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A Framework for Integrated Decision-making In Railroad Networks

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Abstract. Railroad networks are capital intensive operations that involve interaction between thousands of dynamic entities for e.g. trains, passengers, etc. while constrained by a fixed set of limited resources such as tracks, trains and platforms. Mathematical programming models have been used to allocate and operate resources efficiently and effectively but are applied separately at various levels of the decision making hierarchy namely, operational, tactical and strategic. While the individual considerations of the models at the different levels of decision making may be different (for example, the time horizons and problems addressed), decisions made at various levels affect each other due to common constraints originating from the static nature of the railroad topology, long lead times to add resources, etc. Further, real-time operational disruptions provide feedback that should be incorporated back into the tactical and strategic decision models to improve the model's performance. One limitation of the current decision models is their stand-alone development with minimal interaction and feedback between decision levels. For e.g., time tables generated using customer demand form constraints for real-time operational planning. Separate treatment of long term strategic decisions and tactical models and modelling them in isolated fashion reduces its practical utility as interactions between these levels are ignored. We show interdependent nature of decision-making at various levels by bringing out the interplay between inter-level model constraints and variables.

Integrated approaches to tackle multiple problems (as shown by the links in Fig 1) have already been attempted in the literature. Very few studies explore the combined nature of problems originating at different hierarchical levels. This motivated us to develop an integrated framework for decision-making in a capital-intensive constrained railroad network environment. Designing such a framework requires identifying a set of master variables that define the overall structure and operations of the network and local variables specific to subproblems.

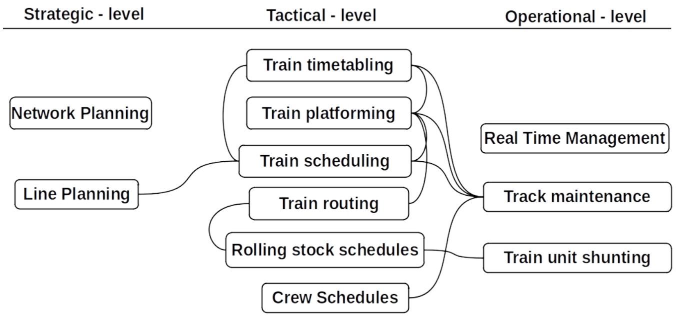

Figure 1: Examples of Rail road problems across decision-levels (Adapted from [1])

Different subproblems in the integrated problem environment are related using decision variables that interconnect these levels and communicate only the required information between them. For example, while the solution of a train platforming model will assign a platform to a particular train independently, real-time train management considers more aspects including platform suitability, availability and train arrival order. Therefore, out of the large number of space-time variables defined to model the real-time management of the railroad network, only variables concerning the assignment of trains to stations are relevant. Thus, multiple rounds of aggregation, re-formulation and reoptimization operations that are often required in a hierarchical model in order to ensure compatibility across various decision levels and improve solution quality can be avoided. The integrated framework developed here is shown in Figure 2.

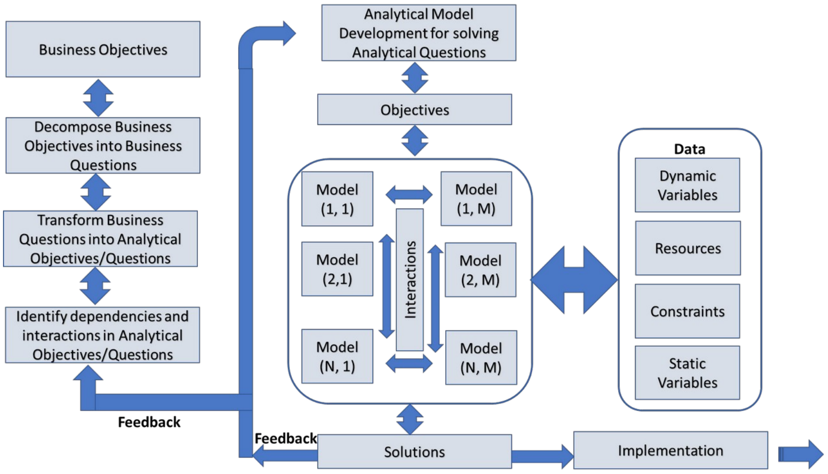

Figure 2: An integrated framework for decision-making design in large resource constrained ecosystems

In the integrated framework, the models (i,j) correspond to the subproblems under consideration. In the current study, we consider train timetabling, train routing, real-time management, railway track maintenance and delay prediction. In the operational level, additional objective of minimal deviation from the schedules proposed by the tactical and strategical-level is enforced. In the strategic and tactical level for scheduling, a macroscopic time-space network model which models stations as nodes and tracks [4] as arcs is considered with a time-granularity of 1 minute. At this stage, microscopic model variables concerning platforming, real-time network delay and crew scheduling are replaced by appropriate estimates. Maintenance tasks are scheduled after the crew and train scheduling. The schedules so generated are input for the microscopic real-time management model, and finer post-optimization operations are done on sliding time-windows with local ruin-and-recreate operations [6]. In case of irreparable infeasibilities, the strategic and tactical level models are re-optimized, however, after a partial variable-fixing operation in order to improve computational performance.

The train platforming problem is not solved explicitly as a model, but is partially taken care of by allocation of tracks in the network model. Business aspects of platforming, however, are currently ignored for simplicity. This formulation decouples platforming which now can be done using simple platform priority rules without major changes in the framework. The real-time management model in the current framework implemented as flow-shop scheduling formulation does not consider major external disruptions. Time delay predictions, typically, made based on a train event-operation dependency graphs, or machine learning [5] approaches can be integrated in this framework for completeness.

One limitation of this integrated model is its large size, which makes exact methods inefficient. Existing practice performs optimization in stages, hierarchically, simplifying the network, aggregating the model to macro or meso-shapes to handle it efficiently [3]. From a combinatorial optimization perspective, this is one of the many possible ways of decomposing the problem. We examine some heuristic decomposition approaches in literature and suggest how they could be applied in this framework. In particular, we extensively test a time-based decomposition, a rolling-horizon based approach, and implement several look-ahead parameters inspired from the relax-and-fix approach.

While railway optimization has been used as an example here, this framework could be generalized to other resourced constrained networks involving decision-making at multiple levels of decision-making hierarchy. Although the models are solved individually at their respective levels, the incorporation of feedback, common variables and data flow ensures that the framework optimizes for the network as a whole, rather than any individual problem. Through preliminary analysis and experiments we show that decision-making can be improved by holistic examination of the nature of decisions, interactions between models rather than creating and solving stand-alone siloed operational models. We conclude with the limitations of our framework and scope for future research.

Keywords: Railroad networks, integrated models, optimization

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