Punctuality analysis by the microscopic simulation and visualization of web-based train information system data

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Abstract

In order to increase the robustness of a railway system, the detailed analysis for a combination of tracks, signalling systems, timetables and operation of trains is indispensable. We introduce an approach to foresee and analyse punctuality for railway lines where trains are densely operated. Our approach consists of three phases, namely, the analysis of the current situation of train operation (observation phase), the forecasting of the future situation of train operation (forecast phase) and the analysis of train operation after some changes are made (checking phase). In the observation phase and in the checking phase, we visualize train traffic record data using the Chromatic diagram. In the forecast phase, we use a microscopic simulator that we have developed. In this paper, we show our experience of applying this approach when a part of a track was relocated in the Odakyu electric railway company.
Keywords: robustness, punctuality analysis, microscopic simulation, track circuit, visualization.

1 Introduction

In urban areas of Japan, there exist big demands for railway transportation. In Tokyo area, about 38 million people use railways a day in average. In order to satisfy such a big demand, trains are running densely. In many railway lines in Tokyo, trains which consist of typically ten or sometimes even 15 cars which are 200m or even 300m long are running every two to three minutes on a double track line. This means that 20 to 30 trains are running per hour per direction.

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One of the recent problems in urban railways in Japan is that small delays often happen during the rush hours. Because we have to operate trains densely, a small delay propagates to succeeding trains and the delay tends to expand. Passengers complain even for delays of several minutes because they use the transfer guidance systems and if trains are delayed, they cannot catch the train as indicated by the system. Thus, railway companies are now very keen to reduce small delays during the rush hours [1].

A railway system should be regarded as a combination of various components, such as a timetable, rolling stock, tracks, signalling systems and operation. In order to improve robustness of a railway system, detailed analysis of this combination is indispensable. For example, in railway lines where trains are running densely, trains are sometimes compelled to stop outside a station and where these trains stop and how to drive these trains between stations are closely related with an increase of delays. In addition, lengths of track circuits, aspects of signals are also relevant. This means that each of these components has to be carefully designed taking the interrelationship between them into account. Thus, when there is a renovation in some components, we have to carefully analyse how the renovation gives an influence to punctuality of the whole railway system well in advance.

In this paper, we introduce our approach of punctuality analysis. Our approach consists of three steps, namely, an observation phase, a forecast phase and a checking phase. In the observation phase, we visualize everyday train traffic record data which we collect from our web-based train traffic information system. We visualize the data by the Chromatic Diagram, which is a train diagram in which each train line is coloured depending on its delay. In the forecast phase, we forecast train traffic under given circumstance using a microscopic simulator. By giving different parameters and repeating simulation, we can get information helpful to make a decision. In the checking phase, again we visualize the train traffic record data after the renovation was made and analyse if punctuality is improved or not.

In the latter half of this paper, we describe our experience of punctuality analysis in detail when a part of a track in the busiest area was relocated. After a detailed examination based on our approach, we made a decision, which was proved to be successful from the viewpoint of regaining punctuality.

2 Odakyu electric railway company

2.1 Outline of Odakyu Electric Railway Company – facts and figures

Odakyu Electric Railway Company (OER) is one of the major private railway companies in Japan. OER operates several railway lines, which connect suburban areas of Tokyo and Shinjuku station, which is located in the centre of Tokyo and known to be the busiest station in the world. The whole length of the tracks is about 120km and there exist 70 stations (see Figure 1). The gauge is narrow (1,057mm) and about 8% (9.5km) of the tracks are quadruple and the remaining parts are double. OER is planning to expand the quadruple tracks by 1.6km but it will take a few more years because it is not an easy job to do such a construction work in populated areas.

OER transports about 721 million passengers a year (about 2 million a day in average). Various kinds of trains are operated: a regular train, several types of express trains and a limited express. The maximum speed of trains is 110km/h. The limited express directly connects Shinjuku and Hakone area, which is known to be one of the most famous resort areas in Japan with a good view of Mt. Fuji.

Figure 1: Odakyu electric railway company.

There exists a big demand for commuting especially in OER Tokyo area. To fulfil the demands, trains are operated very densely. During the busiest time, that is, from 7:47 to 8:49, 29 trains are operated upward. In Figure 2, a part of the diagram (7:30–9:00) of OER and the basic pattern of the timetable around the busiest area are shown (Y, H, S and U are the initials of the stations; details will be explained later). The pattern should be considered as a repetition of a combination of one regular train (Regular) and two express trains (Express 1 and Express 2, respectively) with a cycle time of 6 minutes and 40 seconds.

2.2 Punctuality target of Odakyu electric railway company

OER is also very keen to reduce small delays during the rush hours. The target of punctuality is *two minutes*. This means that all the trains have to arrive at Shinjuku (the terminal) station with a delay less than two minutes every day.

3 Visualization of train traffic record data

3.1 Train traffic record data from Web TID system

3.1.1 Train traffic record data

Train traffic record data, which are a collection of arrival and departure times of all the trains for all stations are very useful to analyse everyday train operation.

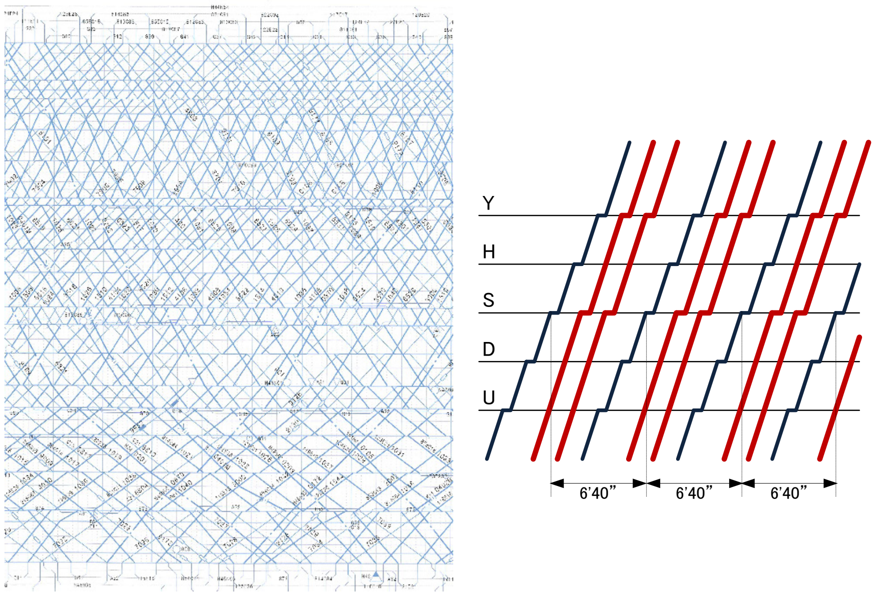

Figure 2: Diagram of OER: 7:30–9:00 (left) and the basic pattern (right).

As far as the authors know, [2] is the pioneering paper to show train traffic record data are very promising to analyse every day train operation. In [3], a data compilation system to analyze punctuality of trains of the whole SBB railway network in a long term is proposed. In [4], it is shown that an appropriate visualization of train traffic record data called the Chromatic Diagram is helpful to intuitively grasp emergence and propagation of delays in busy railway lines. In [5], several expressive styles of the data such as a box plot graph are presented. In [6], an algorithm to detect conflicts of trains based on the train describer event data is presented. In [7], correcting methods of track occupation and release times to get more accurate times of train’s arrival and departure are discussed.

3.1.2 Web TID – Web based Train Information Display

Unfortunately, however, the train traffic control system of OER has not a function to collect train traffic record data: arrival and departure times only at the major stations are recorded, which does not suffice to analyse detailed train operation.

Hence, we looked for another source of data and noticed that an idea to get the data from the Web TID (Web based Train Information Display system) is promising. Web TID, which is shown in Figure 3, is a system used to give information about current locations of trains to the staff in charge of train operation, such as train dispatchers, station staff, workers at car depots and crew bases and so on. They can get the information using web browsers on their PCs. We confirmed that it is possible to collect the data about the time of occupation and release of each track circuit from the Web TID.

But there was a problem. The track occupation and release data obtained from the Web TID do not contain train numbers. There does exist train number information as well because train numbers are also displayed in the Web TID. But the problem is that train numbers are not related with the track occupation and release data. So, we have introduced an algorithm to relate the train numbers with relevant track occupation and release data. The key idea is to trace the movement of a train stepwise, that is, a track circuit by a track circuit. We can know the train number when a train begins its journey and it is possible to relate the information with a track occupation at the station. The basic idea of the tracing algorithm is that if there is an overlap of time between the occupations of consecutive track circuits, these two occupations must be made by the same train. Applying this algorithm iteratively, we can trace the movements of trains.

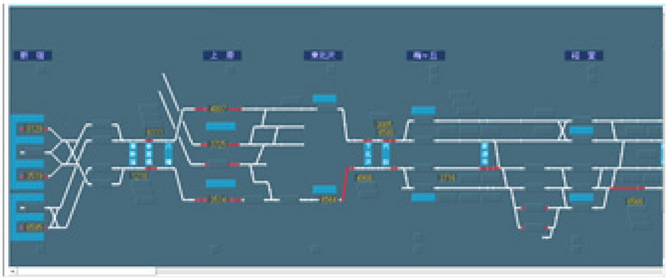

Figure 3: Web TID system of OER.

3.2 Visualization by the Chromatic diagram

We visualized the train traffic record data by the chromatic diagram, which we have introduced in [4]. The chromatic diagram is a diagram in which segments of train lines are coloured reflecting the delay of the train. If a train ran on time, the colour is indigo. The colour gradually changes from indigo to blue, green, yellow, orange and red as the delay increases (in our current version, the number of the steps is 20). Examples of the chromatic diagrams will be shown later.

4 Forecast of punctuality by microscopic simulation

We have developed a simulator to simulate precise behaviour of trains. Although there already exist popular microscopic simulators such as OpenTrack [8] and RailSys [9], we have developed a simulator on our own.

The purposes of our simulator are as follows:

- To examine how delays occur or expand especially during the rush hours when there is a renovation of facilities.
- To examine how difference of operation gives an influence to punctuality.
- To offer versatile information helpful for decision making, including visualization by the mimic panel style (Figure 4), train diagram style, train performance curves and so on.

The simulator deals with detailed information such as exact locations of signals, aspects of signals, performance of trains, parameters of tracks (gradient, curves etc.), exact positions where trains stop at stations etc. then using these data trains' movement is continuously simulated. The overall configuration of the simulator is shown in Figure 5 (we do not go into the details because of the limitation of the space).

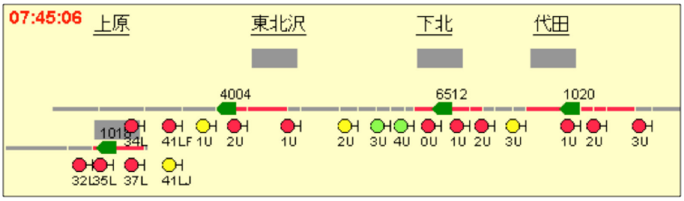

Figure 4: Screenshot of the simulator.

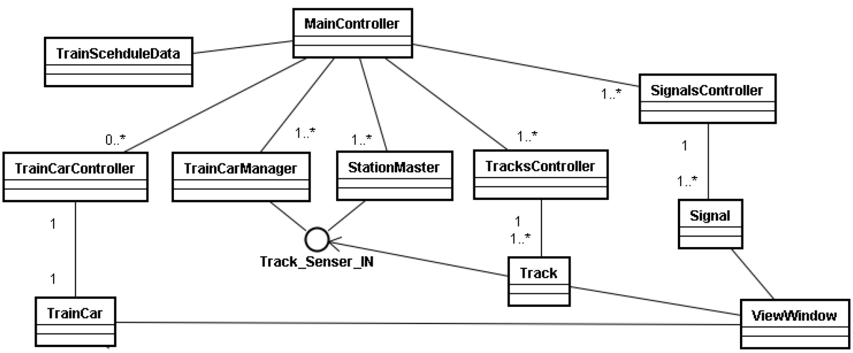

Figure 5: Major classes of the simulator.

5 An actual example of punctuality analysis

5.1 Track relocation

As a part of the construction of expanding quadruple tracks, a relocation of tracks was planned. The purpose of this construction work is twofold. One is a preparation for expansion of quadruple tracks. The current tracks on the ground are removed and new tracks are constructed underground. In the near future, one more pair of tracks (upward and downward) will be newly constructed also in the underground. The other purpose is to abolish level crossings, because level crossings are almost all the time shut in urban areas of Tokyo and there are a lot of complaints from drivers of automobiles and pedestrians.

Details of the construction are as follows (see Figure 6):

- New tracks are constructed underground between Yoyogi-Uehara station (Station Y, hereafter) and Umegaoka station (Staion U). The length of the new tracks is about 2.2km. Please note the tracks between these two stations are still double even after the relocation is completed, because the old tracks on the ground are removed. As the result, nine level crossings are abolished.
- Three stations (Setagaya-Daita, Shimokitazawa and Higashikitazawa; hereafter, we call Station D, Station S, Station H, respectively) are moved to underground.
- Due to some constraints of construction work, locations of Station S and Station D have to be slightly changed. Station S is moved 80m westward and Station D is moved 20m eastward, which means the distance between these two stations is shortened by 100m and the distance becomes only about 750m. Of course, signals of these stations are also moved.

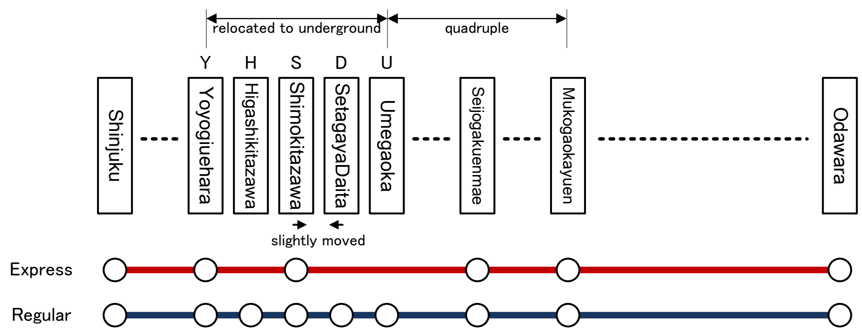

Figure 6: Relocation of tracks.

Taking this opportunity, the signaling operation at Station H is changed. There used to exist two tracks for upper bound direction at Station H, but one track had been already removed. Thus, switches did not exist anymore at Station H. But for some reason, there still remain an arrival signal and a departure signal there. It was decided to change these signals into block signals. There is a difference in the procedure to manipulate the signals. In case of departure/arrival signals, if you want to operate a train which passes the station, you first have to turn the departure signal from red to green (exactly speaking, "an aspect other than red") and after that you switch the arrival signal from red to green ("other than red"). For a train which stops at the station, the departure signal is red when the train arrives at the station. When the train is going to depart, you turn the departure signal from red to green ("other than red"). On the other hand, in case of block signals, there are no such rules and if there exist no trains ahead, signals automatically turn green.

5.2 Estimation of impacts of the track relocation to punctuality

The area where track relocation was planned is the most congested area in OER and trains are running very densely. So, we were strongly concerned about if the relocations of tracks and relevant changes might give a negative influence to punctuality. At the same time, we expected the change of the type of signals at Station H is favourable to reduce delays. We picked up the factors which we believe are related with punctuality and decided to analyse their impacts using our microscopic simulator.

5.2.1 Negative factors

(1) *Steep gradient around Station S*

Because Station S was moved to deep under the ground, trains have to go down a steep gradient when they arrive at Station S. As the result, the braking distance has become longer. In addition, lengths of block sections are very short. So, for safety reason, signal aspects were slightly changed to limit the running speed of trains and this is disadvantageous to recover delays.

(2) *Distance between Station D and Station S is shortened*

The distance between the signals of Station S and Station D becomes shorter. As illustrated in Figure 7, before the relocation of tracks, when a train (typically, Express 1) is stopping at Station S (please note all the trains stop at Station S), the train after the next (typically Regular) can arrive at Station D. But it was proved that after the relocation of tracks, when a train exists at Station S, the train after the next cannot enter Station D. We were very much anxious if this might give a significant influence to punctuality. So, we decided to compare two plans, Plan A and Plan B. In Plan A, if a train has to stop before it arrives at Station S, the location where the train stops is 50m short of the signal of Station S (Figure 8). In Plan A, the next train cannot arrive at Station D and has to wait before it arrives at Station D. In Plan B, the second train stops 30m short of the signal of Station S. If we adopt Plan B, however, it is possible for the third train to arrive at Station D (Figure 9). We thought that Plan B must be better from the viewpoint of punctuality.

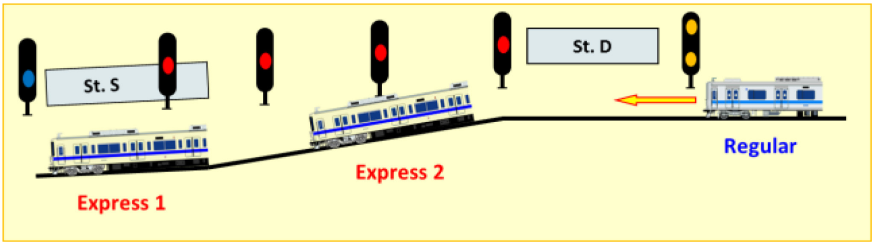

Figure 7: Before relocation of tracks.

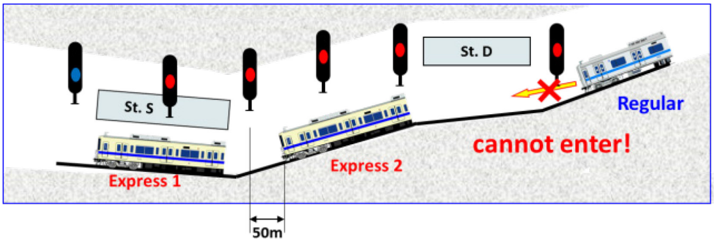

Figure 8: Plan A.

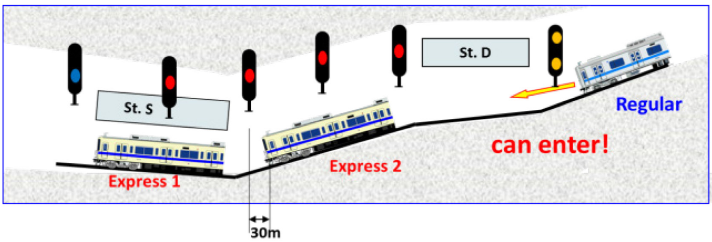

Figure 9: Plan B.

5.2.2 Positive factor

The improvement of the signalling system at Station H was considered to give a favourable influence to punctuality because express can run more closely to the preceding train as illustrated in Figure 10 and it is expected that the express can restore delays.

Figure 10: Station H – before (left) and after (right).

5.3 Results of the simulation

We show the results of our simulation. Figure 11 shows the expected delays at Shinjuku station varying the dwell times at Station S, which is the most critical point because all the trains stop and the dwell times tend to increase due to congestion. From this result, we can conclude that Plan A is better than Plan B especially when the dwell times at Station S become bigger than 65 seconds.

This result is a bit different from our first expectation and we analysed the reason using the results shown in Figures 12 and 13, which are also the outputs of our simulator. From a detailed analysis using these Figures, we can know the reason why Plan A is better is that although Regular has to wait before it arrives at Station D, Express 2 can arrive smoothly at Station S when it restarts after it is compelled to stop outside Station S. The situation is as follows:

- If Express 1 is delayed more than 1min. 50sec., Express 2 is compelled to stop outside Station S.
- In Plan B, a speed limitation of 15 km/h is imposed by the signal of Station S to Express 2, when it restarts.
- Because there is a steep down slope, drivers do not want to operate the notch to speed up.
- Hence, it takes more time for Express 2 before it arrives at Station S.

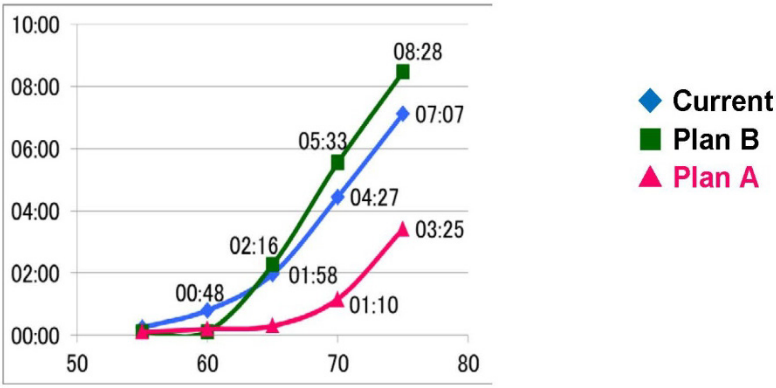

Figure 11: Expectation of delays at the terminal station.

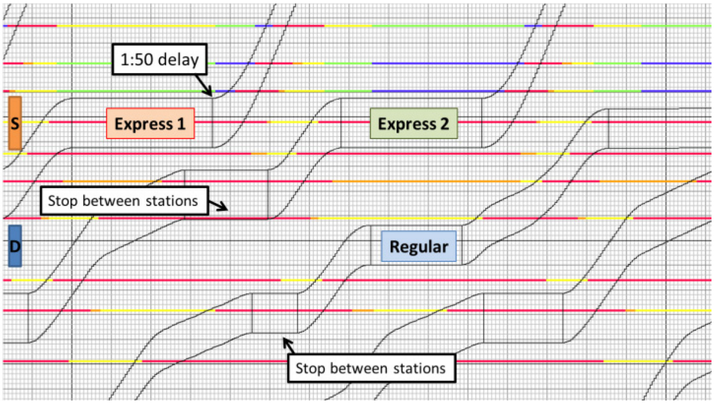

Figure 12: Detailed analysis of Plan A.

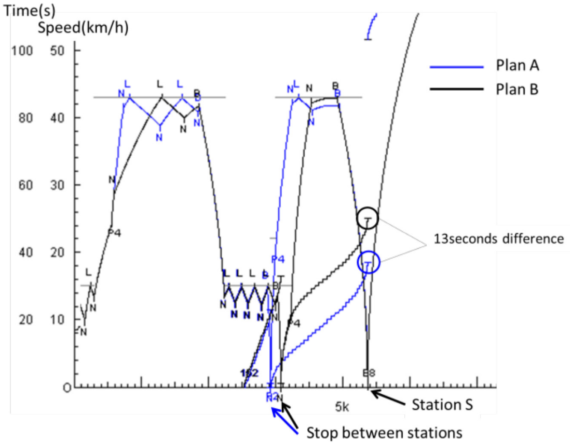

Figure 13: Train performance curves of Plans A and B.

5.4 Checking phase

The relocation of tracks was successfully completed on March 23, 2013. From that time on, we collected the train traffic record data from the Web TID and analysed them. The purposes of analysis are to examine if punctuality was increased and to validate the accuracy of our microscopic simulator.

In Figure 14, we show a chromatic diagram which we made using the train traffic record data of 19 days before the tracks were relocated (train lines are coloured based on average delays). Figure 15 is a chromatic diagram for 32 days after the tracks were relocated.

As you see, Figure 15 is a bit better from the viewpoint of average delays. We examined the result and the reason is the change of signal operation at Station H gave a good impact and our decision to choose Plan A was correct. This result is almost the same as we expected using our simulator.

From this result, we may well say that although there existed negative factors for punctuality, we have made a good decision based on our punctuality analysis approach.

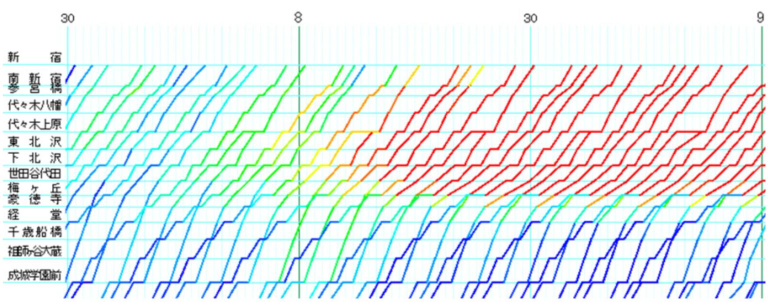

Figure 14: Chromatic diagram before the track relocation.

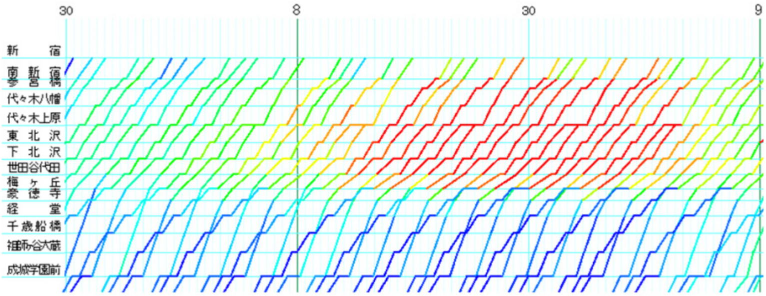

Figure 15: Chromatic diagram after the track relocation.

We also compared actual data and the simulation results. From the comparison, we learned we can insist that our simulation works exactly enough.

6 Future work

Now, we know the occupation and release times of track circuits. From these data, we can reconstruct detailed movement of trains between stations. Then we can visualize the movement in a diagram shown in Figure 16 (track circuit diagram). From track circuit diagrams, we can know how trains were driven and analyse the relationship among trains, signal aspects, timetable and operation. We expect we can get fruitful results from the track circuit diagram.

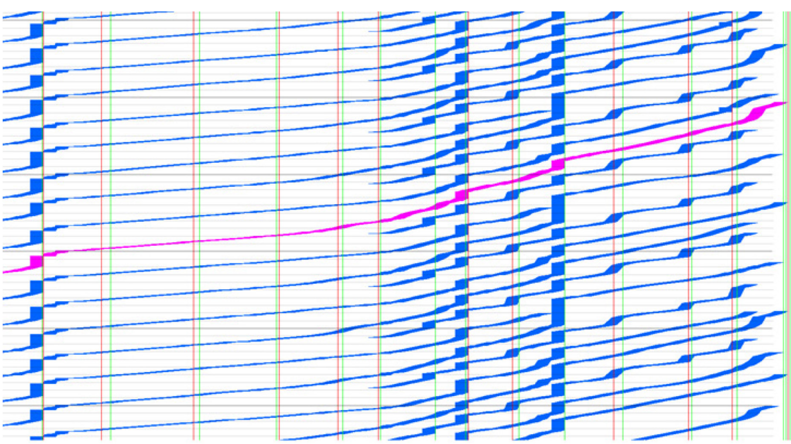

Figure 16: Track circuit diagram.

7 Conclusion

We have introduced a punctuality analysis approach which we have developed in Odakyu Electric Railway Company. The approach consists of the three phases, namely, the observation phase, the forecast phase and the checking phase. For the observation and the checking phase, we have introduced a chromatic diagram which is produced from daily train traffic record data. For the forecast phase, we have developed a microscopic simulator on our own. Through our experience of punctuality analysis when tracks were relocated, we have shown our approach worked successfully.

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