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TOPIC 23
RAIL SECTOR
TRANSPORT

DEVELOPMENT OF NEW RAILWAY TRACK CONTROL SYSTEM (TOSMA) BASED ON CONVERGENCE THEORY

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Abstract

A new track control system called TOSMA (TOkaido Shinkansen track MAnagement system) is developed on the computer operated with WINDOWS based on the "Convergence Theory of Track Irregularity". The system controls track irregularities in 20m lots deciding necessary measures on the screen with the use of related information in windows.

INTRODUCTION

Tokaido Shinkansen is operated with the maximum speed of 270 km/h as the main corridor of Japan between Tokyo and Osaka running 11 trains in an hour. That is, an average train head is less than 6 minutes. Last year, the line's 30 Years' birthday was celebrated marking no fatal accident of passenger since the inauguration of the line.

One of the reasons supporting its fast, steady and safe operation is believed to depend on the high quality of track state which is realized with advanced technologies. As the fundamental of these, a mainframe computer system called "SMIS" (Shinkansen Management Information System) is there. It processes data from track geometry cars, and provides a database of track state, material situation and the history of maintenance works. The computer system "SMIS" has played the main role in the track maintenance works. However, with the increasing demand for higher riding comfort and running stability, the improvement and reconstruction of the system is on discussion. This motivated the start a new study on track control and to provide a plan to develop a new system for it.

The new system is expected to be developed along with other improvements for "SMIS" system, mainly in the area to control track irregularity based on the "Convergence theory" (Sato, 1989, 1992, 1993, 1995) and to constitute a sub-system of "NEW SMIS".

The development of a prototype system for this, the simulation of track irregularity control in it and steps for practical use of it are discussed.

PRESENT FRAMEWORK FOR TRACK MAINTENANCE

Hereafter, the irregularity of longitudinal level (LL) on ballasted track measured by 10 meter versine is discussed because the most part of the maintenance works on track regards it. It is simply called "track irregularity" or "irregularity".

On the ballasted tracks the track geometry deteriorates due to the settlement of track under train loads. Therefore, constant tamping works are necessary to maintain a necessary level of the irregularity. This process of deterioration and rectification is shown in Figure 1.

After a track geometry car runs on a track, recorded data are processed in SMIS and deteriorated spots in track geometry are searched for. If the spot where the irregularity surpasses an aimed value is detected, the system outputs the location and size of the irregularity and related data used for maintenance work. This means the works are executed so as to control the standing out irregularities under an aimed value. The value set for LL as 10 meter versine is 7 mm.

The irregularity in a lot (20 to 30 meters) of track is manually tamped. To suppress the irregularity level in a section (several hundred meters), a large scale mechanized work with use of a Multiple Tie-Tamper (MTT) is executed. However, these tamping works neither stop nor decrease the growth of track irregularity. Especially, in some lots of track where the irregularity grows quickly and frequent maintenance works are necessary, appropriate measures on materials, such as replacing rails and ballast or grinding rail welds and so on, are to be taken.

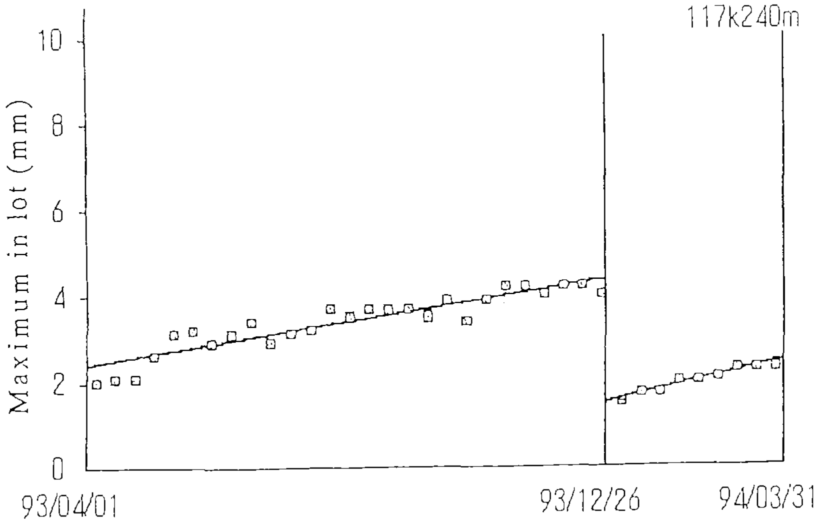


Figure 1 **Variation of irregularity**

THEORETICAL BACKGROUND

Characteristics of track irregularity

To discuss the characteristics of track irregularity, data are successively condensed for the lot of 20m, for the section of several hundreds meters (1 km for the prototype) having the same characteristics for track and subgrade and for the district of several kilometers (30 km for the prototype). Following symbols are adopted to express the characteristics of track irregularity.

(1) D_{20} Maximum measured as 10 meter versine in 20 m lot

This is the track irregularity of lot and represents the irregularity of each 20 m lot.

(2) D_{20} Average of the maxima in 20 m lots in a section

This is the track irregularity in a section.

$$D_{20}=\frac{1}{n}\sum_{i=1}^{n} D_{20} \tag{1}$$

(3) ΔD_{20} Increase of maximum in 20 m lot (in 100 days normally)

This is the growth rate of track irregularity in lot and represents the growth of irregularity in each 20 m lot. As well known, the linearity can be assumed for the growth of track irregularity in a lot as shown in Figure 1. This means that the growth can be expressed with a parametrial value for each lot as

$$\Delta D_{20}=\frac{D_{20}(b)-D_{20}(a)}{b-a} \tag{2}$$

where "b" and "a" are the date counted from the day when the tamping was executed.

(4) ΔD_2 Average of growth in 20 m lots in a section

This is the growth rate of track irregularity in a section and represents the growth of irregularity in each section. As same that in lot, the linearity may be assumed for the growth of irregularity in each section. This is expressed as

$$\Delta D_{20}=\frac{1}{n}\sum_{i=1}^{n}\Delta D_{20} \tag{3}$$

To express the level of track irregularity in a section, the average of D_{20} is used, because it is easier to treat finite number of digitalized data and a linear relationship exists as shown in Figure 2 between the averages and the standard deviations in sections which are necessary for theoretical treatment.

As the growth rates in lots distributed exponentially and they cause the extreme values of irregularity in lots as shown in Figure 3, some lots need more frequent tamping than the others (Sato, 1993, 1995). This is the reason why manual tamping is needed in addition to MTT tamping. If the extreme growth in a section can be excluded, the track irregularity can be in a normal distribution forever. Thus, the section will be maintained only by overall tamping works which cost much less than manual tamping.

These are the fundamentals of the new control system of track irregularity.

Characteristics of maintenance works

The relation between irregularities before and after tamping shown in Figure 4 can be expressed with a linear expression as

$$D_{20after}=kD_{20before}+k_0 \tag{4}$$

where k and k_0 are constant.

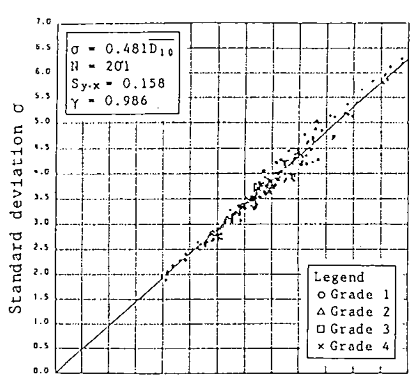


Figure 2 Relation of standard deviation to mean of maxima in lots—LL, 10 m

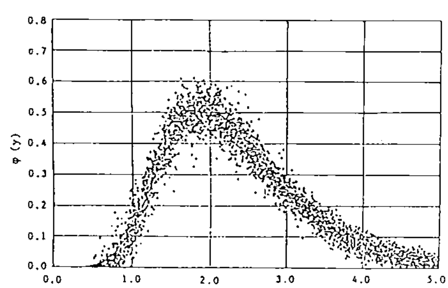


Figure 3 Probability distribution of track irregularity—LL, 10

As k_0 is not large, the constant k may express a ratio of rectification by maintenance work putting k_0 zero.

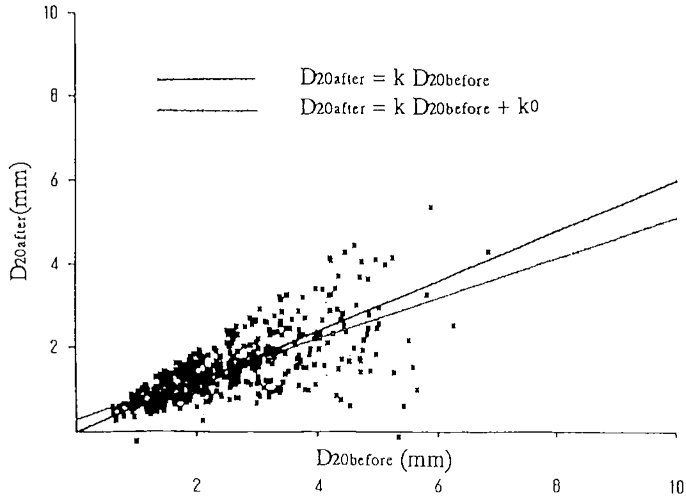


Figure 4 **The relation of irregularity before and after tamping**

Convergence of track irregularity

By combining the growth of irregularity and maintenance works stated above, it is demonstrated that the track irregularity converges to a certain value (Sato, 1989). This process is shown in Figure 5. In the figure, an irregularity on the line A with an angle of 45 degrees is reduced, by tamping work, onto the line C which is determined by the rectification ratio. Then, the irregularity on the line C grows up to the line B which is determined by the growth rate of irregularity and the interval of the tamping works. Then, by moving it horizontally onto the line A, the starting point for the next step can be obtained. By repeating the process, the maximum value of irregularity converges to the point X and irregularity varies between the line B and C at this ordinate.

Assuming a constant growth rate ΔD and a constant rectification ratio k, and also assuming the constant k_0 zero, as stated formerly, the line B is expressed as

$$X_2 = kX_1 + \frac{\Delta D}{W} \tag{5}$$

where W is the number of rectification in a year.

By finding the intersection of line B and line A, the converged value X is given as

$$X = \frac{\Delta D}{W} \frac{1}{1-k} \tag{6}$$

This is expressed as a hyperbola for W as shown in Figure 6. Using this equation, the interval of rectification works can be calculated not only for the section but also for the lot.

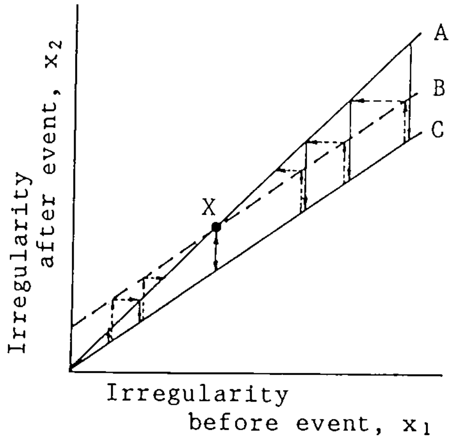


Figure 5 Convergence of irregularity

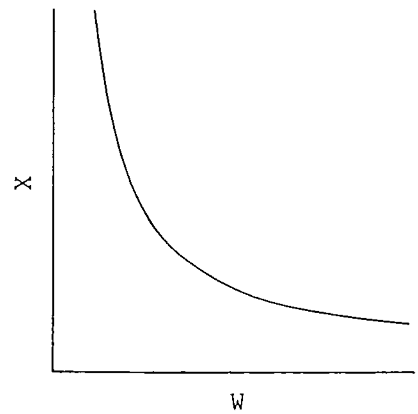


Figure 6 Irregularity determined by work

NEW TRACK CONTROL SYSTEM "TOSMA"

Depending on the above-mentioned background, a new system called TOSMA (TOkaido Sinkansen MAintenance system) has been developed.

Principle

The main purposes of the system are as follows;

- To control track irregularity for running safety
- To give better information on track condition for the planner
- To suppress extreme growth rates in lots in a section in order that irregularities in lots distribute normally. Thus, no manual tamping works are needed and the section can be maintained only by MTT tamping, and
- To assist making the optimum plan for maintenance works (work kind, amount, location and timing of the maintenance works) and reducing the costs for maintenance.

The basic concepts for constructing the system are as follows;

- Forecasting the track condition in the future based on irregularity growth rate, rectification ratio in work and work number in a year depending on convergence theory,
- Finding lots with high irregularity growth rate and planning fundamental measures through the amelioration of materials or that of the structure so as to decrease the growth of irregularity, and
- Recalculating the irregularity in sections assuming that those fundamental measures are taken for lots and repeating it.

Structure of system

The structure of the system is shown in Figure 7. It consists of three parts. The first is composed of "Action" programs to determine the growth and rectification ratio of irregularity, works in section and in district. The second is the "List" for taking a view of the track irregularities, the growth of track irregularity, the numbers of tamping in sections, the lots in which manual taming is necessary and those in which the works for excluding extreme growth. The third is the "Database" consisted of track irregularities including 10 m versines (7 ch), 40 m versines, irregularity growth, work records, rail maintenance records, amelioration works, spot tamping and characteristics of track.

The flow chart for deciding works consists of two parts in Figure 8. The one is for decision making in sections and the other, for that in the district.

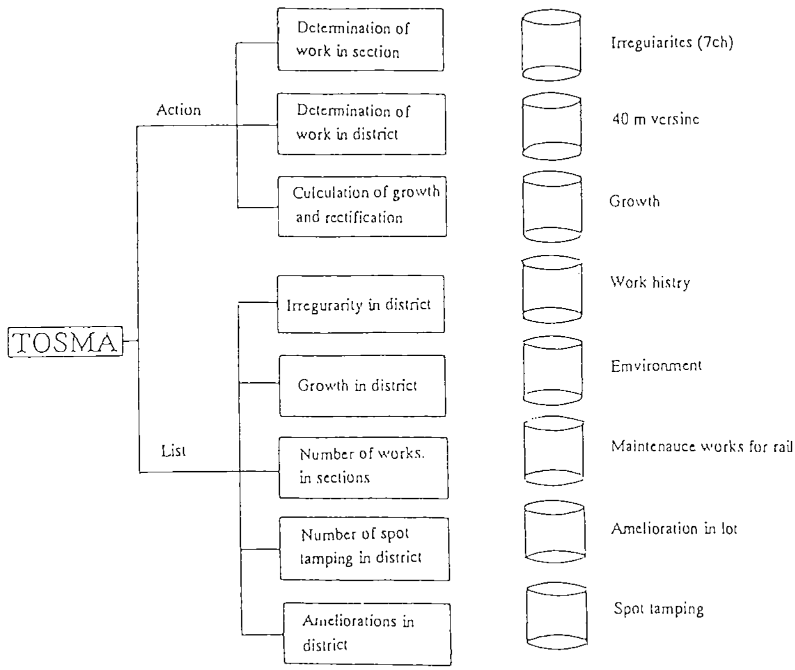
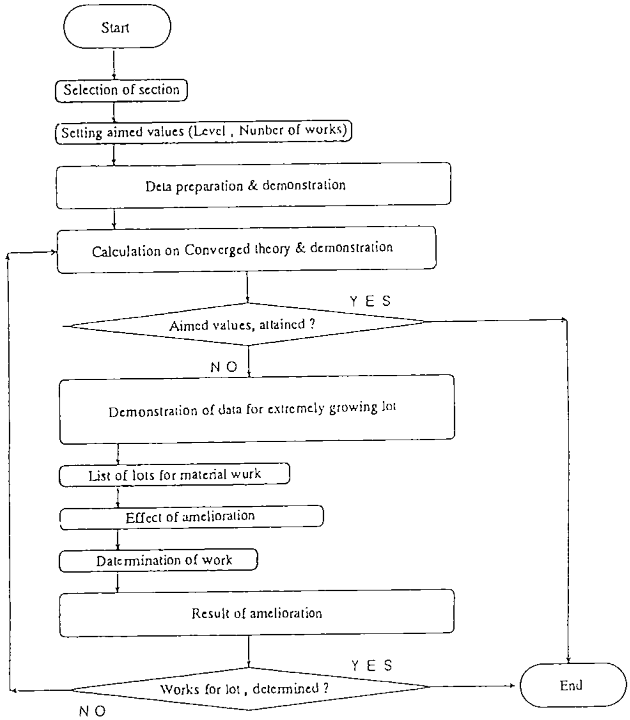
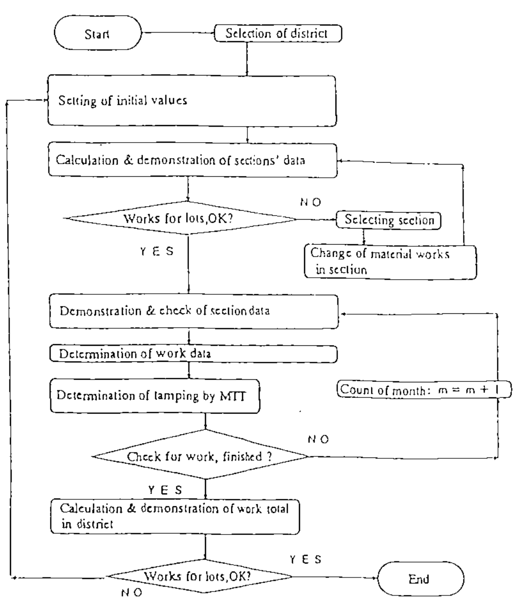


Figure 7 Structure of system



(a) In section



(b) In district

Figure 8 Flow chart of decision making

Input and output of system

Input to system

Basic data used in the system are as follows;

- Track irregularities digitalized for every 1 m
- Records of past maintenance works (date, location, type of works) and
- Structural characteristics of track (line form, type of structure etc.).

The parameters which are set before the operation of the system are as follows;

- Aimed value of track irregularity for every 20 m lot and
- Aimed value of track irregularity for every section

Action by user

The system helps users in following decision making processes.

- To set an aimed value of the cycle of MTT tamping works for each section
- To choose appropriate fundamental measures for 20 m lots so as to decrease track irregularity growth. As for fundamental measures, the replacement of material, the rectification of surface roughness by grinding and the bending-up of welds, the amelioration of subgrade etc. are the candidates.
- To check if the total amount of tamping works and fundamental measures calculated by the system is acceptable.

Output of system

Following lists and charts are shown on a computer screen or printed out from the system.

- Growth ratio of track irregularity in each 20 m lot
- Future track irregularity in each 20 m lot
- Amount and timing of manual tamping works needed in each 20 m lot
- Amount and timing of MTT tamping works needed in each section
- Condensed data shown in each district
- Rectification ratio of each type of maintenance work.

Calculation of track irregularity and tamping works in system

For each 20 m lot, followings are calculated in the system so as to control the size of irregularity in lot.

Track irregularity

Lot representatives are selected by finding the maximum in the lot from the data given by the track geometry car.

Growth rate of track irregularity

Growth rates in lots are calculated by using Equation (2). The track irregularities are traced backwards (from present to past) and the coefficient of slope expressing growth rate is calculated by linear approximation and the representative of them in the lot is given by the mean of them. The calculation is reset when works, such as replacing rails or ballast which decrease the growth rate of irregularity, are executed in the lot. However, the calculation continues when tamping works considered not to change the growth rate are executed in the lot.

Track irregularity forecast

The size of irregularity after 180 days is forecasted from the present irregularity and the growth rate, and also the date when irregularity will exceed the aimed value are also calculated.

Converged value of track irregularity

Using Equation (6), the converged value of irregularity is calculated.

Interval and amount of manual tamping works

Cycle and annual amount of the works to keep the irregularity under an aimed value is calculated using Equation (6). In the equation, the number of works W is calculated by setting the converged value X to an aimed value.

For each section, followings are calculated using data of the lots in the section.

Track irregularity

Using Equation (1), the average of maxima of lots in the section is calculated to represent the irregularity level in the section.

Growth rate of track irregularity

The growth rate of a section is calculated by taking the average of them in lots.

Track irregularity forecast

The future irregularity level for the section is forecasted by taking the same process as for lots.

Converged value of track irregularity

Same as for lots.

Interval and amount of mechanized tamping works by MTT

Same as for lots. However, the cycle of MTT works for the section is obtained independently from that of manual tamping works for each lots in the section. This is because a different level of irregularity is allowed for a section and for a lot.

The characteristics of maintenance works are calculated using Equation (4). The calculations are conducted separately for manual tamping and for tamping by MTT.

Selection of fundamental measures to decrease irregularity growth rate (action by user)

As the tamping works do not decrease the growth rate, fundamental measures must be taken on materials, such as replacing rails and ballast or grinding rail welds and so on, so as to decrease the growth rate of irregularity.

In each section, lots are sorted in the order of the largeness of growth rate. Then the lots in which the fundamental measures must be taken are indicated. Together with such information, the system also demonstrates the work history of the lot, estimated effects of possible measures to be taken, total amount of each measures already taken in this process, a 10 m versine chart, and other information. Then, the user of the system decides what type of measures are to be taken to which 20 m lot.

After the decision is made, the calculations for a new converged value of the track irregularity in the section shown above are executed again to evaluate the effects of those measures. The effects are judged in terms of reduction of the amount of tamping works. If the effects are not sufficient enough, the decision making process shown earlier is repeated. These processes are repeated until acceptable results are obtained.

The system provides two types of calculation flow for suggesting the lots where the fundamental measures must be taken.

Type 1

Excluding the lots, whose growth rate is greater than the double of the average, as the lots for the spot tamping, the works for the lots to obtain aimed number of overall tamping in a year in the section are checked. The works are expected to be planned both lots excluded and suggested, but the work can not always accomplished for the former because of difficulty in work conditions. This allows manual tamping on some lots due to the difficulty accomplishing the amelioration even trying to do it.

Type 2

All the lots which needs the amelioration so as to satisfy the aimed number of MTT tamping in the section in a year are suggested. This means no manual tamping is needed as long as MTT tamping is conducted with its aimed cycle after the amelioration.

DEVELOPMENT OF TOSMA

Hardware and operating system

TOSMA is developed on a personal computer with CPU "Intel 486DX2" and "MS-WINDOWS ver.3.1". By utilizing the features of them, TOSMA shows different kinds of useful information in many windows, and helps the decision making process of the user. As the actions are taken by user using the windows and a mouse, the system can be easily operated by the user who has no special knowledge on computer.

Examples of output

Some examples of the output are shown in Figures 9-12.

Figure 9 shows the screen of maxima and growth rates of them in lots in a section. The upper right table gives abnormal lots for the growth of irregularities, the upper left, the data for the growth of irregularity, the lower left, the maxima in lots in a section and lower left, the growths of irregularity per 100 days in lots.

Figure 10 shows the screen of the present characteristics of irregularity in a section. The upper left gives the figure of maxima in lots and the forecast after 6 months, the upper right, the list of lots for spot tamping with related data, the lower left, the statistical characteristics and lower right, the list of work volumes in the case of amelioration of growth in type 1 or 2.

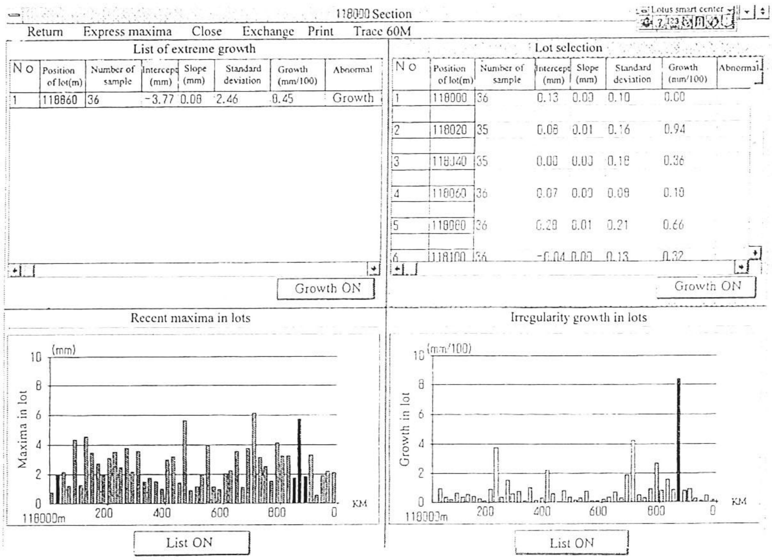


Figure 9 Irregularity and growth of it in a section

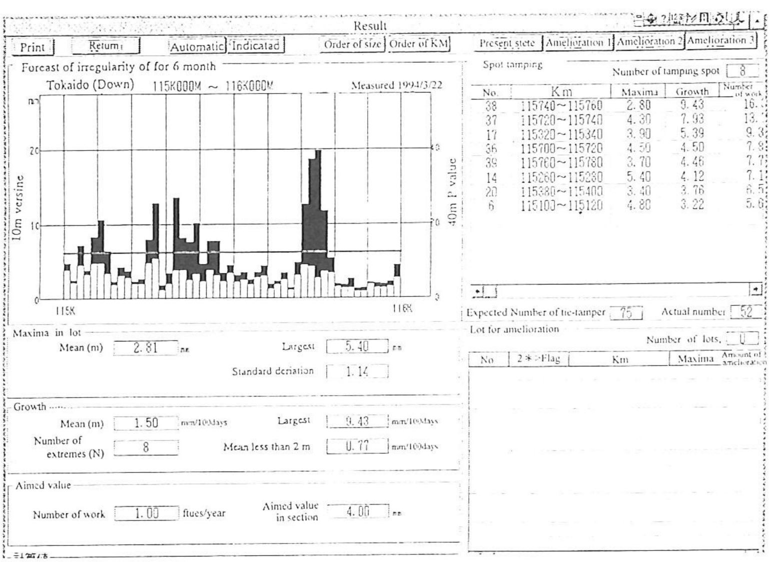


Figure 10 Characteristics of irregularity in a section

Figure 11 shows the screen for determining amelioration work in a selected lot. The upper left gives the positions of the irregularity and growth rate in statistical distribution, the upper right, the form of irregularity with plan, vertical section and structure, the lower left, work records and candidates of works, the lower center, their effect to decrease the growth of irregularity, the determination of work and their effect and the lower right, calculated results for the section and lots with present data.

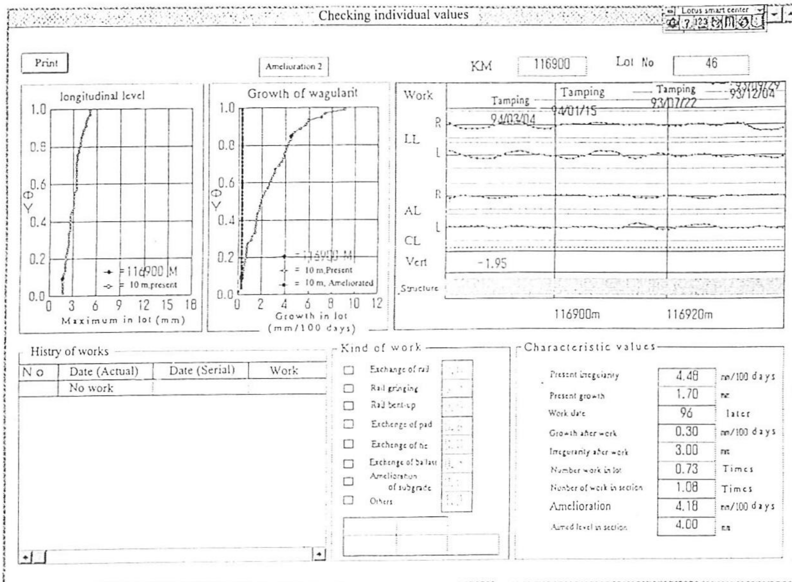


Figure 11 Determination of works to decrease growth of irregularity in lot

Figure 12 shows the data for spot tamping and amelioration works in a district. The upper frame shows the positions and volumes of spot tamping in each section at present and the lower one, the positions and volumes of amelioration works when they are calculated in type 1 or 2.

Figure 13 shows the chart of irregularity in a district. The left figure show the irregularities, plan, vertical section and structure in a district. It can be scrolled. The right one shows the actual figure of irregularities for selected lot.

CONCLUSION

A new kind of track control system has been developed as a prototype for practical use, and its forecasting ability and the applicability has been proved through the study using real data. The merit of the system is demonstrated.

Using this system, decision making in both micro-scale and macro-scale track maintenance works are expected to be made cost effective and optimized. The track irregularities are fundamentally suppressed by eliminating the weak spots which have large growth rates of irregularity. The level of track irregularities in a section as a whole can be rectified effectively for the aimed cycle of MTT tamping works.

As this system is developed mainly to test the framework of the new system, it is still necessary to make some amelioration and to continue further developments so as to make it more user-friendly and to have higher forecasting ability and more detailed support for the decision making process, and especially to show the timing of execution of each work. Even with this prototype system so many useful new fields have been cultivated.

At the time of the future renewal of the SMIS system, the system described here is supposed to work as the main part for controlling the track maintenance works.

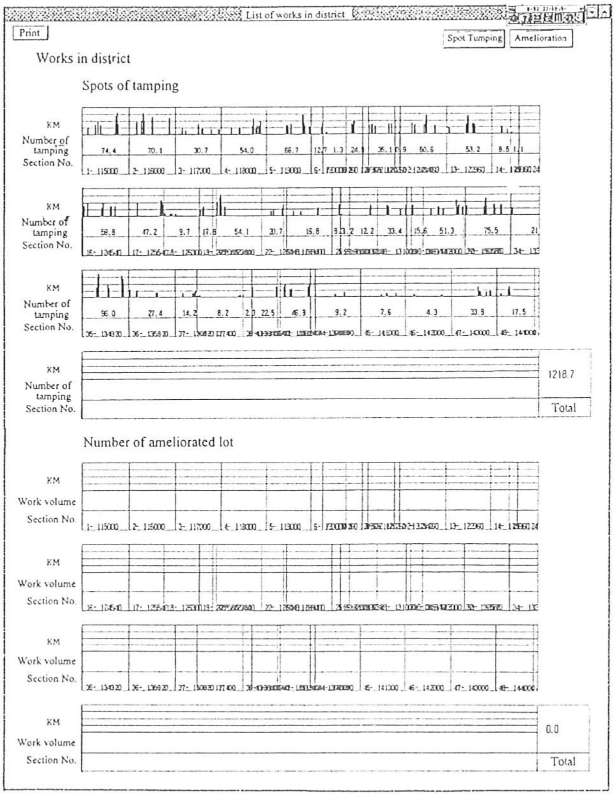


Figure 12 Spot tamping and amelioration work

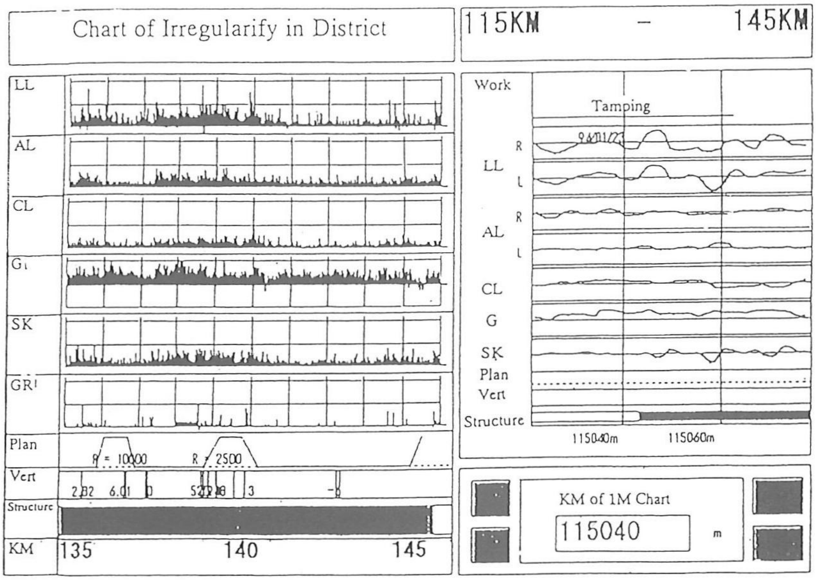


Figure 13 Irregularities in district

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