

INTELLIGENT ADAPTIVE CONTROL IN AN ON-LINE CANE TRANSPORT SCHEDULER

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Abstract

23 out of 28 Australian sugar mills operate privately owned cane railway systems and, as a group, these systems form the third largest rail transport system in Australia.

The purpose of cane railway scheduling is to build a set of locomotive runs, or a schedule, that minimizes the costs involved and satisfies the demands of both the miller and the grower. There are several characteristics of this problem that sets it apart from other scheduling problems:

- Two commodities, empty and full bins must be considered
- Harvested sugar cane is a perishable product that deteriorates at an increasing rate after it is harvested
- The schedule can determine, to a certain extent, the timing of the harvest, and the demand for empty bins by the growers.

This project improves the Automatic Cane Railway Scheduling System, ACRSS, so that the schedules generated by ACRSS more closely reflect operational schedules.

The improvements to ACRSS include:

- Incorporating improved algorithms into the system
- Allowing the harvest pattern to change from one day to the next as harvesters come on and off roster
- Improving the provisions within ACRSS to handle load and speed restrictions in the network.

Since the conclusion of this project ACRSS has been used by over two thirds of the sugar mills that operate cane railway systems.

Non-Technical Summary

The vast majority of the Australian sugar crop is transported from the field to the sugar mill by privately owned cane railways. The total length of the permanent way exceeds 3000 km and approximately 500×10^6 tonne kilometres of cane are hauled during the crushing season, making the combined operation the third largest rail transport system in Australia

Transporting cane from the field to the factory is an expensive process. Both capital and operating costs are large and cane transport is the largest cost unit in the manufacturing of raw sugar accounting for about one third of the total manufacturing costs.

Cane railway systems perform two major tasks. Firstly, they take empty bins from the mill and deliver them to the growers where they are filled with chopped cane, and secondly, they collect the full bins from the growers and return them to the mill. At the mill, the full bins are weighed and then move onto a tip where the cane is removed. The now empty bins are ready for delivery to the growers.

The Cane Railway Scheduling Problem is to design a set of locomotive runs, or a schedule, to satisfy both the mill and the growers. A substantial set of constraints has to be considered and there's no definitive objective function that can be used to assess the merits of the schedules produced.

A system, the Automatic Cane Railway Scheduling System (ACRSS) has been developed to generate schedules solving the cane transport problem.

At the heart of ACRSS is a mathematical model of a cane transport system. This mathematical model is a simplification of an actual system and, as ACRSS has developed, extra features have been added to the model so that more realistic schedules are produced. The use of ACRSS, prior to this project, indicated that the model should be updated to consider the following:

- Harvesting patterns that vary from day to day to allow rostered harvesting and harvester migration to be incorporated into the schedules.
- Locomotive loads and speeds that vary throughout the network.
- Branch line operations that reflect operational practice.
- Shunt times at sidings that vary with the number of bins at the siding.

This project has considered these modifications to the ACRSS model and has updated ACRSS to use the improved searching algorithms that have been developed by Operations Research practitioners for use in similar problems.

Background

23 out of 28 Australian sugar mills operate privately owned cane railway systems and, as a group, these systems form the third largest rail transport system in Australia.

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Cane railway systems perform two major tasks. Firstly, they take empty bins from the mill and deliver them to the growers where they are filled with chopped cane, and secondly, they collect the full bins from the growers and return them to the mill. At the mill, the full bins are weighed and then move onto a tip where the cane is removed. The now empty bins are ready for delivery to the growers.

The Cane Railway Scheduling Problem, CRSP, is to design a set of locomotive runs, or a schedule, to satisfy both the mill and the growers. A substantial set of constraints has to be considered and there's no definitive objective function that can be used to assess the merits of the schedules produced.

One of the features of CRSP is that the product to be transported, harvested, chopped cane, is perishable. Because most of the cane is harvested in daylight hours (between 6am and 6pm), there is a large delay between harvesting and crushing for some cane. During this time, bacterial action occurs that not only reduces the amount of sugar that can be recovered but also produces products that cause problems in the manufacturing process. The rate of the bacterial action increases exponentially over time, and if the delay between cutting and crushing is over 18 hours, the costs associated with aging are of the same magnitude as the operating costs for the cane railway system.

When assessing schedules, mills usually attempt to minimize their operating costs while maintaining an acceptable cane age.

Sugar Research Institute, a research organization founded by the Australian sugar mills has been examining the CRSP since 1968. Considerable advances have been made in this time towards solving the CRSP but there are still areas that need further work.

A system, the Automatic Cane Railway Scheduling System (ACRSS) has been developed to generate schedules solving the cane transport problem. The problem is decomposed into separate routing and scheduling problems and these problems are solved sequentially to produce a trial schedule that is then refined iteratively.

At the heart of ACRSS is a mathematical model of a cane transport system. This mathematical model is a simplification of an actual system and, as ACRSS has developed, extra features have been added to the model so that more realistic schedules are produced. The use of ACRSS, prior to this project, indicated that the model should be again updated to consider the following:

- Harvesting patterns that vary from day to day to allow rostered harvesting and harvester migration to be incorporated into the schedules.

- Locomotive loads and speeds that vary throughout the network.
- Branch line operations that reflect operational practice.
- Shunt times at sidings that vary with the number of bins at the siding.

There have also been significant improvements in the searching algorithms available to address these scheduling programs, and this project allowed these improvements to be incorporated into ACRSS .

Objectives

The objectives of this project were to improve the model used by ACRSS, the schedule generating system, so that the schedules produced more closely reflected operational practices. Specifically, the ACRSS model was updated to consider the following:

- Harvesting patterns that vary from day to day to allow rostered harvesting and harvester migration to be incorporated into the schedules.
- Locomotive loads and speeds that vary throughout the network.
- Branch line operations that reflect operational practice.
- Shunt times at sidings that vary with the number of bins at the siding.
- Make provisions for locomotive passing

Additionally, the algorithms used within ACRSS to optimise the schedules that are generated have been updated to use currently available Operations Research techniques.

The objectives listed above, with the exception of making allowances for locomotive passing, have been achieved and incorporated into ACRSS.

The problem of locomotive passing was considered, but as ACRSS is more suited to medium and long term planning rather than everyday operations and since the problems of locomotive passing are dependent on the small disturbances to the cane transport system that occur frequently throughout the day, it was concluded that this problem was better considered in the proposed real time scheduling system.

As a separate mill funded project, ACRSS has been converted to run in a Microsoft Windows environment. This project involved:

- Converting ACRSS to the Windows environment
- Developing a user-friendly interface to ACRSS
- Integrating ACRSS and TOTools so that ACRSS accepts grower data from TOTools and exports schedules back to TOTools

The user manual attached to this document describes this interface as well as ACRSS itself.

Methodology

This project was directed by a steering committee that included the chief cane inspectors from three Mackay district sugar mills as well as representatives from CQU and SRI. The involvement of Professor JD Smith with this steering committee was very productive and the

success of the project, and of the related project to develop TOTools is in no small way a direct result of the involvement of this steering committee.

Since the schedule generating system ACRSS was already in existence, most of the work completed in this project involved updating the program code of this package.

Results and Assessment of Impact

The modifications to ACRSS have proved successful, with the system being used in over two thirds of the mills that transport cane by rail.

In this time ACRSS has been used to examine a variety of situations including:

- Examining current operations
- Staggering the start time of locomotives to prevent congestion of the system
- The effects of extending the hours of harvesting
- The inclusion of depots to lessen the impact of small siding capacities
- Combining the transport system for a number of mills
- Examining whether an existing railway system should be replaced by a road system
- Planning for expansion

Whilst there has been some involvement by the researchers with these projects, the improvements to ACRSS have enabled mill personnel to complete significant portions of these studies.

Description

This section contains:

- A technical description of how ACRSS generates schedules,
- A comparison, in broad terms, of the ACRSS schedules and the present operational schedules,
- A description of the changes made to ACRSS from this project.

Appendix A to this report is a detailed User's manual for ACRSS.

Historical Development of ACRSS

ACRSS was initially developed as a PhD thesis (Abel, 1978) and was later modified and improved extensively by the Sugar Research Institute. By the mid-eighties, ACRSS was widely used throughout the industry with many mills being able to reduce their cane transport costs by using ACRSS to investigate their cane transport systems (Pinkney, 1989; Page et al, 1985).

How ACRSS Generates Schedules

ACRSS breaks cane transport scheduling into separate routing and scheduling problems. Sequentially solving these problems produces a trial schedule that can then be refined iteratively. This approach is shown diagrammatically in Figure 1.

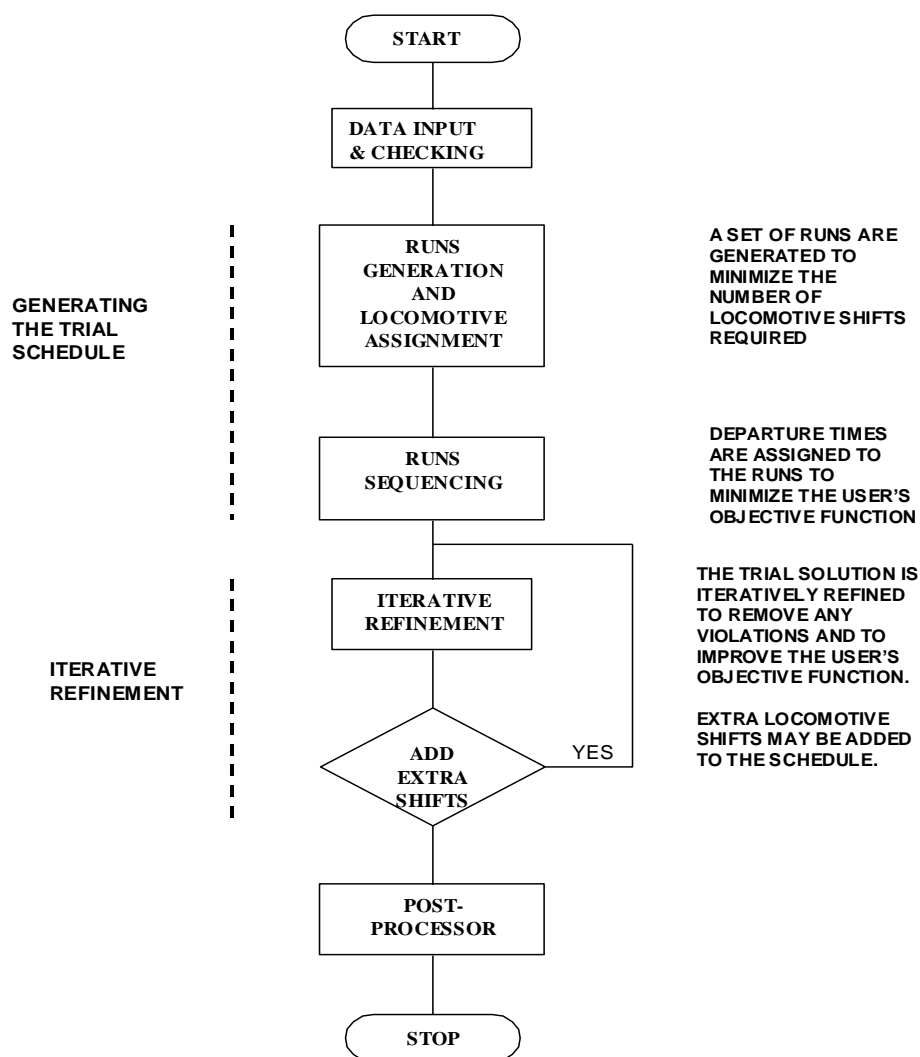


Figure 1 ACRSS Solution Algorithm

The Routing Problem

The routing algorithm breaks the network into a series of segments, where each segment is a section of track terminating at either a branch or at the end of a line. Locomotive runs are generated to service segments of the track, ie. the runs deliver empties to the growers located on the segment and collect full bins from them. The servicing needs of the segments are determined by considering both the total number of bins involved and the distance of the segment from the mill. For each locomotive run, adjacent segments are serviced until the locomotive's capacity is fully utilized or there are no further segments to be serviced before reaching the mill. Additional runs are generated for the locomotive until its available time is fully utilized.

This algorithm performs two functions - it determines the route that the locomotive runs will take and the activities they will perform and it also allocates the runs to locomotives. The objective for this module is to minimize the number of shifts required. The module's performance is shown in Table 1. This table uses data describing a case study used extensively by the Sugar Research Institute and other data from representative Australian sugar mills. The absolute minimum values are calculated by considering a much simpler situation where all the cane is collected at a single point, an average distance from the mill.

	Absolute Minimum		ACRSS Obtained	
	Loco Run Time (mins)	Loco Shifts	Loco Run Time (mins)	Loco Shifts
Case Study	1492	4	1605	4
Mill 1	3122	7	3165	8
Mill 2	4773	11	5095	12
Mill 3	3806	9	4170	10

Table 1. Locomotive Requirements - Run Generation Module

The Sequencing Problem

The next module sequences the runs generated by the routing phase. The original sequencing algorithm used a modified tree search to locate the better schedules. Recently, a genetic algorithm has been used. Genetic algorithms are search techniques that mimic natural selection and use the operators of reproduction, crossover and mutation to move from one solution to the next. Goldberg(1989) describes how genetic algorithms can be used to locate optimal solutions. Locomotive runs are given integer identifiers and integer permutation is used to obtain the best schedule.

The schedule produced need not, at this stage, be a feasible solution. There may be harvest start violations, where the locomotive runs attempt to collect cane not yet cut, and siding capacity violations where the number of bins at a siding exceeds the siding capacity.

The results obtained have been most satisfactory and are summarized in Table 2. The times shown are the computer running times on a Sun Workstation and the violations are the total

numbers of harvest start and siding capacity violations remaining. In all instances the genetic algorithm has been able to sequence the runs in an acceptable time.

	Tree Search		Genetic Algorithm	
	No. of Violations	CPU Time (secs)	No. of Violations	CPU Time (secs)
Case Study	7	3	2	17
Mill 1	39	4325	26	139
Mill 2	44	16	28	39
Mill 3	?	>24h	35	120

Table 2. Genetic Algorithm Performance

Iterative Refinement

The iterative refinement phase improves the schedule by making a series of small changes to it. The sizes of deliveries to and collections from sidings are altered, new deliveries and collections are added, existing deliveries and collections are deleted and runs are swapped to improve the schedule. This process is used to remove violations from the schedule and to improve the schedule parameters. The user specifies which parameters are to be improved and their relative priorities. The parameters that can be considered are:

- Harvest start and siding capacity violations
- Average cane age
- Weighted cane age
- Number of bins
- Yard size

The schedules produced by ACRSS compare favourably with existing schedules. Table 3 compares the generated schedules with those in use at some mills. For all sets of data, ACRSS has been able to generate schedules using fewer locomotive shifts and for mill data, the schedules use fewer bins and improve the cane age. For the case study, improved cane age and bin fleet size could be obtained by adding an extra locomotive shift.

		No. of Shifts	Average Cane Age	Number of Bins
Case Study	Workshop	5	7:45	942
	ACRSS	4	7:56	1000
Mill 1	Existing	18	9:29	2956
	ACRSS	13	8:55	2143
Mill 2	Existing	13	11:30	1543
	ACRSS	8	9:04	1545
Mill 3	Existing	15	10:07	1983
	ACRSS	11	8:50	1823

Table 3. Overall System Performance

Modifications to ACRSS

At the heart of ACRSS is a mathematical model of a cane transport system. This mathematical model is a simplification of an actual system and, as ACRSS has developed, extra features have been added to the model so that more realistic schedules are produced. Recently, the model has been expanded so that:

- Harvesting patterns can vary from day to day. This allows rostered harvesting and harvester migration to be incorporated into the schedules.
- Locomotive loads and speeds can vary throughout the network.
- Branch line operations reflect operational practice.
- Shunt times at sidings can vary with the number of bins at the siding.

Changes in the Harvesting Pattern

Previously, ACRSS modelled a static situation where the number of bins delivered to and collected from a siding equalled the daily allotment at the siding. The model was also cyclical and the numbers of full and empty bins at the siding at the end of the 24 hour period were the same as those at the start of the period. This model did not allow for either rostered harvesting or harvester migration.

Daily changes in the harvesting pattern were incorporated into the ACRSS model by considering four situations:

- A harvester finished cutting at the siding yesterday.
- A harvester finishes cutting at the siding today.
- A harvester starts cutting at a siding today.
- A harvester finishes cutting at a siding tomorrow.

Table 4 summarizes the effects that these situations have on the deliveries to and collections from the sidings, eg. if a harvester is finishing at a siding today, there is no need to deliver bins for tomorrow's harvesting and the number of bins delivered today is reduced by this amount. However, in the 24 hour period being considered, a full allotment of bins must be collected.

	Finished Yesterday	Finishes Today	Starts Today	Starts Tomorrow
No. to be Delivered	0	A - d	A	e
No. to be Collected	b	A	A - c	0

A is the daily allotment.

b fulls remain at the siding from the previous day.

c fulls remain at the siding at the end of the current day.

d empties are at the siding at the start of the current day.

e empties delivered for the next day.

Table 4. Changes in the Harvesting Pattern

Varying Locomotive Loads

Variable locomotive loads and speeds are incorporated into ACRSS by :

- Increasing the length of some sections of the network when the restriction applies to individual sections of the track,
- Including a depot (or a number of depots) when the restrictions apply to whole areas of the network.

Track sections with localized load restrictions, eg. hills, are handled by hauling a complete load to the grade and then splitting the load into a series of smaller loads that can be hauled over the grade. Extra locomotive running time is used to transport the cane over the grade and increasing the length of sections of the network makes allowance for this extra running time. A post-processor programme has been developed to produce locomotive runs that reflect operational practices.

Adding depots or marshalling yards allows ACRSS to produce schedules for cane transport systems that include whole areas where locomotive loads or speeds are restricted. For some mill areas it has been necessary to include a system of depots to obtain realistic schedules. The Animated Cane Transport Scheduling System (ACTSS) has been used to verify that these techniques do allow load and speed restrictions to be handled by ACRSS.

Branch Line Operations

The ACRSS model does not allow mixed locomotive loads, ie. locomotives cannot haul empty and full bins simultaneously. This leads to some inefficient branch line operations. Figure 2 shows how the runs built by ACRSS service a branch line. As this figure shows, the requirement that mixed locomotive loads not be allowed leads to inefficient branch operations.

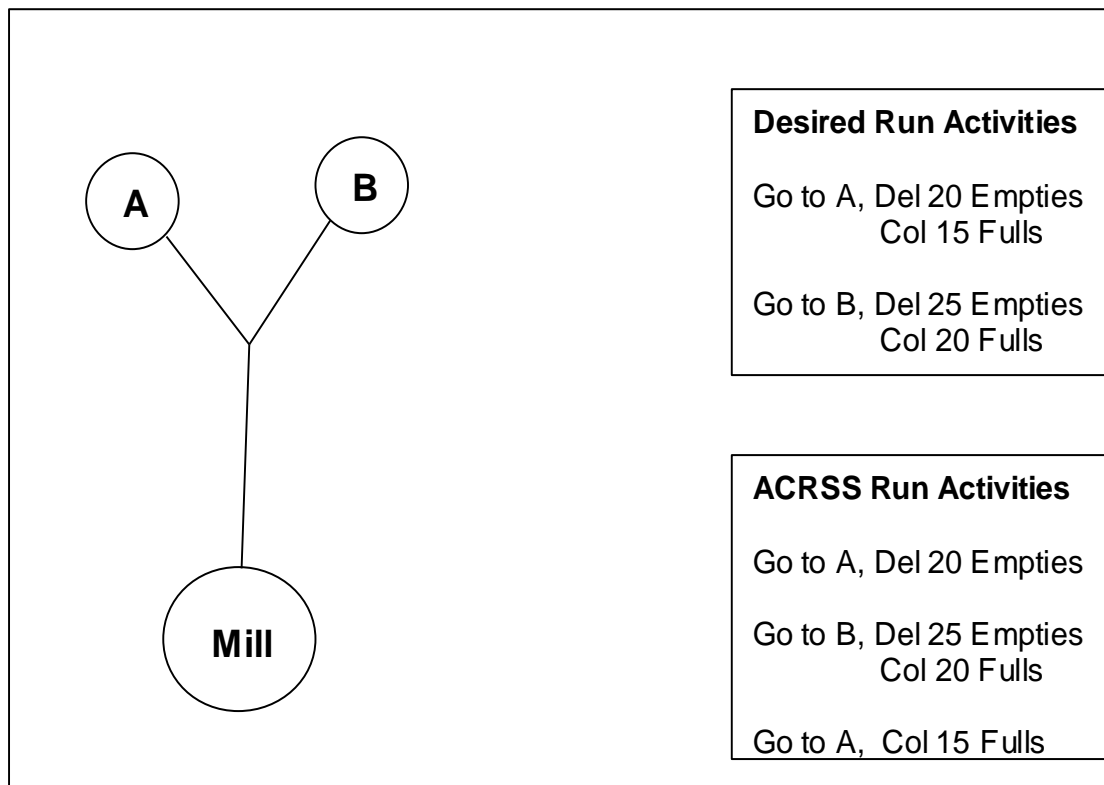


Figure 2. ACRSS branch activities

Variable Shunt Times

The ACRSS model has been expanded to allow the shunt time at sidings to vary as the number of bins at the siding increases. This allows the generated schedules to simulate the significant operator practice of using adjacent sidings. When the number of bins at the siding exceeds the original siding capacity, the shunt time is increased to allow adjacent sidings to be used. Trials with sample data have shown that ACRSS can use the increased siding capacities to produce schedules that use fewer locomotive shifts.

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Recommendations

Harvesting and transport operations are major cost centres for both the milling and farming sectors of the sugar industry. Cane harvesting and transport are complex systems that contain many interacting components and an integrated approach to harvesting and transport is necessary if overall costs are to be reduced or maintained.

There are a number of avenues for further research into cane transport that could prove fruitful:

- Over the last couple of years, ACRSS, as refined in this project has been extensively used in many mill areas to examine harvest and transport operations. This system provides an ideal platform to examine how the combined harvest/transport costs can be minimized
- Real-time or residual scheduling aims to provide traffic officers with a system that produces a good pattern of actions to complete the day's operations given the current state of the system, including the stocks of full and empty bins in the mill yard and at the sidings and the positions of locomotives. At present no such residual scheduling system is available.
- The development and refinement of ACRSS and its model is an on-going procedure. There are indications that other intelligent searching algorithms such as the Tabu search technique would improve the performance of ACRSS.

Publications List

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- **Objectives** and a statement of the extent to which the research has achieved them
- **Methodology** and a justification of it
- **Results** including statistical analysis if appropriate
- **Discussion** of results including analysis of outcomes compared with Objectives
- **Assessment** of the likely impact for the Sugar Industry in Australia and elsewhere and where possible the cost and potential benefit to the Australian Sugar Industry and future research needs
- **Description** of the Project Technology, such as commercially significant developments, patents, licences etc.
- **Technical Summary** of any other information developed including discoveries in methodology, equipment design etc.
- **Recommendations** on the activities or other steps to further develop, disseminate or exploit the Project Technology
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