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Modelling of Metro Railway Signalling using Petri Net

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Abstract: This paper deals with the use of Petri nets in modelling metro railway network and designing appropriate control logic for it to avoid collision. Here, the whole metro network is presented as a combination of the elementary models – blocks and signals within the track. We here model automatic train protection (ATP) and overlap to ensure safeness of the railway network. In this research work, we have actually introduced constraints at the signals in the metro track. These constraints ensure safe working of metro network.

Keywords: Petri nets, safeness constraints, ATP, asynchronous systems.

1 INTRODUCTION

Modeling of complex systems for better understanding is a very wide-spread research activity and researchers all over the world are trying to model more and more complex systems. Several tools have also been developed for this purpose and Petri Net [1] is one of such tools used for quite some time to model various asynchronous systems. Metro railway network is considered as a very complex system and appropriate modeling of it to avoid collision is of very high importance. In our research work, we have used petri net to model metro railway network and avoid collision in tracks.

2 BRIEF OVERVIEW OF PETRI NETS

2.1 Definition of Petri nets

Petri net is a formal modelling technique and consists of places, transitions and arcs directed from either places to transitions or transitions to places, representing flow relations. Pictorially, places are drawn as circles and transitions as boxes or bars (Figure 1). Arcs are labelled with weights. Labels for unity weights are generally not given. A place from which a directed arc goes to a transition is called input place of that transition. A place, to which there is a directed arc from a transition, is called output place of that transition. A Petri net is given a state by marking its places with tokens. A marking M is a function [9] that assigns to each place a non negative integer representing number of tokens at that place. In graphical representation, black dots in circles denote tokens in places. Petri Nets may formally be defined as [1] A Petri net is a 5-tuple - (P, T, F, W, M_0) where :

$P = \{ p_1, p_2, \ldots ,p_m \}$ is a finite set of places,
$T = \{ t_1, t_2, \ldots ,t_n \}$ is a finite set of transitions,
$F \subseteq (P \times T) \cup (T \times P) \}$ is a set of arcs (flow relations),
$W: F \rightarrow \{1, 2, 3, \ldots\}$ is a weight function,
$M_0: P \rightarrow \{0, 1, 2, 3, \ldots\}$ is the initial marking,
$P \cap T = \varnothing$ and $P \cup T \neq \varnothing$.

where, (P xT) and (Tx P) denotes the ordered pair of sets P and T.

By changing distribution of tokens on places the occurrence of events (transitions) may be reflected. The flow of tokens in Petri net are governed by the following rules [2]

A transition t is said to be enabled if each input place p of t contains at least the number of tokens equal to the weight of the directed arc connecting p to t.

A firing of an enabled transition t removes from each input place p the number of tokens equal to the weight of the directed arc connecting p to t. It also deposits in each output place p the number of tokens equal to the weight of the directed arc connecting t to p – giving a new marking. There are also some high-level Petri nets – timed Petri net [6][7], coloured Petri net [8] etc.

2.2 Applications of Petri nets

Petri nets are used for a very wide variety of applications. Especially they are well-suited for systems those are concurrent, asynchronous, distributed, parallel and nondeterministic [1]. In [6], the author presents how timed Petri net is used to model the GPRS charging system and to analyze its performance when the system works in the normal status and how it handles the maximum supportable busy hour call attempts of the GPRS network. [7] also depicts application of timed Petri net to model traffic signal control where two separate subnets are designed for signal indications (green, yellow, and red) and the transitions between indications (one light becomes red before another becomes green).

Besides these, Petri nets have been successfully applied in modeling and performance analysis of communication protocols, flexible manufacturing systems, sequence controllers, distributed-software systems, distributed-database systems, multiprocessor systems, fault-tolerant systems, programmable logic and VLSI arrays [1] etc. Using Petri nets dynamic behavior of the systems can also be studied [2].

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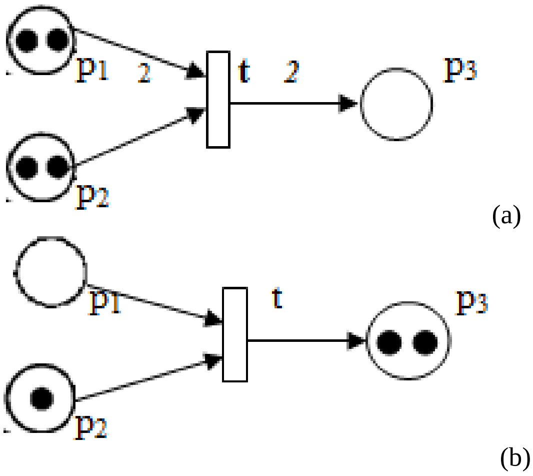

Figure 1: The marking (a)before firing of enabled transition t (b)after firing of t

3 METRO RAILWAY PROBLEM

Signaling used on high density metro (or subway) routes is based on the same principles as main line signaling. The line is divided into blocks and each block is protected by a signal but, for metros, the blocks are shorter so that the number of trains using the line can be increased. They are also usually provided with some sort of automatic supervision to prevent a train passing a stop signal.

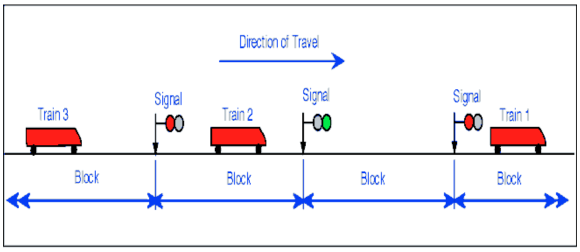

Figure 2: Diagram showing simple Metro-style two-aspect signaling.

Originally, metro signaling was based on the simple 2-aspect (red/green) system as shown above. Speeds are not high, so three-aspect signals were not necessary and yellow signals were only put in as repeaters where sighting was restricted. Many metro routes are in tunnels and it has long been the practice of some operators to provide a form of enforcement of signal observation by installing additional equipment. This became known as automatic train protection (ATP). It can be either mechanical or electronic. The older, mechanical version is the train stop; the later, electronic version depends on the manufacturer. The trainstop consists of a steel arm mounted alongside the track and which is linked to the signal. If the signal shows a green or proceeds aspect, the trainstop is lowered and the train can pass freely. If the signal is red the trainstop is raised and, if the train attempts to pass it, the arm strikes a "tripcock" on the train, applying the brakes and preventing motoring. Electronic ATP involves track to train transmission of signal aspects and (sometimes) their associated speed limits.

On-board equipment will check the train's actual speed against the allowed speed and will slow or stop the train if any section is entered at more than the allowed speed. Petri net representation is given below.

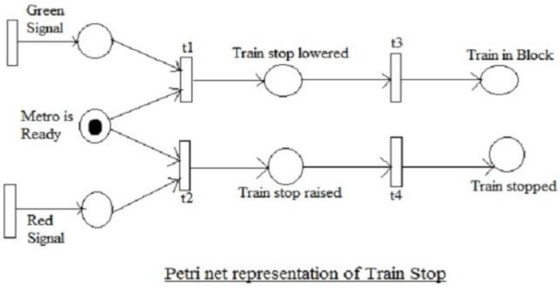

Figure 3 Petri net representations

Here, we can explain the operation of train with respect to signal. If the signal is green and a metro is read (that is a token at both the places), then transition t1 will be fired leading to a token in place 'Train stop lowered' leading to a token 'Train in block', i.e. the train has entered the particular block. If the signal is red and the metro is ready then, t2 and t4 will be fired sequentially, finally getting a token in train stopped, i.e., the train is made to stop.

3.1 The Overlap

If a line is equipped with a simple ATP which automatically stops a train if it passes a red signal, it will not prevent a collision with a train in front if this train is standing immediately beyond the signal.

There must be room for the train to break to a stop - see the diagram above. This is known as a "safe braking distance" and space is provided beyond each signal to accommodate it. In reality, the signal is placed in rear of the entrance to the block and the distance between it and the block is called the "overlap". Signal overlaps are calculated to allow for the safe braking distance of the trains using this route. Of course, lengths vary according to the site; gradient, maximum train speed and train brake capacity are all used in the calculation.

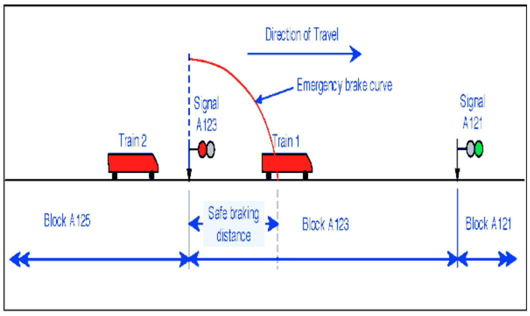

Figure 4: Diagram showing the need for a safe braking distance beyond a stop signal

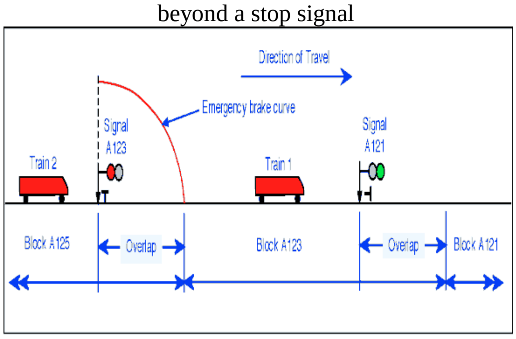

Figure 5: Diagram showing a signal provided with an overlap.

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The overlap in this example is calculated from the emergency braking distance required by the train at that location.

This diagram (Figure 5) shows the arrangement of signals on a metro where signals are equipped with trainstops (a form of mechanical ATP) and each signal has an overlap whose length is calculated on the safe braking distance for that location. Signals are placed a safe braking distance in rear of the entrances to blocks. Signal A2 shows the condition of Block A2, which is occupied by Train 1. If Train 2 was to overrun Signal A2, the raised trainstop (shown here as a "T" at the base of the signal) would trip its emergency brake and bring it to a stand within the overlap of Signal A2.

Overlaps are often provided on main line railways too. In the US, the overlap is considered so important that a whole block is provided as the overlap. It is referred to as "absolute block". This means that there is always a full, vacant block between trains.

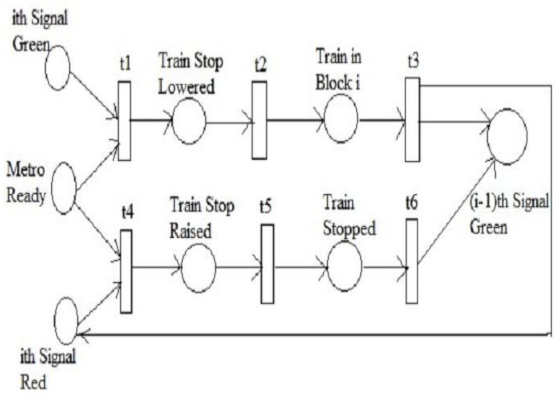
Figure 6

Now, lets see how signaling changes with train. Considering the ith block having ith and (i-1)th signals described as follows:

Adding certain elemnts to above diagram, we get, if ith signal is green and a metro ready then, transition t1,t2,& t3 is fired one after another. Once a train has entered ith block, thus block (i-1) is free, so its signal will be shown green and as a train has entered ith block, so ith signal will be red.

If at beginning ith signal is red, then train will be stopped but the train will stop in the overlap of signal i. So,(i-1)gets free leading to (i-1)th signal green.

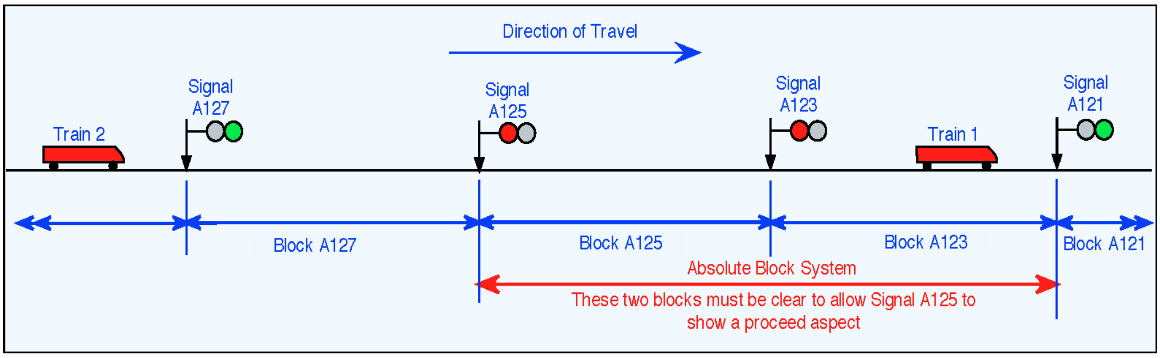
3.2 Absolute Block

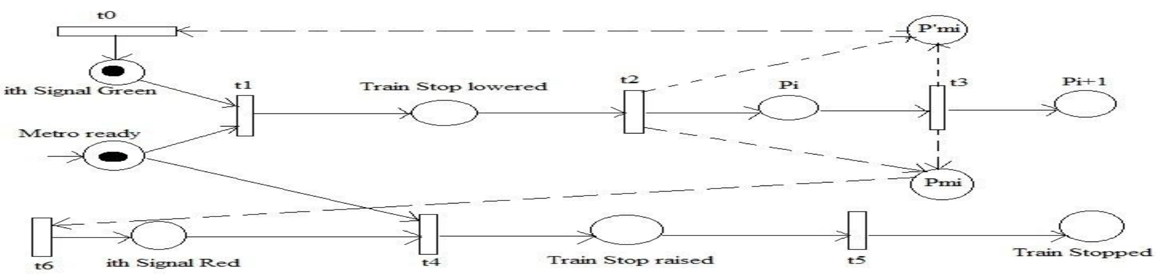


Petri net representation of Overlap in ATP

Figure 7: Schematic showing the principle of he Absolute Block system. Signal A127 is clear because two blocks in advance of it are clear. A125 shows a danger aspect because one of the blocks ahead of it is occupied by a train.

Many railways use an "Absolute Block" system, where a vacant block is always maintained behind a train in order to ensure there is enough room for the following train to be stopped if it passes the first stop (red) signal. In Figure 6, in order for Signal A125 to show a proceed aspect (green), the two blocks ahead of it must be clear, with Train 1 completely inside the block protected by Signal A121. As now we have to check two consecutive blocks for signaling a single signal, so, we included certain constraints into the older petrinet. For, putting constraints we use monitors as used in railway network, so, monitor PM,i and P`M,i are introduced. Two constraints are:





Petri net representation of Absolute Block

Figure 8

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1. For signal to be green, place Pi and Pi+1 should be free, i.e., Mi+Mi+1=0, Managed by P`M,i.
2. For signal to be red, any of the place Pi and Pi+1 should be full, i.e., will get a token Mi+Mi+1>=1, Managed by PM,i.

So, two monitors defined above are introduced into previous petrinet. if any of the place Pi or Pi+1 has a token, i.e., a train is there in that particular block ,then monitor will check and ith signal is made red by PM,i ,else if places Pi or Pi+1 are free then P`M,i and ith signal is made green.

3.3 Electronic ATP

To adapt metro signaling to modern, electronic ATP, the overlaps are incorporated into the block system. This is done by counting the block behind an occupied block as the overlap. Thus, in a full, fixed block ATP system, there will be two red signals and an unoccupied, or overlap block between trains to provide the full safe braking distance, as shown here .As an aside, remember that, although I have shown signals here, many ATP equipped systems do not have visible lineside signals because the signal indications are transmitted directly to the driver's cab console (cab signalling).

On a line equipped with ATP as shown above, each block carries an electronic speed code on top of its track circuit. If the train tries to enter a zero speed block or an occupied block, or if it enters a section at a speed higher than that authorised by the code, the on-board electronics will cause an emergency brake application. This is the system used by London Underground for the Victoria Line from 1968 - the first fully automatic, passenger carrying railway. It was a simple system with only three speed codes - normal, caution and stop. Many systems built since are based on it but improvements have been added.

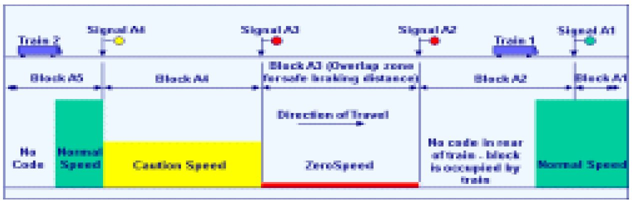

Figure 9: Electronic ATP

3.4 ATP Speed Codes

A train on a line with a modern version of ATP needs two pieces of information about the state of the line ahead - what speed it can do in this block and what speed must it is doing by the time it enters the next block. This speed data is picked up by antennae on the train. The data is coded by the electronic equipment controlling the track circuitry and transmitted from the rails. The code data consists of two parts, the authorized speed code for this block and the target speed code for the next block. The diagram below shows how this works.

Here a train in Block A5 approaching Signal A4 will receive a 40 over 40 code (40/40) to indicate a permitted speed of 40 km/h in this block and a target speed of 40 km/h for the next. This is the normal speed data. However, when it enters Block A4, the code will change to 40/25 because the target speed must be 25 km/h when the train enters the next Block A3. When the train enters Block A3, the code changes again to 25/0 because the next block (A2) is the overlap block and is forbidden territory, so the speed must be zero by the time train reaches the end of Block A3. If the train attempts to enter Block A2, the on-board equipment will detect the zero speed code (0/0) and will cause an emergency brake application. As mentioned above, Block A2 is acting as the overlap or safe braking distance behind the train occupying Block A1.

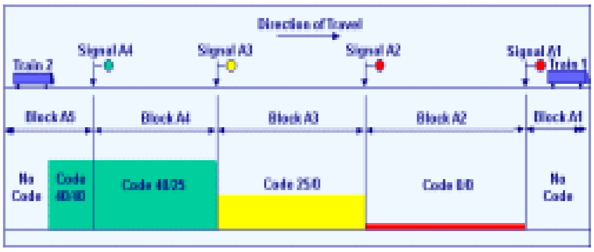

Figure 10: ATP Speed Codes

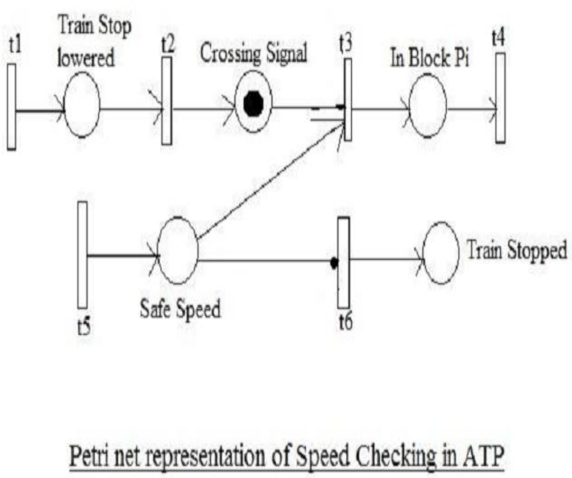

Figure 11

Now, moving towards speed checking, we get fig 11. Here, transition t5 will be fired only if the speed is safe for the upcoming track. Transition t5 is controlled by speed controller, manually done by stations. If speed is safe, we get a token at Safe speed place, then if –else condition is checked if speed safe then transition t3 is enabled else transition t6 is enabled. i.e., if speed is safe the metro is fine and can easily go ti block i else if speed is not safe then train stopped.

3.5 Final Petri net Model for ATP

Combining ATP petrinet and the speed checking Petrinet we get our final Petrinet for Automatic Train Protection as shown above. Here, there are 12 places and 11 transitions, Out of the 12 places, two places are acting as monitor (constantly monitoring the constraints) and out of the 11 transitions, two transitions (t6 & t7) are monitored manually by speed controller from stations. Rest all the places and transitions works as explained above in sub-petrinets.

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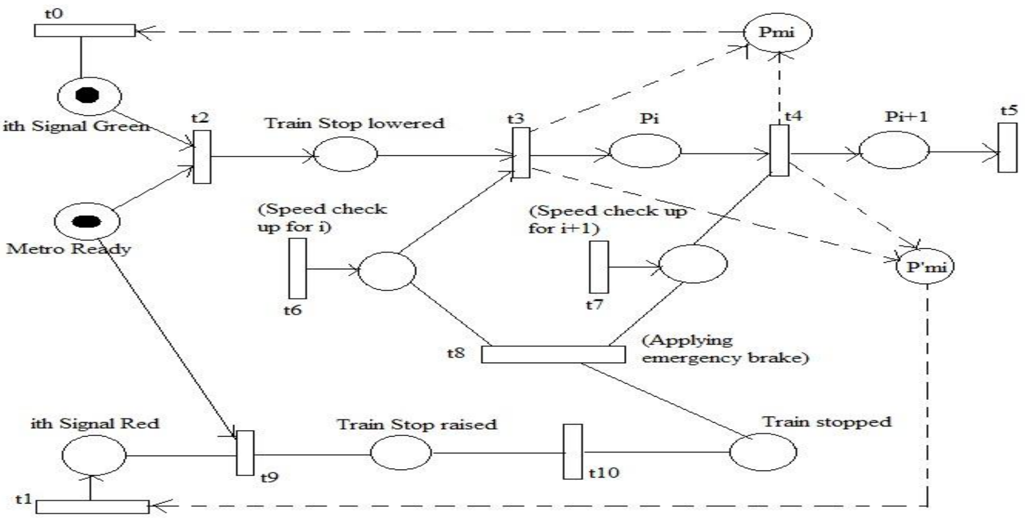

Petri net representation of ATP (Automatic Train Protection)

Figure 12

4 CONCLUSION

Modelling with Petri net is being considered as one of the very helpful tools to detect collision in a metro railway network problem. Following the design model of Giua and Seatzu in [3], in this research work we have modelled the metro network and introduced constraints at the points signals. This ensures correct working of signals in metro network.

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