Metro Traffic Management Scheme Based on Wagons Travelling in Autonomous Mode[1]

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Abstract

In traditional subway traffic management schemes, individual metro wagons are assembled in what is known as metro trains (consists) and these metro trains stop at each and every station. This publication presents a new traffic scheme whereby each wagon travels in a solitary and autonomous fashion. The scheme comprises two modes. The first one is intended for light traffic and reduces the waiting time for boarding passengers by a factor of four. In the other mode, which is designed for heavy traffic, wagons do not stop at all stations, which results in around 30 % of energy savings, shortens travel times by nearly 10 %, and increases the metro tube capacity by 17 %. The new scheme is illustrated in a computer simulation developed with the Prolog programming language.

Keywords – metro system, metro wagon, traffic, energy saving, throughput capacity.

INTRODUCTION

Metro operators around the world are replacing train drivers with computerized systems which keep the trains running in automatic mode. This tendency is certainly the future of metro systems, because, in addition to the sizeable cost savings achieved, automation helps improve the quality of service and the reliability of underground transportation.

This is not the first transformation from manual to automatic control to ever happen. Legacy lifts were handled manually by a human operator. Lifts nowadays are not manned by an operator, instead they travel in an automated manner.

Automated subways will provide new opportunities for the optimisation of metro traffic which are beyond the reach of manual controls.

One optimisation scenario will be presented in this article. We will discuss the implementation of a new traffic scheme comprised of two management modes.

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The first one is referred to as Low Traffic Operating Mode (LTOM). The key feature of the LTOM is that instead of being assembled in train consists, the four metro wagons travel autonomously one after the other. This reduces waiting times at station platforms by a factor of four.

The second one is referred to as Heavy Traffic Operating Mode (HTOM). In the HTOM mode wagons will not stop at each and every station with the benefits being significant reduction of travel times, energy savings, and better capacity utilization of the metro tube.

The new scheme proposed in this article is partly at odds with certain metro system management regulations [1, 2], because these regulations are based on traditional processes and traffic management arrangements. Traditional schemes rely on the physical presence of a train driver onboard the vehicle. Each section is split in block sections and traffic management is supported by electronic and signalling infrastructures which guarantee traffic safety and instruct train drivers how to run their trains. This arrangement has intrinsic limitations arising from the so called limit values which restrict the time intervals between trains as well as the throughput and carrying capacity of the metro system.

The fact that the new scheme challenges certain regulations does not mean that it is unfeasible. What matters here is that it does not challenge the laws of physics. Regulations can be altered while the laws of physics are set in stone.

Other related articles on the organisation of traffic in metro systems, written by us and other authors, are [3, 4, 5, 6].

A simulation program [7], developed with the Prolog programming language [8], provides a visual presentation of the scheme proposed in this article. The scheme under consideration is covered by a patent application [9], and by an international patent application [10].

THE LOW TRAFFIC OPERATING MODE

With the LTOM mode, wagons will stop at all stations provided that there are disembarking or embarking passengers. Waiting times in this mode will be reduced by a factor of four, because the going-through vehicles will be 4 individual wagons instead of one train with 4 wagons. In LTOM mode the vehicles will not skip stations except where nobody wishes to get off or on the wagon. This exception will, however, occur often because low traffic means there will not be too many passengers, and the train will be split in four individual wagons (therefore the expected number of disembarking and embarking passengers will be four times less).

The LTOM mode will require some additional effort on the part of passengers as they will have to indicate (signal) at which station they intend to get off. This however is not a major effort. This effort is acceptable, because the established rule in many urban transportation systems is that passengers are required to flag their intent to disembark the vehicle. Similarly, lift users need to tell the lift which floor they are going to by pressing a button.

THE HEAVY TRAFFIC OPERATING MODE

In the HTOM mode, wagons will not stop at each station and will instead skip stations in accordance with a certain pattern. This will be somewhat more demanding to passengers as they should make sure to board the right wagon. The issue will be solved by installing at each station schematic maps with stations shown in four distinct colours to help passengers identify the vehicle they need to use (see Figure 2). It’s worth noting that every station has a direct connection so making of transfer is never needed.

The station platform will be divided in four smaller platforms, or sub-platforms (see Figures 1 and 2). Only one wagon will dock at each of these smaller platforms. The length of each wagon will be approximately one-fourth of the length of the train consist that can dock at the full platform (i.e. at the four sub-platforms).

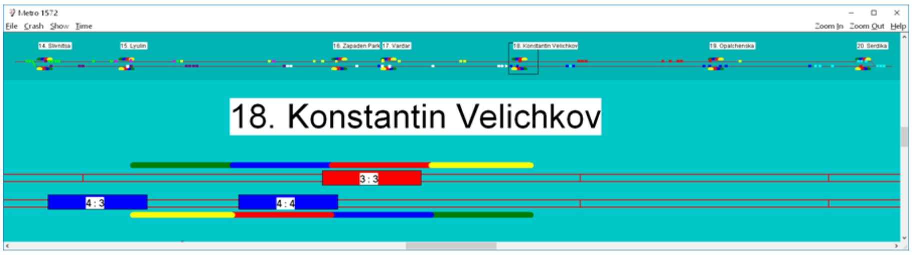

Figure 1

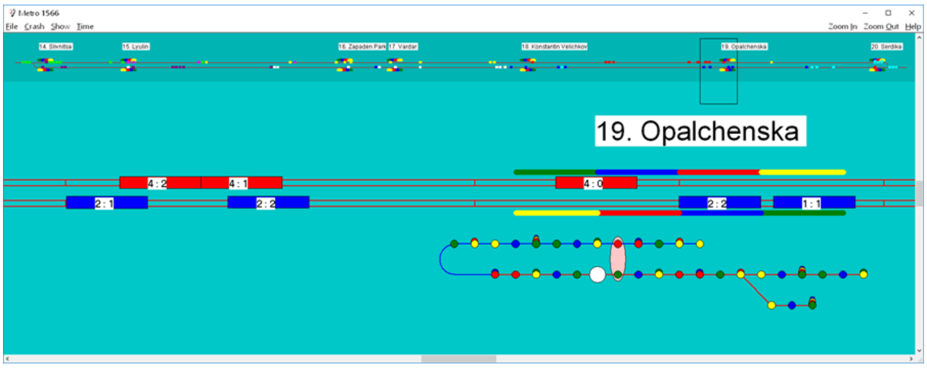

Figure 2

At Sub-platform 1 we will stop only wagons which will skip the next two stations and stop at the third one. (Sub-platform 1 is the rearmost one in traffic direction). Accordingly, at Sub-platform 2 we will stop only wagons which skip three stations and stop at the fourth one. Sub-platform 3 will be reserved for wagons which skip the next station and stop at the station after. Wagons which are due to stop at the next station will dock as the last sub-platform, that is Sub-platform 4 (the foremost one in traffic direction).

The four sub-platforms (lined up in traffic direction) will be identified by the numbers *3, 4, 2, 1* and will be colored in *yellow, red, blue and green*, respectively. With this colour coding system, *green* is the sub-platform for wagons that are due to stop at the nearest station (the next one). *Red* is the sub-platform for wagons due to stop at the furthermost station (the fourth one starting to count from the station of departure).

It will matter from which sub-platform you board the vehicle. You will need to choose the right sub-platform so that the wagon takes you to your station of destination.

DESCRIPTION OF THE HEAVY TRAFFIC OPERATING MODE

We will drive each wagon according to the 1-2-3-4 scheme. This means we will stop the wagon at the next station, then we will skip the next one and stop the wagon at the station after, then we will skip the next two stations and will stop the wagon at the third one, and will finally skip the next three stations to stop the wagon at the fourth one. Then, will run the same 1-2-3-4 cycle from the beginning.

In this way, with 10 stations ahead each wagon will stop at 4 stations only. In other words, the number of stations at which each wagon stops will be reduced by a factor of 2.5.

For each wagon, we must count 1, 2, 3, 4 in order to know in which phase of the 1-2-3-4 cycle it currently is. We must also count the stations of this wagon in order to know at which station we should stop it. Figures 1 and 2 depict the wagons with the values of these two counters shown on each wagon in (X:Y) format. In Figure 1 for example, the blue wagon (4:4) is just leaving the red sub-platform and will not stop until it reaches the fourth station. It is followed by another blue wagon (4:3), which will skip this station and two more stations and will only stop at the third one (from the perspective of this station it will stop at the third one, but from the perspective of the previous station, i.e. the station of departure, it is due to stop at the fourth one).

ESTIMATING THE EFFICIENCY IMPROVEMENTS

Let us have a metro line where stations are 1 200 meters apart. Let the trains travel at 20 m/s (72 km/h). Let the acceleration and deceleration rate be 1 m/s^2. Let the trains stay at each station for 10 seconds on the average.

In this setup, each needless stop will be a waste of 30 seconds (10 seconds to halt, 10 seconds to stay and 10 seconds to depart). At a traveling speed of 20 m/s, a train will need 60 seconds to go from one station to the next one. In this scenario, therefore, one-third of the time will be lost in stops and starts. With the metro management method proposed here, the number of interim stops is reduced by 2.5, so we skip 6 out of 10 stations to achieve time savings of $(6/10)\times(1/3) = 20$ %. We should note that waiting times with the same number of wagons will be 2 times longer (not 2.5 times because our wagons travel 25 % faster), so it can be expected that the average time saving achieved will be in the region of 10 %, assuming that waiting time is 1/10 of travel time. This is possible when the intervals between the wagons are short (e.g. one minute) and the station of destination is two or more stations away. A journey to the next station only will not save time, in fact it will be somewhat slower because the waiting time at the platform is twice longer.

Let us assume that half of the electricity consumed is spent on halting the vehicle and then on setting in motion again, and the other half is spent on keeping the vehicle going at constant speed. Thus, by reducing the number of stops by a factor of 2.5 we achieve electricity savings of 30 %.

Now let us calculate by how much the throughput capacity of the metro line will be increased. Assuming that each wagon is 20 meters long, a train of 4 wagons will need ca. 18 seconds in order to start and halt within 80 meters. Then we add 10 seconds of station time and conclude that it takes at least 28 seconds for 4 wagons to go through. 10 wagons will go through in 70 seconds (28×2.5).

With the new metro management method, at maximum load conditions we will have two stops for 10 wagons. For the first stop we should start and halt within 80 meters and for the second stop — within 120 meters. This makes 18 plus 22 seconds. Let us add 2×10 seconds of station time. The result is that 10 wagons at maximum load will go through in 60 seconds, i.e. the new management method increases the capacity of the metro tube by around 17 %.

This does not factor-in the presumption that with less wagons stopping at the station (one or three instead of four), the time they spent at the station should be less. Therefore, the expected capacity improvement may even exceed 17 %.

Another factor which is not accounted for is that with the new management method the number of passengers getting on or off the wagons will be 2.5 times higher. For example, if the proportion of passengers leaving the wagon in the traditional management method is 10 %, now we will have 25 % of them heading to the doors. This may lead us to presume that vehicles may stay at stations longer because there will be more people getting off and on. On the other hand, in a crowded wagon those who are not disembarking stand in the way of those trying to leave, so 25 % might disembark in roughly the same time as would 10 %.

CONCLUSION

The Low Traffic mode described in this article is appropriate for all metro lines.

Our Heavy Traffic mode is appropriate for metro lines with short interstation distances wherein much time is lost in stops at intermediate stations. In this mode, for the proposed scheme to be efficient, the journeys should be long (in terms of number of stations). For example, if the average metro journey is ten or twenty stations long, our scheme would bring significant time savings.

The interstation distances in the third metro line of Sofia [11] are relatively short. For the time being the line is not too long, but once the line is completed its length will be considerable. Furthermore, according to the plans the line will be served by automated metro trains without train drivers. This makes the third metro line of Sofia a strong candidate for implementing the new scheme. With this in mind, we sent a letter to Sofia Municipality [12] in which we requested assistance in exploring the potential for implementing our proposition in the construction of the third line of Sofia's metro system.

The Heavy Traffic mode of our scheme is also appropriate for congested lines which need solutions to improve their throughput capacity. Subway systems in Asia are the ones most affected by the congestion problem and this is exactly where we expect to see the strongest uptake of the new scheme which we have proposed.

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