Technological innovations: opportunities to reduce costs

Dedicated single track for medium-sized cities

Guillaume Uster. Francis Kuhn. Joaquin Rodriguez [1]

Abstract

This paper presents a comparative study of the conditions of realisation between an automatic dedicated single track people mover and an automatic dedicated double track people mover as regards both "system" and infrastructure aspects. The paper describes the specific operational features of this type of line. An application to a medium-sized French city demonstrates the feasibility of this mode of operation and the savings which can result.

Introduction

Conventional subways are not very suitable for medium-sized cities or the outskirts of major cities. Areas of this type can be quite adequately served by lighter transportation systems with lower capacity. The single track people mover is one example of this type of system and has the advantage over modes such as buses or streetcars that it can be constructed and operated entirely on a dedicated track.

This paper presents the key findings of the VULCAIN study (Voie unique pour Ligne Complémentaire à Automatisme INtégral- Single track for completely automatic additional service). This was financed by the French Ministry of Transport and involved the participation of INRETS (Institut National de Recherche sur les Transports et leur Sécurité- National Institute for Transport and Safety Research) and METRAM (The Lyons Urban Transportation Engineering Company).

After a survey of literature which covers single track transportation systems the paper describes the specific operational features of this type of line. The authors make a theoretical evaluation of VULCAIN's potential for cost reduction as regards both "system" and infrastructure aspects. An application to a medium-sized French city demonstrates the feasibility of this type of mode of operation and the savings which can result.

1.Survey of literature dealing with single track transportation

The aim of this literature survey is to discover what single track systems exist in the world. It covers systems with both automatic and manual control and those with both partial and complete single track operation. Intercity rail links are not covered.

1
INRETS-CRESTA 20 rue Elisée Reclus 59650 Villeneuve d'Ascq FRANCE

In order to target the potential and prevalence of systems of this type, the authors have decided to deal with them in the following groups: systems with automatic or manual control, loop systems (including the monorail), systems with shuttle operation and systems where only portions are under single track operation.

The table below summarises the literature survey, which is not intended to be exhaustive.

TYPE	AUTOMATIC			MANUAL		
	No	Location	Length	No	Location	Length
Loop	5	Leisure Park	1,4 à 22 km	2	Urban	
	2	Airport	1,1 à 1,8 km			
	3	Urban	3,2 à 4,6 km			
Shuttle	2	Airport	0,6 à 2,2 km			
	8	Urban	0,3 à 4,5 km			
Portion of single track	1	Urban	3,5 / 6,4km (loop)	5	Urban (the 5 networks contain a total of 197 km of line, of which on average 35% is single track)	
	1	Urban	2,5 / 15 km (ends)			
Completely single track	1	Airport	20,9 km	5	Urban	2,9 à 8 km

(NB: X km of single track / Y total length of lines or network)

Thus thirty-five systems have been listed in the world. In all they contain 85 kilometers of single track line out of a total of 100 kilometers of automatically controlled line (i.e. 85 %) and 96 kilometers of single track line out of a total of 224 kilometers of manually controlled line (i.e. 42 %).

These figures demonstrate that a large number of small automatic systems make use of single tracks. Relatively few manual systems use single tracks and are for the most part streetcars.

Generally, single track operation is little used in urban transportation systems but is more common on certain sites such as airports and leisure parks.

2.The specific "system" features of a single track line

2.1.Operation

The single track system which we shall refer to as VULCAIN, is an automatically controlled means of public transportation which operates on a dedicated track with or without a driver and which provides a stopping service. The special feature of this system is a type of single track operation in which the trains cross at stations.

It should be able to move between 2000 and 8000 passengers per hour in each direction as a normal load. The single track operation consists of running vehicles in both directions on the same track, crossing occurring at stations by doubling the tracks, which requires two switches one at each end of the station.

Operation of the system therefore depends on the trains waiting for each other in a station; the train which is to leave the station must wait for the train arriving from the opposite direction. Thus, the maximum waiting time is experienced by train which is waiting for the vehicle running between the two stations with the largest distance between them. Let us call this time T_m. To ensure nominal flow on the system and avoid extended periods of waiting due to a build up of trains all vehicles must be controlled by a clock with a period of T_m. T_m can thus be considered as being the basic operating cycle of VULCAIN and can be utilised to determine the best headway on the single track line.

As operation of the single track depends on the trains crossing at stations, there are moments when all trains are between stations. For this reason the maximum number of trains which can be carried on a single track line in nominal operation is equal to the number of inter stations. If the number of trains is increased there is an increase in their waiting times and therefore a reduction in average headway.

So, the basic cycle is determined by the journey time between the two most distant stations and the maximum capacity in terms of the number of trains is limited by the number of inter stations. VULCAIN is therefore a transportation system in which the shortest headway between trains is determined by line design. The number of stations and the distance between stations definitively fix the best frequency.

In order to cope with a long term increase in traffic double or variable length trains are therefore a possibility. It should be noted that in this study the design of station infrastructure takes this change in account.

The diagram "Example of the operation of a single track line" which is appended to this paper shows clearly the operation of a single track line. What is shown clearly the operation of a single track line. What is shown is an ideal VULCAIN line with equidistant stations and equal stopping times in stations. As a result trains leave and arrive at stations in a perfectly synchronised way.

In off-peak periods the number of trains may be fewer than the number of lengths of track between stations. The effect of this would be to increase the headway by a multiple of the cycle. This is why, in some layouts, the system is not able to offer users regular headway. In consequence, it would seem advantageous to provide a passenger information system which can communicate the arrival time of the next train.

The nominal operation of the VULCAIN system is marked by a maximum level of flow and a minimum headway. To achieve this the traffic control system must make the trains comply with the basic cycle time in order to ensure that they cross at stations, while making allowances for the specific features of the line.

In fact, as stations are not equidistant, journey times between stations and stopping times in stations are different according to the volume of passengers boarding and alighting. Lastly, too large a divergence between these various parameters would lead to excessive waiting times.

Optimised operation of a single track line must therefore allow an overall homogenisation of journey times between all stations by slowing down trains between closely spaced stations and speeding up trains between stations which are further apart. The aim of achieving this uniformity is to try to cancel out the differences in the length of inter stations artificially creating ""equitime stations"" to approximate to the basic cycle of the VULCAIN line. To improve this process it would also possible, as far as possible to increase or reduce stopping times in stations.

Once this homogenisation has been carried out, the envisaged control policy is based on a simple idea: allow a train to leave as soon as the downstream inter station is clear on condition that its stopping time in the station has elapsed. As the train leaves the station as soon as its route is available, this policy is referred to as "adaptive with route authorisation".

In order to cope with low amplitude disturbances the control system must be able to allow a rapid return from degraded mode to nominal mode. By continuously updating the theoretical timetable for trains passing through stations, the traffic control system must compute a theoretical passing time for the next trains in order to examine the potential for conflict in the event of two trains attempting to cross. To achieve this, this function makes use of degrees of freedom of operation (advised speed for the lengths of track between stations and duration of stops at stations) to dynamically realign the real timetable of trains with the theoretical timetable. This calculation must be carried out at least for each station where conflict is focused, and perhaps for all stations.

2.2.Degraded modes

When the incident cannot be resolved in a period of time which is operationally acceptable a number of degraded modes have been devised. Implementation of these modes would allow continuity of service to be achieved on all or parts of the line.

2.2.1.Unavailability of a platform

A platform may be unavailable because of a train breaking down, a switch which becomes stuck in one position or even a train which has been stopped intentionally. It is, in fact, quite conceivable for trains to be stopped in a station in off-peak periods to make it possible for the maximum rate to be regained rapidly during peak periods. This solution could be applied in stations with the aid of the passenger information system.

Thus, several solutions can be considered to achieve operational continuity in the event of platform unavailability:

*All trains travel over the entire line using one platform for both directions of travel, which is the equivalent of doubling the length of inter station and generates a longer headway.

*Trains travel on the track on either side of the station with the unavailable platform. The available platform of the station functions alternately as a terminus for trains coming from both partial services.

The disadvantages of this solution is that passenger continuing their journey after the station with a single platform must change trains, as this platform is effectively a terminus.

2.2.2.Unpassable track between stations

The track between stations may become unpassable because of a train which has broken down or a problem with the track. Operation can continue as a partial service or two half lines, the two stations immediately before the unpassable inter station becoming temporary termini. It is important to note that, unlike with a "conventional" track, such a temporary service could operate at any point on the line as a result of the switches at each station.

2.3.Availability

Availability is an essential aspect of the operation of this type of mode of transportation, as a fault may rapidly disrupt or even block the line. For this reason the system must be extremely tolerant of faults, with redundancy of most fixed and on board equipment. The operating personnel must be able to manage incidents in relatively short time periods while complying with safety precautions.

Although it might be thought that the large number of switches would have an averse effect on availability, statistics relating to the failure of these switches indicate that such fears are ungrounded.

3.Assessment of the costs of fully automatic system (VAL type) and automatic system with driver (lines A and B the Lyon metro) adapted to single track

For the economic study to be as accurate as possible we have taken as a reference automatic systems which are tried and tested. There are certainly solutions which are more elegant than those examined in this study and which utilise different technology, but it would be impossible to evaluate the costs of design and development. On the one hand, the fully automatic VAL type offers a good regularity in train operation and an important availability ratio, on the other hand, the automatic with driver type such as lines A and B in Lyon presents a less costly investment.

The economic evaluation of a single track management system of both systems takes into account specific VULCAIN fixed automatic devices and also track equipment. These are two items for which there are significant differences between single and double track.

We felt that it would be interesting to compare solutions of the VAL type and the Lyon A and B type as regards the costs of fixed automatic devices and track equipment on the basis of a theoretical line 10 kilometers long with 18 stations. However, it was impossible to compare the two alternatives as the breakdown of items in the fixed automatic devices and track equipment is specific to each system and does not include the same services. The benefit of such a comparison lies in comparing single and double track operation for each system.

* **Fixed control equipment** (in million de FF exclusive of taxes, 1991 value)

	Double track	VULCAIN
LYON type	82 à 100	121 à 140
VAL type	100 à 110	150 à 160

The two alternatives show that for fixed automatic devices a VULCAIN line implies a cost of between 40 and 50 % more than double track line.

* **Track equipment** (in million de FF exclusive of taxes, 1991 value)

	Double track	VULCAIN
LYON type	159 à 171	109 à 119
VAL type	245 à 255	180 à 190

Both alternatives show that for track equipment a VULCAIN line implies savings of between approximately 25 and 30 % as compared with a double track line.

However, the evaluation for the entire system (i.e. platform and station equipment, fixed automatic devices and the control center, electrical supply and transmission equipment and rolling stock) shows that the additional costs incurred by more complex fixed automatic devices are compensated for by savings on platform equipment.

In view of these price levels the economic appraisal of VAL type and Lyon A and B type systems shows a tendency for the prices of a double track system and a VULCAIN system to coincide.

4.Assessment of civil engineering costs

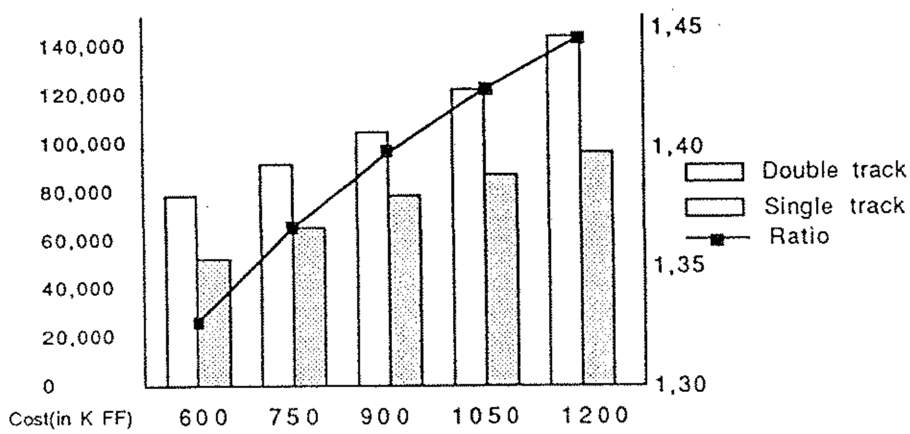
This chapter tackles the economic comparison between infrastructure costs for a transportation system with dedicated double track and the same system with single track. These evaluations used a software program which makes preliminary estimates for subway infrastructure. It should be noted that in the full study the evaluation was made for three types of urban transportation system. Existing examples of rolling stock were used to determine the cross section of engineering structures and the length of stations. These were: the VAL 206, the VAL 256 and the Lyon metro. The respective widths of this rolling stock are 2 m, 2.50 m and 3 m, and the respective lengths of the stations required for the operation of VULCAIN are respectively 52 m, 28 m and 72 m. This paper presents a few findings as regards the first type of rolling stock.

The infrastructures considered in the comparison are underground: cut and cover, driven tunnel; above ground: viaduct.

The civil engineering costs associated with cut and cover and tunnelling have been assessed for the types of ground which are most frequently encountered in urban areas. In underground construction the station is built by cut and cover, irrespective of the type of infrastructure. Furthermore, the importance of station costs must not be overlooked: for example, in the case of a double track structure constructed by cut and cover, the cost of a station represents 22,5 % of the cost with a distance of 600 meters between stations. However, if the distance between stations is 1200 meters this figure falls to 11,2 %. It is for this reason that this study is based on a module consisting of a station of 52 meters and a distance between stations which varies between 600 to 1200 meters.

Once a standard cross section of the urban road system had been determined in order to evaluate the cost of displacing service networks after construction of a single track or double track structure, the module (double track inter station + one station) was compared to the module (single track inter station + one station) in the case of cut and cover, driven tunnel and viaduct for the VAL 206 type system.

Cut and Cover (station with side-loading platforms)



Source : VULCAIN study

The following assumptions have been made about the depth of structures:

-shallow level: 1.5 m of cover for single track and double track lines.

-deep level: 8 m of cover for a double track line, 5 m for a single track line.

A single track line module represents a saving of between 24 % and 30 % with respect to a double track module for the shallow line and a saving of between 33 % and 39 % for the deep line.

This large difference in the saving effected between shallow and deep levels is explained by the assumptions which have been made. These conditions have been determined for designs with sections built with driven tunnel and cut and cover (the deep level provides the minimum amount of cover for tunnelling machines)

The double track / single track ratio (scale on the right hand side of the graph) increases as the distance between stations increases: the influence of the fixed cost of a station on the overall cost becomes less marked, as has been shown above, but tends to reach a ceiling when stations are more widely spaced. However, in urban areas stations should be of the order of 600 to 800 meters apart in order to attract the largest number of potential travellers.

Cut and cover (station with central loading platform)

In cut and cover construction the saving from using a single track rather than a double track module is between 17 % and 26 % for a shallow tunnel and between 25 % and 35 % for a deep tunnel.

The lower saving associated with the above module with a central loading platform as opposed to the previous module with side loading platforms is mainly accounted for by the influence in the cost of connecting structures at each end of the station.

Driven tunnel (station with side loading platforms)

The saving made by a single track module as opposed to a double track module is between 14 % and 19 %. This low level is due to the size of the connecting structures at stations.

Viaduct (station with side loading platforms)

The saving made by a single track module as opposed to a double track module is between 21 % and 27 % depending on the length of the module.

For trains of the VAL 206 type (width of 2 meters and stations 2X26 meters long) the savings in construction costs between a single track and a double track structure are as follows:

17 % to 39 % for a cut and cover tunnel
14 % to 19 % for a driven tunnel
21 % to 27 % for a viaduct

Following on from these theoretical evaluations a more thorough study of a VULCAIN line for a medium-sized French city of 250,000 inhabitants has been carried out.

5 The case of a French city: Le Havre
5.1.The line

Of the designs which were submitted by eight French cities in the context of the VULCAIN study it is that from Le Havre which was chosen for in-depth study because it was possible to make use of an existing tunnel and an existing exclusive bus lane. Furthermore, this design would provide a rapid link between the lower part of the town, which contains the jobs, and the higher part of the town, where 62 % of the population lives.

Thus, Le Havre would have 9 stations on a line of 6230 meters, of which 4130 would be single track (i.e. 66 %) and 2100 double track. The considerable length of double track is caused by the length of the stations and the zones of connection between single and double track (of the order of 120 meters per station). The line would connect the City Hall (lower part of the town) to Mont Gaillard (higher part of the town) via the railway station and the tunnel Jenner. There would be a by-pass in the Jenner tunnel making it possible to reduce what would otherwise be an excessive length between stations. It has been evaluated that a fleet of 11 vehicles would be necessary to operate the line, in view of operational and maintenance requirements. Expected traffic is of the order of 2700 passengers per hour in the most loaded direction.

5.2.Detailed study using the Le Havre line performance simulation model (developed by J.Rodriguez, INRETS)

Digital simulation is a computerised modelling tool which evaluates the performance of guided transport systems. It is thus possible to observe the operation of systems in nominal mode, to measure the influence of disruptions or optimise the traffic control policy.

The model used in this study was written in an "object oriented" computer language called Smalltalk. The benefit of development using an object oriented language environment is that it is possible to write reusable software modules. hen "traditional" languages are used a large number of modules need to be rewritten if the model is only slightly modified, whereas object programming makes it possible to create interchangeable modules.

In order to optimise the nominal operation of the line, speed were varied between 13 and 20 m/s which gives journey times between stations of between 39 and 60 the stations separated by the longest and the shortest section of track and the station on either side of the by-pass.

The by-pass is a station of a special type in that the stopping time is fixed at zero second. For this reason it has not been considered as a true station and we have operated the simulation model with 8 trains.

The simulation gave some quantitative and qualitative results which appeared interesting in the context of system design.

The journey time for a complete circuit of the line is on average 20 minutes 37 seconds, i.e. a commercial speed of 32.90 km/h. Without traffic control which optimises flow the simulation evaluated average headway at 2 minutes 30 seconds in 85 % of cases.

The simulation drew our attention to some problems of which we were more or less intuitively aware. For example, in the event of a serious disruption on a single track line, as the delay is passed onto other trains and affects traffic in both directions the line will cease operation immediately. In the situation where the system has not been blocked it has been found that the repercussions of an incident are limited to the neighbourhood of the stations with the longest inter station and to the stations before the single track termini.

Unlike a double track system of the Lille VAL type where there is a 2 minute latitude for control, the VULCAIN system must be interrupted immediately in order to avoid a long period of degraded mode operation or even a line blockage.

The development of specific traffic control software was outside the scope of this study and without such a tool we are not able to give precise figures for availability.

The simulation model does allow for adaptive control with route authorisation, but not for the dynamic modification of inter station journey times or in-station stopping times to compensate for small disturbances. Despite some large delays in stations the system exhibited a good capacity for self regulation.

5.3. Summary table of cost evaluations for le Havre

Various alternatives are presented for infrastructure costs: viaduct, track formation, cut and cover, use of the Jenner tunnel.

Length: 6230 m, number of stations : 9 + 1 by-pass, vehicle fleet: 11.

* VAL type automatic system (in million de FF exclusive of taxes, 1991 value)

	VULCAIN	Double track	Saving
System Cost	600 to 650	600 to 650	
Infrastructure Cost	470 to 800	550 to 1000	14% to 20%
Total cost	1070 to 1450	1150 to 1650	7,5% to 14%

* Lyon A or B type automatic system (in million de FF exclusive of taxes, 1991 value)

	VULCAIN	Double track	Saving
System Cost	450 to 550	450 to 550	
Infrastructure Cost	470 to 800	550 to 1000	14% to 20%
Total cost	920 to 1350	1000 to 1550	8,7% to 14,8%

Conclusion

The VULCAIN study provided an opportunity of evaluating some aspects of a single track transportation system and also of overturning a number of received opinions.

Thus, the theoretical examination of the technical and economic aspects of civil engineering shows that the gains for single versus double track infrastructure may attain 40 % for a viaduct or cut and cover tunnel but are nearer 15 % for driven tunnels.

Examination of the "system" aspects of VULCAIN has shown the satisfactory operation of this type of line in nominal mode and the various degraded modes which have been envisaged. Contrary to received opinion, it has been shown that the two switches at each station provide a single track line with remarkable operational flexibility as they enable a partial service to be offered at any point on the line.

Examination of the technical and economic aspects has shown that in the case of VAL type fully automatic systems or Lyon line A or B automatic systems with driver the additional costs due to automatic devices were of the order of 40 % to 50 %. However, in view of the shorter length of track, a VULCAIN line with 60 % to 70 % of single track would lead to savings of the order of 25 % to 30 % on rail formation equipment. Thus, broadly, "system" costs are equivalent in single and double track operation.

A simplified preliminary design for a VULCAIN system for the Le Havre site with a variety of infrastructure alternatives estimated the saving as between 7.5 % and 15 % as compared to a double track line.

A single dedicated track line with either fully automatic control or a driver and which corresponds to the needs of a medium-sized city or the suburbs of a major city can be operated under satisfactory conditions. In the case under consideration, however, the savings resulting from choosing the single line are modest.

Finally, this study demonstrates that the main advantage of single track systems is their ease of integration. For example, a single track viaduct causes less visual obstruction, and in central areas a double track could not be constructed without major engineering works. However, the use of portions of single track on a "conventional" line is conceivable, in central areas because of problems of integration or at the ends of the line where transportation demand is lower.

Lastly, the possibility of re-using existing structures should be noted, as with the Jenner tunnel in Le Havre or the track formation in other projects.

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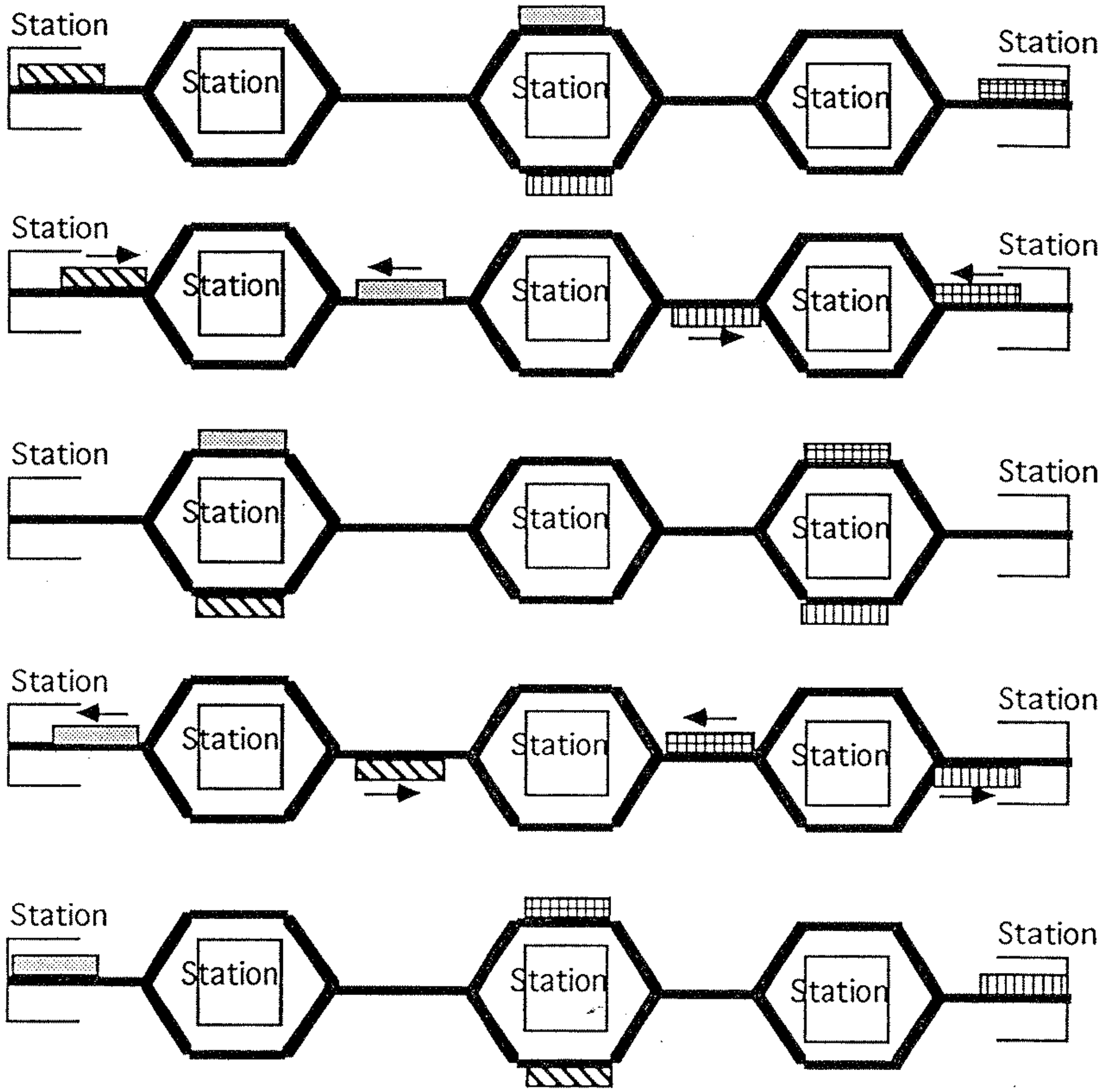
Annex



Example of the operation of a single track line