Dynamic delay management at railways: a Semi-Markovian Decision approach

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Chapter 9

Epilogue

9.1 General discussion and summary

The topic of this research is dynamic delay management at railways. ProRail, the Dutch railway infrastructure manager, is interested in finding new methods in order to improve train service through optimisation of the usage of the railway network. This optimisation step is needed, since the railway capacity is scarce while the demand is growing in terms of both passenger and freight traffic. With this growing demand, the current way of railway operation will become unsustainable and needs to be reviewed. The Dutch government is aware of this and has expressed its ambitions to gradually increase the number of trains in the most dense part of The Netherlands and gradually move to a system which can be described best as a metro system. In such a system, a high number of trains operate and run close to each other. This way a higher demand can be met. The drawback of such a system is that it is more vulnerable to delays. Due to less buffer space, small delays will more often lead to train conflicts. This change in railway operation will lead to a more dynamic railway service which increases the need for new techniques that can solve train conflicts dynamically.

Train conflicts occur also in the present day situation where timetables are a common practice. Although, timetables are designed to separate trains from each other, some trains get delayed which leads to train conflicts. Currently ProRail relies on the so-called TAD conflict resolution rules which are strongly related to the timetable. Train dispatchers use these rules to resolve train conflicts. The rules are the result of the negotiation process between different operators and prescribe a certain train order per conflict situation. On a number of locations within the Dutch railway network, these rules are however not satisfactory. ProRail is interested in alternative conflict resolution strategies which may have a better performance.

The main goals of the thesis are thus to explore a new technique which is designed to resolve train conflicts within the metro-like system of the future. But also to examine whether such a system can serve as an alternative for the TAD rules used nowadays by ProRail. The theory that we use in this thesis is that of the Semi-Markovian Decision processes. This approach has never been tried before. The idea behind this approach is to be able to construct rules off-line but solve the conflicts on-line pretty much the same way TAD rules are used nowadays. The train dispatchers have an overview of the rules. When a conflict arises, the conflict resolution rule is found and applied.

Due to interdependencies in the railway network, the large part of the delays are knock-on delays which are transmitted from one train to another. Most of these delays are transmitted either at the junctions where trains from different directions come together, or at the track sections when a fast train catches up with a slower one. The goal of our research is to optimize the situation at junctions and taking into consideration the track behind it. Moreover, the rules of the SMD strategy will be local rules designed to resolve the conflicts locally.

In the first chapters we develop the so-called SMD model and show how the conflict resolution problem can be modelled as such. We start with a simple model where trains from different directions come together and need to share the same infrastructure from then onwards. We call the tracks where the trains arrive the arrival tracks and the track they need to share the destination track. We then show how the model can be extended by allowing trains to leave the destination track prematurely and allowing for bidirectional traffic. The performance of the SMD strategy is compared to a number of heuristics through an extensive simulation study. In all of the cases, the SMD strategy outperforms other strategies, however, in some situations some heuristics turn out to be almost optimal.

While developing the SMD model, a number of modelling choices were made. One of these choices concerns the modelling of the destination track. It turns out that modelling the destination track by means of the so-called track speed concept reduces the number of states and solves an issue, concerning the headway concept, the original model had where both location and type of each train were modelled. This SMD$_{ts}$ model has comparable results to the original model while being more compact and thus able to model more complex situations. In a number of cases, though, modelling the destination track by a single variable, which represents the speed of the 'flow', may be inadequate. In these cases, one might think of extending the model to a multiple track speed model (see next section for model extensions) or using the SMD model instead.

In a later chapter we apply the SMD model to some fictive networks to study the performance of the SMD model within a network environment. The idea is to solve train conflicts locally but study their effects globally. In the studied network environments the difference in performance between the SMD strategy and the heuristics was substantial. The three networks we have studied had a growing complexity. The last network had a number of complicated aspects which are comparable to characteristics found in the real-life situations. The SMD strategy proved to perform very well, outperforming all other strategies.

The results of the SMD strategy within the fictive cases we studied, encouraged us to apply the model to a real-life situation. In cooperation with ProRail a study area has been chosen involving the line segment Utrecht - Gouda. This line segment is being heavily utilised by both passenger and freight traffic. The line includes Utrecht Central Station which is the largest station in The Netherlands and the main hub where trains from different parts of The Netherlands come together. Moreover, the freight traffic running to and from the Rotterdam harbour makes use of this line segment too. The trains entering this line segment are often delayed which leads to a large number of conflicts which need to be resolved. The TAD rules do solve these conflicts but the train punctuality within the area can still be improved.

The line segment Utrecht - Gouda has been decomposed into a number of areas where local SMD rules have been applied. We have explained how the line segment is divided into areas and how the situation in each area can be translated into the SMD model. By means of a simulation study, the performance of the SMD strategy is compared to that of the TAD rules and to a number of heuristics. The SMD strategy turns out to perform very well, even though it does not hold any information of the timetable and falsely assumes that the train arrivals are Poisson. Within the simulated environment the SMD strategy, when compared to the TAD strategy, has substantially improved the overall train punctuality. Again, some heuristics performed very well and have even in a number of cases outperformed the SMD strategy. These heuristics, however, are strongly dependent on the model settings and perform differently when other settings are applied (in the case we have studied in Section 8.4.4 the heuristic IC-FR-IR-RE has performed almost as well as the SMD strategy but its performance dropped substantially when the number of freight trains was increased). The SMD model does not have these drawbacks since it produces strategies which are optimised for each individual case.

The SMD strategy defines a rule for every possible situation. By grouping the situations together, for which the same rule applies, we can construct compact SMD tables which present the SMD strategy on a comprehensive sheet. These tables can be used by train dispatchers pretty much in the same manner they use the TAD rules today. This similarity between the two can contribute to a fast adaptation and acceptance of the SMD strategy by the train dispatchers.

The goal of this thesis has been to examine the possibility of using the theory of the Semi-Markovian decision processes to resolve train conflicts dynamically. The presented results not only show that this is possible but that this approach has a potential to improve the current train conflict handling procedures and hereby improve the train punctuality. Due to the complete independence from the timetables, the approach is ready for the metro-like situation which is likely to be implemented in the near future. Moreover, we believe that the model can be easily extended to cover specific railway situations that can be found in practice.

9.2 Limitations of the thesis and recommendations for further research

As is stated, the main goal of the thesis has been to examine the possibility of using the theory of the Semi-Markovian Decision processes to resolve train conflicts dynamically. Thus, the emphasis laid on developing a model which can resolve conflicts occurring at the most common junctions found in practice that is, (1) fork junctions where trains from different directions come together and share the same track or a portion of it afterwards and (2) bidirectional junctions. When examining the line segment Utrecht - Gouda we have explained how already with this equipment, complex areas can be modelled. Moreover, the SMD strategy, provided by the model, proved to perform substantially better than the TAD strategy. However, not all possible conflicting situations are covered with the presented model. Modelling these situations requires model extensions. A number of these extensions are proposed hereunder.

Multiple destination tracks. It is possible that in the real world a certain combination of trains can cross the junction without conflicting with each other while another train combination will have a mutual conflict. This is the case with multiple destination tracks. An example of such a junction has been presented in Section 8.3.2.1 when the modelling of the Gouda station has been explained. There we have approximated the junction with the SMD model. In this section we want to explain how the SMD model can be extended to facilitate this kind of junctions. In our model, an action a has been associated with an arrival track from which a train will be allowed to cross the junction. In the extended model, the action a should be associated with a combination of train types that can cross the junction simultaneously. As has already been the case with a bidirectional junction, the current state can limit the number of possible actions. In case of a bidirectional junction, a train can not enter a destination track when it is being used in the opposite direction. In case of the extended model, an action is only possible when all involved destination tracks are available. Another difference with the current SMD model, is the Track Speed variable that has been used for tracking the state on the destination track. In the extended model, this variable will be an array with each entry describing the situation on a certain destination track.

Multiple track speeds. Independently from the above extension, one may think of situations where modelling one single destination track with one single variable representing the speed of the 'flow' on the track will not be adequate. For instance, consider a long destination track but where after already a short distance a slow freight train leaves the model. This situation should lead to a low track speed on the first part of the track and a high track speed at the rest of the track. With only one variable representing the speed of the flow on the whole destination track, the track speed of both parts will be averaged. As a result, the speed of the flow on the first part of the track will be overestimated. As a result, fast trains leaving the track shortly after entering it will be hindered less by their predecessors than it will be the case in reality. To model this in a correct way, one should consider using two (or even more) track speeds to model the speed of each part of the destination track separately. When in such a model, a slow train will enter the track, it will lower the first track speed the most, the second less and the last track speed only slightly. When after that, a fast train enters the destination track, then its delay should be based on the track speed, which corresponds with the last part it will cross before leaving the track. This way, the delays of all trains will be calculated in a correct way.

Phase type arrival process. Although the Poisson-type process, that has been used throughout this thesis, has yielded promising results even in real-life situations, it is still worthwhile to extend the model to allow for Phase type arrival processes. The idea behind this is that the trains in real-life run less disorderly than it is the case with the Poisson-type process. Approximating arrivals with a Phase type process, which is less chaotic than the Poisson-type process can lead to better results. The extension itself is very easy to implement. The state space needs to be extended with an extra variable k for every arrival track. This variable gives the phase that the arrival process on that track is currently on. Then, when during the simulation, a conflict occurs which needs to be solved with the SMD strategy, the corresponding SMD state can be obtained by translating the time the last train has entered the track into the arrival phase state of that track. The idea is, that the longer this idle interval lasts, the higher the possibility of the new arrival.

Dynamic train types. The SMD model introduced in this thesis can handle train priorities implicitly. This allows for modelling practical situations where for example international trains have a higher priority than domestic trains, or trains having a lot of connections to other trains having higher priority than trains without connections. There are however situations where other types of priorities arise. In many countries, the train companies are judged by their punctualities. The punctuality is the percentage of trains that have a delay of less than x minutes. In such a case, protecting the trains with the delay around or below this value can be a good idea. As a result, the priority of the train will be dynamic, based on its current delay. To model this, one could consider the following: When an action a gives some train the right of crossing the junction, the trains on other arrival tracks get delayed. When the resulting delay of the train falls within a certain interval, the train type of the train should be changed to a type with a higher priority. This way, the SMD strategy will take into account the fact that some actions can cause an extra delay to trains that are better not to be delayed.

Next to the above extensions which are meant to extend the SMD model itself to increase its ability to model real-life situations, the research can be expanded to areas involving the implementation of the model into practice. Think of automating the process of dividing a complex area into manageable sub-areas or building a global monitoring system that examines the local SMD decisions and checks whether they do not conflict with other decisions.

Moreover, it would be interesting to compare the quality of the SMD strategy to strategies obtained from other models, taken from the literature. Due to limited time this comparison had to be omitted in this research.

A very interesting extension of the research presented in this thesis is to examine the performance of the different strategies on a more global scale. For this, a commercial simulator software can be used where the whole Dutch railway net is incorporated. The software that comes to mind is Simone, developed by the Incontrol Enterprise Dynamics, which is used by ProRail for a variety of research objectives. The SMD strategy can then be applied to a number of conflicting areas and the effects studied on the scale of the whole network. By comparing these results to the results of another simulation where the TAD rules are applied to the same areas, the added value of the SMD rules can be studied. This extension requires building some additional software which allows for the communication between the SMD and the Simone environments. Alternatively, this global environment can be used to study the performance of the SMD approach for the situation where the metro-like environment is applied to the most dense part of The Netherlands, as is likely to happen in the near future.