A framework for integrating a complex harvesting and transport system for sugar production

Andrew Higgins a,*, George Antony a, Gary Sandell b, Ian Davies c, Di Prestwidge a, Bill Andrew d

a CSIRO Sustainable Ecosystems, Level 3, QBP, CRC for Sustainable Sugar Production, 306 Carmody Road, St. Lucia, Qld 4067, Australia
b Bureau of Sugar Experimentation Stations, PMB 57, Peak Downs Highway, Te Kowai, Mackay Mail Centre, Qld 4741, Australia
c Bundaberg Sugar, P.O. Box 77, Mourilyan, Qld 4858, Australia
d AEC Group, P.O. Box 255, Brisbane Albert Street, Qld 4002, Australia

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Abstract

The Australian sugar industry is seeking to increase profitability through better integration across a value chain fragmented among many owners. Within the cane harvesting and transport sectors, many existing inefficiencies are a result of excessive numbers of harvesting machines owned by harvester contractors and growers, and the fact that most harvesters operate within a short time window each day. In order to improve the complex system from a tactical and strategic planning perspective, leading to reduced costs of production, a modelling framework identifying the key drivers and links must first be developed. Upon developing the framework, techniques in operations research, financial modelling, and simulation can be applied to investigate opportunities to enhance the system in partnership with industry. This paper describes the development of such a framework through participation with two case-study mill areas within the Australian sugar industry, along with its application to improve the efficiency of the harvesting and transport system. Through reducing the number of harvesters in the region and implementing best practice principles for harvesting, one of the case study mills showed potential gains in profitability of up to AU$1 million per annum.

* Corresponding author. Tel.: +617-3214-2340; fax: +617-3214-2308.
E-mail addresses: andrew.higgins@csiro.au (A. Higgins), George.Antony@csiro.au (G. Antony), gsandell@bses.org.au (G. Sandell), irdavies@bundysugar.com.au (I. Davies), Di.Prestwidge@csiro.au (D. Prestwidge), bill@aecgroupldt.com (B. Andrew).

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Implementation took place in one of the case study regions during the 2003 harvest season for which the region is now pursuing further adoption in 2004.

Keywords: Sugarcane; Modelling framework; Participatory research; Case study

1. Introduction

In Australia, most sugarcane is grown on the north east coast, where the harvest season extends from early winter to late spring, since this is when the percentage of extractable sugar from cane (‘commercial cane sugar’, or CCS) is highest. A typical mill region in Australia consists of 200–300 privately owned and operated farms (contained in 8–12 geographical districts), covering about 15,000 ha of land under cane, and producing around 1.5 million tonnes of cane annually. Harvesting machines are usually either privately owned and operated by a separate contractor or owned and operated by a grower. There are between 15 and 100 harvesters within a mill region, each requiring up to three haulout units (which transports cane from the field to the rail siding). A harvester will service between 1 and 30 farms, for which the group of farms serviced by the harvester is referred to as a harvesting group. Each farm usually contains between 20 and 100 paddocks, for which a paddock is a single farm field. After the harvester cuts the cane in the paddock, it is transported to the mill by either road or narrow-gauge rail transport (about 80% of cane in Australia), which is owned by the mill.

Unlike the world’s largest sugar producer, Brazil, the Australian sugar industry consists of large numbers of small family businesses that privately own and control their farms and/or harvesting machines. Sugar mills are owned either by public companies (e.g., CSR, Bundaberg Sugar) or by co-operatives in which growers are shareholders. The Australian sugar industry was built around institutions with deep historical roots and a long-standing culture of pervasive industry regulation. This limits efficiency gains across the industry value chain of growing, harvesting, transport, milling, storage and marketing, thus denying the industry the flexibility needed to fully benefit from innovation. ABARE (1990) has pointed to potential improvements in profitability if regulations were removed. In their assessment, industry-wide gains of AU$130 million (1984/85 prices) could have been made via savings in transport and processing through the removal of marketing restrictions in industry regulations, and a AU$54 million (1986/87 prices) increase in profitability could have been achieved through the removal of excess harvesting capacity. Together, potential gains amounted to 9% of production costs. The emergence of Brazil as the world’s largest sugar producer has lowered long-term international prices, and increased pressure for improved supply-chain efficiency within the Australian industry.

Because of its regulatory culture until the mid-1990s, the Australian sugar industry has long considered technology advances within individual sectors as the primary targets for improving its performance. These include farming issues such as new
plant varieties (Berding et al., 1997), fertiliser-application recommendations, pest-management and harvesting technologies (Powell et al., 2001). Tools were developed for daily transport scheduling (Pinkney and Everitt, 1997 and Grimley and Horton, 1997), and milling technologies (Allen et al., 1997). Such research addressed only specific issues within sectors of the sugar-industry value chain. As a result, the industry has achieved technical efficiency within individual sectors but neglected the issue of efficiency across the sectors of the value chain. Since the mid-1990s, however, just as the sugar industry began to face several new major challenges, the effectiveness of component-based research has been in serious decline. This gave rise to the need to look for efficiency gains across sectors of the value chain.

From the scientific and implementation perspectives, optimisation of the full sugar industry value chain is an intractable task. However, exploiting efficiency gains through better integration across the harvesting and transport sectors of the value chain has been regarded as the highest priority in an independent evaluation of the Australian sugar industry (Hildebrand, 2002). These sectors are seen as having the potential of quick cost reductions over the next five years. Developing a more efficient harvesting and transport system raises a number of scientific and change-management issues. There are a large number of logistical and economic linkages and drivers within the system that need to be identified and measured to identify opportunities for improvements. In contrast with gradual improvements in single systems components, the adoption of a more efficient, different harvesting and transport system is hampered by its complexity and the radical change required. Hence, encouraging adoption will require increased participation and learning (Pannell, 1999) between the growing, harvesting and milling sectors – supported by outside help in systems development and change management.

This paper describes the methods developed to identify opportunities for increased harvesting and transport efficiencies as well as the process intended to facilitate implementation. Main components of the work were: (a) the establishment of case studies with steering groups, (b) development of a modelling framework that captures the key linkages and drivers, and (c) the application of a range of models in an integrated manner to improve systems efficiency. The participatory cooperation between researchers and stakeholders, followed throughout the project, is seen as the key to eventual implementation.

2. Case-study approach

Two case studies were developed in a participatory research setting, in Plane Creek and Mourilyan in North East Queensland. In each region, a steering group comprising of growing, harvesting and milling representatives were already established prior to the commencement of this research, with an aim to develop and extend cost-reducing techniques within their regions. These groups had about 20 members each and represented the local industry of about 250 cane farmers, 50 harvester contractors (including haulout operators) and 100 milling staff. The steering groups invited the research team to work with them in early 2002, to explore
opportunities for increased efficiencies within the harvesting and transport system. Thus, the research was initiated and driven by an industry 'demand pull' rather than a 'science push' approach.

The research team represented a number of research and extension organisations and it was endowed with a large range of core skills in operations research, economic modelling, mechanical engineering, statistical modelling, change management, crop physiology, database design and development, software development and systems agronomy. Formal meetings at least four times per year constitute the main communications interface between the research team and the steering groups. These workshops were always facilitated for maximum effectiveness, and a focus within the workshops was collective learning to develop the greatest capability to address the issues of the harvesting and transport system. There is a growing view within the agricultural scientific community (see Kropff et al. (2001) and Douthwaite et al. (2002) for more detail and examples) that this level of interdisciplinary analysis and participation is required to promote adoption of solutions for a more efficient system.

The way in which the research team and the steering groups worked together incorporated many of the participatory research principles, such as those found in Martin and Sherington (1997). Most of the agricultural participatory research examples in the literature (see Gladwin et al. (2002) and Carberry et al. (2002) for an overview of some recent examples) are aimed at improving practices at the farm (household) level. A unique feature of this initiative is that change is required by millers, harvester contractors and growers collectively to achieve increased profitability. Thus the participatory research requires a broad representation of participants to develop solutions that are not only accepted by individuals, but are accepted by all stakeholders. Fig. 1 illustrates how we worked and learned together.

Establishing the operating protocols of Fig. 1 provides a basis for promoting trust and transparency between the research team and steering group, as well between members within the steering group. It includes the steering group being confident that the research team can get the job done, which members of the team would have demonstrated this in their past activities. The research team needs to be confident that the steering group will be pro-actively seeking systems improvements. After operating protocols are developed with the steering group, we collectively identified tangible priority issues that we aimed to address. We then quickly (after the first one or two workshops) moved to the stage of constructing a framework and the preliminary development of the necessary analytical tools. Milling-company partners, by virtue of their oversight of the whole value chain, assisted in construction of the analytical tools and validation of these from a technical perspective. Even though the development of the analytical tools required specialist technical skills, industry partners provided valuable input into model formulation, as well as making available cost data and information on technical parameters and relationships. At each iteration of development, the steering group has to fully understand ('make sense' in Fig. 1) what goes into the analytical tools, what comes out, and a basic understanding of how they work, in order to have confidence that it was going to work
for them. In ‘reflecting’, we collectively validated the tools and preliminary results from a practical viewpoint, and assessed the validity of inputs and assumptions. We then took action on necessary steps to improve the tools and analysis, and refined our timelines for the next iteration. Throughout these action learning cycles (see McGill and Beaty (1995) for principles on action learning), the scenarios also evolved towards those that have the best “gain to pain” ratio for the industry, where pain is described as the level of resistible change required.

Research scientists worked closely with the steering group throughout the life of the project to ensure the project was not derailed by misperceptions spread by negatively disposed growers or harvester contractors within the local industry. One of the most important outcomes was developing an understanding of how to best incorporate potential grower, harvester–contractor and miller concerns in the modelling and implementation facilitation. While developing a pathway to implementation, we often revisited the development of analytical tools in light of on-going learning with the steering group and feedback from the local industry.

While this type of participatory research increases the likelihood of adoption, it does have drawbacks. The “transaction costs” (communication and interaction) are much greater than with traditional research, development and extension practices. A high level of interaction between researchers and the steering group, along with the multiple cycles within action learning, required researchers to spend a considerable proportion of their time outside the comfort zones of their disciplines and offices.
3. Development of a modelling framework

A full sugar industry value chain is represented in Fig. 2 for which the mill owns the transport system while the growers pay for harvesting. As a result, harvesting and transport have not been integrated activities in the past and are the two sectors of the value chain with the largest potential gains through an integrated approach.

The activities within harvesting and transport sectors of the sugar value chain contain a range of logistical, economic and social links that constitute the system, and trying to improve efficiencies requires capturing for these linkages into a conceptual framework.

The development, integration and application of analytical tools was preceded by the formulation of a modelling framework. There is evidence of this approach within the literature, in that: (1) Ruben et al. (1998) developed a modelling framework for a simultaneous appraisal of agro-ecological and socio-economic parameters for sustainable natural resource use; while (2) Alberto et al. (2002) developed a framework to integrate a range of operations research methodologies for the optimal design and operation of an industrial plant.

In this paper, building a modelling framework provided the research team and steering group with the capability to: (1) build and link various models; (2) make the complex harvesting and transport system more tangible; (3) account for financial transfers and effective incentives across the system; and (4) explore opportunities for efficiency gains that were previously not thought possible. To construct the framework, the harvesting and transport system needed to be broken down into components that represent activities or major managerial decisions, or are more conducive to being modelled.

Prior to the start of this study, the Mourilyan steering group broke up the harvesting and transport system into 12 components, each of which is easily interpreted from an industry perspective. Through slight modifications and merging of some of these components, the research team was able to formulate five components (summarised in Fig. 3), each of which is a tangible model from a scientific perspective.

Two of the components of Fig. 3 already exist as stand alone models, for which a description of these models, along with references for further reading, are listed below:

1. **Siding and harvester rosters**: These are schedules showing: (1) which days each harvester contractor operates throughout the harvest season given that nearly

![Fig. 2. Australian sugar industry value chain showing flow of material (solid arrows and flow of payments (dashed arrows).](image-url)
all contractors operate fewer than seven days per week and (2) a sequence of sidings that each harvester delivers cane to, on the days that they are operating. Tools have been developed specifically to optimise these rosters (Higgins, 2002; and Higgins and Postma, 2003).

2. Harvest haul model: It has been shown by Agnew et al. (2002) that implementation of harvest best practice principles of extractor fan speed and harvester speed can yield gains of AU$100 per hectare through reduced cane and CCS losses. A database model exists (Sandell and Prestwidge, 2004), called the 'harvest haul model', to plan and cost out harvesting activities with individual contractors on a farm-paddock basis. The database model also accounts for harvest best practice principles. Given information about each farm paddock (e.g., crop size, row spacing and paddock length) and details of the harvesting and haulout equipment, the harvesting contractor can accurately estimate the full cost of harvesting that paddock.

Fig. 3 not only highlights the major components of the harvesting and transport system, but also shows the key inputs/outputs and the key linkages across them. These logistical relations also carry economic or social meanings. It is not practical to build a single 'supermodel' to describe and optimise the whole system in Fig. 3. However, it is feasible to model the individual components, some of which lend themselves to being models of a database, simulation or optimisation form. Once the linkages between system components are implemented as data links between the model components, sequential application of the component models achieves a capability akin to a single model. That is, the set of linked models of Fig. 3 provided a capability to conduct the a range scenario analysis for the Mourilyan and Plane Creek case studies, while ensuring the full range of impacts across the complex
system are accounted for. The only conceptual advantage of a single, unified model is systems optimisation. However, conflicts between whole-of-system objectives and those of individual system components in the sugar industry, the very reason of the study, negate this advantage.

4. Analytical methods

The previous section outlined the modelling framework and the major components within it. Two of these components, namely, the harvest haul model and siding/harvester roster models were already produced in the past for separate applications but needed to be re-shaped to be applicable to a whole mill region and integrable with the other components of Fig. 3. Models were produced for the remainder of the components of the modelling framework (Fig. 3) in light of the harvesting and transport case studies at Mourilyan and Plane Creek. These are briefly described in this section.

4.1. Harvesting group and siding location model

These two components were ideally suited to combinatorial optimisation due to the existence of a clear analytical objective, that is financial returns, and the fact that constraints on the system (e.g., maximum harvesting group size) easily lent themselves to mathematical description. We were able to do this without having to apply simplifying assumptions as in many operations research applications, and were able to produce models that were integrable into the modelling framework. The modelling techniques applied fall into the category of location science. Optimising the location of sidings is formulated similarly to a capacitated \( p \)-median problem (Maniezzo et al., 1998) and involves determining the optimal location of \( p \) sidings from the existing \( P \). That is, if the steering group wished to look at the consequences of keeping 50 of the existing 150 sidings, the model would indicate which sidings should be kept. A mathematical formulation and solution technique is contained in Higgins and Laredo (2003).

The position of the sidings can have an impact on the number of locomotive shifts and cane bins required, and this is captured using the transport capacity planning component. The steering group collectively agreed that if siding numbers were to be reduced then the increase in harvester haulout distances between the farm paddock to the siding must be minimised. Harvesting contractors are sensitive towards efficiency gains to the mill (i.e. reduced sidings to maintain) that lead to increased expenses for themselves, thus the \( p \) sidings must be selected to minimise their haulout costs.

Optimising which farms are allocated to each harvester, subject to a given number of harvesters, is a form of capacitated clustering problem (Osman and Christofides, 1994). The objective is to form a set of harvesting groups so that the sum of distances from the farm centroids to the centre of the harvesting group is minimised. This objective can vary if some harvesting and haulout equipment is more suited to partic-
ular terrain or soil types. Both the harvesting and milling sectors represented by the steering groups agree that harvesting groups with farms clustered close together are conducive to reduced costs in harvesting and transport.

4.2. Transport capacity model

Modelling of transport is a complex discipline with a huge range of methodological approaches available. In choosing a methodology, it was important that:
1. key industry issues in the transport system could be represented without causing excessive complexity;
2. any model developed was still easily integrable with the other components of the modelling framework to reduce demand for computational resources;
3. it had the capability to be adapted to a wide range of scenarios;
4. data required by the model were from existing records and simple enough for mill staff to collate, avoiding the need for time-consuming surveys;
5. it could be produced within the short time frame of less than one year.

In light of industry requirements, we dismissed scheduling methodologies in favour of tools that measure capacity requirements for a given demand. These types of capacity planning models are commonly used for railway applications (e.g., Higgins and Kozan (1997) for urban planning and Chen and Harker (1990) for single-line freight planning) as well as for road planning (e.g., Lo and Tung, 2003).

The approach we took was to develop a capacity-planning model based on stochastic simulation, for which details of the model can be found in Higgins and Davies (2004). Key outputs from the model are number of locomotives and shifts needed, bin requirements and delays to harvesters when there are limitations on locomotives and bins. These have flow-on impacts on other components in the system (particularly harvest best practice) as seen in Fig. 3.

4.3. Financial module for benefit calculation

The purpose of the financial module is to provide a common denominator across the individual component models of Fig. 3, and allow system wide scenarios to be conducted. The purpose of the research is to improve financial returns along the value chain, accounting for the possibly divergent or conflicting interests of some sectors. The long-term aim is to develop an incentive system that encourages individual sectors to operate in a way that maximises whole-of-system returns. This is not possible, however, without first identifying the financial implications of proposed changes to the industry system, for each sector and overall: the purpose of this stage of the research.

To this end, individual component models calculate the financial outcomes of harvest-transport scenarios for the sector(s) whose operation is modelled. The way the different sectors derive their earnings varies. Growers and mills share the proceeds from sugar sales. The payment formula for growers in the Mourilyan region is

\[
\text{Cane price} = 0.009 \times \text{raw-sugar price} \times (\text{CCS} - 4) + 0.6275,
\]
where cane price and raw-sugar price are in AU$ per tonne and the values of 0.009 and 0.6275 are particular to each mill district.

Harvesting contractors are currently paid a flat amount of around AU$6.5 per tonne of the cane, measured when delivered at the mill. Haulout within paddocks is part of the harvesting operation.

Sectoral financial returns must be compared with care, as their economic meanings have important differences. There is also a variation in sectoral interests that may conflict with one another and that of the whole industry:

- **Growers**: By the time of harvesting, growers have incurred all growing costs, and the only outstanding cost item for them is harvesting. Once harvesting costs are deducted, their benefits constitute net, pre-tax profits. Growers would benefit from less cane loss of the harvested material when harvest best practice principles are implemented.

- **Harvesting contractors**: Detailed costings available for the harvesting sector include direct costs only, i.e., those directly associated with the harvesting operation. Gross margins (excluding general business overheads) are calculated and monitored for this sector. The current system of payment encourages harvesting contractors to move as fast as possible and take little notice of harvest best practice principles.

- **Transport system**: Any savings in transport costs add to the pre-tax profits of mills. Hence, the incentive is to minimise transport costs, as long as this does not negatively affect cane deliveries.

- **Mill processing**: It is in the mill's interest to increase cane throughput within its physical capacity by, e.g., reducing cane lost during harvesting. The value of additional sugar from more cane, and the mill's share of that, are easily calculated. However, this is a gross figure, before processing costs are deducted. A detailed analysis of the mill's overhead and variable costs is needed before mill profits can be identified, and the present work did not extend to this.

In scenario analyses, all of the sector benefits above have been compared to the benchmark scenario (see Section 5), yielding the marginal benefit associated with each. The sector benefits are assumed to be generated in a steady-state operation following systems transformation. As a matter of general approach, costs of transformation were not included in the benefit estimation at this stage, as a complete coverage is not yet available. For example, the capital requirement of siding upgrade is known, but the cost involved in reducing harvester numbers (through buying out or retiring harvesting contractors) is not.

### 5. Scenario analysis with the Mourilyan case study

Mourilyan was selected for the initial analysis, since the scenarios formulated by the Plane Creek steering group closely resemble those of the Mourilyan case study, and Mourilyan was more advanced in the research/implementation process. There were three fundamental scenarios formulated by the Mourilyan steering group, though there are several variations within these as shown in Table 1. All scenarios
in Table 1 (except 0, the first scenario) incorporate harvest best practice principles. The scenarios were not formulated immediately by the steering group, but required about three iterations following the consideration of preliminary results for earlier versions of the scenarios.

In scenario 0 (Table 1), most harvesting contractors commence harvesting at about 5 a.m. in the morning and finish at about 3 p.m., thus harvesting is across a 10 h time window. This puts a massive demand on the transport system to meet the transport needs within this short time frame, and it also leads to long queue times at the mill. Scenario 0.1 tries to overcome this by spreading out the harvesting over an 18 h time window. While this scenario would not result in as high a gain as the others, it requires no capital expenditure and is easier to implement. In Mourilyan, sidings are short sections of track (about 300 m long) that branch off the main track. This layout leads to long shunt times (between 30 and 45 min) for the locomotive to remove full bins and deposit empty bins. By spending AU$25,000 a siding can be upgraded to a crossing loop which would reduce the shunt time down to about 10 min. This reduction in time would reduce the transport capacity requirements and delays upon the system. In scenarios 1.1 and 1.2, 24-h harvesting means that there are 10 harvesting contractors who staggered their start times so that cane harvesting takes place throughout the day. The harvest hours for the scenarios are illustrated in Fig. 4.

When reducing the number of harvesters, the best harvesting and haulout equipment is retained and surplus equipment is assumed scrapped. The mill has a fleet of seven locomotives, 549 rail bins with a capacity of 6 tonnes of cane, 947 bins of 4 tonnes.

For scenarios 1.1–2.2 of Table 1, the optimal location of sidings was determined using the siding location model of Fig. 3. The 100 sidings are spread out on the network to minimise the haulout distances from the farm paddocks to sidings. With the existing 143 sidings, the average haulout is 0.86 km. This increased to 0.87 km with 100 sidings and 1.03 km with 50 sidings, the latter was of concern to harvesting contractors. In the scenarios 1.1–2.2, the formation of harvesting groups was optimised with the harvesting group model to minimise the amount of movement that harvesters make across farms. Given solutions from the harvesting group and siding location models, a siding roster was produced to show the movements of harvesters across the sidings. This is a key input to the transport capacity model since the transport needs to service the harvesters delivering cane to the sidings.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>15 Harvesters/143 sidings – existing harvesting hours (existing system)</td>
</tr>
<tr>
<td>0.1</td>
<td>15 Harvesters/143 sidings – harvesting across 18 h time window</td>
</tr>
<tr>
<td>1.1</td>
<td>10 Harvesters/100 sidings – sidings upgraded – harvesting across 24 h time window</td>
</tr>
<tr>
<td>1.2</td>
<td>10 Harvesters/100 sidings – sidings not upgraded – harvesting across 24 h time window</td>
</tr>
<tr>
<td>2.1</td>
<td>13 Harvesters/100 sidings – sidings upgraded – harvesting across 18 h time window</td>
</tr>
<tr>
<td>2.2</td>
<td>13 Harvesters/100 sidings – sidings not upgraded – harvesting across 18 h time window</td>
</tr>
</tbody>
</table>
Fig. 4. Hours of harvest in each harvester for each of the scenario listed in Table 1.
Table 2 shows the transport impacts from applying the transport capacity model to the scenarios of Table 1. Locomotive shifts (Table 2) are rounded to whole numbers, since the steering group did not want part shifts. The biggest reduction in the number of locomotive shifts comes about from siding upgrades. Spreading out the harvest hours reduces the number of bins required by up to about 420 (scenario 1.1). Since the 6 tonne bins are lower maintenance, such a reduction in bin fleet would allow scrapping of the surplus 4 tonne bins. Spreading out the harvest hours also reduces the queue time of bins to the mill. Any spreading out of harvest hours will lead to a major reduction in the delays of supplying bins to harvesters. By staggering the start times of the existing harvester (scenario 0.1), the percentage of time that a harvester is left idle waiting for bins is reduced from 14.3% to 4%.

Fig. 5 shows overall marginal gains for each scenario, broken up into the different industry sectors. Most of the increased efficiencies in the harvesting and transport

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Number of loco shifts required each day</th>
<th>Total bins required</th>
<th>Average cut to crush delay (h)</th>
<th>Percentage of time the harvester waits for bins</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>15</td>
<td>1489</td>
<td>8.8</td>
<td>14.3</td>
</tr>
<tr>
<td>0.1</td>
<td>12</td>
<td>1228</td>
<td>5.3</td>
<td>4.0</td>
</tr>
<tr>
<td>1.1</td>
<td>11</td>
<td>1066</td>
<td>5.5</td>
<td>0.0</td>
</tr>
<tr>
<td>1.2</td>
<td>9</td>
<td>1066</td>
<td>5.5</td>
<td>0.0</td>
</tr>
<tr>
<td>2.1</td>
<td>13</td>
<td>1489</td>
<td>9.2</td>
<td>1.5</td>
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<tr>
<td>2.2</td>
<td>11</td>
<td>1489</td>
<td>9.1</td>
<td>1.3</td>
</tr>
</tbody>
</table>

Fig. 5. Overall marginal gain for each scenario of Table 1 versus the base case, scenario 0, where $\text{F}$, scenario 0.1 (Table 1); $\text{F}$, 1.1; $\text{F}$, 1.2; $\text{F}$, 2.1; and $\text{F}$, 2.2.
system are primarily attributed to reduced cane losses from harvest best practice, though the reduced transport costs are still significant from a milling perspective. An overview of impact in each sector of Fig. 5 is as follows:

- The losses to the harvesters are attributed to longer hours of harvest from slowing down and having to have two shifts per day in the case of harvesting across a time window of 24 h. Harvester losses for scenarios 1.1–2.2 are less than that for scenario 0.1 due to reduced time spent waiting for bins (derived from increase transport system efficiencies) and from declining capital costs of operating fewer harvesters.

- The gains to growers are solely from reduced cane losses through implementation of harvest best practice principles, thus the gains for the growers (shown net of harvesting costs in Fig. 5) are the same for all scenarios.

- Significant cost reductions in transport are due to requiring fewer locomotive shifts, and reduced maintenance of locomotives and bins. While siding upgrades can reduce the number of loco shifts (Table 2), the costs of the upgrades (AU$25,000 per siding assuming a 10% per annum interest charge and no future capital replacement) means that the net return on investing in upgrades is negative. This is evident in Fig. 5 as scenario 1.2 has a smaller gain than scenario 1.1.

- An increase in mill processing returns from harvest best practice, which is the same for all scenarios.

- Despite Fig. 5 clearly showing losses for the harvesting sector, the net return to the industry is still a very large positive.

The result of gains in Fig. 5 led the steering group to consider the degree of difficulty/change that would be caused by implementing the different scenarios during the 2003 harvest season. The steering group agreed that it would be too difficult to reduce the number of harvesters to 10 or implement siding upgrades for the 2003 harvesting season. Their preference was to take a small step and try out scenario 0.1 first, and if this works well proceed to some of the “bigger gain and bigger pain” scenarios.

To implement scenario 0.1, harvesting contractors need to agree to change their start times to resemble that in Fig. 4. The steering group’s view was that harvesters would not start before 3:00 a.m. or harvest beyond 10:00 p.m., due to the lower efficiency of night harvesting. The Mourilyan steering group formulated a slightly modified version of scenario 0.1 to sell to the growing and harvesting community of the Mourilyan region. To reduce the level of change for the harvester contractors, an approach was for harvester contractors who already start early (e.g., between 3:30 a.m. and 5 a.m.) to start at 3:00 a.m. and for harvester contractors who start later (e.g., between 6 a.m. and 10 a.m.), to start at a time so that they finish at about 9 p.m. The slightly modified version of 0.1 accounted for reluctance of some harvester contractors to change their start times, but had negligible effect on the gains shown in Fig. 5. Through the Mourilyan steering group holding an open day presentation for the growers and harvester contractors of the region, there was general agreement to trial scenario 0.1 in 2003. Implementation of scenario 0.1 was generally successful, though there were some early teething problems in terms of disruptions from wet weather at the start of the harvest season and
transport traffic officers needing to familiarise themselves with new start times of harvesters. These teething problems did create delays to harvesters for which the steering group needed to communicate the reasons of the delays to the harvester contractors. Failure of such communication would have discouraged participation from future implementation. By the end of the harvest season, implementation was considered successful and the steering group, with the aid of the research team, are looking at further implementation in 2004.

6. Conclusions

The Australian sugar industry and others around the world constitute a physically and managerially complex system of growing, harvesting, transport, milling and marketing. Managerial complexity is further increased when the value chain is fragmented by the separate ownership of these sectors. Nevertheless, the Australian sugar industry has in recent years increased its emphasis on whole-of-system approaches to reduce costs of production, particularly in the harvesting and transport system. We have shown that while developing an overarching single model to optimise the harvesting and transport system is not practical, a modelling framework can be used to break the system down into tangible components. Key links and drivers were identified and measured across the components, so that the suite of models/tools representing the components can be used to explore the potential benefits of system-wide opportunities along the value chain.

Rather than the research being a science push, we developed the modelling framework and component models in partnership with steering groups from two mill regions within the Australian sugar industry. This partnership approach embodies the principles of participatory research and action learning, vital for industry acceptance and ownership. Lack of the latter contributed to a track record in the past of poor adoption by the industry of research results that were aimed at improved value-chain efficiency.

Through the researchers working with the steering groups from the case study regions, we collectively applied interdisciplinary research in developing models for the system components. In the Mourilyan case study we showed that there were potential cost reductions of up to AUS$1 million per year to the mill area, under the scenarios that the industry steering group formulated. The industry in the Mourilyan region has initially opted for scenarios requiring minimal change, even though these promise lesser gains. However, implementation of all scenarios requires change management, which is complicated by the current payment systems not distributing the gains fairly across the industry sectors.

Initial implementation during the 2003 harvest season has been generally successful, for which the industry steering group are anticipating further implementation in 2004, and hopefully a more adventurous one. This will likely lead to the need for further research, particularly relating to the adoption of scenarios requiring capital investment and fewer harvesters.
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