Crystal diagram: a technique for making high-density diagrams

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Abstract

We propose "crystal diagram" as a base for making high-density diagrams. In high-density railway sections such as metropolitan commuter lines, there is a great demand for increasing train density in order to relieve traffic congestion. However, it becomes more difficult to shorten train headway, as the track layout, train type and so on become more diverse. Therefore, making train diagrams needs the expertise of skilled specialists. In order to raise the train density, this paper aims to calculate the train minimum intervals between all trains within a certain accuracy and derive an original train diagram. It is a crystal diagram to refer to one cycle of the pattern and station diagram whose periodic time is shortest, on the assumption that instructions to all trains in one period are fixed. In practice, we obtain the effective results for operation planning, train dispatching and equipment design when we derive the crystal diagrams of model cases.
Keywords: diagram, high-density, pattern, station, operation planning, train dispatching, equipment design.

1 Introduction

Making a train diagram is one of the most important tasks in railway businesses, because the train diagram controls the transportation power of the railway.

Much work has focussed on calculating the basic data such as train running curve and train headway [1][2], making a train diagram from the basic data [3], and implementing train dispatching strategy by immediately changing a train diagram. What seems to be lacking, however, is work deriving a train diagram

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which raises train density in situations needing complicated train operation, e.g., when track form is complex, train type is diverse, etc.

The purpose of this paper is to derive a high-density train diagram. To satisfy this purpose, we calculate the minimum train interval to secure safety and optimize the train schedule based on it. We explain approaches for making a high-density diagram in section 2, and present a diagram which we aim to derive in section 3, a method to derive it in section 4, and implementation results in section 5. The final two sections present some future work and our conclusions.

2 Key points

We begin by considering two train diagrams. The key points to derive a high-density train diagram efficiently are explained.

2.1 Pattern diagram

A pattern diagram is composed of the same short train diagrams, as shown in fig. 1. In Japan, many pattern diagrams are used in metropolitan commuter lines. The main reason is that they are very useful for passengers and they make timetables easy to remember. We emphasize that the scale of the train diagram can be small. Accordingly, it is efficient to consider periodicity for making a train diagram.

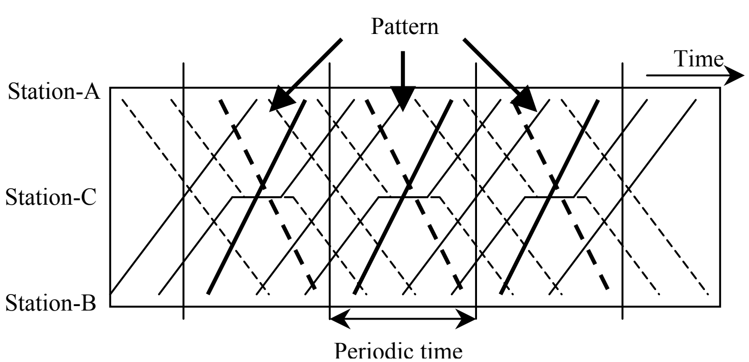

Figure 1: Example of a pattern diagram.

2.2 Station diagram

We use the term “station diagram” to refer to a train diagram within station premises only. Train operation is restricted by the location of other trains basically. In the area between stations, the train interval seldom becomes small suddenly, because the change of train speed is small. Within station premises, on

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the other hand, the train interval becomes small suddenly, because trains stop there (fig. 2). In practice the train density is always restricted by train turning operation at a terminal station where point switches are shared. Accordingly, it is enough to consider the station diagram in order to increase train density.

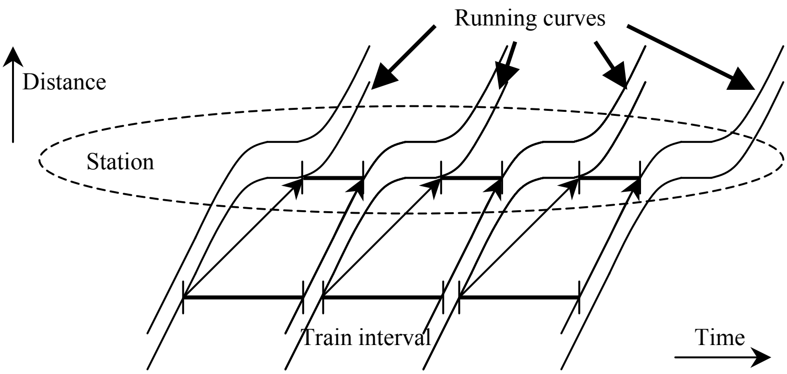

Figure 2: Change in train interval.

3 Proposed diagram

3.1 Periodic time

We use the term "periodic time" to refer to time required for one period of a pattern diagram. Even if instructions to all trains such as "depart from track-1" in one period are fixed, the periodic time is controlled by the schedule. The reason is that the values of the minimum interval time between trains vary. The minimum interval time is necessary for securing safety and it is dependent on the performance of the signaling system, the rolling stock and so on.

We illustrate the periodic time in the following example case:

- Track layout is shown in fig. 3.
- Two trains turn in one period.
- Instructions to trains
  - One train turns at track-1.
  - Another train turns at track-2.
- Schedule-A:
  - (1) train-a arrives, (2) train-b which arrived in the previous period departs, (3) train-a departs, and (4) train-b' which will depart in the next period arrives.

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- Schedule-B:
    - (1) train-a arrives, (2) train-a departs, (3) train-b arrives, and (4) train-b departs.

⇒ The periodic time of schedule-A is shown in fig. 3.
⇒ The periodic time of schedule-B is shown in fig. 4.
⇒ The former is shorter than the latter.

The following result is obtained by comparing the periodic time:

- The key point to increase the train density is to operate one train on track-2 while another train is stopped on track-1.

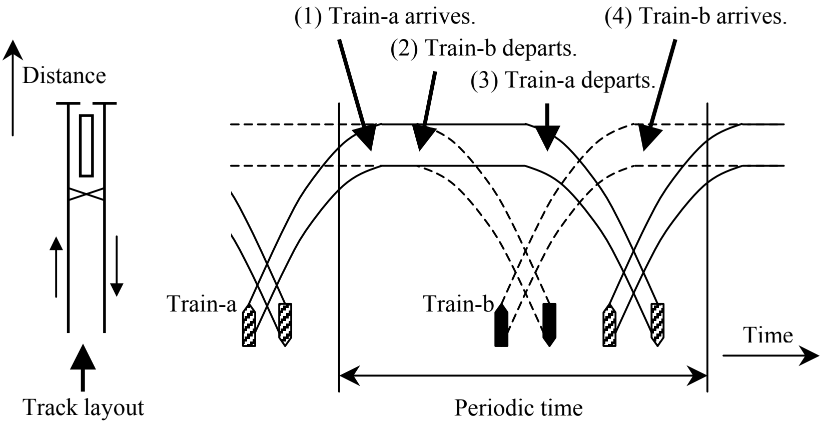

Figure 3: The periodic time of schedule-A.

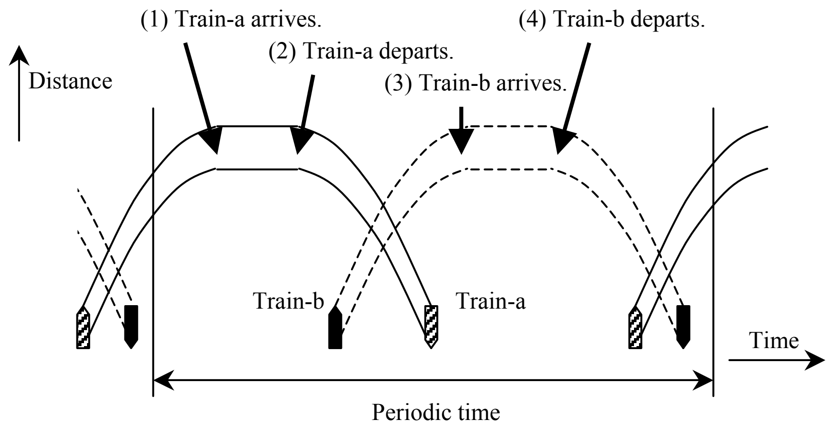

Figure 4: The periodic time of schedule-B.

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3.2 Crystal diagram

We propose a crystal diagram to refer to one cycle of the pattern and station diagram whose periodic time is shortest, on the assumption that instructions to all trains in one period are fixed.

By deriving the crystal diagram at the station where the train operation is most complex, we can make a high-density diagram using the following two steps. The first step is uniting the crystal diagram periodically, and the second step is making the whole diagram so that the united diagram may be fitted smoothly. The purpose of this paper can be realized by deriving the crystal diagram.

4 Deriving the crystal diagram

We must consider three steps in order to derive the crystal diagram. The first step is how to calculate the minimum interval time between trains. The second step is how to calculate the periodic time of schedules. The final step is how to derive the schedule which has the shortest periodic time.

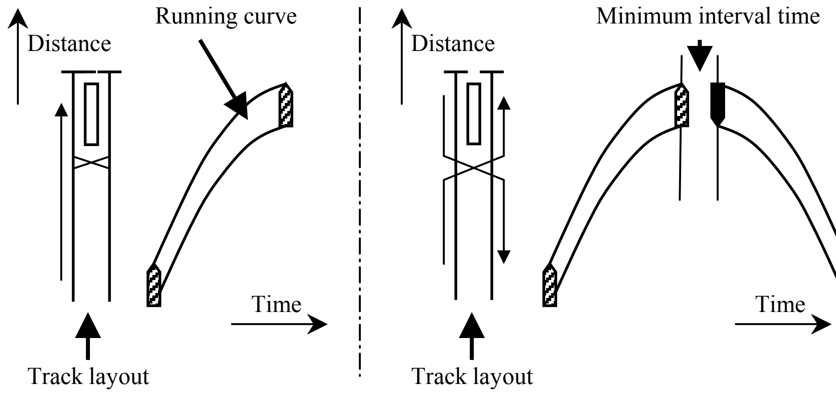

Figure 5: Example of running curve (left) and minimum interval time (right).

4.1 Calculating the minimum interval time

We explain how to calculate the minimum interval time between trains as follows.

- Prepare the following data:
    - Track layout data which are stored data of the connection of track circuits etc.
    - Rolling stock data which are stored data of the deceleration of trains etc.

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  - Equipment data which are stored data of the point switching time etc.
  - Routes data stored the sequences of circuit tracks where trains run.
- Make all train running curves, as shown in fig. 5 (left).
- Calculate the timing when shared point switches are available for the following train, from the running curve of the previous train.
- Calculate the minimum interval time between the trains based on the timing, as shown in fig. 5 (right).

4.2 Calculating the periodic time

Next, we explain how to calculate the periodic time of a schedule as follows.

- Prepare the following data:
  - The minimum interval time between all trains calculated above.
  - Schedule data which are stored data of schedules such as Schedule-A of 3.1.
  - Restriction data which are stored data of the necessary stopped time for passenger boarding etc.
- Add the minimum interval time according to the schedule, as shown in fig. 6.
- Correct the added time considering periodicity, stopped time, etc.

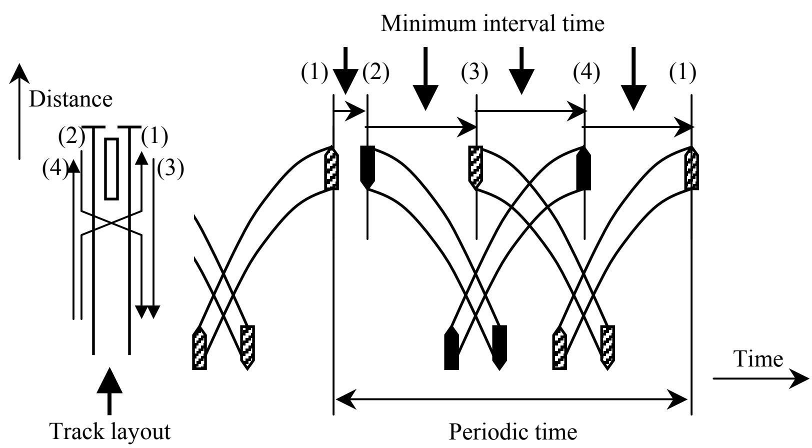

Figure 6: A method to calculate the periodic time.

4.3 Deriving the schedule which has the shortest periodic time

Finally, we explain how to derive the schedule which has the shortest periodic time as follows.

- Prepare the following data:

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    - Instruction data which are stored data of instructions to all trains such as Instructions of 3.1.
- Make the schedules considering all permutations.
- Calculate the periodic time of all schedules in the method of 4.2.
- Take the schedule which has the shortest periodic time.

5 Results

5.1 Deriving the crystal diagram

We derive the crystal diagram in the following model case:

- Track layout is shown in fig. 7.
- Three trains turn in one period.
- For all trains, the brake is controlled as a continuous curve.
- Parameters:
    - Speed limit at point switches: 45km/h, switching time: 10s.
    - Train length: 160m, acceleration and deceleration: 3.0km/h/s.
    - Stopped time: 60s.

⇒ The crystal diagram of this model case is shown in fig. 7.

⇒ We can see that it is possible to turn three trains every 230s.

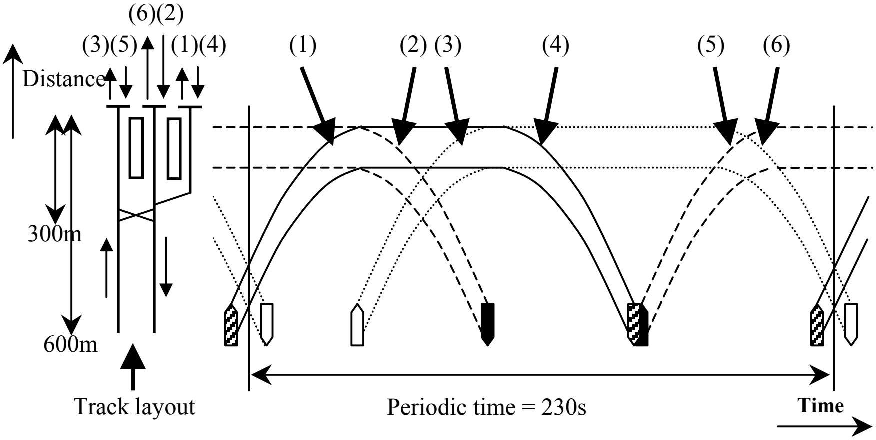

Figure 7: The track layout and the crystal diagram of model case in 5.1.

This crystal diagram is an effective result for operation planning and train dispatching, because we can use it as a base for making a train diagram by efficiently adjusting the train density planned beforehand. Furthermore, the completed diagram has much time to spare, in short, it is robust against delays. We show a display from a tool to derive a crystal diagram in fig. 8.

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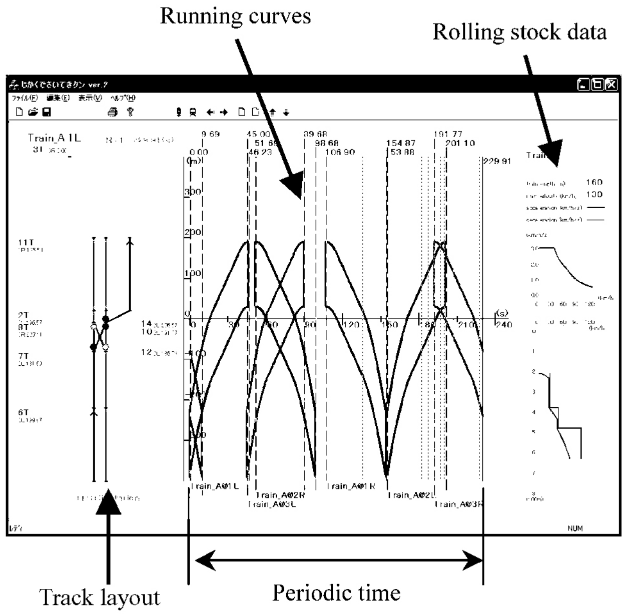

Figure 8: Display from a tool to derive a crystal diagram.

5.2 Comparing crystal diagrams

Similarly we derive crystal diagrams in the model cases shown in fig. 9. Then, we calculate and analyse the average interval time between trains.

Some effective results which we can obtain are as follows.

- For the average interval time between trains, <1>, <2> and <3> are influenced by stopped time. On the other hand, <4> is not influenced by it.

⇒ We can see that shortening stopped time at <4> is ineffective for raising the train density more than it already is.

- For the average interval time between trains, <3> is as large as <2>, though <3> has more tracks than <2>.

⇒ We can see that the expansion of equipment from A to B is ineffective for raising the train density, because the speed limit section must be lengthened by moving the point switch forward.

These results are effective for equipment design, because we can use them as bases for designing equipment by efficiently adjusting the train density planned beforehand.

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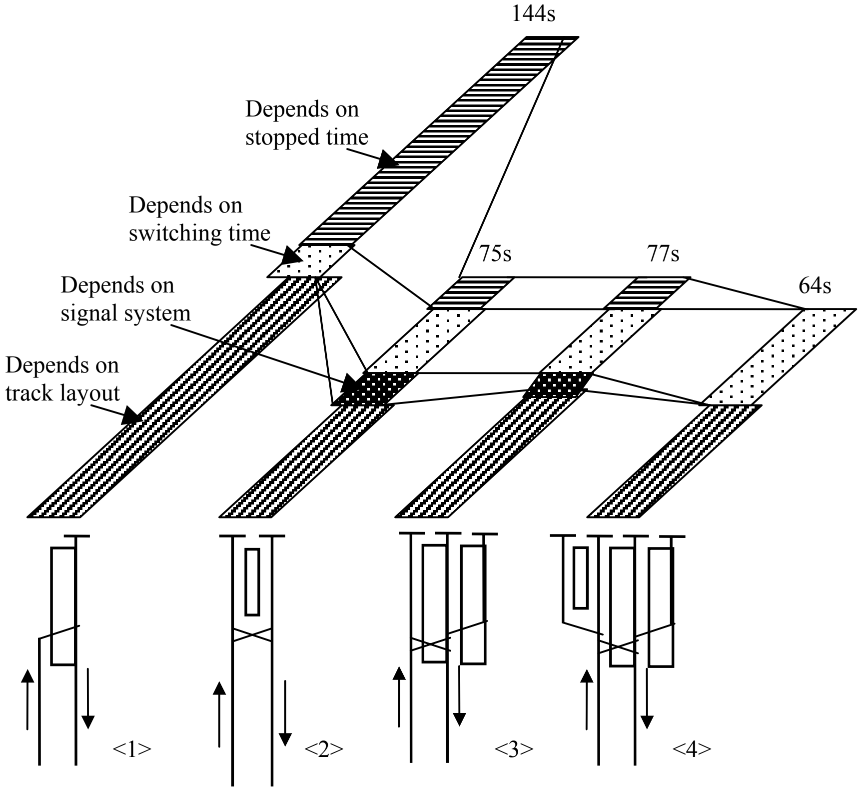

Figure 9: The average interval time of each station.

Table 1: The relation between the required time and the number of instructions.

Instructions	Permutation(*1)	Required time
2-5	---	<<1s
6	$1.2*10^2$ (5!)	0.01s
7	$7.2*10^2$ (6!)	0.07s
8	$5.0*10^3$ (7!)	0.5s
9	$4.0*10^4$ (8!)	4s
10	$3.6*10^5$ (9!)	34s
11	$3.6*10^6$ (10!)	5m40s
12	$4.0*10^7$ (11!)	1h

CPU: 2.0GHz, Memory: 256MB.
(*1) Circular permutation by periodicity.

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6 Future work

For the method to derive the crystal diagram, the required time increases explosively as instructions to all trains in one period increase. The reason is that we must calculate the periodic time of all permutations. We show the relations between the required time and the number of instructions in table 1. In the future, we must devise an algorithm by pruning, reducing in calculations, etc.

7 Conclusions

We have aimed at increasing train density, i.e., making a high-density diagram. In this paper, we proposed the concept of a crystal diagram to refer to a pattern and station diagram whose periodic time is shortest, on the assumption that instructions to all trains in one period are fixed. We explained the method to derive it. We derived the crystal diagrams for some model cases and obtained effective results for operation planning, train dispatching and equipment design.

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