vans (box cars)
- Opens
- Container flats
- Non container flats
- Steel product carriers

Loaded wagons are identified with a specific origin and destination (by definition) which ensures these wagons move on predictable schedules of connecting trains with minimum delay.

Empty wagons on the other hand have several options available:

- wait at their current location for loading (if any)
- return to their last loading location for further loading
- be directed to the location where there is (or will be) a need for them

Conceptually, empty wagons move prior to loading, so their re-positioning needs to be seen as part of the action required to move a load, and generate income. Repositioning is not seen as a revenue generating activity at present.

Patterns of demand for empties over time can be identified in general but specific demands will vary day by day. The number of empty wagons available for repositioning to demand points will be the number released after unloading, which also fluctuates day by day.

Intercapital transit times vary from overnight to five days. It is possible to foresee the availability of wagons on some routes up to four days in advance. Certainty increases as the lead time gets shorter. Mr Michell said the factors to be considered when making decisions about repositioning empty rollingstock were:

- location and volume of demand for specific types of empty wagons
- relative importance of competing demands for the same group of wagons
- transit time to the demand location
- day of week of arrival at demand location (weekends are generally non working days at terminals)
- train capacity - trains are limited by either length (metres), number of wagons, or gross tonnage.

- connecting train schedules
- relative priorities for train space with other empty and loaded wagons

3. Choice of Model

The Group addressed the mathematical core of the problem. If this could be solved satisfactorily the way would be open to attack data transfer, and other implementation issues. Papers that have reviewed the problem are Dejax and Crainic (1987), Feeney (1957), Johnson and Kovitch (1963). The following approaches were suggested.

Optimisation

Transportation or Trans-shipment algorithms

Network flow

Linear Programming, e.g. see Misra (1972)

Other

Simulation

Inventory Management, e.g. Bookbinder and Sereda (1987), Tyworth (1977)

Probabilistic and Stochastic

Expert Systems

After discussion, we favoured a linear programming optimisation approach. It has the advantage of optimising, and gives greater flexibility in formulation than either a transportation or network approach. One model was developed from a network viewpoint, although not fully specified.

Simulation can still be used with an optimisation model, but is expensive, and was not able to be addressed at the workshop. A probabilistic or stochastic approach should be left until a deterministic model is devised and greater understanding of system data has developed.

Two linear programming approaches were developed, one for empty wagons only, and the other for both empty and full wagons.

4. Simplifications

The group agreed the bogie exchange would be neglected. We understand it rarely causes hold-ups. If it did, then the solution would be to increase the

buffer stocks of bogies held at the exchange. Also better wagon control should help balance flows through exchanges.

Because most intersystem traffic is intercapital, we assumed only one or two nodes per State were necessary (Figure 1). This assumption can be modified if required.

For the Full Wagons model, the interaction between intersystem and local state traffic was neglected, in line with Cenwag's current practice.

Wagons were considered to be in one of either six or eleven wagon types. Freight was also divided into a number of distinct freight types, each with a preferred wagon type.

Each Wagon was considered to be in one of a number of mutually exclusive states, at any one time. The states were:

- allocated/loaded** – either allocated for loading at a node or loaded and in transit to destination (either on a train, or waiting in marshalling yard), or being unloaded at destination.
- empty** – either awaiting redirection, being repositioned, or having been repositioned
- local** – unavailable because being used by the local state system
- repair** – unavailable because awaiting or under repair

The decisions which need to be made each day are:

- (i) how many empty wagons of each type to reposition from one node to another.
- (ii) the number of empty wagons to allocate for loading, at each node.

Transit times were considered a fixed number of days (overnights actually). As transit time for the longest journey is five days, a time horizon of 14 days was assumed. This allows modelling a complete cycle, including weekends. It may be appropriate to have a shorter time horizon. Tests should be carried out when a prototype model is built.

5. Notation

We use the following indices.

- t = time period index (days) $t = 1, \dots, 14$
- p = wagon type index $p = 1 \dots 6$, or $1, \dots, 11$
- i, j = node index - city, or source (i) or destination (j) nodes.
Usually there are 5 cities, but this will vary with the commodity p .
- l = link index, a different index for each constrained link direction.

The following data is required:

- demand (t, p, i) - demand (in wagons) for loading on day t , of wagon type p , at node i .
- demand (t, p, i, j) - as above, but between origin i , and destination j .
- released (t, p, i) - number of wagons of type p released (i.e. becoming available) empty at node i , at the start of day t , either after being unloaded there, or coming available from repair or the state system. (i.e. does not include empties shipped in, or carrying over from the previous day).
- $T(i, j)$ - average travel time between node i and node j , usually along the most direct path. (Independent of wagon types).
- mcost (p, i, j) - the marginal cost of moving an empty wagon of type p from node i to node j , e.g. wagon maintenance costs, plus a small fuel component.
- lcost (p, i, j) - the cost of not being able to supply a wagon of type p to move freight from i to j , e.g. the freight delay cost.
- lcost(p, i) - the cost of not being able to supply a wagon of type p to move freight from i , e.g. the average freight revenue lost.

- $n_{\max}(t,l)$ – for the link l , the upper bound on the number of empty wagons that can be shipped out on all trains travelling on the directional link l , starting on day t .
- $l_{\max}(t,l)$ – the upper bound on the length of all empty wagons that can be shipped on the directional link l , on day t . It is determined by passing siding length, and length of full wagons.
- $w_{\max}(t,l)$ – the upper bound on the maximum weight of empty wagons able to be pulled on the directional link l , on day t . It is determined by the locomotive drawbar pull minus the weight of full wagons.
- $l_{th}(p)$ – length of a wagon of type p .
- $w_t(p)$ – weight of an empty wagon of type p .
- $fwt(p)$ – weight of a full wagon of type p .
- $revenue(p,i,j)$ – the revenue gained from a full wagon of type p moved from i to j .

The following non-negative decision variables are used in the models.

- $movemt(t,p,i,j)$ – the number of empty wagons of type p allocated to be moved from node i to node j , starting on the evening of day t .
- $waitmt(t,p,i)$ – number of empty wagons of type p unallocated at node i at the end of day t . i.e. not shipped out, nor allocated for loading.
- $alloc(t,p,i)$ – number of empty wagons of type p allocated for loading from those available at i , during day t .
- $full(t,p,i,j)$ – number of wagons of type p assigned during day t , to be loaded, and travel full between i and j .

$\text{unmet}(t,p,i,j)$ - the unmet demand (in wagons) for wagons of type p , between i and j , during day t .

Initial conditions must be specified, for wagons that started their journey before the initial day, e.g. movemt , full , for t less than 1, and waitmt initially ($t = 0$).

Final conditions should also be specified, to encourage the sensible return of empties. Experimentation with a prototype will be needed to determine appropriate final conditions.

6. The Empties Model

This considers only empty wagons. These enter the system as specified by the data, and are trans-shipped, and allocated to meet demand by the model. Empty wagons arriving or released after the start of the day, are assumed not available until the next day. The model uses the decision **variables**:

movemt , waitmt , alloc .

The **constraints** on these decision variables are:

(1) Conservation of wagons

Empty wagons available, plus those released, plus those arriving, minus those redirected, minus those allocated, equals empties initially next day. For each node i , wagon type p and day t :

Empties of type p unallocated from day $(t-1)$
+ the sum over j of all Empties from j to i , arriving during $(t-1)$
+ Empties becoming available at i , during $(t-1)$
= Empties allocated to meet demand for p at i during t
+ Empties of type p moved from i , starting their journey during t , to other nodes j
+ Empties of type p unallocated at the end of t

(2) Capacity Constraints on train length, weight

For each constricted link, l , the number/weight/length of empties of all types must be less than the maximum space, length, weight available for empties in the specified direction on that day.

(3) Bounds

The wagons allocated must be less than or equal to demand, for each t , p and i .

The **objective function** is to minimise the cost of

- (a) repositioning and
- (b) non supply

The model differs from a time staged transportation model in that wagons may be shipped early and go into a pool (waitmt) before being allocated, and in having capacity constraints.

The output from the model is the set of decisions movement (t, p, i, j) , and, where the allocation is less than demand, the number of wagons actually allocated $alloc(t, p, i)$

7. The Fulls Model

This considers both full and empty wagons in the pool, so is more consistent in looking at the whole system. When there is a wagon shortage, it also recommends which demand should be left unmet that day.

Wagons are assumed loaded on the day they are allocated for loading, and leave that day, usually in the evening. They are assumed able to be unloaded at j and redirected empty on their day of arrival, but are not considered available for loading at j until the start of the next day. These assumptions need to be verified.

The decision **variables** used are:

movement, waitmt, full, unmet

The **constraints** are

(1) Conservation of wagons.

For each source i , wagon type p and day t :

- Empties unallocated from day $(t-1)$
- + the sum over j of all empties from j to i arriving during $(t-1)$
- + the sum over j of all fulls from j to i arriving during $(t-1)$
- + wagons returned from repair at i
- = sum over j of all fulls sent from i to j , starting loading on day t
- + sum over j of all empties sent from i to j , starting their journey on t
- + empties unallocated at the end of day t
- + wagons sent for repair at i .

- (2) Try to satisfy demand. The unmet variables deal with the case where it is uneconomic to meet demand. A proportion of unmet demand, currently 100%, is backlogged.

For each source i , destination j , wagon type p and day t :

unmet demand from i to j on day $(t-1)$ + demand from i to j on day t
 = fulls sent on day t + unmet demand on day t .

- (3) Wagon Availability for Fulls. Fulls sent must be less than empties available.

For each source i , wagon type p and day t :

sum over j of full wagons sent from i on day t
 < empties at i unallocated on day $(t-1)$
 + empties that arrived at i on day $(t-1)$

- (4) Capacity Constraint on train length, weight, and number of wagons.

Capacity constraints are calculated from the timetable, siding length, and locomotive horsepower. Full plus empty wagons must be less than the fixed capacities. This is a simpler data requirement than the capacity constraint for the Empties model.

The **objective** function is to maximise

revenue from full wagons
 less cost of moving empty wagons
 less penalty cost of unmet demand

It is necessary to decide the most appropriate penalty cost for not meeting demand immediately, i.e. the data set $lcost(p,i,j)$.

The output of the model is:

which demand to satisfy - $full(t,p,i,j)$, $unmet(t,p,i,j)$
 which empty wagons to move - $movemt(t,p,i,j)$

8. Network Model

A network model for both full and empty wagons was proposed. This has the advantage of being computationally simpler, but the disadvantage of not being as flexible in what it can model. It was formulated in terms of links of half day length. This allows greater operational detail, in terms of allowing more close matching of link capacity. However, it is the bottleneck link that determines capacity, so it is not clear that this greater detail is helpful.

If the linear programming model computation time becomes a problem, then it would be worth evaluating network methods.

9. Relative Merits of the Approaches

The main difficulty expected with the linear programming models is that they will be large and computation time will be long and restrict interactive solving. The number of variables and constraints determine model size, and computation difficulty. These will depend on specifics of the system. For instance, one-way traffic, or weekends may reduce variables and constraints considerably.

Let

- P = number of wagon types
- T = number of days
- N = average number of nodes
- M = average number of i-j pairs allowing trans-shipment of empties
- C = number of links with capacity constraints
- K = average number of i-j pairs with full wagon traffic

Formulae for maximum size of the two models are shown in Table 1. Also shown as the example, is the actual size when $P = 6$, $T = 14$, $N = 5$, $M = 10$, $C = 5$ and $K = 10$ ie the upper bound on the present system.

Model	Empties		Fulls/Empties	
	Formula	Example	Formula	Example
Variables	$TxP(2N+M)$	1680	$TxPx(M+N+2K)$	2940
Constraints	$Tx(PxN+3C)$	630	$Tx(2NxP+PxK+3C)$	1890
Bounds	$TxPxN$	420		

Table 1: Comparison of Model Sizes

The Fulls model is about twice the size of the Empties model. Size depends very much on T and P.

The problem size is in the medium to large category. It is well within the capability of mainframes, and within the range of the latest work stations and personal computers. The main difficulty will be the need for good procedures for data input, prediction and management.

The Empties model has the advantage of being smaller. It does not directly require data on full wagon origin-destination, although it requires releases, which are derived from this information. Consequently, it would be easier to set up, but is not as consistent. The Fulls model has the advantage that at a time of

shortage it makes the allocation of wagons to loads to maximise returns. But such allocation may be best done on other criteria or directly by staff and the situation may not arise very often. The Fulls model can look directly at wagon fleetsize. The Empties model treats fleetsize indirectly, although this should be equally as effective.

10. Use and Benefits

What are the likely benefits to Railways of Australia from developing one of the above models? Such a model could be used to help management with

- (i) daily empties redeployment
- (ii) wagon fleetsize planning
- (iii) evaluating schedule changes
- (iv) enhanced revenue generation by identifying empty backhaul space

Potential benefits include:

- (a) better wagon redeployment
- (b) more economic wagon fleetsize
- (c) improved revenue generation
- (d) better short-term forecasting of demand and empties release

It is difficult to estimate the dollar value of any savings without further assessment. However, the replacement value of the combined wagon fleet is over \$1 billion. So a small reduction in fleet size could mean a medium term saving of millions of dollars. Savings come from saving maintenance through mothballing, rebuilding surplus wagons into more useful types, or in reducing the need for new wagons.

Improved revenue generation is a potential benefit, because the model highlights backhaul opportunities. It should also improve the service to customers. (See Tyworth (1977)). There is also major benefit in having a quantitative model to structure and summarise all the wagon data for management purposes. Other improvements may well come from having the model.

11. Conclusion

Our results show it would be possible to develop a linear programming model to assist in empty wagon re-allocation. The model would supply information on empties re-allocation and illuminate the strategic question of appropriate fleetsize. It should give major financial and management benefits.

This work is only a first step to setting up a successful model however. There is still a major amount of work to be done in developing the model to meet the client's needs, providing easy data management interchange with the client's database, forecasting, and reports, documenting, testing, and maintaining the system, and familiarising staff with its use. The consultancy cost of carrying this through to completion is likely to be between \$100,000 and \$200,000. It would also require considerable liaison with Railways of Australia staff, and the individual rail networks.

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