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

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Chapter 5

Modelling a Bidirectional junction

In the previous chapters we have discussed the Semi-Markovian Decision approach and explained how a Fork_R junction can be modelled within the SMD setting. In this chapter we will explain how the model can be extended to facilitate bidirectional traffic. We will refer to the junction involving the bidirectional traffic as a Bidirectional junction.

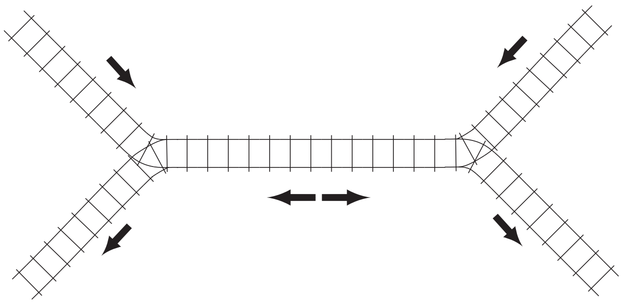

Figure 5.1: Bidirectional junction where the central part is used in both directions

The Bidirectional junction typically consists of a number of arrival tracks, a destination track and a number of sink tracks. The Bidirectional junction differs from the Fork junction in that the destination track is used by trains in both directions. When a train is on the bidirectional destination track, the track is blocked for the trains in the opposite direction. The situation is illustrated in Figure 5.1.

To model this kind of junction the state space, as introduced in Chapter 3, is extended with a new variable z. This new variable denotes the direction in which the bidirectional track is being used. The inclusion of this new variable influences the transitions and the costs.

We will start by discussing the physical differences of the two types of junctions. This will be done in Section 5.1. Then in Section 5.2 we will address all the changes that should be applied to the model in order to facilitate the bidirectional traffic. In Section 5.3 the performance of the model will be compared to that of other strategies. The chapter will be closed with conclusions.

5.1 Physical differences

At first glance there are two major differences when comparing the Bidirectional junction with the Fork junction, namely, the bidirectional characteristics of the destination track and the presence of a new type of tracks, the sink tracks. While the first difference does result in a number of changes to the model, the second difference does not.

Modelling sink tracks does not have an added value to the model and will only increase the state space. Instead, we will let the trains disappear from the model as soon as they reach the end of the destination track. Depending on the direction of movement this can be either the right or the left end of the destination track (see Figure 5.2).

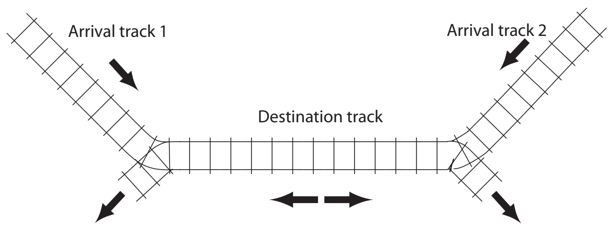

Figure 5.2: The bidirectional junction where the sink tracks are omitted

Looking closely at this junction, one sees the resemblance with the Fork$_R$ junction introduced in Chapter 3. In fact, we can model the bidirectional junction as the Fork$_R$ junction by adding new features to the existing Fork$_R$ model. Figure 5.3 depicts the bidirectional junction modelled as Fork$_2$ junction with two types of traffic. The *LR traffic* stands for traffic that will use the bidirectional destination track in the direction left-to-right whilst the *RL traffic* uses it in the direction right to left. Of course, in the Fork$_R$ representation of the bidirectional junction, all trains will be travelling from left to right but it will be prohibited to allow LR traffic and RL traffic to use the destination track at the same time.

Figure 5.4 pictures the situation with more than 2 arrival tracks. In the figure, two arrival tracks are used by LR traffic and other two by RL traffic.

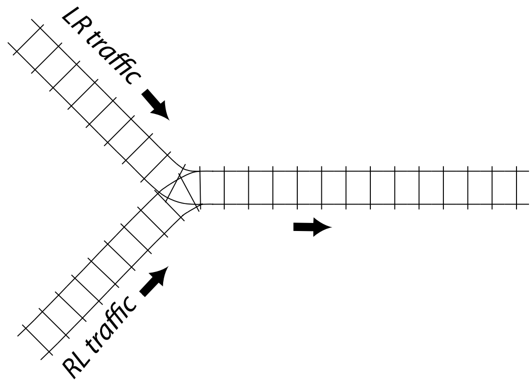

Figure 5.3: The bidirectional junction with two arrival tracks modeled as Fork_2 junction

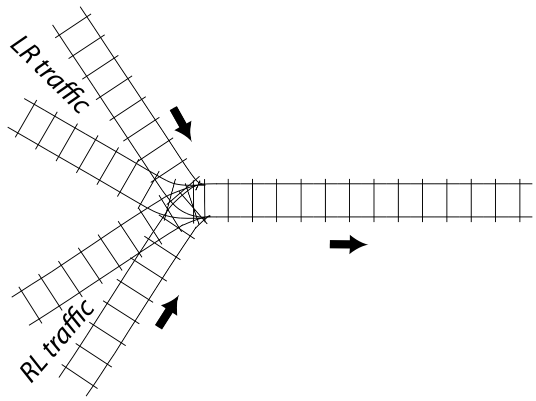

Figure 5.4: The bidirectional junction, with two arrival tracks at every edge of the bidirectional track, modeled as Fork_4 junction

5.2 Model changes

As stated, the bidirectional junction will be modelled as a Fork junction. The bidirectional characteristic of the destination track involves a number of changes to the original Fork_R model. These changes will be addressed here.

The changes to the model can be divided into the changes to the state space, the decisions and the changes to the transitions. We will discuss these model elements together with the unchanged ones in Sections 5.2.1 - 5.2.5. Furthermore, the bidirectional characteristic of the destination track influences the state space reduction technique introduced in Section 3.6. The discussion about this will be held in Section 5.2.6.

5.2.1 States

In Chapter 3, the state space was characterized by a combination of x and y variables. The variable x provided the positions and the types of all trains in the system while variable y denoted the train speeds.

In this chapter the state will be extended with a new variable z that indicates the direction in which the trains at the bidirectional track, if any, are moving. The variable z can have one of the following three values:

- 0 indicates that the bidirectional track is empty and thus is not being used in any direction.
- 1 indicates that the bidirectional track is being used in the direction left to right.
- 2 indicates that the bidirectional track is being used in the direction right to left.

Note, that in the light of keeping the state space as compact as possible, the value $z = 0$ can be omitted since the same information can be obtained from the vector x_0 (i.e. if vector x_0 is a vector of zero's then z must be 0 and thus the current value of z can be ignored). However, in order to simplify the discussion in this chapter we will make use of all three values of z.

The state space is now a combination of three variables and is denoted by (x, y, z).

5.2.2 Decisions

Unlike the case with the Fork$_R$-junctions, the decision now depends on the state of the destination track. If the destination track is occupied, then it is being used in a certain direction. In that case, the trains from the opposite direction may not enter the destination track.

Let $\mathcal{A}$ be the set of all possible decisions, that is $\mathcal{A} = \{0, 1, \cdots, R\}$ where R is the number of arrival tracks then $\mathcal{A}_{LR} \subset \mathcal{A}$ is a subset of $\mathcal{A}$ which contains only the decisions that are valid when the destination track is used in the direction LR. Subsequently, $\mathcal{A}_{RL} \subset \mathcal{A}$ is a subset with valid decisions when the direction of movement is RL. Note, that both subsets include the decision $a = 0$ since it is always valid to deny all trains from entering the destination track. Figure 5.5 depicts all possible scenarios and the corresponding decisions.

If the destination track is empty, then $z = 0$ and the decision a is not bounded by the traffic on the destination track (Branch B in Figure 5.5). However, if there is at least one train running on the destination track, then the track is being used in direction z. Now,

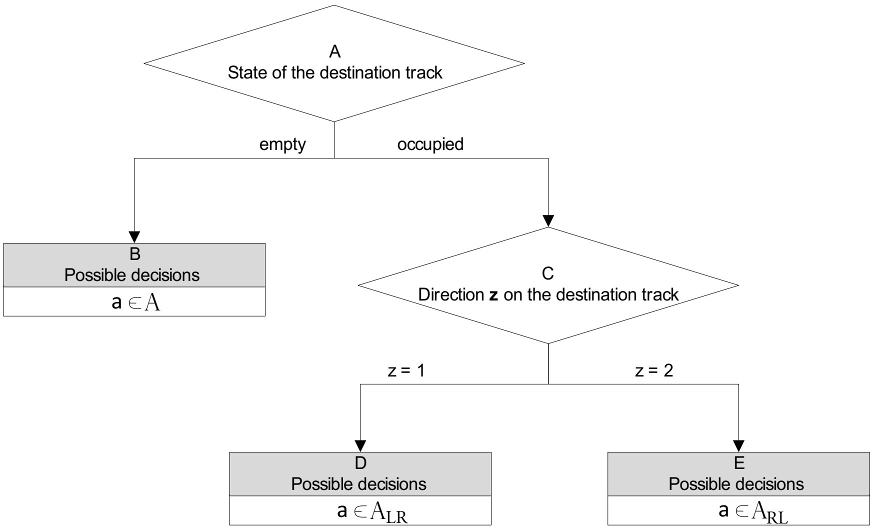

Figure 5.5: Chart with possible decisions depending on the state of the bidirectional destination track

the trains from the opposite direction may not enter the destination track. So if $z = 1$ then the decision a is restricted by subset $\mathcal{A}_{LR}$. Alternatively, if $z = 2$ then a is restricted by $a \in \mathcal{A}_{RL}$.

5.2.3 Time advance

As it was the case for Fork$_R$ junction, after the decision is made, the time is advanced with $\tau(x, y, a)$ time units. This time is called the Jump Time and reflects multiple processes as is indicated in Section 2.2.3. And again, if the decision is $a = 0$, i.e. no train crosses the junction, then the time advances with headway h time units.

5.2.4 Transitions

In Chapter 3 we have introduced three phases for transitions:

1. The Destination track phase: Trains on the destination track $r = 0$ change their position.

2. The Junction crossing phase: The train that receives permission to cross the junction, crosses it and enters the destination track. Also the speed indicators of the arrival tracks are updated.

3. The New arrivals phase: New trains arrive at the arrival tracks.

The introduction of the new variable z changes only the junction crossing phase. The other two phases remain unchanged.

The junction crossing phase changes since the train that enters the destination track defines the direction of movement on the destination track. The value of z is completely determined by the arrival track from which the train originated. If no train enters the destination track then the z value is left unchanged. There are no changes to the way the speed indicators of the arrival tracks react to the decision being made. The speed indicators act according to the procedure described in Chapter 3.

The destination track phase is not changed, since the movement of the trains on the destination track is not altered. The trains still move from the first block to the last and the movement is coupled in the same manner as it has been discussed before (see Section 2.2.7).

5.2.5 Costs

Our goal is again to minimize the total traverse time of the trains. As has been explained previously in Section 3.5 there are three cost components that together form the total costs: The arrival track costs, the destination track costs and the train rejection costs. The equations for these three components do not need to be changed and can be used here as well.

5.2.6 State space reduction

The state space reduction for the Fork$_R$ junction, which has been discussed in Section 3.6, involved omitting trains which have travelled a certain distance on the destination track. The idea behind it was the fact that the trains which do not hinder trains behind them can be omitted from the model without loss of information. The procedure involved a two step approach. In the first step the trains were omitted from the destination track if these do not hinder the trains running behind them at the destination track. In the second step the remaining trains were examined. If these trains can not hinder even the fastest train that may enter the destination track in the near future (that is after the minimal time jump interval τ), then these remaining trains may be omitted from the model as well.

As a result of the above state space reduction procedure, the state on the destination track could be simplified to the state that the destination track becomes empty. This practice will clearly lead to a loss of information in case of bidirectional case. Therefore, the procedure of the state space reduction has to be changed: The idea is that the last train on the track should never be omitted. Moreover, if the train is hindered by its predecessors, then these predecessors should remain part of the model as well. Therefore the second step in the above procedure must not be carried out. In mathematical terms the Equation 3.6.4 located on page 57 should be omitted.

5.3 Results

In order to study the structure of the SMD strategy and examine its performance, we will keep things simple and consider the case of the bidirectional junction with only 2 arrival tracks.

In Sections 5.3.2 and 5.3.3 the basic scenario will be defined and the structure of the corresponding SMD strategy will be studied.

In Section 5.3.4 the performance of the SMD strategy will be compared to that of other strategies. To this end, we will use simulation again. The strategies that are used for comparison have been introdued and defined in Section 4.5. However, since the destination track can now be blocked for trains in a certain direction, in Section 5.3.1 the definition of these strategies will need to be updated.

Next, in order to examine the robustness of the SMD model, in Section 5.3.5 a number of variations of the basic scenario will be studied.

5.3.1 Strategies

In Chapter 3, we have compared the SMD strategy with the following strategies: FCFS, P-F, F-P and Follow. Except for the latter, the strategies are expected to perform poorly in the setting of the bidirectional junction. This is due to the fact that these strategies do not account for the efficient usage of the bidirectional destination track. The FCFS strategy, for example, is expected to be the worst strategy since it will change the direction of movement of the bidirectional track very frequently which will cut down on the available capacity dramatically. The train type priority strategies (P-F and F-P) are expected to perform somewhat better, but since these strategies ignore the situation on the destination track, the strategies will be far from optimal. This is typically the case when same type of trains are found on both sides of the destination track. The train type priority strategies will then give priority to a train according to the FCFS principle.

In this chapter we will introduce modified versions of the P-F and F-P strategies. We will call these new strategies P-F-Follow and F-P-Follow respectively. The two strategies also give priority to one train type above the other but will act differently when two trains of the same type compete for the right to enter the bidirectional track. In this case, the decision will be to authorize a train using the Follow principle. These new strategies are expected to perform much better than their 'standard' counterparts.

The Follow strategy has proved to perform very well in the setting of the Fork_2 junction. This strategy implicitly tries to minimize the number of changes in the movement direction and thus is expected to do well in the setting of the bidirectional track. We introduce two new strategies (Follow-P-F and Follow-F-P) that in a number of cases will differ from the Follow strategy. The nature of these cases is however very specific so that the differences between these strategies are expected to be small. Yet, it is interesting to investigate whether a better version of the Follow strategy can be constructed.

Let us define these new strategies along with the already introduced strategies for the case of the bidirectional junction:

FCFS This strategy will give the priority to the train which has arrived at the junction first, regardless of the situation on the destination track. If the destination track turns out to be blocked for this train (since it is being used in an opposite direction), no train will be allowed to enter the destination track until it is cleared of trains. Only then, the previously chosen train enters the destination track.

P-F This strategy will give the priority to the passenger train above the freight train, regardless of the situation on the destination track. If two trains of the same type are found at each side of the destination track, then the FCFS strategy is used. Again, if the destination track is blocked for the train that is chosen to enter the destination track first, then no trains are allowed to enter the destination track until it is cleared of trains. Only then, the previously chosen train enters the destination track.

F-P See, strategy P-F, but now the freight train is chosen above the passenger train.

Follow The follow strategy needs some explanation. In the first place the strategy implies to process trains from a certain direction until that direction is exhausted. Then the attention is moved to trains from another direction. If at some point in time, all arrival tracks are exhausted, then the first next arrival for which the destination track is not blocked will get the right of way. If the destination track is not blocked (i.e. no trains are found on it) and there are trains at both sides of the destination track, then the priority is given to the first arrival.

Follow-P-F This is in essence the Follow strategy. However, whenever there are trains on both arrival tracks while the destination track is empty, the decision will be based on the P-F strategy (and not on the FCFS strategy as is the case with plain Follow strategy).

Follow-F-P same as Follow-P-F strategy but now the freight trains are prioritized above the passenger trains.

P-F-Follow This is in essence the P-F strategy. However, whenever the two trains on both sides of the destination track are of the same type, the decision will be based on the Follow strategy (and not on the FCFS strategy as is the case with plain P-F strategy).

F-P-Follow same as P-F-Follow strategy but now the freight trains are prioritized above the passenger trains.

5.3.2 Basic scenario

Unlike the Fork junction, which has been described in an earlier chapter, the capacity of the bidirectional junction, i.e. the number of the trains that can be processed in a certain amount of time, strongly depends on the length of the destination track. When the destination track is used in a certain direction, then the track is blocked for trains from other directions. The longer the destination track, the longer the blocking period. As a result of this, the bidirectional junction will in general have a lower capacity than the Fork_R junction. Therefore, in the basic scenario which we introduce, less trains will arrive per our (10 instead of 12 which was the case with Fork_R junction) and the length of the destination track is reduced from 12 km to 8 km. Table 5.1 summarizes the characteristics of the basic scenario.

Characteristics	**P**	**F**
Speed (km/hr)	120	80
Approach time[1] (sec)	180	270
Acceleration time loss[2] (sec)	25	75
Arrival rate (per hour)	$6\frac{2}{3}$	$3\frac{1}{3}$

Table 5.1: Characteristics of the trains in the basic scenario of the bidirectional junction

[1]Recall that the approach time denoted the time that the trains need to cross the junction from the moment they entered the arrival track without being delayed by other trains.

[2]Recall that the acceleration time loss denoted the extra time that the trains lose when delayed at the arrival track above the time that the trains wait until the junction is available to them.

Note, that except for the number of trains per hour, all characteristics are unchanged when compared to Table 4.1 in Chapter 4. The ratio between the number of passenger trains and the number of freight trains is also unchanged and equals 2 to 1.

5.3.3 SMD strategy of the basic scenario

To understand the SMD strategy we will examine the SMD decision matrix. How this matrix is constructed and how it should be read has already been explained in Section 4.3. However, due to the extra variable (direction variable z), the matrix will now be more complex. Therefore, the optimal strategy will be presented in three matrices. The first one (Table 5.2) is constructed for the situation with direction variable $z = 0$, the second one (Table 5.3) for $z = 1$ and the third one (Table 5.4) is for the situation $z = 2$.

Tables 5.3 and 5.4 learn us that the SMD strategy will keep processing trains from a certain direction until all trains are processed. However, if the destination track is empty (Table 5.2), then the strategy is more complicated and depends on the type of trains at the arrival tracks and their speed. A number of conclusions:

- A moving freight train is prioritized above a moving passenger train. This way the high acceleration time loss is avoided.
- A moving train is prioritized above a stopped train. Again, this avoids additional acceleration time loss.
- Two trains on a track are always prioritized above 1 train on a track. The reason for this is that delaying two trains is more damaging than delaying one train. Moreover, the probability that a new arrival is lost is also lower.
- When two trains are located on each of the arrival tracks, then the moving train is prioritized above the stopped train to avoid extra acceleration time loss and minimize the probability that new arrivals be lost.
- A conflict between two moving passenger trains on one arrival track and a moving passenger train and a freight train on the other track (regardless of their order) is always resolved in the favour of the trains on the track containing a freight train.
- A conflict between two moving freight trains on one track and two moving trains on the other track is always resolved in the favour of the two freight trains.
- A conflict between a moving passenger train followed by a freight train on one track and a moving freight train followed by a passenger train on another track is resolved by giving the freight train the right of way.

The SMD strategy thus seems to be a very intuitive strategy giving the right of way to a track based on the train types and the speeds of the trains on the arrival tracks. Then, the trains on that track are processed until no trains are left on that track. Then if the destination track is empty, the arrival track to process next is chosen based on the types and speeds of the trains on both arrival tracks. If however the destination track is not yet empty but new trains arrive which can enter the destination track without delay, then these trains are processed first.

			x_1						
x_2	y_1	y_2	**-**	**P**	**P P**	**F P**	**F**	**P F**	**F F**
-	0	0	0	1	1	1	1	1	1
-	1	0	0	1	1	1	1	1	1
-	0	1	0	1	1	1	1	1	1
-	1	1	0	1	1	1	1	1	1
P	0	0	2	1	1	1	2	1	1
P	1	0	2	1	1	1	1	1	1
P	0	1	2	2	1	1	2	1	1
P	1	1	2	1	1	1	1	1	1
P P	0	0	2	2	1	1	2	2	2
P P	1	0	2	2	1	1	2	1	1
P P	0	1	2	2	2	2	2	2	2
P P	1	1	2	2	1	1	2	1	1
F P	0	0	2	2	2	1	2	2	2
F P	1	0	2	2	1	1	2	1	1
F P	0	1	2	2	2	2	2	2	2
F P	1	1	2	2	2	1	2	1	1
F	0	0	2	1	1	1	1	1	1
F	1	0	2	1	1	1	1	1	1
F	0	1	2	2	1	1	2	1	1
F	1	1	2	2	1	1	1	1	1
P F	0	0	2	2	1	1	2	1	1
P F	1	0	2	2	1	1	2	1	1
P F	0	1	2	2	2	2	2	2	2
P F	1	1	2	2	2	2	2	1	1
F F	0	0	2	2	1	1	2	2	1
F F	1	0	2	2	1	1	2	1	1
F F	0	1	2	2	2	2	2	2	2
F F	1	1	2	2	2	2	2	2	1

Table 5.2: SMD decision matrix of the basic scenario when $z = 0$. For each combination of (x_1, x_2, y_1, y_2) a decision is given. 1 indicates that a train from arrival track 1 receives permission to cross the junction. 2 indicating that a train from arrival track 2 may proceed.

			x_1						
x_2	y_1	y_2	**-**	**P**	**P P**	**F P**	**F**	**P F**	**F F**
-	0	0	0	1	1	1	1	1	1
-	1	0	0	1	1	1	1	1	1
-	0	1	0	1	1	1	1	1	1
-	1	1	0	1	1	1	1	1	1
P	0	0	0	1	1	1	1	1	1
P	1	0	0	1	1	1	1	1	1
P	0	1	0	1	1	1	1	1	1
P	1	1	0	1	1	1	1	1	1
P P	0	0	0	1	1	1	1	1	1
P P	1	0	0	1	1	1	1	1	1
P P	0	1	0	1	1	1	1	1	1
P P	1	1	0	1	1	1	1	1	1
F P	0	0	0	1	1	1	1	1	1
F P	1	0	0	1	1	1	1	1	1
F P	0	1	0	1	1	1	1	1	1
F P	1	1	0	1	1	1	1	1	1
F	0	0	0	1	1	1	1	1	1
F	1	0	0	1	1	1	1	1	1
F	0	1	0	1	1	1	1	1	1
F	1	1	0	1	1	1	1	1	1
P F	0	0	0	1	1	1	1	1	1
P F	1	0	0	1	1	1	1	1	1
P F	0	1	0	1	1	1	1	1	1
P F	1	1	0	1	1	1	1	1	1
F F	0	0	0	1	1	1	1	1	1
F F	1	0	0	1	1	1	1	1	1
F F	0	1	0	1	1	1	1	1	1
F F	1	1	0	1	1	1	1	1	1

Table 5.3: SMD decision matrix of the basic scenario when $z = 1$

			x_1						
x_2	y_1	y_2	**-**	**P**	**P P**	**F P**	**F**	**P F**	**F F**
-	0	0	0	0	0	0	0	0	0
-	1	0	0	0	0	0	0	0	0
-	0	1	0	0	0	0	0	0	0
-	1	1	0	0	0	0	0	0	0
P	0	0	2	2	2	2	2	2	2
P	1	0	2	2	2	2	2	2	2
P	0	1	2	2	2	2	2	2	2
P	1	1	2	2	2	2	2	2	2
P P	0	0	2	2	2	2	2	2	2
P P	1	0	2	2	2	2	2	2	2
P P	0	1	2	2	2	2	2	2	2
P P	1	1	2	2	2	2	2	2	2
F P	0	0	2	2	2	2	2	2	2
F P	1	0	2	2	2	2	2	2	2
F P	0	1	2	2	2	2	2	2	2
F P	1	1	2	2	2	2	2	2	2
F	0	0	2	2	2	2	2	2	2
F	1	0	2	2	2	2	2	2	2
F	0	1	2	2	2	2	2	2	2
F	1	1	2	2	2	2	2	2	2
P F	0	0	2	2	2	2	2	2	2
P F	1	0	2	2	2	2	2	2	2
P F	0	1	2	2	2	2	2	2	2
P F	1	1	2	2	2	2	2	2	2
F F	0	0	2	2	2	2	2	2	2
F F	1	0	2	2	2	2	2	2	2
F F	0	1	2	2	2	2	2	2	2
F F	1	1	2	2	2	2	2	2	2

Table 5.4: SMD decision matrix of the basic scenario when $z = 2$

5.3.4 Results of the basic scenario

Now it is time to compare the performance of the SMD strategy with that of other strategies through simulation. Table 5.5 summarizes the results of the basic scenario. The FCFS strategy is not able to route the trains through the bidirectional junction. Under the FCFS strategy the direction of the junction is switched too often, decreasing the available capacity dramatically and results in ever growing queues on both sides of the junction.

On the other hand, the behaviour for the rest of the strategies is stable, which indicates that these strategies can cope with the bidirectional junction for the current junction loads. However the differences in performance for these strategies are substantial. Prioritizing the freight trains above the passenger trains (F-P strategy) turns out to be a very poor strategy. The delays of the passenger trains are exceptionally high compared to other strategies which results in the very high mean delays. By reversing the priority and giving passenger trains the right of way above the freight trains (P-F strategy) the mean delays of trains are cut almost by a half. This is due to the fact that the delays of the passenger trains in the latter case are decreased by 17 minutes while the increase in delays of the freight trains is only 40 seconds.

Discipline	**P**	**F**	**Mean**
SMD	364	328	352
Follow	396	368	386
Follow-P-F	391	378	387
Follow-F-P	401	360	387
P-F-Follow	409	727	515
F-P-Follow	527	307	454
P-F	600	1139	779
F-P	1626	1098	1450
FCFS	∞	∞	∞

Table 5.5: Mean delays in seconds of the basic scenario

An interesting result gives us the combination of the train type priority strategies with the Follow strategy. The difference between the P-F strategy and the P-F-Follow strategy arises in cases where on both sides of the destination track the same type of trains are willing to enter the track. While the former strategy will treat these trains via the FCFS rule, the latter strategy will use the Follow principle. This reduces the delays significantly since there are far less direction switchings of the destination track. Curiously enough, the F-P-Follow strategy performs now better than the P-F-Follow strategy while this was exactly the opposite in case of the F-P and the P-F strategies. This result is due to the fact that the F-P-Follow strategy tries to minimize both the number of direction switchings and the acceleration time loss of the freight trains.

The Follow strategy cuts back the delays even further. The mean delays are only a half of the delays found at the P-F strategy. This is due to the fact that the destination track is being used in a very efficient way by minimizing the number of direction switches. The Follow-P-F and the Follow-F-P strategies do not perform better than the Follow strategy. A few cases where the strategies differ from each other do not cause any significant differences in performance.

The difference between the Follow strategy and the SMD strategy is still substantial. The SMD strategy cuts down the delays by 9 percent. The difference between the two strategies occurs when the destination track becomes empty. In this case, there are two possibilities:

- the arrival track which has been served latest is still empty
- the arrival track which has been served latest is occupied again

In the first case, the Follow strategy will choose according to the FCFS principle among the occupied arrival tracks while in the latter case, the same track will be 'served'. On the other hand, The SMD strategy takes the decision based on the current situation on the arrival tracks.

5.3.5 Variations of the basic scenario

The SMD strategy performed very well for the case of the basic scenario. In this section we will examine whether the performance changes when tested in different settings. We will start by studying the case where the system load is increased, i.e. the number of trains arriving per hour is increased. This will be done in Section 5.3.5.1. Then, the ratio between the passenger trains and the freight trains will be changed in Section 5.3.5.2. As the length of the destination track changes the time that the junction can be blocked for a certain direction, changing this length should have consequences for the different strategies. This will be investigated in Section 5.3.5.3. Next, in Section 5.3.5.4 a number of different conclusions of other tests are summarized.

5.3.5.1 System load

The load of the system has a direct influence on the available capacity of the junction. Figure 5.6 depicts how different strategies perform at various system load rates.

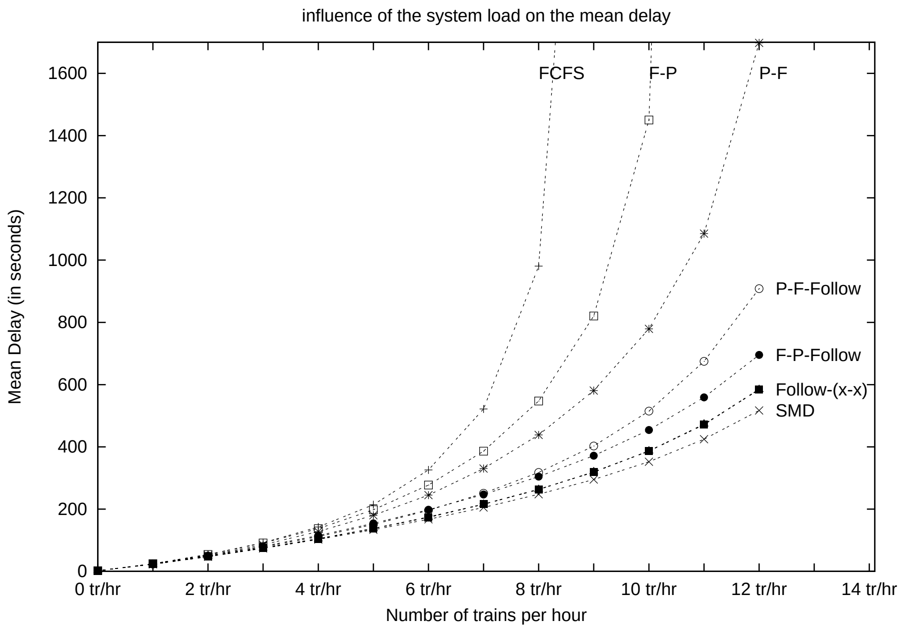

Figure 5.6: Influence of the system load on the mean delay

It is clear that the FCFS strategy has a growing difficulty with processing the trains when the system load is risen. The delays of trains rise exponentially and already at the load of 9 trains per hour, the strategy can not cope with the train flow anymore. The strategies F-P and P-F can handle higher loads but eventually fail in processing the trains. The difference between the SMD and the Follow strategy grows when the system load increases. In Figure 5.7 we can see that at the load of 12 trains per hour, the delays of the SMD strategy are 10% lower than that of the Follow strategy. In the figure the strategies Follow, Follow-P-F and Follow-F-P are denoted as Follow(-x-x) since the three strategies have similar performance.

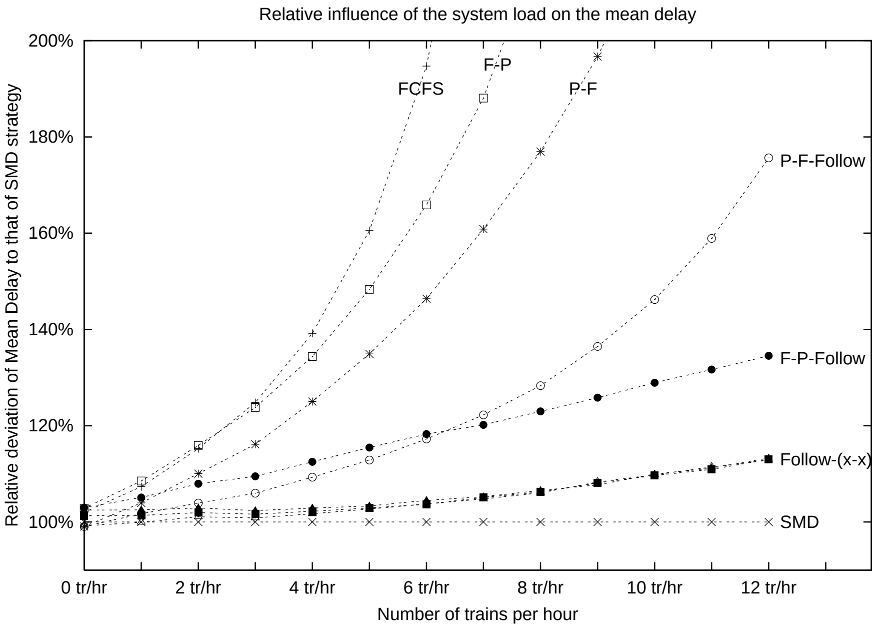

Figure 5.7: Relative performance of different strategies at increasing system load

5.3.5.2 The passenger-freight train ratio

The passenger-freight train ratio is the ratio between the number of passenger and the number of freight trains. We indicate this ratio by P:F (e.g. 7:3 indicates that on average 7 passenger trains and 3 freight trains arrive per hour). Figure 5.8 depicts the influence of this ratio on the mean delays.

The results of the FCFS strategy is omitted since it is unstable for the system load 10 trains per hour, regardless of the P:F ratio. One of the things that draws our attention in the figure, is that the F-P strategy is the only one that performs better as the percentage of freight trains increases. This is true since less passenger trains suffer from this strategy: On the one hand, there are less passenger trains which are stopped in favour of the freight trains and on the other hand less passenger trains get stuck behind the freight trains on the destination track.

The difference between the P-F-Follow strategy and the F-P-Follow strategy decreases when more passenger trains are found in the system. In this case, giving freight trains the right of way becomes gradually more unattractive.

The mean delays of both the Follow and SMD strategy increase when the percentage of freight trains increases. But at all ratio's, the SMD strategy performs significantly better than the Follow strategy.

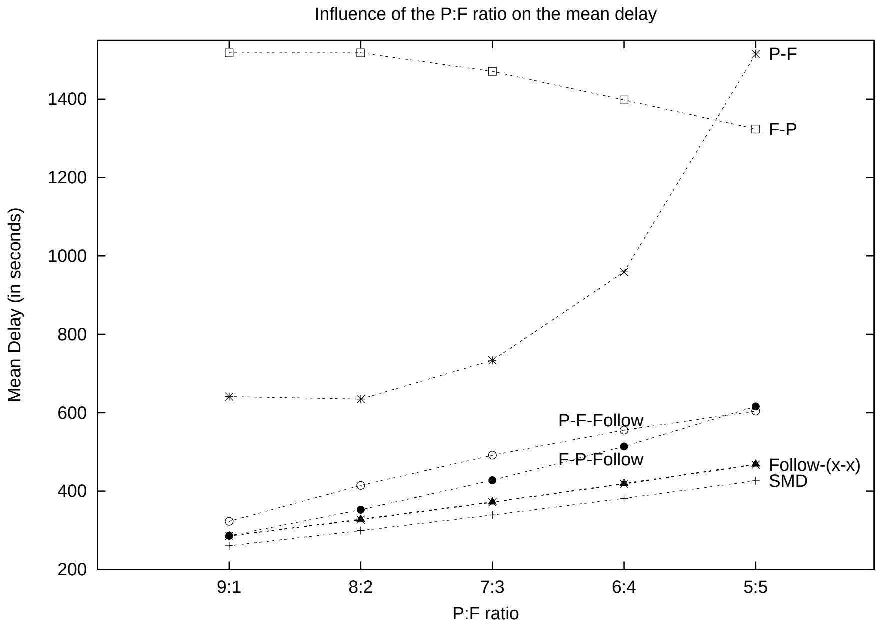

Figure 5.8: Performance of different strategies at different P:F ratio

5.3.5.3 Length of the destination track

The length of the bidirectional destination track has a huge influence on the junction capacity. Figure 5.9 shows how different strategies perform when the destination track is 4, 8 or 12 km long.

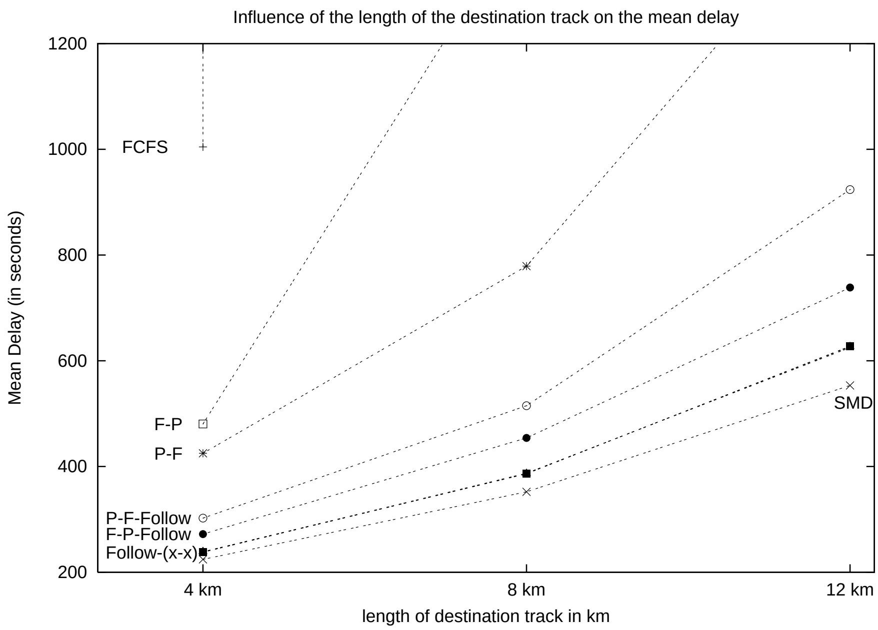

Figure 5.9: Influence of the length of the destination track on the mean delay

The FCFS strategy can only manage trains when the destination track is 4 km long. When the length of the track is risen to 8 km then the queues begin to pile up resulting in ever growing train delays. Although the F-P and P-F strategies can manage a longer track length, their performance is very poor. Combining these train type priority strategies with the Follow strategy does result in a better performance, yet this performance is still poor in comparison to the Follow and the SMD strategies. The Follow family of strategies does almost optimal when the destination track is only 4 km long but the difference with the SMD strategy grows when the track gets longer.

5.3.5.4 Other results

Among the other tests that we have studied are the tests involving the influence of the acceleration time loss of the freight trains. As expected, the higher the value of the acceleration time loss the more important it becomes to keep the freight trains moving. The SMD strategy adapts itself and as a result keeps performing very well.

Shortening the headway between trains enables trains to run closer to each other. As a result more trains can cross the junction within the same time interval. Also in this case the performance of the SMD strategy is good.

When it comes to situations where trains have different priorities, the true added value of the SMD strategy becomes evident. The SMD strategy is the only strategy that gives priority to prioritised trains without delaying other trains much. It does so by prioritizing the trains only when it is not that damaging to others rather than giving blindly the full priority.

Finally, when changing the load of the arrival tracks and thus making one arrival track busier than the other track, the SMD strategy adapts accordingly giving a train from a busier track more priority than to the traffic coming from the other track. As a consequence, the results of the strategy remain good.

5.4 Conclusions

In this chapter the SMD model has been extended to incorporate junctions involving bidirectional traffic. It has been shown that with minor changes the existing description can be extended to facilitate this new type of junctions. For a basic scenario involving two type of trains and two arrival tracks, the SMD strategy is quite intuitive. The strategy showed good performance too. While the difference between the Follow strategy and the SMD strategy was small for the case of the Fork_2 junction, the delays of the SMD strategy turn out to be around 10% less in case of the basic scenario of the bidirectional junction.

Moreover this difference tends to grow when the situation around the bidirectional junction grows in complexity, e.g. when the number of arriving trains grows or when the length of the destination track is increased.