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Impact of Moving Block System on Railway Timetable Planning: a qualitative study on existing timetables

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Abstract— This paper proposes a quick way to examine the impact of moving block system on railway timetable planning from minimal amount of data. In general, this method is developed to quickly determine the possible capacity improvement for lines operated in fixed block system if they were upgraded into more sophisticated moving block system. In this paper, railway timetables are characterized by four parameters, the train number, the average speed, the stability and the heterogeneity. Particularly, through examining the interdependency between the capacity improvement and these four parameters, qualitative conclusions are drawn for moving block system upgrade from fixed block system.

Index Terms— Capacity, Moving block system, Railway, Timetable, Block System

1 INTRODUCTION

Capacity on Railways has long been a hot issue and enormous amount of efforts have successfully turned into reality. Among all the new technological achievements in railway domain, moving block system shall be one of the most promising. It is because it can greatly reduce the headway between successive trains and thereby improve the capacity significantly.

This paper intends to study the capacity improvement when existing fixed block system is substituted by moving block system. For a given open time window, if any improvement is achieved, it should be reflected as an increasing unused time proportion, meaning more vacancy is available to load more vehicles on the line. Therefore, in this paper, the increased unused time ratio, or reduced used time ratio is the focus and the impact of moving block system is evaluated by the time proportion it can reduce from existing timetables.

Matlab and Adobe Illustrator are used in this paper to calculate as well as visualize the unused capacity. To start, reduced headway in moving block system compared to fixed block system is studied, after which the compression method is used to illustrate the amount of time which can be saved from the already consumed in order to demonstrate the extra capacity attained.

Also, in this paper, rail line timetables will be characterized by four parameters as the train number, the average speed, the stability and the heterogeneity. A qualitative approach to moving block system's impact on timetables with respect to these parameters is conducted. In order to do so, control variate method is applied. For each time, only one of the four parameters changes and the outcome for each is examined.

This paper is outlined as follows: Section 2 formulates a mathematical module for fixed block system as well as puts forward the variables under consideration. Section 3 discusses the main differences between moving block system and fixed block system, and particularly the improvement in capacity. Section 4 discusses the qualitative interdependency between increased capacity produced by moving block system and four major parameters. Section 5 briefly concludes the study and future direction of this work.

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2 ASSUMPTION AND DYNAMIC MODULE

For the purposes of this paper, the existing timetable including the trains' dynamic running diagram and blocking diagram are deemed as already known. Whereas during the study, some of other parameters may change, running diagram and blocking diagram of each train should be considered as unchangeable. Meanwhile, trains with similar dynamic characteristics are categorized as a reference train set. In other words, the impact of moving block system studied here is not only on any specific infrastructure but also on particular timetables.

This section defines the variables and the restrains of this module.

2.1 Definitions

The set of the reference trains is given by R = {r1,r2,…,rn} wherein all the trains are moving towards the same direction. Since moving block system does not improve the flow of the trains in stations, the rail route studied is solely a double track line between two stations without joints. Assume that the initial station is A and destination station is B, between which p block sections exist and are indicated as S= {1,2,…,p}. Other definitions are as follows.

Tbb^r_s : time train r claims s block. It is when the exclusive occupation begins;

$Tsig^r_s$: time train r enters s block and is kept 0 for all $r \in R$ and s=1. It is when the train enters the block.

Tbe^r_s: time train r clears s block. It is when the exclusive occupation ends;

For all, $r \in R$ and $s \in S$.

All other information such as speed curve, block section

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length and train length are not necessary as the information is already encompassed once the aforementioned data is given.

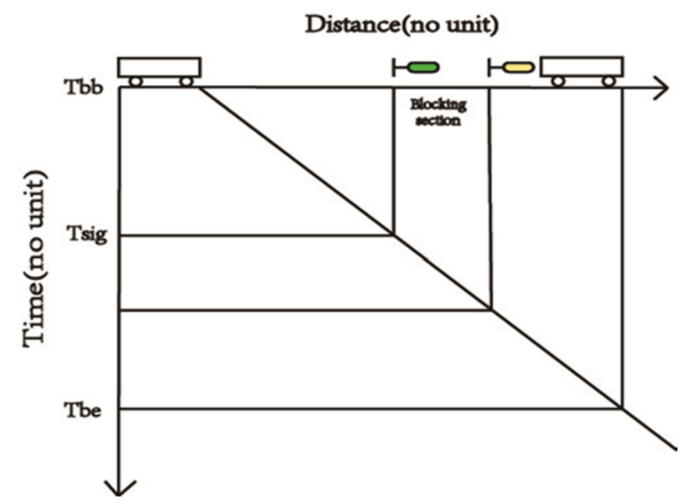

Fig. 1. to demonstrate the defined Tbb, Tsig and Tbe. As can be seen, one train claims its occupation before it enters a block section and clear the occupation after it leaves the blocking section.

2.2 Minimum Headways

As a massive transportation making up more than 50% of the total freight share in some countries [1], railway transportation is at any time and at any place carefully planned and monitored. The capability of drivers, or locomotive engineers, is heavily dependent on a sophisticated central control system. This is also the reason that one train claims one block section long before it enters it to ensure enough time for visual confirmation, path establishment and pre-signal confirmation [2] and the block section will not be released until the train completely clears the signal. In order to avoid train crashes, headways are kept strictly by CTC (Centralized Train Control).

Meanwhile, headways differ from one case to another, depending on the trains and the features of the lines. Nonetheless, in this case, where all the significant time points are clear, the minimum headway in the form of time can be presented as follow:

$$MH_{rj}^{ri} = \max\left(Tbe_s^{ri} - Tbb_s^{rj}\right) \quad (1)$$

For any ri, rj ∈ R while ri departs first and for every s in S.

MH_{rj}^{ri} stands for the minimum time interval rj train has to keep to depart after the departure of ri train, otherwise train collisions may occur. As can be seen from (1), in timetable planning, the headway in between depends on both of the leading train and the following train.

2.3 Buffer Policy

Buffer time is a matter of stability. Buffer time reduce the risk of transmitting delays between trains or they reduce the size of the knock on delay transferred from one train to the following trains. [3]. Usually, more stable the timetable is, the less dependent it is on buffer time. Most railways use the following basic rules [2].

1 Great buffer time when the second train has a higher priority.
2 Low buffer time when the first train has a higher priority.
3 Middle buffer time when both trains have the same priority.

Suppose there is a train dispatch order L= [l_1, l_2,…,l_m], where l_i ∈ R for any i ∈ [1,m], the buffer time needed should be a function with respect to L as BU(L). BU(L) will not change once L is fixed.

2.4 Occupation Time

With this module, all kinds of different capacity consumptions like infrastructure occupation (meaning resources are used for exclusive operation) and buffer time can be theoretically computed. Infrastructure occupation time is a period of time when the relating resources are used because of the operation and it can be derived from solely the train dispatch order.

For any train dispatch order in the form of L= [l_1, l_2,…,l_m], where l_i ∈ R for any i ∈ [1,m].

Then the total infrastructure occupation time should be

$$OT(L) = -Tbb_1^{l_1} + \sum_{i=1}^{m-1} MH_{l_i}^{l_{i+1}} + Tbe_p^{l_m} + BU(L) \quad (2)$$

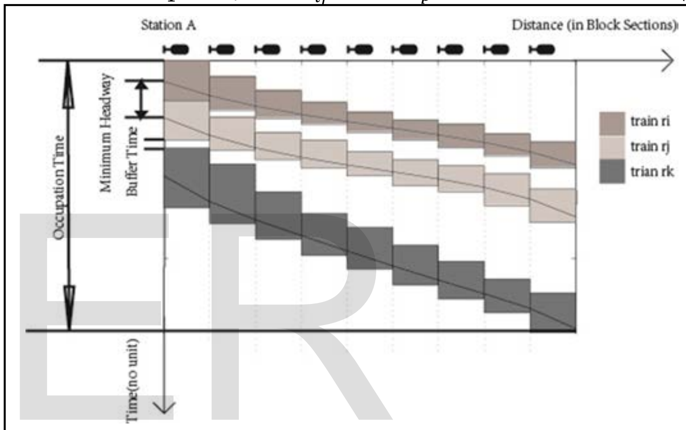

Fig. 2. to demonstrate the components of occupation time. Given a train dispatch order L=(ri, rj, rk), occupation time can be calculate as is in equation (2).

In (2), OT, standing for occupation time, is the minimal time needed to operate a train dispatch L provided no delay bigger than buffer time occurs. The reduction of which is also the main target in this paper, namely, to what extent can moving block system reduce OT(L) is discussed in this paper.

3 MOVING BLOCK SYSTEM

Moving block system is designed to reduce the minimum headway between consecutive trains in order to further improve the line capacity. As the name itself indicates, unlike fixed block system where the block sections are fixed, the block sections can be seen as moving along together with the leading train.

3.1 Mechanism

Unlike fixed block system, where the safety of trains is guaranteed by the principle that in one physical block section only one train can exist, in moving block system, no physical blocking section is needed. Meanwhile, a block section is demarcated by two main signals in fixed block system while the necessity is replaced in moving block system by more sophis-

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ticated cab signals in order to carefully keep a safety distance for the leading train from the following train [4].

With the fast-paced technology development, the technological hurdles which used to hamper the utilization of the moving block system have now been removed. Real-time and anti-hacking communication technology has been developed to a high level that it is possible now to transit the identity, location, direction and speed of each vehicle to the Centralized Train Control to conduct important calculations in real time.

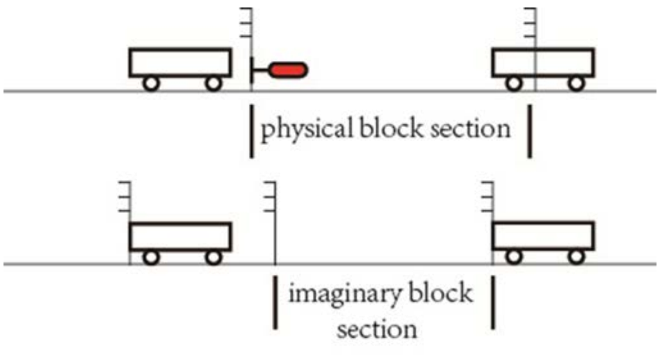

Fig. 3. to demonstrate the difference between fixed block system and moving block system. In fixed block system, following train is strictly kept out of occupied section by red signal while in moving block system the following train is kept a safety distance from the leading train.

As is clearly depicted in Fig. 3, the imaginary block section's moving generates a constant movement authority for the following train to nearly the rear of the leading train [5].

3.2 Minimum Headway Reduction

In this paper where capacity is mainly discussed, the most significant improvement of moving block system compared to fixed block system is that it can considerably reduce the headways. In order to create an analogy with fixed block system, the improved part of moving block system is equivalent to enabling the train to claim the ending point of a block section later and release the occupation of the beginning point of the block section earlier.

In Fig. 4, through cutting one triangle from each rectangle, the diagram is more space-effective compared to Fig. 2 just as how an oblique parking would save space in a parking lot.

While in real moving block diagram, the outline shall be smoother which can be achieved by high degree polynomial curve fitting in simulation visualization, for the purpose of capacity study however, this complexity can be avoided. Results derived from this method shall be enough to offer a qualitative conclusion.

Using this linear approximation obtained, it is possible to calculate all the new minimum headways needed for the moving block system.

Following the assumption that no further variables will change during the upgrading from fixed block system to moving block system, reduced headways can be computed as follow.

$$MH_{rj}^{ri} = \max\left(Tbe_{s-1}^{ri} - Tbb_{s}^{rj}\right) \quad (1)$$

For any ri, rj ∈ R while ri departs first and for every s in S while the edge effect is ignored.

With reduced headways, the occupation time which comprises headway and butter time, will decrease.

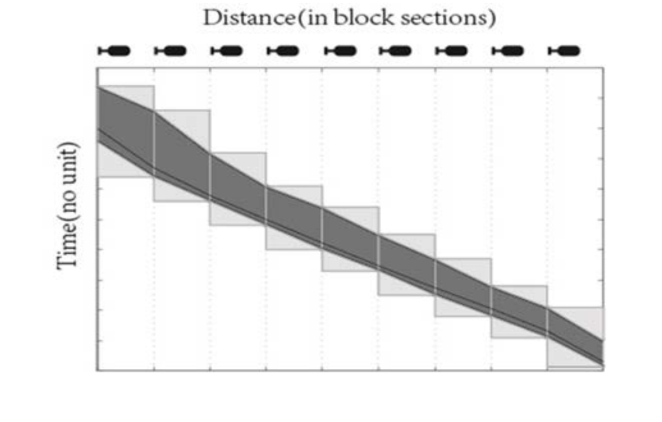

Fig. 4. to demonstrate the blocking time reduction moving block system can generate on a fixed block system based timetable. The lighter part in this illustration stands for the extra time or distance that can be gained by moving block system upgrade.

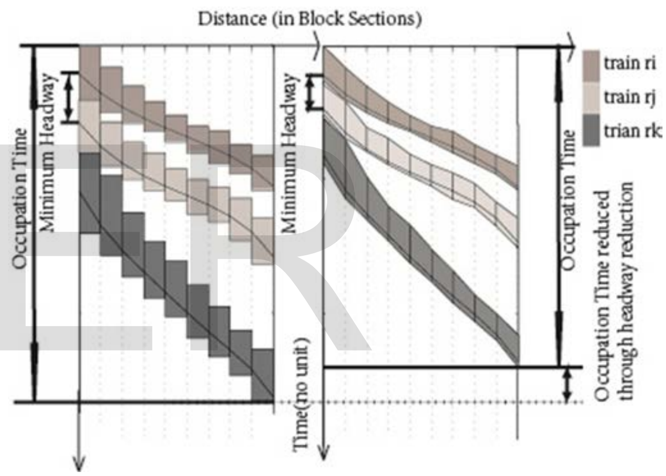

Fig. 5. to demonstrate the occupation time reduction. In this case, with L being [ri, rj, rk], the proportion of occupation time reduced is indicated in the right-down area.

Noteworthy is that so far no additional information or data is needed. Nevertheless, a straightforward way is presented to demonstrate how moving block system can improve railway capacity and the fact that capacity improvement is heavily dependent on the headway reduction is made clear.

However, conclusions are never robust on one specific case. Symbolic calculation and deduction must be conducted to further evaluate the moving block system in regard to railway capacity.

4 RAILWAY CAPACITY EVALUATION

Railway capacity is a hot issue and there exists no universal definition. Enormous work has been conducted in order to define railway capacity in a way so that it can be accepted everywhere. Among which the UIC 406 leaflet [6] from 2004 offers a way which is both simple and effective.

Oddly enough, the very first point of UIC 406 is capacity as such does not exist but depends on the way it is utilized.

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However, what is revolutionary is it puts forward a brief introduction of parameters underpinning capacity as the number of trains, the average speed, the stability and the heterogeneity. Meanwhile, all these parameters have a positive correlation with capacity as implied in this leaflet.

This leaflet imposes huge impacts on how railway engineers understand capacity. Thus it is a wise way to examine all four parameters when evaluating a new system. In the following part of this session, these four basic parameters are examined one by one while other three are kept unchanged and they are denoted as N, A, Sa, H respectively.

Additional definitions:

UC(L) = $-Tbb_1^{l_1}+Tbe_p^{l_m}$: fixed part in OT if L is fixed.

RE(L): theoretical occupation time reduction benefited from moving block system with respect to train dispatch order L. RE(L)=OT(L)-OT(L)$_M$, where OT(L)$_M$ represents the theoretical OT in moving block system.

$\rho(L)=\frac{RE(L)}{OT(L)}$: proportion of time a moving block system can save from the existing system.

$C(X)=\frac{d\rho(L)}{dX(L)}$: correlation between ρ(L) and X(L), where X can be N, A, Sa or H, standing four parameter aforesaid. In addition ρ(L) ∝ X(L) means ρ is positive correlated with X and vice versa.

4.1 Number of trains

Consider a timetable which can be represented as L= [l_1, l_2,…,l_m]. In order to study the correlation between ρ and train number N while keeping the average speed, stability and heterogeneity unchanged, L can be multiplied by a constant α > 1. Following the definition,

$$C(X)=\frac{\rho(\alpha L)-\rho(L)}{(\alpha-1)}=\frac{\frac{RE(\alpha L)}{OT(\alpha L)}-\frac{RE(L)}{OT(L)}}{(\alpha-1)}.$$

When the edge effect is negligible, the effect on minimum headways should be proportional increased by a factor α. Thus the deduction continues as follow.

$$C(N)=\frac{\frac{\alpha*RE(L)}{\alpha*OT(L)-(\alpha-1)*UC(L)}-\frac{RE(L)}{OT(L)}}{(\alpha-1)}>0 \quad (3)$$

4.2 Average Speed

Similarly, to keep all other three parameter besides train speed unchanged, two imaginary timetables can be assumed as L1=[ri, ri, …, ri] and L2=[rj, rj, …, rj] with the same train number m and suppose train rj is faster than train ri.

Since there is no heterogeneity in either timetable, every minimum headway in between is the same. Following the equation to calculate the minimum headways for every two trains, the combined minimum headway for Li in fixed block system is $m*(Tbe_s^{ri}-Tbb_s^{ri})$ while in moving block system is $m*(Tbe_{s-1}^{ri}-Tbb_s^{ri})$ where s is one specific block section which make these expressions maximal. Therefore,

$$\rho(Li)=\frac{RE(Li)}{OT(Li)}=\frac{m*(Tbe_s^{ri}-Tbe_{s-1}^{ri})}{-Tbb_1^{ri}+Tbe_p^{ri}+BU(Li)+m*(Tbe_s^{ri}-Tbb_s^{ri})}.$$

Let Q= $Tbe_s^{ri}-Tbe_{s-1}^{ri}$ and P= $Tbe_s^{ri}-Tbb_s^{ri}$.

Note that Q is positive correlated to the reciprocal of speed since this is basically the travel time between block sections. However, P is not strongly related to average speed since the majority of P is for visual confirmation, path establishment and pre-signal distance. Therefore, provided m is a big enough integer, ρ(L)∝ 1/Sa. And furthermore,

C(A)<0 (4)

4.3 Stability

Stability on railway timetable can be reflected as the need for buffer time. On timetables in which unexpected delays are rare, it is relatively more lenient to not assign as much buffer time as it has to do on timetables otherwise. Meanwhile, under the assumption of this paper, moving block system has no positive effects on the buffer policy, meaning that buffer time is independent from the system in use. Therefore, according to the definition of ρ(L) and the fact that BU(L) ∝ 1/Sa(L), the deduction is not quite strenuous.

$$C(Sa)=\frac{d\rho(L)}{dSa(L)}\propto\frac{\frac{RE(L)}{OT(L)+\Delta BU(L)}-\frac{RE(L)}{OT(L)}}{-\Delta BU(L)}>0 \quad (5)$$

4.4 Heterogeneity

Heterogeneity is a subject hard to define, especially in quantitative perspective [7]. Therefore, study into heterogeneity stops at whether the existence of heterogeneity makes the moving block system more effective.

Assume there is one timetable represented as L= [l_1, l_2,…,l_m] in which ri exists but rj and rk do not. The average speed of rj and rk equals to the average speed of ri. By adding two ri trains or one rj and one rk, the heterogeneities are changed while train number and average speed are remained the same.

$$\begin{cases}\Delta OT(Li)=Tbe_p^{ri}+Tbe_{s1}^{ri}-Tbb_{s1}^{ri}-Tbb_1^{ri}\\ \Delta OT(Ljk)=Tbe_p^{rk}+Tbe_{s2}^{rj}-Tbb_{s2}^{rk}-Tbb_1^{rj}\end{cases}$$

$$\begin{cases}\Delta OT(Li)_M=Tbe_p^{ri}+Tbe_{s1-1}^{ri}-Tbb_{s1}^{ri}-Tbb_1^{ri}\\ \Delta OT(Ljk)_M=Tbe_p^{rk}+Tbe_{s2-1}^{rj}-Tbb_{s2}^{rk}-Tbb_1^{rj}\end{cases}$$

$$\begin{cases}RE(Li)=Tbe_{s1}^{ri}-Tbe_{s1-1}^{ri}\\ RE(Ljk)=Tbe_{s2}^{rj}-Tbe_{s2-1}^{rj}\end{cases}$$

$$\begin{cases}\Delta\rho(Li)=\dfrac{Tbe_{s1}^{ri}-Tbe_{s1-1}^{ri}}{Tbe_p^{ri}+Tbe_{s1}^{ri}-Tbb_{s1}^{ri}-Tbb_1^{ri}}\\ \Delta\rho(Ljk)=\dfrac{Tbe_{s2}^{rj}-Tbe_{s2-1}^{rj}}{Tbe_p^{rk}+Tbe_{s2}^{rj}-Tbb_{s2}^{rk}-Tbb_1^{rj}}\end{cases}$$

$$\frac{\Delta\rho(Li)}{\Delta\rho(Ljk)}=\frac{length(s1)}{length(s2)}*\frac{vj}{vi}*\frac{Tbe_p^{rk}+Tbe_{s2}^{rj}-Tbb_{s2}^{rk}-Tbb_1^{rj}}{Tbe_p^{ri}+Tbe_{s1}^{ri}-Tbb_{s1}^{ri}-Tbb_1^{ri}}$$

In railway design, the length of each block shall not differ in a significant way and usually, s1, s2 in above expression are much likely to be on the edge when trains are accelerating or decelerating. Furthermore, when the length from beginning to destination is long enough, the edge effect is negligible. Therefore,

$$\frac{\Delta\rho(Li)}{\Delta\rho(Ljk)}\sim=\frac{vj}{vi}*\frac{Tbe_p^{rn}}{Tbe_p^{ri}}\sim>1$$

In this expression, rn is the slower one while j is the first departing train which can be the faster one or not.

If the assumptions here are plausible in railway industry, C(H) is more likely to be positive, meaning that heterogeneity has negative effects on moving block system upgrade.

C(H)>0 (6)

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5 CONCLUSIONS

In this paper, moving block system's impact on capacity is studied and in particular its relation between four parameters underpinning is studied.

Moving block system can reduce the headway by significant amount and thereby further reduce the total occupation time. However, the impact of moving block system differs according to the characteristics of the train and infrastructure.

Specifically, four basic parameters of capacity are studied. Moving block system performs better on lines with large train numbers, relatively low average speed, high stability where buffer time is not largely assigned and low train type heterogeneity. It then leads to a suggestion: moving block system should be applied on lines preferably with large train number, normal average speed, high stability and low heterogeneity.

However, the future of traffic planning should be done by gathering real-time data from the field [8]. This study is solely based on existing timetables, which means the complexities on real operation including unexpected events and emergency response, are not considered. In future study, such events can be considered so it can offer further suggestions on railway planning.

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