



A demand-responsive decision support system for coal transportation

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ABSTRACT

In this paper, a demand-responsive decision support system is proposed by integrating the operations of coal shipment, coal stockpiles and coal raiing within a whole system. A generic and flexible scheduling optimisation methodology is developed to identify, represent, model, solve and analyse the coal transport problem in a standard and convenient way. As a result, the integrated train-stockpile-ship timetable is created and optimised for improving overall efficiency of coal transport system. A comprehensive sensitivity analysis based on extensive computational experiments is conducted to validate the proposed methodology. The mathematical proposition and proof are concluded as technical and insightful advices for industry practice. The proposed methodology provides better decision making on how to assign rail rolling-stocks and upgrade infrastructure in order to significantly improve capacity utilisation with the best resource-effectiveness ratio. The proposed decision support system with train-stockpile-ship scheduling optimisation techniques is promising to be applied in railway or mining industry, especially as a useful quantitative decision making tool on how to use more current rolling-stocks or whether to buy additional rolling-stocks for mining transportation.

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1. Introduction

Australia is the world's largest coal exporting country and produced around five hundred million tonnes of coals in 2008–2009 [22]. Railways play a vital role in transporting the coal from mines to ports, where the majority of the coal is transported by rail. Many large coal mining operations in Queensland heavily rely on the rail network to transport coal from various mines to coal terminals at ports for shipment. The coal mining railway system performs two main tasks: delivering empty wagons to the mines at sidings; and collecting the full wagons of coal from mines and transporting them to the port. The transport sector has an important effect on the overall costs of a coal mining system.

Over the last few years, due to the fast growing demand, the coal transport system including coal railway network and port terminal is becoming one of the worst industrial bottlenecks in Australia. As reported in 2007–2009, “furious coal producers blamed sheer incompetence by the state-owned railway for the backlog when more than 150 ships were anchored off the east coast – waiting to load coal” [41]. The bottleneck was costing mining companies millions of dollars on demurrage charges per month, threatening hundreds of jobs in the industry and risking the future of exports to key Asian customers. As a result, it was announced that “Australian Rail Track Corporation hoped to double capacity on its national freight network by switching to a \$500 million computerised management system” [42] and “the port facility at Abbot Point is currently expanding from 25 mtpa

capacity to 50 mtpa with further potential to expand to beyond 100 mtpa” [22].

Many practical issues of system interoperability need to be considered when decisions are made about whether to upgrade the rail network or build a new corridor that should be consistent with the port expansion projects. For example, Queensland Rail Network identified a range of potential expansion plans for upgrading the rail/port infrastructure [22]. However, the rail industry recommends that rail capacity be underwritten and constructed to meet industry demand ahead of underwritten port expansion projects. In this way, the undesirable impacts of construction of new rail capacity on existing throughput should be minimised or reduced. This also eliminates the unbalanced situation of port capacity being available without enough rail capacity in place to match.

In central Queensland, there are currently three major coal export ports (i.e. Abbot Point, Hay Point and Gladstone) servicing central Queensland supported by four major rail corridors, i.e., Goonyella, Newlands, Blackwater and Moura [22]. The port precincts at Gladstone and Hay Point have a plan for significant expansion. However, it appears that the total coal export demand before 2020 would be still met by three existing major port precincts. This means that the central Queensland coal supply chain will probably remain concentrated on four existing major rail corridors at least in the medium term, which may lead to strategic risks associated with route diversity, increasing congestion and system interoperability [22]. As throughput demand increases on each major rail corridor, the raiing capacity should be successively augmented to match the growing demand. When a rail corridor is serviced at saturation, future expansion may be able to continue on the existing corridor by adding sections of

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the third and fourth tracks (i.e. increasing the capacity of crossing loops). Strategically in the long term, it may be necessary to build a new rail corridor instead to meet the expansion demand. At this stage, it may be a better option to generate more reliable and more efficient transport systems under the given capacity of existing rail and port infrastructure.

In this background, both rail and port industries in Australia demand more new features in the planning and scheduling process and are keen to implement better modelling and solution techniques, in order to improve efficiency and capability of raiiling coal from various mines to ports. By generating better operating schedules, it is possible to increase the utilisation rate of the coal transport system and reduce the transportation cost and demurrage charges. The current situation provides great incentives for pursuing better optimisation and control strategies for the operation of the whole coal transport system. Operating a coal transport system efficiently requires a series of complicated planning and scheduling problems to be solved. As railways and ports are the most critical infrastructure of this transport system, the foremost amongst these planning and scheduling problems are train scheduling, ship berthing, coal stockpile management, determination of train services (railling roundtrips), assignment of empty rolling-stocks (locomotives and wagons) to train services, and loading/unloading operations.

To the best of our knowledge, limited numbers of research papers on the integrated coal transport system are published in the literature, maybe due to its considerable complexity or the protection of its substantial commercial value by industrial practitioners or consultation companies. Abdekhodae et al. [1] integrated the operations in a coal rail network with operations in a coal terminal system, because the infrastructures of these two systems are tightly connected under a high service demand. They developed mixed integer programming models to analyse the integrated systems and then discussed the advantages and disadvantages of this integration. However, they mentioned that their proposed mathematical programming models are quite complicated and too difficult to be exactly solved. For other sub-systems especially about the optimisation of coal train timetables, they only provided the simulation approaches to analyse three raiiling policies. Singh et al. [36] reported a decision-support tool for the coal supply chain of Hunter Valley Coal Chain (HVCC) in Australia. They presented the underlying mathematical models implemented in this decision-support tool along with simulation modelling and approximation algorithms used to identify the capacity requirements and make effective capacity improvement. However, to simplify their models, they made many assumptions especially without considering the capacity constraints of the coal rail network. In addition, they did not provide any approaches that can optimise coal train schedules.

The following recent literature has addressed the train scheduling problems. Zhou and Zhong [39] dealt with a double-track train scheduling problem with multiple objectives by a branch-and-bound algorithm with an effective dominance rule and a beam search algorithm with utility evaluation rules. The performance of the proposed solution approaches is evaluated by a Beijing-Shanghai high-speed railroad case study. Caprara et al. [10] incorporated several additional constraints into a mathematical model for a fundamental train timetabling problem using Lagrangian heuristic. Carey and Crawford [11] used heuristic algorithms to assist in the task of finding and resolving conflicts in draft train schedules. Yuan and Hansen [38] proposed a stochastic model to estimate the knock-on delays of trains with a case study in the Dutch railway. Salido [35] modelled train scheduling problems as constraint satisfaction problems (CSP). Abril et al. [3] presented a technique to solve the CSPs modelling for train scheduling problems by distributing the constraint network in tree structures. Liebchen [28] reported that the optimised timetable based on the results of the periodic-event-scheduling problem had been implemented in Berlin railway. Chung et al. [13] addressed a train sequencing problem in the Korean railway and proposed a hybrid genetic algorithm to solve the problem.

D'Ariano et al. [16] studied reactive train scheduling problem when some train operations are perturbed. D'Ariano, et al. [17] further examined new approaches to improve punctuality of flexible timetable without diminishing the capacity usage of a rail network. Cacchiani et al. [9] proposed LP relaxation methods for the periodic and non-periodic train timetabling problems. Li et al. [27] presented a discrete-event simulation method based on travel-advance strategy for train scheduling. Zografos and Androutsopoulos [40] presented a decision support system for assessing alternative distribution routes with the hazardous materials. Cheng and Yang [12] adopted a fuzzy Petri Net method to formulate the decision rules of train dispatchers in Taiwan's railway network. Lee and Chen [26] presented a decomposing heuristic algorithm both for train pathing and train timetabling problems. Kuo et al. [24] determined elastic freight train timetable with multi-commodity by a train slot selection model. Fischetti et al. [19] improved the robustness of given train timetables for an Italian railway company using four different methods based on linear programming and stochastic programming techniques. Corman et al. [14] described a tabu search algorithm with rescheduling and rerouting strategies to set up a real-time traffic management system. Corman et al. [15] extended their research to consider two objectives that minimise train delays and maximise train punctuality. Krasemann [23] developed a fast heuristic to effectively deliver the train re-scheduling solution to a railway traffic disturbance management problem. Min et al. [32] developed a column-generation-based algorithm to resolve train conflicts in Seoul metropolitan railway network. Burdett and Kozan [6] developed capacity analysis techniques for estimating the absolute traffic carrying ability of a railway system under various operational conditions. Burdett and Kozan [7,8] dealt with inserting additional train services into existing train timetables by constructive and metaheuristic algorithms based on an extended disjunctive graph model. Liu and Kozan [29] proposed a new scheduling model, "blocking parallel-machine job-shop scheduling (BPMJSS)", which solves single-line train scheduling problems in a standard and convenient way. In the model, trains, single-track sections and multiple-track sections, respectively, are synonymous with jobs, single machines and parallel machines, and an operation is regarded as the movement/traversal of a train across a section. Furthermore, Liu and Kozan [30] investigated train scheduling problems with priority when both passenger and freight trains are simultaneously traversed in a single-line rail network. In this case, no-wait conditions arise because the prioritised (passenger) trains should traverse continuously without any interruption. In comparison, non-prioritised (freight) trains are allowed to enter the next section immediately if possible or to remain in a section until the next section on the routing becomes available.

To assist decision makers at their convenience, researchers in multi-disciplines such as operations research (OR), artificial intelligence (AI) and information technology (IT) successively presented the structures, frameworks, mechanisms or architectures on the use of scheduling optimisation techniques to systematically set up the decision support systems for industry practice. Hee and Lapinski [20] gave a precise definition of a decision support system, that is, "a decision support system is a computerised part of information systems that consult decision makers with their tasks by modelling the effects of actions that decision makers propose and generating the actions that optimise specific objective functions". They also discussed the components in the architecture of a decision support system, including "mathematical models to describe the effects of actions, algorithms to obtain the optimal actions with respect to specific criteria, human-computer-interaction (HCI) modules such as database to input values of parameters and graphic user interfaces to view the actions". Then, they presented a so-called job-shop scheduler to illustrate the specification of such a decision support system. Hsu et al. [21] described a decision support system called mixed-initiative scheduling workbench that embodies OR, AI and HCI characteristics. Due to the complex nature of scheduling environments, they classified

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