A proposal of intelligent operating method considering the change of constraint conditions

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***Abstract*—Train plays an important role as public transportation in our daily life. However, if transport volume decreased due to irregularities in the timetable of train, it'll be shock to our society. In that case, it is needed for train operators to recover the transport volume by their operating skills. In this study, we proposed an operating method considering the change of constraint conditions by intelligent control using an intelligent operating support system based on operating knowledge of expert operators in the dynamic environment. By providing appropriate support information to operators, it is confirmed that the proposed method is effective for shortening arrival time and the recovery of transport volume in such environment.**

I. Introduction

In modern Japanese society, public transportation such as train, bus, ship play an important role in our daily life. Actually, easy access, short waiting times, comfortable trips are important factors in attracting passengers to use public transportation. However, if the transport volume decreased due to irregularities in the timetable, they have risks that it'll be shock to our society.

Generally, when irregularities in the timetable of train occured and the transport volume decreased, train operators attempt to recover the transport volume by arriving at the destination as fast as they can. At that time, they use the information of environment and constraint conditions which are changing dinamicaly while their runnning and consider some methods to shorten arrival time.

But actually, it's hard work for them to operate train and recover the transport volume in the environment where constraint conditions change because operating with consideration of safety and accuracy is multipurpose operation. And moreover, they cannot use the information of constraint conditions well because the information change dynamically. Expert operators, on the other hand, operate the train in such environment using available information such as constraint conditions effectively, and arrive at the destination faster than non-expert operators by passing at the traffic signal smoothly.

Actually, Seiji Yasunobu has created a suitable control method by predictive fuzzy control which samples a skilled operator's operating knowledge, and it actually applied to subway in Sendai as Automatic Train Operation system[1], [2]. It indicated that it could realyze the smooth stopping of train at scheduled time by predictive fuzzy control.

In this paper, we applied predictive fuzzy control which integrated human sense and knowledge of expert train operators into the controller of the train, and developed an intelligent operating support system which aims to recover the transport volume by shortening arrival time[3]. Finally, we proposed an intelligent control method to shorten arrival time by using the intelligent operating support system which is considering the change of constraint conditions and confirmed the effectiveness of its method by simulation experiment.

II. Operation of train

Although the operation of train is only acceleration and deceleration using a master controller, it is hard work for train operators to pass the fixed positions at scheduled time and finally stop at the destination smoothly because it is needed for them to operate train with considering dynamic environment and its constraint conditions in the rail way.

In this section, we considered how the train operators operate the train and their operating skills near the traffic signals to pass smoothly.

A. Operation

Generally, train operators use the following information well which could be provided while running, and operate some actions such as (A)-(D).

- Time until the state of the traffic signal switches
- Distance from current position to each traffic signals
- Distance from current position to the destination

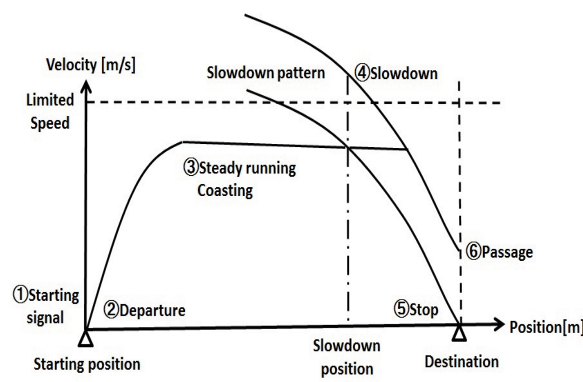

Fig. 1. Running pattern

(A) Departure:After safety confirmation, train operator powers notch on and accelerates to start runnning.

(B) Steady Running:The operator stops acceleration and notch off if the speed reaches the limited speed. And the operator coasts until train arrives at starting point of braking for the passing and stopping positions. At that time, it is necessary to be careful for the slowdown sizing at uphill slope and the speed up at downhill slope.

(C) Passing:Near the traffic signals and nonstop stations, train once stops there and re-start runnning after confirming the traffic signal, or keep the speed and pass there considering the timming that the state of traffic signal switches to blue. In this case, the train operator decides starting position of braking and its size considering remaining of distance to the passing position, and passage time.

(D) Arrival:The train operator considers the starting position of braking and its size using various information such as remaining distance to the desitinations, numbers of passengers, the weather, and slow down when train approaches the fixed position. The fixed positions are displayed on railways and platthome, so the operator brakes as the displayed infomation. After arriving at the destination, the operator promptly brakes to prevent rolling due to the incline.

In these cases, the operator is obeing some constraint conditions shown in (1)-(3). By obeying these constraint conditions, safe operations are guaranteed.

(1) Observance of the limited speed V_{lim}
(2) Observance of the passage time T_{sg} at the trafic signal and nonstop station
(3) Stop precisely at the destination X_g

These operating methods are shown in Fig.1. Generaly, if the train runs at over limited speed, the stopping operation will be taken by ATS, Automatic Train Stop system, which is working in every block section. It can prevent over running and accident due to over limited speed.

B. Operation near traffic signals

In this subsection, we considered the operation of train near traffic signals to shorten arrival time and to recover the transport volume.

As for the operating method of train near traffic signals, sudden stop just before the state of traffic signal switches to blue, and immediate acceration is optimal speed pattern for operating a train. However, it is difficult for train to stop and start running immediately due to the functional reasons. As for these problems, expert operators pass the fixed position at limited speed $V_{lim} = V_a$ as Fig.2 using provided information such as $T_{sg} and V_{lim}$. Non-expert operators, on the other hand, cannot take advantages of the information well, so they once stops near the traffic signals and re-start running after switching the state of traffic signal to blue. As for the time to stop and re-start running the train, the result has a time lag of arrival time compared with expert operators. It is shown in Fig.2.

III. Analysis of the Operation of Expert Operators

As shown in table 1 and Fig.2, the state when traffic signal is red means ”stop here”, and it also means limited speed V_{lim} = 0[m/s]. In short, it means that the constraint condition of slope in the S-T graph indicates ∞. The state when the traffic signal is blue, on the other hands, means ”pass here”, and it also means you can pass here at a certain speed $V_{lim} = V_a$[m/s]. It also means that the constraint condition of slope in the S-T graph indicates a certain constant value.

Final goal is to arrive at the destination X_g[m] at the speed of $V_{(X_g,T_g)}$ = 0[m/s] in the environment where constraint conditions change dynamically such as T_{sg}[s] and V_{lim}[m/s]. At first, the train starts running from X_{st} = 0[m] at the speed of $V_{(X_{st},0)}$ = 0[m/s] and performs steady running. If it approaches near the traffic signals X_{sg}[m], train operator control master controller to pass X_{sg}[m] at the speed of $V_{(X_{sg},T_{sg})} = V_a = V_{lim}[m/s]$ considering the information of X_{sg}[m] and T_{sg}[s] while their running. And finally, stop at the destination X_g[m] at the speed of 0[m/s], that means, $V_{(X_g,T_g)}$ = 0[m/s], where T_g[s] indicates the arrival time.

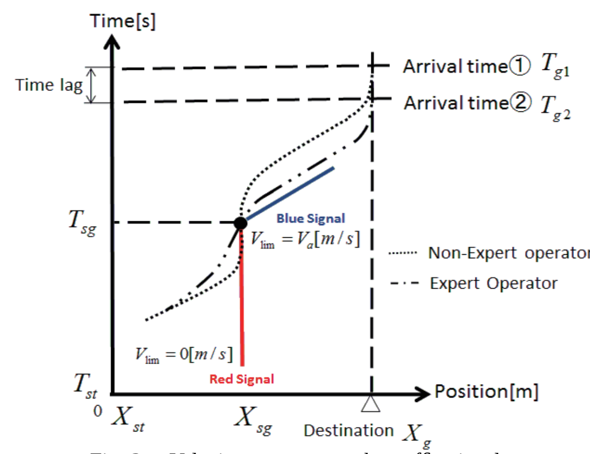

Fig. 2. Velocity pattern near the traffic signals

TABLE I
Constraint conditions

State of traffic signal	Limited speed V_{lim}[m/s]
RED	0
BLUE	V_a

IV. Predictive Fuzzy Control

Expert operators have extensive experience through their experiments with operations and events, and they can satisfy objectives of system via their high-level control method.

The predictive fuzzy control calculates the next state of system when selecting and propose control methods according to the next best state of the system at any moment. It does not need to construct the mathematical model but constructs fuzzy model, so this model can apply to linear, nonlinear problems because fuzzy model is expressed with linguistic variable and can control an object flexibly. It anables us to control an object precisely and flexibly by choosing an appropriate control method from some control candidates. Fig.3 shows the configureration of the predictive fuzzy control system. Thus, predictive fuzzy control enables us to control an object by integrating human sense and knowledge into the controller of the system.

In this study, we exemined operating simulation using intelligent operating support system which applied predictive fuzzy control. At that time, we input the output of control commands generated from department of operation decision into department of supportive information displaying as supportive information.

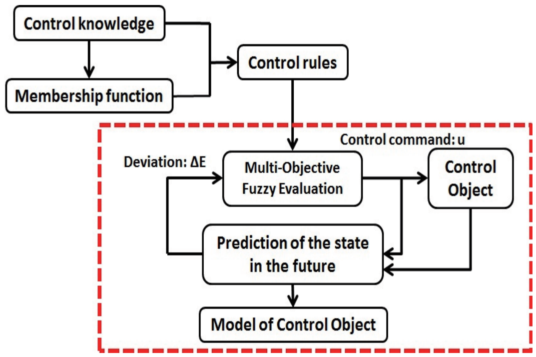

Fig. 3. Configureration of predictive fuzzy control

V. Intelligent operating support

In this section, we considered how expert operators (supporters) consider when they support the non-expert operators.

A. Decision of support intention

Operating supporters do not have clear singleton support intention such as ”0” or ”1”. They control the operation notch considering whether they can reach the desired speed. If they will not able to reach the desired speed, they control the operation notch so that they can reach the desired speed considering the situation in each moment. The supporters perform such procedures repeatedly until train pass or arrive at the fixed position. In this way, they decide behavior of operation notch so that they could reach the desired speed to pass and arrive at fixed position considering current position, speed if they decelerate near the fixed position such as stop position and passage position.

B. Control knowledge

Expert operators acquire operation knowledge of train from their past operating experience. They also make various decisions using these knowledge and realize flexible and precise running. Here are some examples of the operating knowledge.

1) Steady running: Operators operate a master controller so that speed reaches desired speed considering environmental information which is changing dynamically. And also, while running, they consider the time from the time they operated the notch beforhand and evaluate it as comfortability. Here are some examples of fuzzy rule.

- If speed error is ”Good” in the case an operator powers N notch, then gradually powers N notch.
- If speed error is ”Very Good” and comfortability is ”Good” in the case an operator powers N+1 notch, then gradually powers N+1 notch.
- If speed error is ”Very Good” in the case an operator sets the notch as 0, then sets the notch as 0.
- If speed error is ”Bad” in the case an operator sets the notch as 7, then sets the notch as 7.

2) Passage at the fixed position: Operators consider the size and the timing of braking for passage, and also consider comfortability using environmental information which is changing dynamically to pass the traffic signals at limited speed V_{lim}. At that time, they decide operation notch comparing the predictive position with the desired position in each moment. And also, while running, they consider the time from the time they operated the notch beforhand and evaluate it as comfortability. Here are some examples of fuzzy rule.

- If possitioning error for passage is ”Very Good” and remaining time for braking is ”Good” and comfortability is ”Good” in the case an operator powers N+1 notch, then gradually powers N+1 notch.
- If remaining time for braking is ”Usual” and comfortability is ”Good” in the case an operator sets the notch as 0, then sets the notch as 0.
- If remaining time for braking is ”Very Long” and comfortability is ”Good” in the case an operator sets the notch as 7, then sets the notch as 7.

3) Stop at fixed position: When operators operate train, they consider the size and the timing of braking, and comfortability using environmental information which is changing dynamically to stop at the fixed position precisely and smoothly. At that time, they decide quantity of notch operation comparing the predictive position with the desired position in each moment. And while running, they consider the time from the time they operated the notch beforhand and evaluate it as comfortability. Here are some examples of fuzzy rule.

- If possitioning error for stopping is ”Very Good” and remaining time for braking is ”Good” and comfortability is ”Good” in the case an operator powers N+1 notch, then gradually powers N+1 notch.
- If remaining time for braking is ”Usual” and comfortability is ”Good” in the case an operator sets the notch as 0, then sets the notch as 0.
- If remaining time for braking is ”Very Long” and comfortability is ”Good” in the case an operator sets the notch as 7, then sets the notch as 7.

VI. Configuration of intelligent operating support system

Develloped intelligent operating support system which applied predictive fuzzy control is consisted of 3 departments as ”Dept. of goal setting”, ”Dept. of operation decision”, ”Dept. of supportive information displaying” and it is shown in Fig.4.

In this way, quantity of appropriate operation notch is calculated for each targeted value, and by displaying it as appropriate supportive information for non-expert operators, they can operate train as same as expert operators. And the operator can adapt to the change of constraint conditions in each moment and operate train because supportive information is calculated by this system at any moment.

A. Goal setting

In this department, desired speed V_{mf} is calculated based on information of current speed and limited speed, distance to the fixed position, and the remaining time. Train operator decides the desired speed to pass or stop at the destination obeying constraint conditions in the dynamical environmental.

Latest desired speed V_{mf} will be decided as a minimum one by comparing calculated desired speed with deceleration pattern, limited speed.

B. Decision of operation

In this department, the error between desired speed V_{mf} and predicted speed of next state V_p, the remaining time and remaining distance until braking starts, and comfortability are evaluated based on knowledge of expert operators and decide control notch.

Specifically, this department is also consisted of 3 sections as "Runnning Control" which enable us steady running, and "Passing Control" which enable us to pass the fixed position X_{sg} at limited speed $V_{(X_{sg},T_{sg})}$ = $V_a[m/s]$, and "Stopping Control" which enable us to stop at the destination $V_{(X_g,T_g)}$ = 0[m/s] smoothly, and precisery. And minimum output from each section is decided as an output of this department.

1) Runnning Control: In this section, speed error V_e = V_{mf} - V_p is evaluated with menbership function and decide control notch, where V_{mf} indicates latest desired speed calculated in department of operation decision and V_p indicates the predictive speed in the next state. Moreover, by evaluating the time from the time they operated the notch beforhand with menbership function, comfortability is evaluated to decide control notch. By evaluating these elements by membership function, this section decides an output for the highest evaluative value in each moment.

2) Passage Control: In this section, positioning error of passage X_{ep} = X_{tp} - X_{pp} and the remaining time for the braking t_{zp} are evaluated with menbership function and decide control notch, where X_{tp} indicates the desired passage position and X_{pp} indicates the predictive passage position in the next state. And t_{zp} indicates the remaining time until the deceleration starts for the passage position. Moreover, by evaluating the time from the time they operated the notch beforhand with menbership function, comfortability is evaluated to decide control notch. By evaluating these elements by membership function, this section decides an output for the highest evaluative value in each moment.

3) Stop Control: In this section, positioning error of stopping X_{es} = X_{ts} - X_{ps} and the remaining time for the braking t_{zs} are evaluated with menbership function and decide control notch, where X_{ts} indicates the desired stopping position and X_{ps} indicates the predictive stopping position in the next state by changing the control notch. And t_{zs} indicates the remaining time until the deceleration starts for the stopping position. Moreover, by evaluating the time from the time they operated the notch beforhand with menbership function, comfortability is evaluated to decide control notch. By evaluating these elements by membership function, this section decides an output for the highest evaluative value in each moment.

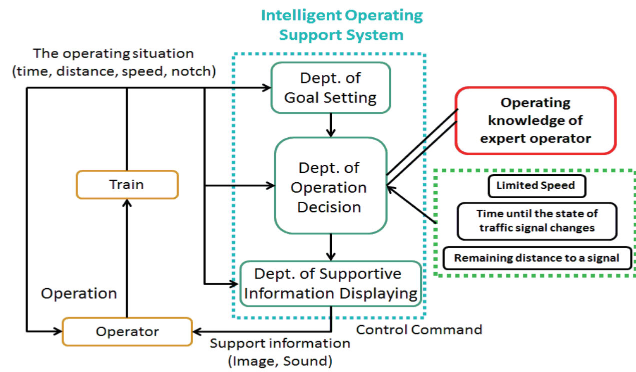

Fig. 4. Configuration of intelligent operating support system

C. Displaying of supportive information

We used on-displayed supprotive information as shown in Fig.5 to provide supportive information to train operator. Left side of Fig.5 indicates the current operation of user and right side of Fig.5 indicates the appropriate control information based on expert operators. This is, supportive information and was calculated based on knowledge of the expert operators.

Users operate a master controller as shown on the right of Fig.5 so that they can operate train as same as expert operators by passing the traffic signals at the limited speed $V_{(X_{sg},T_{sg})}$ = V_a[m/s] and smooth, accurate stopping at the destination. Hence, we can realize operation of train for shortening arrival time.

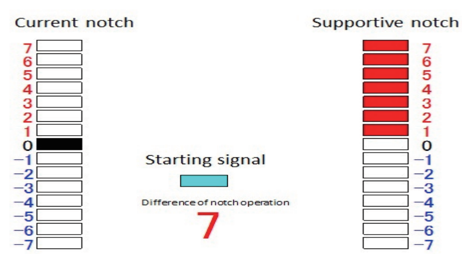

Fig. 5. Display of supportive information

VII. Simulation Experiments

A. Simulation assumption

To confirme the effectiveness of the proposed method, simulations using MATLAB were performed in 2 ways.

The simulation environment is shown in Fig.6. We set up a traffic signal at 1300[m] point between 2 stations and simulated where starting position X_{st} = 0[m], original speed V_{st} = 0[m/s], limited speed of first section V_{l1} = 23[m/s], limited speed of second section V_a = 15[m/s] , the distance to the destination from starting position X_g = 2000[m]. Considering current information and the constraint conditions which change dynamically, we performed simulation using developed intelligent operating support system by non-expert operators. At that time, we set the simulation environment as same as real environment, where safety is guaranteed by the ATS, automatic train stop system. In this way, safety runnning is guaranteed while operating by taking brakes automatically, and slowing down if the current speed beyonds the limited speed. Constraint conditions are shown below.

I: V_{lim} changes to $V_a = 15[m/s]$ from $0[m/s]$ due to the switching of the signal state as shown in Fig.7. T_{sg} is constant as 80[s].

II: T_{sg} and V_{lim} change due to the switching of the signal state as shown in Fig.7. Specifically, T_{sg} changes to 80[s] from 100[s] after 30[s] from starting. V_{lim} also changes to $V_a = 15[m/s]$ from 0[m/s] with the change of T_{sg}.

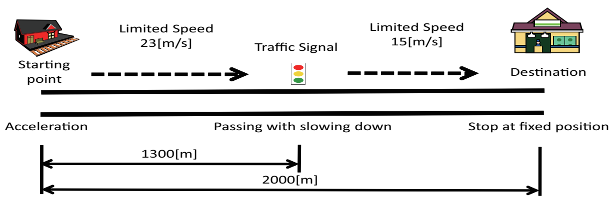

Fig. 6. Simulation environment

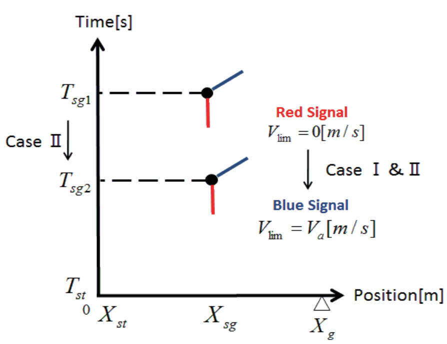

Fig. 7. Constraint conditions

B. Case I

1) Result and Discussion: Fig.8 shows the relation of position x[m] and time. Now, we can consider that final stopped pisition X_g was 2002.4[m] in the case that operator didn't use the developed support system. In the case that operator used the intelligent operating support system and information of constraint conditions, on the other hand, final stopped position X_g was 2000.01[m]. Thus it is indecated that the error between desired stopping positon and actuall stopped position was smaller than the case that operator didn't use the developed support system. And also, as for the passage position, although in the case that operator didn't use the developed support system, positioning error between desired passage positon and actuall passage position was 1[m], in the case that operator used intelligent operating support system, on the other hand, has the passage positioning error only 0.3[m]. According to the exminative result, it is indicated that the method using intelligent operating support system considering the change of constraint conditions is effective for the preciesly operating at passing and stopping position.

As for Fig.10, although the numbers of notch changing was 52 times in the case that operator didn't use the developed support system, the numbers of notch changing in the case that the operator used the developed system was only 27 times. This result indicates that using of this system is effective for the decline of numbers of notch changing. In other words, it is also indicated that proposed method is also effective for prevention of the aggravation of comfortability because it could largely reduce the numbers of notch changing.

As for Fig.8 and Fig.9, in the case that operator didn't use the developed support system, they restart runnning just after the state of traffic signal switched to blue because they couldn't use provided information well. In the case that the operator used intelligent operating support system, on the other hand, they passed at the traffic signal after 80[s] at limited speed V_a = 15[m/s] and it indicates that arrival time is 15.5[s] shorter than the case that the operator didn't use the developed support system by passing through X_{sg}[m] at V_a[m/s].

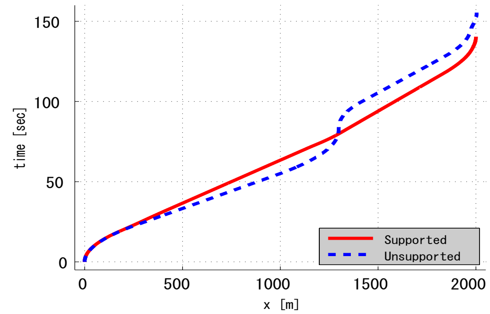

Fig. 8. S-T graph

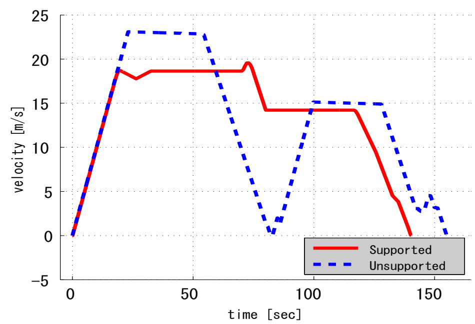

Fig. 9. Relation of time and velocity

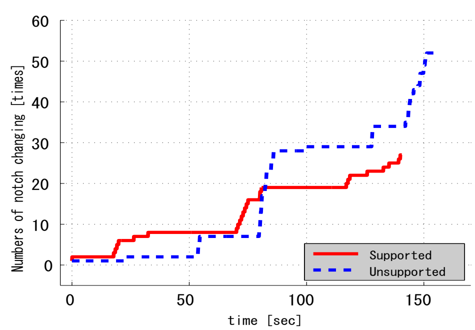

Fig. 10. The numbers of notch changing

C. Case II

1) Result and Discussion: Fig.11 shows the relation of posision x[m] and time. Now, we can consider that final stopped pisition X_g was 2001.3[m] in the case that operator didn't use the developed support system. In the case that operator used the intelligent operating support system, on the other hand, final stopped position X_g was 2000.02[m]. Thus it is indecated that positioning error between desired stopping positon and actuall stopped position was smaller than the case operator didn't use the developed support system. And also as for the passage position, althogh in the case that operator didn't use developed support system has passage positioning error between desired passage positon and actuall passage position was 1[m], in the case that operator used intelligent operating support system, on the other hand, has passage positioning error only 0.3[m]. According to the exminated ressult, even though T_{sg} was changed, it is indicated that proposed method using intelligent operating support system considering the change of constraint conditions is effective for the preciesly operating at the passing and stopping position.

As for Fig.13, although the numbers of notch changing was 80 times in the case that operator didn't use the developed support system, the numbers of notch changing in the case that the operator used the developed system was only 32 times. This result indicates that using of this system is effective for the decline of numbers of notch changing. In other words, it is also indicated that proposed method is also effective for prevention of the aggravation of comfortability because it could largely reduce the numbers of notch changing.

As for Fig.11 and Fig.12, in the case that operator didn't use the developed support system, they restart runnning just after the state of traffic signal switched to blue because they couldn't use provided information well. In the case that the operator used intelligent operating support system, on the other hand, they passed at the traffic signal after 80[s] at limited speed V_a[m] even though T_{sg} was changed. And it indicates that arrival time is 23.5[s] shorter than the case that the operator didn't use the developed support system by passing through X_{sg}[m] at V_a[m/s].

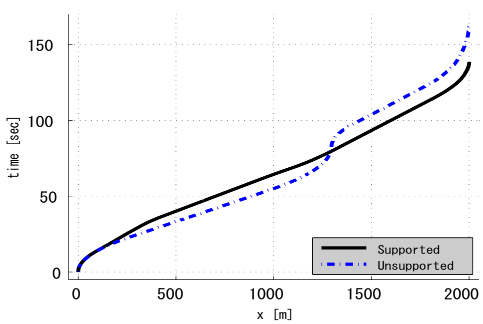

Fig. 11. S-T graph

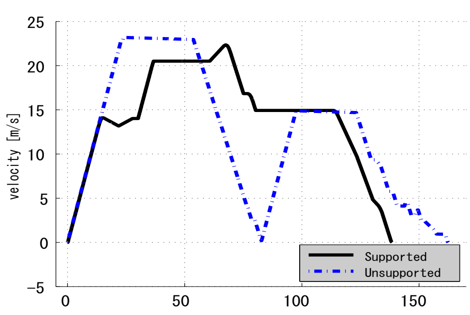

Fig. 12. Relation of time and velocity

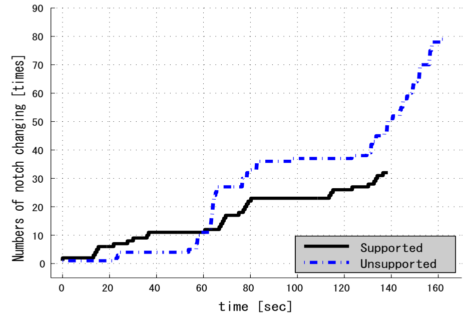

Fig. 13. The numbers of notch changing

VIII. Conclusions

In this study, we analyzed the operation of the expert operators near the traffic signals and developed an intelligent operating support system based on the knowledge of the expert operators. Then we exmined operating simulation of train by non-expert operators using the developed intelligent operating support system. And we confirmed that we could arrive at the destination comfortably, precisry, smoothly and could shorten arrival time by proposed intelligent operating method using developed support system considering the change of constraint condtions. By confirming these contents, we confirmed the effevtiveness of proposed intelligent operating method for shotening arrival time and the recovery of transport volume.

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References

[1] S. Yasunobu et al, *Fuzzy Control for Automatic Train Operation System*, 4th IFAC/IFIP/IFRS int. Conf. on Transportation Systems,1983,pp39-45.

[2] S.Yasunobu, S.Miamoto, H.Ihara, et al, *Application of Predictive Fuzzy Control to Automatic Train Operation Controller*, 4th Proc. Of IECON 1984,pp657-682

[3] S.Takahashi, S. Yasunobu, *A Development of Intelligent Operating Support System under the dynamic environment* The 60th the study meeting for intellectual control, pp.12-13, 2011.