CAPACITY PLANNING IN A SUGARCANE HARVESTING AND 
TRANSPORT SYSTEM USING SIMULATION MODELLING

By

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Abstract

Reducing costs within the harvesting and transport system is a high priority for many sugar milling regions in Australia. Typical issues include reducing the number harvesting groups, harvesting over a longer time window in a day, rationalising infrastructure and achieving a better co-ordination between harvesting and transport activities. As part of a series of integrated models to conduct the analysis, a simulation model for capacity planning was developed to estimate the: 1) number of locomotives and shifts required; 2) the number of bins required; and 3) the period of time harvester operators spend waiting for bins. The model belongs to the category of planning models for unscheduled traffic, which means a locomotive schedule does not need to be produced. While new for the Australian sugar industry, these types of models have been used in the past extensively for planning in road and urban/freight railroad systems. Some key advantages of the model versus a scheduling tool are the ability to: 1) work in situations with high probabilities of delay and down time in the transport system; 2) measure capacity independently of a schedule or in applications where it is impossible to produce an effective transport schedule using a model; and 3) fully integrate with other models within the sugar harvesting and transport system for whole-of-system optimisation. The benefits of the model are demonstrated through application to the Mourilyan case study, to provide the region with an understanding of the impacts from: 1) removing double handling of bins; 2) extending the time window of harvesting; 3) reducing the number of harvesting groups; 4) and upgrading bin fleet and sidings. A scenario for harvesting during a time window of 18 hours was piloted within Mourilyan during the 2003 harvest season. The benefits of integrating the capacity planning model with a model for scheduling harvesters into sidings is demonstrated with the Mossman case study, showing significant reductions in the daily variability of demand on the transport system.

Introduction

Several mill regions within the Australian sugar industry are exploring opportunities to reduce costs within their harvesting and transport system. Scenarios include extending the time window of harvest, amalgamating harvesting groups, rationalising/upgrading transport infrastructure, implementing harvest best practice and removing some of the inefficient practices in cane transport such as the double handling of rail bins.
Addressing most of these required the systems modelling of harvesting and transport combined since they are closely linked activities. A modelling framework of the harvesting and transport system was developed (Higgins et al., 2003) and is illustrated in Figure 1. It shows some of the major interactions between different models for transportation and harvesting planning. The Harvest Haul model (Sandell and Prestwidge, 2004) and harvester/siding rostering models (Higgins and Postma, 2003) of Figure 1 are existing models redeveloped for a whole-of-system modelling capability. Other models developed for the framework were a model for optimising the location of harvesting groups and rail sidings/loading pads, a financial model for calculating the costs and benefits to the industry sectors (Antony et al., 2003), and a simulation model for capacity planning in harvesting and transport. The objective of this paper is to highlight the capacity planning model and its benefits using case studies in Mourilyan and Mossman.

Capacity planning in transportation is a large research field in the literature for which most models fall into two major categories: 1) models based on scheduled traffic; and 2) models based on unscheduled traffic. While cane transport models are not new to the Australian sugar industry (Pinkney and Everitt, 1997; Grimley and Horton, 1997), they are based on scheduled traffic. This means each scenario requires the production of a locomotive or truck schedule in order to assess regional characteristics such as and locomotive and bin requirements. The capacity planning model of this paper is based on unscheduled traffic which means the outputs (locomotive and bin requirements, waiting time for bins, etc.) are calculated without first producing a traffic schedule. While new for the sugar industry, capacity planning models based on unscheduled traffic are commonly used for freight railway applications (Higgins and Kozan, 1997) for urban planning; and Chen and Harker (1990) for single-line freight planning. Models based on producing schedules have advantages over models based on unscheduled traffic in that they provide schedules for operational use, which in turn allows a traffic officer to immediately see how it would work in practice.
However, models based on unscheduled traffic have the following advantages over those that produce schedules:

- They better handle scenarios where it is difficult/impractical to produce a schedule. Some strategic scenarios, such as redesigning a transport track system for use in five years time, have a large amount of unknowns at the operational level needed for an effective application of a scheduling tool. It can also be impractical to apply a scheduling model when a schedule requires several major changes during the day.

- They cater for a transport system that has large amounts of unforeseen delay (e.g. locomotive breakdowns), by incorporating probability distributions to account for such delays. Models based on producing schedules only capture certainty and do not capture the unforeseen events that lead to increased infrastructure requirements and waiting time for bins.

- They produce scenarios independent of a schedule. When using a model based on scheduled traffic, the outputs of locomotive and bin requirements are biased towards the schedule it was based on. That is, if the schedule is changed, so are the outputs. This makes it difficult to make fair comparisons between scenarios if their schedules are very different.

- Models based on scheduled traffic require large resources to apply compared to models based on unscheduled traffic, since more detail is required at the operational level to produce schedules. This is an important characteristic because some scenarios require assessing impact across each day of the harvest season, while a scheduling model would require a large amount of resources to set-up.

- It is very difficult to explicitly integrate models based on scheduled traffic with other models in the sugar value chain for whole-of-system analysis and optimisation, compared to models based on unscheduled traffic. For example, using a scheduling tool, it is almost computationally impossible to simultaneously optimise the start time combinations of harvesters and their migration schedule across sidings to achieve the most efficient utilisation of the transport system.

The capacity planning model calculates the following key attributes across the harvest season: number of locomotive shifts and bins required; and the time harvesters spend waiting for bins when there are limitations on shifts and bins. Other attributes such as cut-to-crush time, siding and yard utilisations can also be calculated.

In this paper, we highlight the simulation model for capacity planning in harvesting and transport, along with the benefits of the model through applications to the Mourilyan and Mossman case studies. The latter case study highlights the benefits of the model within a whole-of-system optimisation framework through integrated rostering of harvesters into sidings and transport planning, which is a modelling capability not available to the sugar industry in the past.

**Model description**

The capacity planning model for cane transport is based on the principles of stochastic simulation (Ripley, 1987) for which a time horizon can be anything from one day to a whole harvest season. A summarised description of the model follows:
1. Given the inputs—harvester start times; average harvester delivery rates into bins (tonnes of cane per hour); harvester finish times; harvester and siding rosters; siding capacity; and maximum train capacity—we can produce a timetable for when each harvesting group will require empty cane bins at the sidings, together with the number of bins.

2. The average rake size that a locomotive pulls is estimated as a function of: the delivery timetable of bins; the location of harvesters; and the capacity of sidings. A smaller average rake size will require more locomotive shifts to bring the cane to the mill.

3. Given 1 and 2 above, locomotive shift requirements are calculated across each time interval in the planning horizon. If there are insufficient bins or locomotive shifts for any time interval, the harvester and/or locomotive will wait until either becomes available. Unproductive time such as crew changes, meal breaks and servicing are accounted, along with breakdowns. Yard activities and double handling of bins are calculated where necessary.

4. Given 1, 2 and 3, the queue time for crushing and cut-to-crush times are calculated.

5. Given the number of bins at the sidings, in transportation, and waiting at the mill for cane to be crushed, we can calculate the number of bins required. This calculation is correlated to 3 and 4 above since limitations on bin availability have two-way impacts on calculation of locomotive shift requirements and queue time. A system of equations results, which means 3, 4 and 5 may need to be performed for several cycles.

**Application to Mourilyan**

Since early 2002, a steering group of growing, harvesting and milling representatives at Mourilyan have been formulating a range of short and long term scenarios for reduced costs in the harvesting and transport system. The base case scenario has the existing 15 major harvesting groups on the same daily allotments and start times as experienced during the 2002 season.

All scenarios formulated by the steering group assumed a total cane yield of 850 000 tonnes and a milling crush rate of 370 t/h. Each scenario was run using a four-week planning horizon for which four weeks of actual harvester movements across sidings from the 2002 season was used. This provided the added capability of assessing the day-to-day variability of impacts on transport utilisation and the time harvesters spend waiting for bins.

The mill crushed five out of seven days and each harvester operated on these days, except for a couple of small groups. The Mourilyan rail network has about 140 sidings and crossing loops of which most are sidings. These sidings have long shunt times of between 20 and 60 minutes. Crossing loops have much shorter shunt times of up to 15 minutes. Harvesting groups use some of the loops as sidings while others are used as passing loops only by locomotives.

Mourilyan uses three bin types, 4 t, 5 t and 6 t, with the 6 t bins having the greatest demand. In the past, Mourilyan had a large amount of double handling of bins. This occurs when the locomotive transports the bins from the farm being harvested, to a siding near the mill, and a yard locomotive then transports the bins from that siding to the mill yard when there is room.
Much of the doubling handling of bins occurs because of short sidings and many growers wanting to see the cane transported to the mill immediately after the harvester has filled the bins. As one of the scenarios, the mill is keen to remove this double handling.

Table 1—Transportation impacts of scenarios formulated by Mourilyan steering group.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Locomotive shifts per day</th>
<th>Bin fleet needed</th>
<th>Average cut-to-crush time (hrs)</th>
<th>Time spent waiting for bins (% of total harvest hrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base case</td>
<td>15</td>
<td>1362</td>
<td>7.5</td>
<td>15.0</td>
</tr>
<tr>
<td>No double handling of bins</td>
<td>14</td>
<td>1362</td>
<td>7.5</td>
<td>15.0</td>
</tr>
<tr>
<td>10 groups, 24 hr harvesting window</td>
<td>13</td>
<td>956</td>
<td>4.4</td>
<td>0.3</td>
</tr>
<tr>
<td>Harvest and transport whole-of-crop to mill, with no trash blanketing</td>
<td>19</td>
<td>1696</td>
<td>7.2</td>
<td>10.9</td>
</tr>
</tbody>
</table>

Four different scenarios are contained in Table 1. Removing the double handling of bins reduces the number of locomotive shifts by one, which does not change capital infrastructure. While the bin fleet requirement in Table 1 is less than the actual Mourilyan fleet, the high demand on 6 t bins was the main reason for the large amount of time harvesters spent waiting for bin deliveries.

On average, 15% of the total harvest hours were spent waiting for bins (base case of Table 1), though harvester operators would use some of this time for servicing and meal breaks. A scenario for 10 groups scheduled over 24 hours was considered for possible implementation in the future (See Figure 2 for the hours of harvest compared to the base case). The 10 group scenario produced significant reductions in everything, with the harvesters spending a negligible amount of time waiting for bins.

A scenario was tested on whole-of-crop harvest, which means that the leaf matter and tops are transported to the mill along with the stalks. Extraneous matter was assumed to increase to 30% and the average bin weight of cane decrease by about 20%. To accommodate this, an extra 200 6 t bins and two extra locomotives were assumed to be available.

As a result, whole-of-crop harvest would require an extra four locomotive shifts while maintaining an average waiting time for bins of about 11% of total harvest hours (four percent less than the base case). If only 150 extra bins were available, the percentage of time spent waiting for bins would be higher than the base case.

![Fig. 2](image-url) Hours of harvest of each harvesting group in base case of 2002 (left) and 10 harvesting groups (right).
A scenario considered for implementation in 2003 was to keep the same harvesting groups but to stagger the start times so that harvesting is carried out over a longer time window. The base case in Figure 2 shows that when harvesting groups 1 and 4 were removed, harvesting was carried out over a time window of about 12 hours.

In order to select a time window for implementation in 2003, the impact of various time windows needed to be assessed.

In Table 2, all parameters except locomotive shifts reduced substantially with increased harvesting time windows, with the biggest impact being on the time spent waiting for bins. A small increase in the harvesting time window led to a significant reduction in the time spent waiting for bins.

Average cut-to-crush time was almost five hours when harvesting over 24 hours. Cut-to-crush time would only be minimised in a just-in-time system where the arrival rate of cane to the mill is in perfect alignment with the mill crush rate.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Locomotive shifts per day</th>
<th>Bin fleet needed</th>
<th>Average cut-to-crush time (hrs)</th>
<th>Time spent waiting for bins (% of total harvest hrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base case (12 hour harvest window)</td>
<td>15</td>
<td>1362</td>
<td>7.5</td>
<td>15.0</td>
</tr>
<tr>
<td>15 hour harvest window</td>
<td>15</td>
<td>1265</td>
<td>7.1</td>
<td>3.5</td>
</tr>
<tr>
<td>18 hour harvest window</td>
<td>15</td>
<td>1241</td>
<td>6.4</td>
<td>1.5</td>
</tr>
<tr>
<td>21 hour harvest window</td>
<td>15</td>
<td>1147</td>
<td>5.9</td>
<td>0.6</td>
</tr>
<tr>
<td>23 hour harvest window</td>
<td>14</td>
<td>1128</td>
<td>5.1</td>
<td>0.5</td>
</tr>
<tr>
<td>24 hour harvest window</td>
<td>14</td>
<td>1109</td>
<td>4.9</td>
<td>0.4</td>
</tr>
</tbody>
</table>

In order to remove some of the bottlenecks from the transport system, the impacts of upgrading sidings were considered. Upgrading a siding meant converting it to a crossing loop, which allows the shunt time to be substantially reduced. In selecting the sidings to be upgraded, sidings were sorted in descending order of tonnes of cane utilisation within any given year.

Several scenarios were tested from five to fifty sidings being upgraded, with the impacts shown in Figure 3. With increased number of sidings upgraded, the largest savings were with the time spent waiting for bins, though there are direct monetary savings to the mill with reduced locomotive shifts.

Upgrades in sidings had minimal effects on bin fleet requirements or cut-to-crush time. While calculating a monetary benefit-to-cost ratio is out of the scope of this paper, this analysis could be used within the modelling framework of Figure 1 to determine how many and which sidings should be upgraded, accounting for the costs of upgrades.
For implementation in Mourilyan during 2003, the main focus was to increase the time window of harvest, keeping the existing harvesting groups. While Table 2 shows that the benefits increase with harvesting time window, a time window longer than 18 hours received too much resistance from the harvester contractors, even though reductions in time spent waiting for bin deliveries was favoured.

While Table 2 showed a 90% reduction in the time spent waiting for bins, the 2003 harvest season was complicated by harvesting group 4 being toll crushed at South Johnstone. This meant that the turn around rate of 6 t bins was substantially reduced in 2003 compared to 2002, thus increasing the demand on the 6 t bins.

Also in 2003, the crop in Mourilyan continued to grow after the season start resulting in a mill crush rate of 390 t/h compared to the anticipated 370 t/h. With these changes in the 18 hour scenario, the model showed that 15 locomotive shifts were required, with an average time spent waiting for bins being 7.1% of total harvest hours. While this is higher than the scenario in Table 2, if the harvester remained at their start times of 2002, the average time spent waiting for bins would have been 16% of the total harvest hours.

With the implementation in 2003, the steering group agreed the estimates produced by the model were in close alignment with what was happening on the ground. This includes the impacts in peak periods of traffic where there were potential shortages of bins through to prediction of periods where the mill might have run out of cane. An evaluation workshop was held with the steering group after the season. The milling representatives on the group agreed it was a better system than 2002. While the growing and harvesting representatives reported some long waiting times for bin deliveries, there were mainly attributed to early season wet weather and a learning curve for traffic officers to produce pick up and delivery schedules given the new harvester start times. Most of the early teething problems had settled by mid-season.
Application to Mossman

The capacity planning model discussed above was also adapted to assess scenarios for extended time window of harvest in Mossman. In 2003, a 16 hour time window of harvesting was implemented, with harvesting staggered from 4 a.m. to 8 p.m. A focus in Mossman was to reduce locomotive shifts. While extending the time window of harvest had minimal impact on locomotive shifts in Mossman, staff from Mossman Agricultural Services and Mossman Central Mill saw opportunities to produce a siding roster of movements of harvesters that minimises the number of locomotive shifts to service the harvesters. From a modelling perspective, this was achieved by combining the capacity planning model with the siding roster optimisation model of Higgins and Postma (2003) to provide an innovative capability for integrated harvesting and transport planning.

The position of harvesters each day of the harvest season has a direct impact on the average rake size. A larger average rake size will reduce locomotive shifts. The impacts of producing a siding roster to minimise locomotive shifts is shown in Figure 4 for the Mossman case study, when applied to the entire harvest season. The most noticeable impact was the reduction in variability from actual to optimised. This would produce a more constant demand on the transport system, leading to better utilisation and reduced infrastructure requirements. While there was considerable demonstrated potential from optimising siding rosters, it can interfere with grower equity and farm rotations within a harvesting group. This would require some manual effort to produce a practical roster from that optimised by the model.

Conclusions and future developments

A simulation model for capacity planning was developed as part of a whole-of-system modelling framework to assess scenarios for cost reductions in harvesting and transport. For a given scenario, the model measures the impacts of locomotive shift, bin requirements, and the time that harvesters spend waiting for bins. The benefits of the model were demonstrated through application to two case studies, namely Mourilyan and Mossman. The model helped provide representatives of the Mourilyan region with an understanding of the system impacts from increasing the time window of harvesting as well as some big picture scenarios such as rationalised harvesting groups and rail sidings. As a result of this understanding, the region acted and implemented an 18 hour harvesting time window during the 2003 harvest season. The Mossman case study demonstrated the benefits of integrating the capacity planning model with a model for rostering harvesters into sidings to achieve a more whole-of-system optimisation capability.
The capacity planning model in its current form can be adapted to other mill regions within the Australian sugar industry. It is particularly effective in regions with a complex transport system and where there are large amounts of unforeseen delays and harvester migration, as demonstrated with Mourilyan. From a modelling perspective, a next step will be to extend the capacity planning model to other important industry scenarios. These include optimising the start time combinations of harvesters to minimise transport costs and the amount of time harvesters spend waiting for bin deliveries, given a pre-specified harvesting time window. This would help remove many of the bottlenecks in the system, which are experienced by harvesters requiring deliveries at inefficient times. Another extension of the model will be to optimise the start times of locomotive shifts to achieve the best coverage of shifts versus demand.

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