A New Method for Marshaling of Freight Train with Generalization Capability Based on the Processing Time

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Abstract—**This paper proposes a new marshaling method for assembling an outgoing train from freight cars incoming with a random order. In the proposed method, marshaling plans based on the processing time can be obtained by a reinforcement learning system. Also, the incoming freight cars are classified into several ``sub-tracks'' searching better assignment in order to reduce the total processing time. Then, the number of sub-tracks utilized in the classification is obtained by learning in order to yield generalization capability. In order to evaluate the processing time, the total transfer distance of a locomotive and the total movement counts of freight cars are simultaneously considered. In the proposed method, each set of freight cars that have the same destination make a group, and the desirable group layout constitutes the best outgoing train. Then, the order of movements of freight cars, the position for each removed car, the layout of groups in a train, the arrangement of cars in a group and the number of cars to be moved are simultaneously optimized to achieve minimization of the total processing time for obtaining the desired arrangement of freight cars for an outbound train.**

Index Terms— **Container Transfer Problem, Freight train, Marshaling, Q-Learning, Scheduling**

I. Introduction

Railway transportation has an important role in logistics due to its large transportation capacity and small environmental load. However, since freight trains can transport goods only between railway stations, modal shifts are required for area that has no railway. Thus, the marshaling operation at freight station is required to joint several rail transports, or different modes of transportation including rail. A freight train is consists of several freight cars, and each car has its own destination. The train driven by a locomotive travels several destinations decoupling corresponding freight cars at each freight station. In intermodal transports including rail, containers carried into the station are loaded on freight cars and located at the freight yard in the arriving order. The initial layout of freight cars in the yard is determined by considering both arrangement of incoming train and the arriving order of the containers carried by non-rail methods. Containers carried into the station are loaded on freight cars and the initial layout of freight cars is thus random. For efficient shift in assembling outgoing train, freight cars must be rearranged before coupling to the freight train. In general, the rearrangement process is conducted in a freight yard that consists of a main-track and several sub-tracks. Freight cars initially placed on sub-tracks are rearranged, and lined into the main track. This series of operation is called marshaling, and several methods to solve the marshaling problem have been proposed [1]-[3]. However, these methods do not consider the processing time for each transfer movement of freight car that is moved by a locomotive. Moreover, in these methods, the marshaling is based on the layout generated by the classification process that assigns each car into a certain sub-track. This causes restrictions on the number of sub-tracks and the number of cars in a sub-track. On the other hands, in our research group, several methods that can generate marshaling plans from the random layout have been proposed [4],[5]. Although these methods do not require pre-process to ease the marshaling process, they do not consider optimization of the initial arrangement of the cars in sub-tracks based on the processing time.

In this paper a new method for generating marshaling plan of freight cars in a train is proposed. In the proposed method, the incoming freight cars are classified into several sub-tracks searching better assignment in order to reduce the total processing time. Then, classifications and marshaling plans based on the processing time are obtained by a reinforcement learning method [6]. Then, the number of sub-tracks used in the classification is selected to yield generalization capability in the learning process. Simultaneously, the desirable classification of incoming cars as well as, the optimal sequence of car-movements, the number of freight cars that can achieve the desired layout of outgoing train is obtained by autonomous learning.

In the learning process, a movement of a freight car consists of 4 elements:

1. moving a locomotive to the car to be transferred,
2. coupling cars with the locomotive,
3. transferring cars to their new position by the locomotive,
4. decoupling the cars from the locomotive.

The processing times for elements 1. and 3. are determined by the transfer distance of the locomotive, the weight of the train, and the performance of the locomotive. The total processing times for elements 1. and 3. are determined by the number of movements of freight cars. Thus, the transfer distance of the locomotive and the number of movements of freight cars are simultaneously considered, and used to evaluate and minimize the processing time of marshaling for

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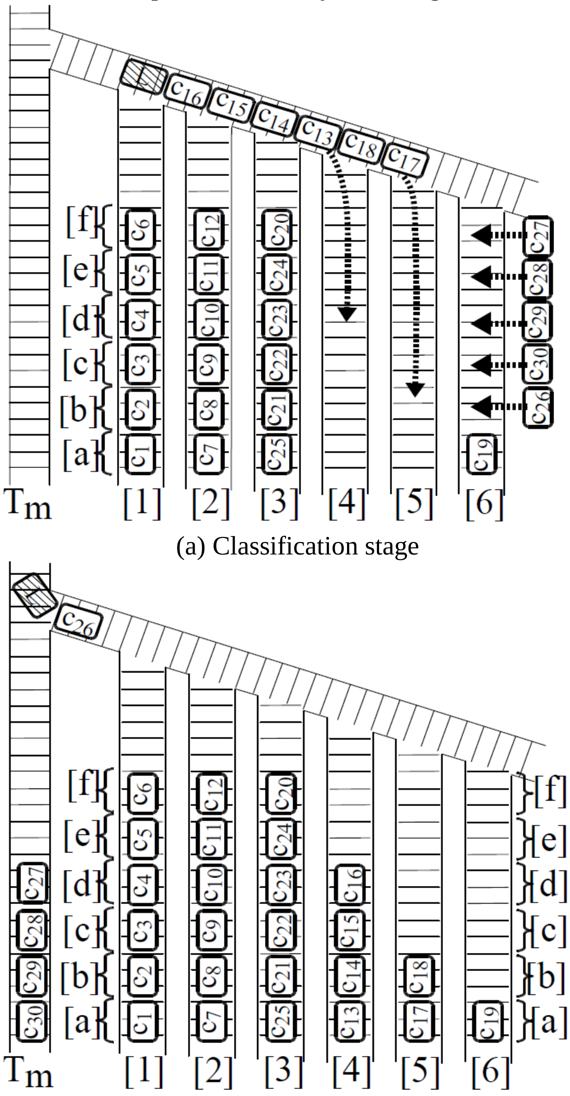
obtaining the desired layout of freight cars for an outbound train. The total processing time of marshaling is considered by using a weighted cost of a transfer distance of the locomotive and the number of movements of freight cars. Then, the order of movements of freight cars, the position for each removed car, the arrangement of cars in a train and the number of cars to be moved are simultaneously optimized to achieve minimization of the total processing time.

In the learning algorithm, the number of sub-tracks utilized in the classification is evaluated. Then several layouts generated by the classification with the selected sub-tracks are simultaneously updated. This feature yields generalization capability. In the realistic scale of problems, individual update for results of classification is not effective because the number of layouts is huge. By selecting the number of sub-tracks that has the better evaluation, the learning performance of the proposed method can be improved.

II. Problem Description

A. Freight Yard

A freight yard is assumed to have 1 main track and m sub-tracks. Define k as the number of freight cars carried in and assigned to sub-tracks in a classification stage. Then, they are moved to the main track by the desirable order based on their destination in a marshaling stage. In the yard, a locomotive moves freight cars, and the movement of freight cars from sub-track to sub-track is called removal, and the car-movement from sub-track to main track is called rearrangement. For simplicity, the maximum number of freight cars that each sub-track can have is assumed to be n, the ith car is recognized by an unique symbol c_i, (i=1, $\cdots$, k). Fig. 1 shows the outline of freight yard in the case k=30, m=n=6. In the figure, track Tm denotes the main track, and other tracks [1]-[6] are sub-tracks. The main track is linked with sub-tracks by a joint track, which is used for moving cars between sub-tracks, or for moving them from a sub-track to the main track. Fig. 1-(a) depicts an example of classification and Fig. 1-(b) is an example of marshaling. In Fig. 1-(a), after cars c_1 through c_{12}, and c_{20} through c_{26} are classified into sub-tracks [1] [2] [3], c_{19} is placed on the sub-track [6]. Then, c_{26} through c_{30} carried by trucks are placed on sub-track [6] by the arriving order. In Fig. 1-(b), freight cars are moved from sub-tracks, and lined in the main track by the descending order, that is, rearrangement starts with c_{30} and finishes with c_1. When the locomotive L moves a certain car, other cars locating between the locomotive and the car to be moved must be removed to other sub-tracks. This operation is called removal. Then, if $k \leq nm-(n-1)$ is satisfied for keeping adequate space to conduct removal process, every car can be rearranged to the main track. In each sub-track, positions of cars are defined by n rows. Every position has unique position number represented by mn integers, and the position number for cars at the main track is 0. Fig. 2 shows an example of position index for k=30, m=n=6 and the layout of cars for Fig. 1-(b). In Fig. 2, the position ``[a][1]" that is located at row ``[a]" in the sub-track ``[1]" has the position number 1. For unified representation of layout of cars in sub-tracks, the first car is placed at the row ``[a]" in every track, and a newly placed car is coupled with the adjacent freight car.



(a) Classification stage

(b) Marshaling stage

Fig. 1: Freight yard

	Position						Marshaling					
[f]	31	32	33	34	35	36	c_6	c_{12}	c_{20}			
[e]	25	26	27	28	29	30	c_5	c_{11}	c_{24}			
[d]	19	20	21	22	23	24	c_4	c_{10}	c_{23}	c_{16}		
[c]	13	14	15	16	17	18	c_3	c_9	c_{22}	c_{15}		
[b]	7	8	9	10	11	12	c_2	c_8	c_{21}	c_{14}	c_{18}	
[a]	1	2	3	4	5	6	c_1	c_7	c_{25}	c_{13}	c_{17}	c_{19}

Fig. 2 Example of position index and yard arrangement

B. Desired layout in the main track

In the main track, freight cars that have the same destination are placed at the neighboring positions. In this case, removal operations of these cars are not required at the destination regardless of arrangements of these cars. In order to consider this feature in the desired layout in the main track, a group is organized by cars that have the same destination, and these cars can be placed at any positions in the group. Then, making a group corresponding to each destination, the order of groups lined in the main track is predetermined by destinations. This feature yields several desirable layouts in the main track.

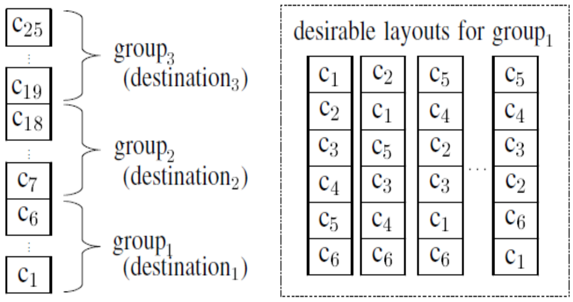


Fig 3: Groups and arrangements of freight cars

Fig. 3 depicts examples of desirable layouts of cars and the desired layout of groups in the main track. In the figure, freight cars c_1, ⋯, c_6 to the destination1 make group1, c_7, ⋯, c_{18} to the destination2 make group2, c_{19}, ⋯, c_{25} to the destination3 make group3. Groups1,2,3 are lined by ascending order in the main track, which make a desirable layout. Also, in the figure, examples of layout in group1 are in the dashed square.

The layout of groups lined by the reverse order does not yield additional removal actions at the destination of each group. Thus, in the proposed method, the layout lined groups by the reverse order and the layout lined by ascending order from both ends of the train are regarded as desired layouts. By defining *r* as the number of groups, the total number of layouts of group is 2^{r-1}.

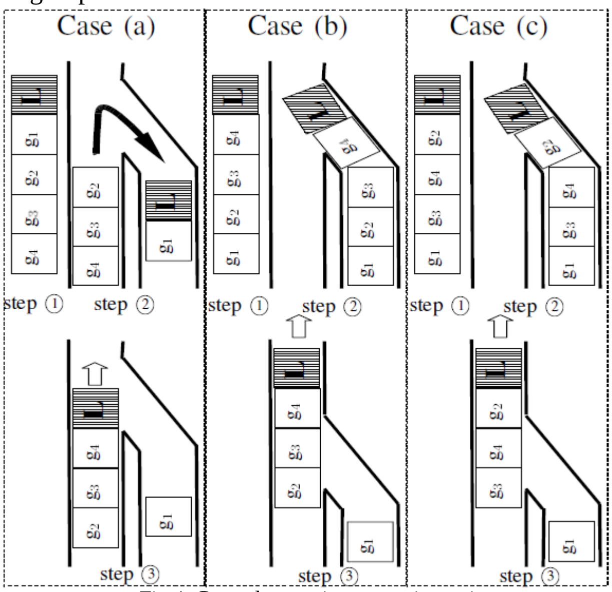


Fig 4: Group layouts in a out going train

Fig. 4 depicts examples of material handling operation for extended layout of groups at the destination of group1. In the figure, step 1 shows the layout of the incoming train. In case (a), cars in group1 are separated at the main track, and moved to a sub-track by the locomotive L at step 2. In cases (b),(c), cars in group1 are carried in a sub-track, and group1 is separated at the sub-track. In the cases, group1 can be located without any removal actions for cars in each group. Thus, these layouts of groups are regarded as candidate for desired one in the learning process of the proposed method.

Fig. 5 shows an example of arrangement in sub-tracks existing candidates for rearranging cars that require no removal. At the top of figure, from the left side, a desired layout of cars and groups, the initial layout of cars in sub-tracks, and the position index in sub-tracks are depicted for $m=n=4$, $k=9$. c_1, c_2, c_3, c_4 are in group1, c_5, c_6, c_7, c_8 are in group2, and group1 must be rearranged first to the main track. In each group, any layouts of cars can be acceptable. In both cases, c_2 in step 1 and c_3 in step 3 are applied the direct rearrangement. Also, in step 4, 3 cars c_1, c_4, c_5 located adjacent positions are coupled with each other and moved to the main track by a direct rearrangement operation. In addition, at step 5 in case 2, cars in group2 and group3 are moved by a direct rearrangement, since the positions of c_7, c_8, c_6, c_7 are satisfied the desired layout of groups in the main track. Whereas, at step 5, case 1 includes 2 direct rearrangements separately for group2 and group3.

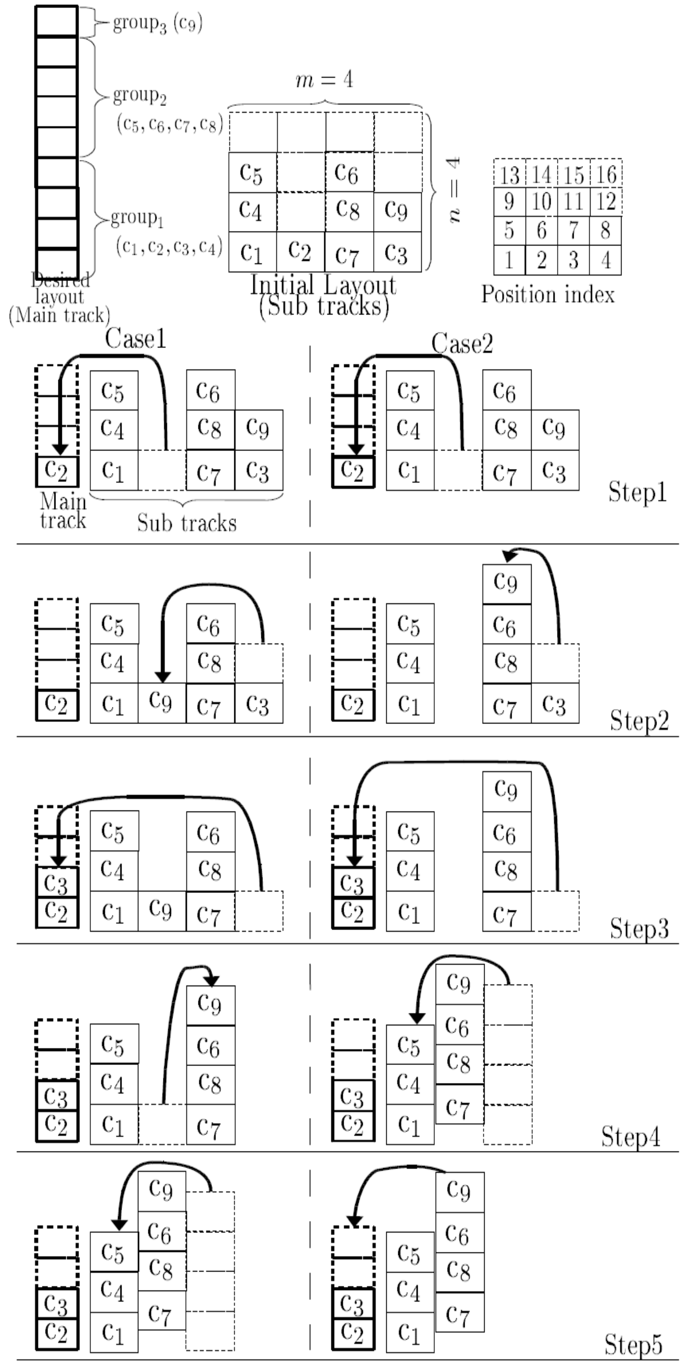


Fig 5: Examples of marshaling

C. Marshaling process

A marshaling process consists of following 7 operations:

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(I) selections: group-layout in the main track, the number of sub-tracks used in the classification,
(II) classification of the incoming freight cars into sub-tracks,
(III) rearrangement of freight cars to the main track, when they can be moved directly,
(IV) selection: a freight car to be rearranged into the main track,
(V) selection: removal destinations of the cars in front of the car selected in (IV),
(VI) selection: the number of cars to be moved in (V),
(VII) removal of the cars determined in (VI) to the selected sub-track in (V).

After operations (I),(II) are finished, (III)-(VII) are repeated until one of desirable layouts is achieved in the main track, and a series of operations from the initial one in (I) to the final one in (III) achieving the desirable layout is defined as a trial.

Now, define Go as the desired layout, m_c as the number of sub-tracks used in the classification stage and h as the number of candidates of (Go, m_c). Each candidate in operation (I) is represented by u_{j1} ($1\leq j_1 \leq h$, $h=2^{r-1}m_c$.)

In the operation (II), a sub-track for each car is determined from the tail of the train. The determined sub-track is defined as T_C, and candidates of T_C are defined as u_{j2} ($h+1\leq j_2\leq h+m$). u_{j2} are sub-tracks each of which satisfies a part of the layout in Go. When there is no such sub-track, T_C is selected from m sub-tracks. Then, the number of groups classified to T_C is determined. Candidates are groups that satisfy a part of the layout in Go, and are defined as u_{j3} ($h+m+1 \leq j_3 \leq h+m+v$), where v is the number of the candidates.

In the operation (IV), each group has the predetermined position *in* the main track. Then, the car to be rearranged is defined as c_T, and candidates of c_T is determined by the number of freight cars that have already rearranged to the main track and the group layout in Go. n_g is defined as the number of freight cars in group to be rearranged, and u_{j4} ($h+m+v+1\leq j_4\leq h+m+v+n_g$) as candidates of c_T.

In the operation (V), the removal destination of cars located on the car to be rearranged is defined as T_R. Then, defining u_{j5} ($h+m+v+ n_{gi} +1 \leq j_5 \leq h+m+v+ n_{gi} +m-1$) as candidates of T_R, excluding the sub-track that has the car to be removed, and the number of candidates is m-1.

In the operation (VI), defining n_p as the number of removal cars required to rearrange c_T, and defining n_q as the number of removal cars that can be located the sub-track selected in the operation (V), the candidate numbers of cars to be moved are determined by u_{j6} ($1\leq u_{j6}\leq \min\{n_p,n_q\}$, $h+2m+v+ n_g +m \leq j_6\leq h+2m+v+ n_g +m +\min\{n_p, n_q\}$). (III)-(VII) are repeated until all the cars are rearranged into the main track.

D. Transfer distance of Locomotive

When a locomotive transfers freight cars, the process of the unit transition is as follows: (E1) starts without freight cars, and reaches to the joint track, (E2) restarts in reverse direction to the target car to be moved, (E3) joints them, (E4) pulls out them to the joint track, (E5) restarts in reverse direction, and transfers them to the indicated location, and (E6) disjoints them from the locomotive. Then, the transfer distance of locomotive in (E1), (E2), (E4) and (E5) is defined as D_1, D_2, D_3 and D_4, respectively, and the distance of the unit transition D is calculated by $D= D_1+ D_2+ D_3 +D_4$. Also, define the unit distance of a movement for cars in each sub-track as D_{minv}, the length of joint track between adjacent sub-tracks, or, sub-track and main track as D_{minh}. The location of the locomotive at the end of above process is the start location of the next movement process of the selected car. The initial position of the locomotive is located on the joint track nearest to the main track.

Fig. 6 shows an example of transfer distance. In the figure, $m=n=6$, $D_{minv}=D_{minh}=1$, $k=18$, (a) is position index, and (b) depicts movements of locomotive and freight car. Also, the locomotive starts from position 8, the target is located on the position 18, the destination of the target is 4, and the number of cars to be moved is 2. Since the locomotive moves without freight cars from 8 to 24, the transfer distance is D1+D2=12, D1=5,D2=7, whereas it moves from 24 to 16 with 2 freight cars, and the transfer distance is D3+D4=13 (D3=7,D4=6).

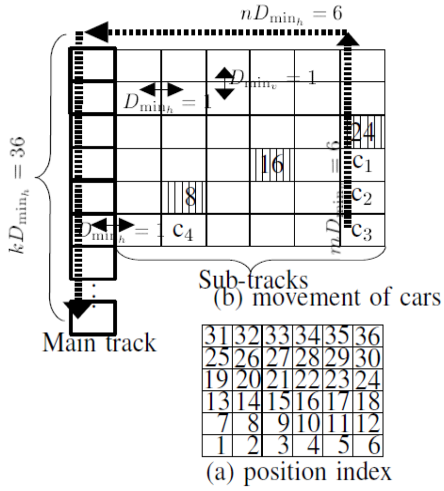

Fig 6: Transfer distance

E. Processing time for the unit transition

In the process of the unit transition, the each time for (E3) and (E6) is assumed to be the constant t_E .

The processing times for elements (E1), (E2), (E4) and (E5) are determined by the transfer distance of the locomotive D_i (i=1,2,3,4), the weight of the freight cars W moved in the process, and the performance of the locomotive. Then, the time each for (E1), (E2), (E4) and (E5) is assumed to be obtained by the function $f(D_i, W)$ derived considering dynamics of the locomotive, limitation of the velocity, and control rules. Thus, the processing time for the unit transition t_U is calculated by $t_U = t_E + \sum_{i=1}^{2} f(D_i, 0) + \sum_{j=3}^{4} f(D_j, W)$.

The maximum value of t_U is defined as $t_{\max}$ and calculated by

$$t_{\max} = t_E + f(kD_{\min v}, 0) + f(mD_{j\min h}, 0) + f(mD_{\min h} + n, W) + f(kD_{\min v}, W) \quad (1)$$

F. Direct rearrangement

When there exists a rearranging car that has no car to be removed on it, its rearrangement precedes any removals. In the case that several cars can be rearranged without a removal, rearrangements are repeated until all the candidates for rearrangement requires at least one removal. If several candidates for rearrangement require no removal, the order of selection is random, because any orders satisfy the desirable layout of groups in the main track. In this case, the arrangement of cars in sub-tracks obtained after rearrangements is unique, so that the movement count of cars has no correlation with rearrangement order of cars that require no removal. This operation is called direct rearrangement. When a car in a certain sub-track can be rearrange directly to the main track and when several cars located adjacent positions in the same sub-track satisfy the layout of group in the main track, they are coupled and applied direct rearrangement.

III. Learning Algorithm

Defining Q_1 as an evaluation value for (Go, m_c), $Q_1(Go, m_c)$ is updated by the following rule when one of desired layout is achieved in the main track:

$$Q_1(Go, m_c) \leftarrow \max\left\{Q_1(Go, m_c), (1-\alpha)Q_1(Go, m_c) + \alpha R\prod_{i=1}^{l}\gamma_i\right\} \quad (2)$$

where l denotes the total movement counts required to achieve the desired layout, α is learning rate, γ_i is discount factor calculated for each movement, R is reward that is given only when one of desired layout is achieved in the main track. In order to yield generalization, evaluation for each (Go, m_c) is conducted only in the classification stage, and Go is used alone for evaluations in marshaling stage.

Define $\boldsymbol{s}(t)$ as the state at time t, Tc as the sub-track selected as the destination for the removed car, p_C as the number of classified groups, q_M as the movement counts of freight cars by direct rearrangement, and $\boldsymbol{s}'$ as the state that follows $\boldsymbol{s}$. In the classification stage, Q_2,Q_3 are defined as evaluation values for ($\boldsymbol{s}_1$,u_{j2}), ($\boldsymbol{s}_2$,u_{j3}) respectively, where $\boldsymbol{s}_1$=[$\boldsymbol{s}$, Go], $\boldsymbol{s}_2$=[$\boldsymbol{s}_1$, T_C]. $Q_2(\boldsymbol{s}_1,T_C)$ and $Q_3(\boldsymbol{s}_2, p_C)$ are updated by following rules:

$$Q_2(\boldsymbol{s}_1, T_C) \leftarrow \max_{u_{j3}} Q_3(\boldsymbol{s}_1, u_{j3}) \quad (3)$$

$$Q_3(\boldsymbol{s}_2, p_C) \leftarrow (1-\alpha)Q_3(\boldsymbol{s}_2, p_C) + \alpha V_1$$

$$V_1 = \begin{cases} \mathbf{R}\prod_{\mathbf{i=1}}^{\mathbf{l}}\gamma_i & \text{(all cars assigned)} \\ \gamma \max_{u_{j2}} Q_2(\boldsymbol{s}_1, u_{j2}) & \text{(otherwise)} \end{cases} \quad (4)$$

In the rearrangement, define q as the number of direct movements conducted sequentially, p_M as the number of cars moved. Q_4,Q_5 and Q_6 are defined as evaluation values for ($\boldsymbol{s}_1$,u_{j4}),($\boldsymbol{s}_3$,u_{j5}),($\boldsymbol{s}_4$,u_{j6}) respectively, where $\boldsymbol{s}_3$=$\boldsymbol{s}_1$, $\boldsymbol{s}_4$=[$\boldsymbol{s}_3$, c_T], $\boldsymbol{s}_5$=[$\boldsymbol{s}_4$, T_R]. $Q_4(\boldsymbol{s}_3,c_T)$,$Q_5(\boldsymbol{s}_4, T_R)$ and $Q_6(\boldsymbol{s}_5,p_M)$ are updated by following rules:

$$Q_4(\boldsymbol{s}_3, c_T) \leftarrow \max_{u_{j5}} Q_5(\boldsymbol{s}_4, u_{j5}) \quad (5)$$

$$Q_5(\boldsymbol{s}_4, T_R) \leftarrow \max_{u_{j6}} Q_6(\boldsymbol{s}_5, u_{j6}) \quad (6)$$

$$Q_6(\boldsymbol{s}_5, p_M) \leftarrow \begin{cases} (1-\alpha)Q_6(\boldsymbol{s}_5, p_M) + \alpha\left[\mathrm{R} + V_2\prod_{i=1}^{q+1}\gamma_i\right], \\ V_2 = \max_{u_{j4}} Q_4(\boldsymbol{s}_3', u_{j4}) \quad (u \text{ is a rearrangement}) \\ (1-\alpha)Q_6(\boldsymbol{s}_5, p_M) + \alpha[\mathrm{R} + \gamma V_3], \\ V_3 = \max_{u_{j5}} Q_5(\boldsymbol{s}_4', u_{j5}) \quad (u \text{ is a removal}) \end{cases} \quad (7)$$

where α is the learning rate, R is the reward that is given when one of desirable layout is achieved, and γ is the discount factor that is used to reflect the transfer distance of locomotive and calculated by the following equation:

$$\gamma = \delta\frac{t_{\max} - \beta t_U}{t_{\max}}, (0 < \beta < 1, 0 < \delta < 1). \quad (8)$$

Propagating Q-values by using eqs.(2)-(7), Q-values are discounted according to the transfer distance of locomotive. In other words, by selecting the removal destination that has the largest Q-value, the transfer distance of locomotive can be reduced.

In the learning stages, each u_j, ($1 \le j \le h+2m+v+n_g+m+\min\{n_p, n_q\}$) is selected by the soft-max action selection method [6] In the addressed problem, Q_2, Q_3, Q_4, Q_5, Q_6 become smaller when the number of discounts becomes larger. Then, for complex problems, the difference between probabilities in candidate selection remain small at the initial state and large at final state before achieving desired layout, even after repetitive learning. In this case, obtained evaluation does not contribute to selections in initial stage of marshaling process, and search movements to reduce the transfer distance of locomotive is spoiled in final stage. To conquer this drawback, Q_2, Q_3, Q_4, Q_5, Q_6 are normalized, and probability P for selection of each candidate is calculated by

$$\tilde{Q}_i(\boldsymbol{s}_{i-1}, u_{j_i}) = \frac{Q_i(\boldsymbol{s}_{i-1}, u_{j_i}) - \min_{u_{ji}} Q_i(\boldsymbol{s}_{i-1}, u_{j_i})}{\max_{u_{ji}} Q_i(\boldsymbol{s}_{i-1}, u_{j_i}) - \min_{u_{ji}} Q_i(\boldsymbol{s}_{i-1}, u_{j_i})}, \quad (8)$$

$$P(\boldsymbol{s}_{i-1}, u_{j_i}) = \frac{\exp(\tilde{Q}_i(\boldsymbol{s}_{i-1}, u_{j_i})/\xi)}{\sum_{u \in u_{ji}} \exp(\tilde{Q}_i(\boldsymbol{s}_{i-1}, u)/\xi)}, \quad (9)$$

(i = 2,3,4,5,6)

$$P(u_{j_1}) = \frac{\exp(\tilde{Q}_1(u_{j_1})/\xi)}{\sum_{u \in u_{j1}} \exp(\tilde{Q}_1(u)/\xi)},$$

wherer ξ is a thermo constant.

Since Q_1 is updated considering the number of sub-tracks used in the classification, the initial arrangement of cars in sub-tracks after operation (II) reflects the evaluation of m_c. In the following operations, the evaluation of m_c affects commonly to several arrangements in accordance with selected m_c. As a consequent, a generalization capability is yielded over the updates of Q-values derived from the initial arrangement of cars in sub-tracks. In addition, since update rules in operations (IV),(V),(VI) are independent from m_c, corresponding Q-values are used commonly for all the m_c.

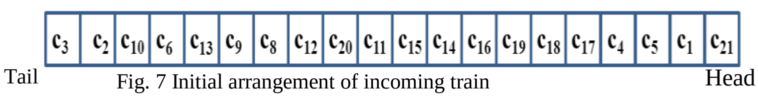

Fig. 7 Initial arrangement of incoming train

IV. Computer Simulations

Computer simulations are conducted for m=n=6,k=21 and learning performances of following 3 methods are compared:

(A) Proposed method considering the layout of groups with generalization capability,

(B) Proposed method without generalization capability[5],

(C) Triangular sorting method [1].

The initial arrangement of incoming train is described in Fig.7. The original groups layout is $group_1$, $group_2$, $group_3$, $group_4$, $group_5$, $group_6$. Cars $c_1, \cdots, c_7$ are in $group_1$, $c_8, \cdots, c_{13}$ are in $group_2$, $c_{14}, \cdots, c_{17}$ are in $group_3$, c_{18}, c_{19} are in $group_4$, c_{20} is in $group_5$ and c_{21} is in $group_6$. Other parameters are set as α =0.9, β =0.2, δ =0.9, R=1.0, ξ =0.1. (C) accepts only the original layout of groups, whereas other methods consider extended layout of groups. In (B), the evaluations in the classification are conducted for Go alone, so that no generalization capability is yielded. The locomotive and freight cars assumed to have the same length, and D_{minv}=D_{minh}=20m. The locomotive assumed to accelerate and decelerate the train with the constant force 100×10^3 N and to be 100×10^3 kg in weight. Also, all the freight cars have the same weight 10×10^3 kg. The velocity of the locomotive is limited to no more than 10m/s. Then, the locomotive accelerates the train until the velocity reaches 10m/s, keeps the velocity, and decelerates until the train stops within the indicated distance D_i (i=1,2,3,4). When the velocity does not reach 10m/s at the half way point of D_i (i=1,2,3,4), the locomotive starts to decelerate immediately.

The results are shown in Fig.8. In the figure, horizontal axis expresses the number of trials and the vertical axis expresses the minimum processing time found in the past trials. Each result is averaged over 20 independent simulations. In Fig.8, the learning performance of method (A) is better than that of (B), because (A) spreads the evaluation of the best solutions for the selected (Go,m_c) by the generalization capability.

Since the group layout for the outbound train and classification are fixed, (C) is not effective to reduce the total processing time as compared to (A),(B). Since (A)(B) evaluate the processing time directly, the plans generated by them are much better than that by (C) based on the total movement counts of freight cars. Since the group layout for the outbound train and classification are fixed, (C) is not effective to reduce the total processing time as compared to (A),(B). Since (A)(B) evaluate the processing time directly, the plans generated by them are much better than that by (C) based on the total movement counts of freight cars.

Total processing time for each method at the 1.0×10^6th trial are described in Table 1 for each method.

V. Conclusion

A new scheduling method has been proposed in order to rearrange and line cars in the desirable order onto the main track considering classifications for incoming freight cars.

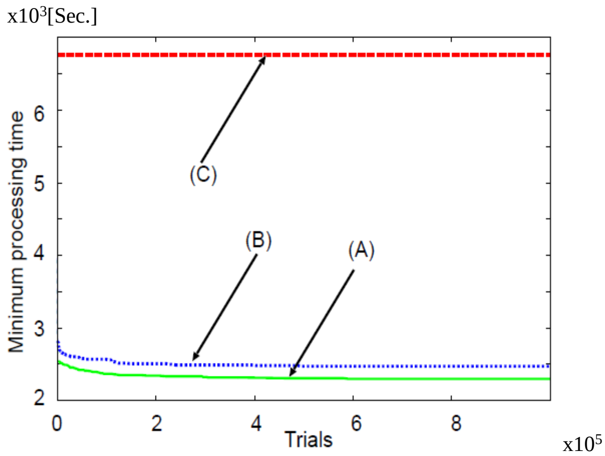

Fig 8 Learning performances

The learning algorithm of the proposed method is derived based on the reinforcement learning that evaluates the total processing time of rearrangement. In order to reduce the total processing time of marshaling, the proposed method yields generalization capability for obtaining the number of sub-tracks used in the classification stage. In computer simulations, the total processing time of the marshaling plan derived by the proposed method has been reduced by over 50% as compared to the conventional triangular sorting algorithm. In addition, the layout of freight cars in the classification, the rearrange order of cars, the position of each removal car, the number of cars to be removed, and the group layout in the outgoing train has been obtained simultaneously so that the learning performance of the proposed method has been improved

Table 1 Results at 1.0×10^6th trial [Sec.]

	Best	Average	Worst
(A)	2252.5	2299.9	2371.8
(B)	2321.7	2477.1	2529.6
(C)	6755.2	6755.2	6755.2

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