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SWP 13/93 METRO-FREIGHT: THE AUTOMATION OF FREIGHT TRANSPORTATION

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Abstract

The nature of modern global production and retailing means that levels of freight transport activity are rapidly increasing, and some estimates suggest that they could double within the next 10 years. The need for freight transport extends to almost all European industries, and the requirement for us to provide economic and efficient freight transport is vital for Europe to maintain its international competitiveness.

At the same time, however, environmental concerns, and concerns about dependency on oil, are bringing into question the long term viability of our current methods of freight transport. Rail is usually proposed as an alternative to road, but the nature of modern rail operations make them ineffective for all but a few transport requirements. Even if the problems inherent with rail could be overcome, it is difficult to see how rail could make anything but a slight impact on the problem.

The conclusion, therefore, is that alternative methods of freight transport need to be found, and the current move towards a single European market means that now is the most opportune time to research such alternatives. This paper describes an alternative being developed called Metro-Freight. The major principles of Metro-Freight are:

1. *Vehicles.* Small, driver-less, vehicles will be used to carry small unitized loads. Vehicles will be able to carry up to about 4 conventional pallets, and up to about 4 tonnes in weight. The vehicles will be electrically propelled.
2. *Infrastructure.* There will be a dedicated, multi-user, infrastructure, consisting of small tarmac roads. The width of each road will be about 2 metres, and about 2 metres of height clearance will be provided. The roads will allow for sharp curves and steep gradients so that they can easily accommodate geographical or man made features.
3. *Control.* Advanced communications and control technology will be used in order to maximize the utilization of the infrastructure, and maximize the utilization of the vehicles. The control systems will mean that vehicles will be capable of travelling in close proximity, at high speeds, and will be capable of coordinated braking.
4. *Operation.* Private sector finance will be used for infrastructure construction, and there will be a competitive operational framework established with multiple suppliers of infrastructure and operational services. Users will operate their own vehicles and tolls will be charged for use of the infrastructure.

The advantages of Metro-Freight will be:

1. *Labour.* The labour requirement of freight transport will be substantially reduced. Labour costs account for approximately 50% of freight transport costs.
2. *Efficiency.* The use of advanced control technology will mean that the speed and operational efficiency of freight transport will be increased.
3. *Safety.* By taking existing freight transport off conventional roads, the safety of conventional transport will be increased.
4. *Environment.* The smaller size of the transport system, and the use of electrical propulsion, will mean that there will be substantial reduction in the adverse environmental impact of freight transport; and, in particular, air pollution, noise, and visual intrusiveness.
5. *Energy.* The increased efficiency of freight transport will result in reduced energy consumption; and the use of electrical propulsion will reduce Europe's dependence on oil.
6. *Competition.* The use of a competitive operational framework will encourage efficient operation and provide maximum incentive for entrepreneurial initiative and technological development. It will also reduce the need for government intervention to plan and finance transport requirements.
7. *Economy.* Freight transport cost will be reduced due to greater efficiency of operation and an elimination of direct labour costs. It will become cost effective to transport goods in smaller shipment sizes, hence reducing inventory holding costs, and increasing the efficiency of retailing and manufacturing. These benefits will boost the European economy and strengthen the competitiveness of European industry.

An industrial consortium has been assembled for the development of Metro-Freight, and a feasibility study is currently being undertaken.

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METRO-FREIGHT

THE AUTOMATION OF FREIGHT TRANSPORTATION

1. INTRODUCTION

Most modern industries employ a substantial amount of automation and, as a result of the progressive application of this automation, the productivity of these industries has risen substantially, in many cases by several orders of magnitude. A glaring exception to this, however, is the road freight industry. In the road freight industry very little, if any, progress has been made towards automation, and productivity levels remain constrained by some highly labour intensive operating methods.

Whilst there are many examples of freight movements in private utilities that have been successfully automated, there are currently very few examples of freight movements in public utilities that have been automated. If, however, significant progress could be made towards automation of these freight movements, then very substantial benefits could be realized for the economy, the environment, and many sectors of industry and commerce.

This paper evaluates the need for freight transport automation; it describes concepts for the design of automated freight systems; and it goes on to describe a system for automated freight transport, called Metro-Freight, which is being developed by an industrial consortium.

2. THE ROAD FREIGHT TRANSPORT DILEMMA

The volume of freight transported in Europe is vast and is increasing. In 1990 the total freight traffic on UK roads was 1.749 billion tonnes or 136 billion tonne-km, and the total freight traffic in the European Community amounted to 9.459 billion tonnes or 800 billion tonne-km. Over the last 10 years growth in UK freight transport has averaged 3.2% p.a, and if we continue to use existing technology then there is every reason to suppose that such growth will continue. The Department of Transport predict that levels of freight transport will double by the year 2025, but some estimates suggest that they could double within the next 10 years.

2.1 Trends in freight transport growth

In the foreseeable future we can expect levels of freight transport to continue to increase, not just on a national level, but also on a european and global level. The main reasons for this are as follows:

1. Increased economic activity

Economic growth tends to cause a rise in freight transport levels that is between 1.5 and 3 times the associated rise in GNP. Long term economic growth rates in Europe are expected to be about 2.5% which implies very large scale increases in levels of freight transport on this basis alone.

2. The Single European Market

The single european market is making it easier to supply and source goods across national boundaries, and the travel distance of the associated freight movements is increasing as a consequence.

3. Increased specialisation and centralisation

As products and services become increasingly specialized they are being marketed across wider geographical areas, which causes the associated transport distance to increase.

4. Just time manufacturing

Whilst the trend towards just in time manufacturing results in savings in production and warehousing, it can also result in increased levels of freight transport activity.

5. Development of East European and third world economies

As economies in East Europe and the third world continue to grow we can expect to see associated increases in levels of freight transport activity.

6. Rising global populations

Whilst populations are stabilising in Europe, they are continuing to grow rapidly in third world countries, resulting in an increased demand for freight transport.

2.2 The consequences of freight transport growth

If the projected increase in demand for freight transport is to be met using existing technology then the consequences are likely to be:

1. Widespread environmental damage.
2. Large scale depletion of natural resources.
3. Saturation of existing transport networks.

Given the current concern by governments for environmental issues, the increasingly stringent international environmental standards such as the stabilisation of carbon dioxide emissions, and a very great reluctance of governments to finance the expansion of existing transport networks, it seems inevitable that more efficient alternatives will eventually need to come into being.

3. THE EFFICIENCY OF EXISTING ROAD FREIGHT TRANSPORT

We have become so used to the low efficiency and the adverse environmental impact of freight transport, that it has become easy to overlook the fact that substantial improvements are possible. Evidence for this can be found by comparing road freight movements with other forms of materials movement, and this is illustrated by a comparison between the M25 motorway and the London water ring mains.

3.1 Comparison between the M25 motorway and the London water ring mains

In February 1993 the London water ring main was completed. The ring main has a tunnel with a diameter of 2.54 metres, a length of 80 km, and a flow capacity of 1300 megalitres per day. This corresponds to a flow rate of 15 m³/s and a flow velocity of 3 m/s.

Table 1 provides a comparison between the transport characteristics of the London water ring mains with those of the M25.

The London water ring main has a flow of material movement which is 19 times that of the M25, and it has a transport capacity which is 8 times that of the M25. However, it was cheaper to construct, it is cheaper to operate, and by just about any standards it is environmentally much more acceptable.

Whilst the flow velocity of the London water ring mains (6.7 mph) is less than the peak travel speed for freight along the M25 (60 mph), it is still high in comparison with the average speed of goods movement over the cycle between order and receipt. For example, someone located in West London might order some goods from East London, but are unlikely to receive them until at least the following morning (that is at least 16 hours), since it would take time to assemble the order and load the vehicle. This would mean that the effective travel speed along a route of 50 miles was only 3.1 mph.

It can be argued that the comparison between road freight transport and water transport is not a fair one, and that there are problems associated with the movement of road freight which are not applicable to the movement of liquids such as water. However, it can also be argued that, through the application of advanced technology, many of the efficiencies inherent with the transport of water could be achieved for the transport of road freight.

3.2 Improving the efficiency of road freight transport

In seeking ways to improve road freight transport it is worth examining the main differences between road freight transport and water transport. Specific differences are as follows:

1. Infrastructure utilization.
2. Supervision overheads.
3. Sensitivity to congestion and bottlenecks.

3.2.1 Infrastructure utilization

Liquids, by their nature, are able to be transported in an infrastructure with a very high volumetric utilization. Freight, by comparison, tends to be transported in an infrastructure with a very low volumetric utilization.

The volumetric utilization of the London water ring main will normally be at or near 100%, whereas the volumetric utilization for freight transported along the M25 (if fully dedicated to freight traffic) is only 0.54% . This is equivalent to the M25 being utilized for only 2 days in an entire year. What manufacturing organisation could ever stay in business with production lines this highly utilized?

In spite of such poor volumetric utilization, however, it is the general perception that the M25 has insufficient capacity, and additional lanes are being planned in order to cater for this. The reasons for this are as follows:

1. Substantial stopping distances are required between successive vehicles in order to ensure safe braking.
2. Large clearances are required between vehicles in adjacent lanes.
3. There is a general incompatibility between the size of roads and the size of freight units being carried.
4. The nature of traffic is intermittent and flow varies considerably throughout the day.

Whilst it will never be possible for the volumetric utilization of road freight transport to be as high as that of a water ring main, there is reason to suppose that it could be very significantly increased, probably by at least an order of magnitude. This could be done in the following way:

1. Through the application of technology for coordinated braking it should be possible for vehicles to travel safely in close proximity.
2. Through the application of technology for accurate guidance it should be possible for the clearance between vehicles in adjacent lanes to be safely reduced.
3. Through the use of vehicles and infrastructure that are of a standard size, and a size which is compatible with standard units of handling and storage (i.e the standard pallet) it should be possible to greatly reduce wasted infrastructure space.
4. Through the use of advanced vehicle scheduling techniques it should be possible for traffic to flow within an infrastructure in a consistent and controlled manner, hence reducing unused infrastructure capacity.

3.2.2 Supervision overheads

Water can be transported with very little supervision but road freight requires considerable supervision, that is a driver, in order to ensure that the freight safely arrives at the required destination. The consequences of this are:

1. High labour costs are incurred.
2. Additional transport capacity is required in order to accommodate the driver.
3. Goods need to be assembled into large loads so that they can be economically transported with a single driver. This reduces effective travel speed; it increases energy consumption where there are multi-drop deliveries; and it means that a large infrastructure and large vehicles are necessary.
4. Restrictions are imposed on range, speed, and flexibility due to the need to take breaks and return within the constraints of a working day.

Modern communication and control technology could be used to eliminate the need for a driver and greatly reduce the need for supervision. The consequences of this would be as follows:

1. Labour costs would be greatly reduced.
2. Less transport capacity would be necessary since drivers would not need to be transported.
3. Goods could economically be transported in smaller loads allowing for: increased effective travel speed; reduced energy consumption; a smaller infrastructure; and smaller vehicles.
4. The elimination of driver restrictions would increase range; it would increase effective travel speed; and it would increase flexibility. It would also make 24 hour operation more economic.

3.2.3 Susceptibility to congestion and bottlenecks

Systems for water transport tend not to be very susceptible to congestion and bottlenecks, and the throughput that can be achieved in practice tends to be close to that which is theoretically possible. Road freight transport, however, is very susceptible to congestion and bottlenecks which means that the throughput that can be achieved in practice is only a fraction of that which is theoretically possible. Reasons for this include:

1. Large delays are caused at junctions due to lack of coordination and the need to slow down or stop before travelling through.
2. Bottlenecks such as sharp bends can greatly reduce traffic flow at high traffic densities since a dense stream of traffic cannot travel faster than the slowest vehicle in that stream.
3. Traffic flow tends not to be well balanced between alternative routes.
4. It takes a long time for traffic to be rerouted in the event of this being necessary due to a blockage in the system such as an accident or breakdown.

Modern communication and control technology could be used to greatly reduce the susceptibility of road freight transport to congestion and bottlenecks. This could be done in the following way:

1. By providing vehicles with advance traffic information it should be possible for them to travel through junctions at high speed in a coordinated manner, with a greatly reduced need to slow down or stop.
2. At bottlenecks, such as sharp bends, advanced control systems could be used to subdivide a stream of fast moving vehicles into two or more streams of slow moving vehicles, hence removing the limiting affect of bottlenecks on traffic flow.
3. By providing vehicles with information on infrastructure availability, there could be an improved balance of traffic flow between alternative routes.
4. Through the use of an efficient traffic monitoring system, traffic could very quickly be rerouted in the event of a blockage such as an accident or breakdown.

3.3 The potential of road freight transport

Whilst variances in the size of road freight items will always limit volumetric efficiency, road freight transport allows for higher speeds to be achieved, and it should, therefore, be possible for a road freight system to have a capacity for materials movement than is at least as great as that for water transport systems.

It, therefore, does not seem unreasonable to suppose that a road freight transport system the size of the London water ring main could have a freight carrying capacity considerably in excess of that of the M25.

4 THE METRO-FREIGHT CONCEPT

As a result of the problems associated with existing freight transport and the immense efficiency gains that are possible, an initiative from Cranfield led to a group of organisations forming a partnership in order that they could develop a solution. The founding organisations were: The Cranfield School of Management, Logica, and Global Logistique Conseil. The solution developed has been called Metro-Freight, and the major principles of this are as follows:

1. The use of small vehicles and small shipment sizes.
2. The use of a dedicated road infrastructure.
3. Driver-less vehicles.
4. The use of electrical propulsion.
5. The use of advanced control technology in order to maximize the utilization of the infrastructure, and maximize the utilization of vehicles.
6. A multi-user infrastructure.
7. Private sector operation and finance.

4.1 Vehicle size

With conventional freight transport labour is normally the biggest single cost element being, on average, about 50% of overall cost. The consequence of this is that freight transport systems have been designed to minimize labour which has tended to mean the use of large vehicles so that a single driver can supervise a large load.

If the element of labour is taken out of the cost equation, however, there is no longer the same justification for large vehicles, and the optimum vehicle size is found to be much smaller. Taking into consideration all factors including vehicle cost, infrastructure cost, and energy usage, the optimum vehicle size is found to have a carrying capacity of about 4 tonnes. Conveniently, such a small vehicle size has environmental benefits and operational benefits as well as economic ones.

Consequently, Metro-Freight is being designed to cater for vehicles which have a nominal 4 tonne carrying capacity, and an infrastructure of compatible size. Whilst such a design will not be able to accommodate all freight items, it will be able to accommodate well over 80% of freight which is currently carried on roads. The small amount of freight remaining will still be able to be transported using conventional vehicles on conventional roads.

4.2 Vehicle design

The main features of Metro-Freight vehicles will be as follows:

1. Each vehicle will be able to carry a unit with nominal dimensions 1.5M by 1.5M by 4.5M, sufficient for 4 conventional pallets or 5 euro-pallets.
2. Each vehicle will have an on-board computer which will be used for the purpose of communications, vehicle routing, and vehicle control.
3. Vehicles will be capable of travelling in close proximity, at high speeds, and will be capable of coordinated braking.
4. Vehicles will have a limited on-board battery supply for short distance travel, and the ability to receive an external power supply during long distance travel along major trunk routes.
5. Vehicles will be capable of travelling at moderately high speeds: about 50 km/hr using an on-board battery supply and about 100 km/hr using an external power supply.

Vehicle guidance technology

Various types of vehicle guidance technology are being considered including: inductive guidance; laser guidance; inertial guidance; and direct imaging.

Inductive guidance is a well proven and established technique that would fulfil the minimum requirements of a guidance system but other technologies, such as laser guidance, would provide greater flexibility.

Collision avoidance technology

Various technologies are being considered for collision avoidance including: microwave radar; millimetre wave radar; and direct imaging.

Whilst the necessary functionality of the collision avoidance system can feasibly be achieved, it seems likely that no single technology will be able to meet all the requirements of a collision avoidance system, and hybrid solutions are, therefore, being considered.

Battery technology

Various types of battery technology are being considered for Metro-Freight including: lead acid batteries; nickel-cadmium batteries; and sodium sulphur batteries. Much research is currently taking place in this area and developments are being closely monitored.

4.3 Infrastructure

The main features of Metro-Freight infrastructure will be as follows:

1. The infrastructure will consist of flat, tarmac, roads which will be similar to conventional roads but will be much smaller. Roads will have a nominal width of 2 metres, and a nominal height clearance of 2 metres. The roads will be small enough to be non visually intrusive, but large enough to allow for good accessibility and ease of maintenance.
2. The small size and low weight requirements of the roads will mean that construction costs and construction lead times will be much less than those for conventional roads.
3. The infrastructure will be designed to be sympathetic to the environment and will allow for sharp curves and steep gradients so that geographical or man-made features can easily be accommodated. This will reduce the cost of construction; it will maximize the potential for road development; and it will minimize the environmental impact and visual intrusiveness of roads.
4. Extensive use will be made of tunnelling for road construction. The small width and height clearance of roads will mean that the cost of tunnelling will be low, and it will be a feasible technique to employ through areas of particular natural beauty; areas of conservational importance; or areas of high land cost.
5. Control stations will be placed along roads at regular intervals (about every 1 km) and also at junctions, for the purposes of vehicle control and communications.
6. Along major trunk routes there will be an external electrical power supply for efficient vehicle propulsion and battery recharge.

4.4 Control

Vehicle control software

Vehicle control will be provided by means of an on-board computer which will run the vehicle control software. The vehicle control software will essentially provide the vehicles with "intelligence" and will do the equivalent job that a driver does in a conventional vehicle.

Signalling and communications system

The signalling and communications system will be a central system which manages the infrastructure and traffic flow. This will act mainly in a supervisory role, and will provide the vehicles with the directives necessary to ensure the safe and efficient operation of the system. It will have no direct control over vehicles except in emergencies. In comparison with conventional transport it will fulfil the roles of: road-signs, road markings, traffic lights, and police.

4.5 Operation

A competitive operational framework will be established with multiple suppliers of infrastructure and operational services. Because of the low cost of infrastructure construction it will be feasible to have more than one operator in regions where the volume of traffic is high.

Users will operate their own vehicles and will be charged tolls for use of the infrastructure. Toll recording will be automatic.

5 THE IMPLICATIONS OF METRO-FREIGHT

5.1 The environmental implications of Metro-Freight

Metro-Freight will have many environmental benefits including:

1. Increased safety of conventional roads due to the removal of freight vehicles.
2. Reduced visual intrusiveness of transport infrastructure.
3. Reduction in noise and vibration from vehicles.
4. Elimination of pollutants from vehicle exhaust emissions.
5. Reduction in carbon dioxide emissions.
6. Reduction in the requirements of raw materials for vehicles and warehouses.

Metro-Freight will be of particular benefit to smog ridden cities where it will become possible for very high volumes of freight to be transported with minimal environmental impact.

5.2 The energy implications of Metro-Freight

Road freight transport is an activity that receives very little attention in relation to its energy saving potential yet, in the UK in 1990, road freight transport consumed 10.8 million tonnes of petroleum, or 25% of petroleum consumed for all transport activities combined (including road, rail, air, and water).

Metro-Freight has many benefits in relation to efficient energy usage including:

1. Smaller vehicle sizes will allow for more direct deliveries which will reduce freight travel distances.
2. Smaller vehicle sizes will greatly reduce the need for multi-drop deliveries which make highly inefficient use of energy.
3. By allowing vehicles to travel at high speed in close proximity there will be potential savings in energy consumption due to a reduction in aerodynamic drag.
4. By reducing the need for vehicles to slow down and stop at junctions there will be a reduction in energy consumed due to vehicle acceleration.

5.3 The implications of Metro-Freight for industry and commerce

Metro-Freight has many benefits for industry and commerce including:

1. Faster deliveries will lead to a reduction in stock holding and warehousing requirements.
2. Retailers will be able to achieve higher throughput from the same selling space since more frequent deliveries will be possible, and it will be possible for shelves to be replenished more frequently.
3. Manufacturers will be able to more fully realize the "just-in-time" concept and hold even emergency stock remotely.
4. Smaller vehicle sizes will lead to a reduction in space requirements for freight handling, and it will be possible to release space for expansion of retailing or manufacturing facilities.

5.4 The political and economic implications of Metro-Freight

The political and economic implications of Metro-Freight are as follows:

1. There will be a much reduced need for governments to plan and finance infrastructure developments.
2. It will be possible to provide an improved road infrastructure without the need for government borrowing.
3. It will reduce dependence on oil.
4. It will provide a strong stimulus for the economy and, in particular, for the manufacturing and construction industries.

6 METRO-FREIGHT DEVELOPMENT

6.1 The business opportunity

The widespread use of Metro-Freight will result in substantial cost savings to industry due to savings in freight transport, warehousing, and inventory holding. The cost of road freight to European industry is estimated to be £209 billion p.a; the cost of warehousing is estimated to be £192 billion p.a; and the cost of inventory holding is estimated to be £128 billion p.a. Taken together this corresponds to a total cost for logistics services of £529 billion p.a.

This clearly represents a massive opportunity for users and operators of freight transport services to save costs and increase profits, and will provide a very strong incentive for companies to use and operate Metro-Freight services. Most companies will stand to benefit directly or indirectly, and many companies could achieve very substantial competitive advantage as a result.

6.2 Achieving the critical mass

Before the benefits of Metro-Freight can be realized there will need to be a critical mass of companies using and operating Metro-Freight and, in order to facilitate the formation of such a critical mass, the Metro-Freight Association is being established.

The Metro-Freight Association will be a body which will act as a focus for business activity, and will allow members to keep up to date with the opportunities and developments of Metro-Freight. Membership will have no obligations, and the association will maintain contact with members by means of meetings, presentations, newsletters, and an information service.

The Metro-Freight Association will bring together all parties that have or might have an interest in Metro-Freight including users, operators, manufacturers, construction companies, banks, investment organisations, and governments. Through collaboration on developments it will then be possible for the critical mass to be achieved.

Whereas conventional road development is constrained by limits on government spending, Metro-Freight development will have no such constraints and, since substantial efficiency gains will be achieved, developers are likely to obtain a high return on their investment. It should, therefore, be possible for an extensive infrastructure network to be developed within a fairly short time span.

6.3 Timescales

A feasibility study is currently being carried out which is due to be completed by mid 1993.

It is intended that development of a demonstrator will commence in early 1994, and that initial exploitation will commence in 1996, with full exploitation taking place from 1997 onwards.

7 CONCLUSION

Freight transport is a vital service and the efficient movement of freight is fundamental to the international competitiveness of European industry and the strength of the European economy. Levels of freight transport activity, however, are rapidly increasing, and are expected to continue to increase for the foreseeable future. Existing technology for freight transport is expensive, and is causing widespread environmental and social damage, and there is a strong and growing need to develop alternative technologies.

Metro-Freight is being developed as a solution to the freight transport dilemma, and it is a solution that has a great many benefits for industry, commerce, the economy, the environment, and government. It will provide substantial business opportunities, and substantial opportunities for companies and other organisations involved in technology or services for road vehicle automation.

Table 1 Comparison between the transport characteristics of the London water ring main and the M25

TRANSPORT SYSTEM	London Water Ring Mains	M25 Motorway
Length	80 km	187 km
Cross section	2.54m dia	28m by 5m
Cross sectional area	5 M ²	140 M ²
Maximum speed of materials movement	6.7 mph	60 mph
Flow of materials movement (thousand tonnes/day)	1300	67♦
Annual material transport capacity (billion tonne-km)	37.96	4.59♦♦
Cost	£250 million♣	£1,000 million♣♣
Volumetric utilization	100%	0.54%♣
Visual intrusiveness	Very Low	Very high
Noise generation	Very Low	Very High
Energy consumption	Low	High
Pollution	Low	High
Danger to the public	Very Low	High

♦ Flow in both directions of the M25 ♦♦ Value for all freight moved along the M25 in 1990.

♣ Cost in 1990 ♣♣ Cost in 1986

♣ Utilization that would be achieved if fully dedicated to freight transport.

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