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An integrated approach to optimise sugarcane rail operations

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ABSTRACT

In Australia, the railway system plays a vital role in transporting the sugarcane crop from farms to mills. The sugarcane transport system is complex as it routines a daily schedule, which consists of a set of train runs to satisfy the requirements of the mills and harvesters. A constrain programming approach is used to formulate this complicated system. Metaheuristic techniques and constraint programming are hybridised as an efficient solution approach. Thus, a better sugarcane transport scheduling system is achieved to maximise the throughput of sugarcane transport. A numerical investigation is presented and demonstrates that high-quality solutions are obtainable for industry-scale applications in a reasonable time.

1. Introduction

1.1. Background

Railway networks are significant assets in Australia and play an important role in hauling the nation's freight, serving interstate markets and promoting economic activities in Asia–pacific regions. The agriculture products are hauled safely and efficiently from inland production areas to warehouses, stores, processing plants and ports by traversing a railway network of hundreds of kilometres (Australian Logistics Council 2014).

The railway network is vital in transporting other agricultural such as wheat and sugarcane as well as minerals such as coal and iron ore. In Australia, 100% iron ore, 90% of wheat, 80% of coal and 70% of sugarcane are hauled by rail. In addition, the railway hauls many farm inputs such as fuel, fertiliser, equipment and a wide range of general freight commodities. Particularly, Australia is the world's third largest exporter of raw sugar after Brazil and Thailand and 90% of sugarcane is transported by rail with around $2.0 billion in export earnings. Approximately 85% of the raw sugar produced in Queensland is exported (Australian Sugar Milling Council 2014).

Freight transport systems play a vital role in the commodities production process by transporting the crops between farms and workshops (mills). The fright transport system uses a daily schedule of runs to meet the needs of both the harvesters and the mill. The sugarcane transport system is an important element in the raw sugar production system, accounting for over 35% of the total cost of raw sugar production in Australia. Approximately 4400 cane farming entities are growing sugar cane on a total of 380,000 hectares annually, supplying 24 mills, owned by 8 separate milling companies. Up to 35 million tonnes of sugarcane produce up to 4.5 million tonnes of raw sugar, 1 million tonnes of molasses and 10 million tonnes of bagasse annually. The sugar industry directly employs about 16,000 people across the growing, harvesting, milling and transport sectors (Australian Sugar Milling Council 2014).

The fright rail system is a complex system that includes a large number of variables and elements. These elements work together to achieve the main objectives of satisfying both mill and harvester requirements and improving the efficiency of the system in terms of low overall costs. The fast growing demand of Australian commodities was affected by the inefficiency of the fright rail system, in which the railing bottlenecks increase the interruption time of crushing at a mill and reduce the crop quality after harvesting. The transport sector has a critical impact on the overall cost of a crop rail system. Millions of dollars was costed by = companies and risking the future of exports because of these bottlenecks. Some potential negative effects of fright transport on the whole system include delaying the arrival of crops to the mill; delaying the arrival of empty sugarcane bins to harvesters at farms; causing the harvesters to wait for empty sugarcane bins and increasing their costs; and increasing extra costs through the need for the larger numbers of locomotives and sugarcane bins. Integration of the harvesting, transport and milling elements in the value chain of the Australian agriculture industry can increase the overall system efficiency. For example, optimising the delivery and collection

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times throughout the rail system requires the information about harvesting times, harvesting rate, harvesters' locations, the crushing rates at mills, etc. Producing efficient schedules for the fright rail transport system can reduce the costs and limit the negative effects on the raw crops production.

1.2. Literature review

Many publications have discussed and modelled the sugarcane rail transportation problems to improve the system's efficiency (Besinovic, Goverde, Quaglietta, & Roberti, 2016; Gafarov, Dolgui, & Lazarev, 2015; Masoud, Kozan, & Kent, 2014; Sels, Dewilde, Cattrysse, & Vansteenwegen, 2016). However, advanced solutions techniques for the sugarcane rail scheduling problems are rare in the literature. The scheduling of locomotive movements on sugarcane railways has proven to be a challenging task (Masoud et al., 2014).

Everitt and Pinkney (1999) described an integrated set of tools to manage the performance of a sugarcane transport scheduling system. This work was designed to achieve integration between the schedule simulation programme, the schedule generating programme and Traffic Officer Tools. Higgins and Davies (2005) introduced a simulation model for the capacity of sugarcane transport systems in Australia. This capacity was determined by estimating variables such as the number of trains used in the system and their movements, the number of sugarcane bins and the time spent waiting for the empty sugarcane bins at farms.

In comparison to Mixed Integer Programming (MIP), constraint programming (CP) approaches have been widely used to solve complicated scheduling problems. CP has the ability to model many different types of combinatorial optimisation problems especially rail transport system problems (Rodriguez, 2007). CP techniques have the ability to solve feasibility problems and can deal with conflicting objectives (Cortés, Gendreau, Rousseau, Souyris, & Weintraub, 2014 and Goel, Slusky, Hoeve, Furman, & Shao, 2015). CP that deals with problems defined within a finite set of possible values for each variable is the main technology used for solving mathematical formulation problems (Henz, Müller, & Thiel, 2004; Hoeve & Katriel, 2006; Russell & Urban, 2006; Schaerf, 1999). Moreover, CP has been applied to solve many types of real-world scheduling problems. Martin, Pinkney, and Yu (2001) proposed a new approach using Constraints Logic Programming to solve sugarcane railway scheduling problems using a Prolog language with extra features suitable for the system. This technique produced daily schedules to minimise the number of locomotives and their runs, and satisfy constraints of the system such as siding capacity and locomotive hauling capacity. Isaai and Singh (2001) developed train scheduling algorithms based on an object oriented constraint based heuristic and two hybrid algorithms which integrate the heuristic techniques with Tabu Search and simulated annealing strategies. Masoud, Kozan, and Kent (2010) developed a new CP model for the sugarcane rail transport system problem and solved small-size instances by ILOG-CPLEX. However, the CP techniques cannot obtain accurate solutions for large-scale instances in a reasonable time.

1.3. Problem description

Sugarcane is transported in specially designed sugarcane bins called sugarcane bins. The railway system can generally operate for 24 h a day, while the harvesting period is limited to about 12 h each day. A sugarcane railway network uses a single track and has many interconnecting lines (segments) and sidings (delivering and collecting points). Each line has different sections and each section can be defined between track features such as sidings or passing loops. The sugarcane railway system performs the following two main tasks: delivery of empty sugarcane bins from the mill to sidings and collections of full sugarcane bins to the mill. From the perspective of the whole transport system, the mill serves the function of converting full sugarcane bins into empty sugarcane bins, while the harvesters convert empty sugarcane bins to full sugarcane bins.

Each harvester operating at a siding has a daily allotment of sugarcane bins, which often exceeds the capacity of one siding. Sidings have a finite capacity that should not be exceeded in practice. In this case, several empty bin deliveries are typically required each day to maintain an empty bin supply to the harvesters. Each train can haul a limited number of empty sugarcane bins and full sugarcane bins, depending on the capacity of the train. For safety reasons, the train does not generally haul mixed trains of empty sugarcane bins and full sugarcane bins. Thus, empty bin deliveries must take place before full bin collections during each train run.

The sugarcane transport system uses a daily schedule, consisting of a set of train runs, to satisfy the requirements of the mill and harvesters. The sugarcane transport system plays a significant role on the performance of the sugar production process. Potential negative effects of a poor transport system include: stopping the supply of cane to mill, causing interruptions to the raw sugar production process; delaying the arrival of sugarcane to the mill; allowing cane to deteriorate and lose sugar quality; delaying the arrival of empty cane sugarcane bins to harvesters causing the harvesters to waste time and money waiting for empty sugarcane bins; increasing cane production costs through inefficiencies in the sugarcane transport system itself, and in the harvesting and raw sugar production processes. Sugarcane transport systems are very complicated systems and these systems face many challenges which affect the overall cost or the performance of sugarcane system. The challenges include:

- Scheduling passing of trains on the single rail track to improve performance of the railway system.
- Maintaining a non-interrupted supply of full sugarcane bins to the mill and empty sugarcane bins to the harvesters.
- Limited harvesting hours. In Australia, most harvesting operations occur during daylight hours while the transport system and mill operate continuously. As a result, the cane sugarcane bins are used for temporary storage of the harvested crop at sidings and at the mill. Long storage times reduce sugarcane quality and crop profitability.
- Minimising the number of locomotive runs to reduce operating costs.
- Reducing the time between harvesting and crushing (cane age) to keep sugarcane quality high.

Due to these real-life challenges, there is an urgent need for an efficient sugarcane transport schedule that will be produced by rail scheduler. A real-time schedule optimiser should be developed to maximise the throughput of the overall sugar production system.

In this paper, single track railway systems use blocking constraints to achieve safe operations. Blocking constraints work by preventing more than one train from occupying a track section at the same time and help in resolving conflicts throughout the railway network (Liu & Kozan, 2009, 2011). Blocking constraints have been applied to different types of railway networks such as mining or freight railways (Kozan & Liu, 2012, 2015). A segment blocking approach was also considered in the model of Masoud et al. (2011, 2014) in which a new model was presented to solve the sugarcane rail transport system problem. In comparison, sugarcane railway networks include many segments (branches or lines), as shown in Fig. 1. Some of these branches do not have passing loops. Thus, complete branches are sometimes used as substitute passing loops.