# THE UP-TO-DATE DESIGN OF THE PUBLIC TRANSPORTATION SYSTEM: THE FULLY-AUTOMATED SYSTEM KNOWN AS T.A.U. (Transport Automatisé Urbain)

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ABSTRACT. Particularly well adapted to cities of 100,000 to 1,000,000 inhabitants, the TAU is a public transportation system, capable of the performances, the comfort and the service quality of a metro, with high savings in investment and operating costs. The TAU system, an integrated public transportation system presents the following highlights:

- A total automatization of the transport network : unmanned vehicle driving and remote control of the complete network from the dispatching : basic criteria for the operating costs reduction,
- An easy integration within the urban network thanks to specific construction methods for the tunnels and the stations, to a new design of articulated bogie with four independent wheels and to small-profile vehicles : basic criteria for the construction works costs reduction.
- The whole automatization enables to reduce notably the operating costs against those of existing transportation systems, for which the expenses for the operating personnel are high.

The flexibility of adaptation to the transportation demand enables to manage optimally the park of vehicles, having also in mind the economy of energy.

The infrastructure costs, which represent nearly 3/4 of the investment costs of the existing transportation systems, have been minimized thanks to a specific design of the vehicles enabling to reduce largely the gauge of the civil engineer works and to the design of new methods of civil works using prefabricated units for the tunnel realization.

The TAU system permanently realizes the adaptation of the transport capacity to the demand variable between off-peak hours and rush hours, by programmed control of the headways and the train compositions.

During rush hours, 2 or 3 coupled traction units will circulate with headways of 60 to 90 seconds, while during off-peak hours a single-traction unit circulating every 3 minutes will enable to keep acceptable waiting times.

Within the TAU system, the functions, usually performed by the operating personnel, which highly burden the operating costs, are realized by automatisms : drivings of vehicles, serving of stations, traffic management, selection of time tables and headways, yard management, selection of routes, manoeuvres in terminals, injection on line and returning in depot.

Regularized operation with short headways and keeping of high-passage frequencies during off-peak hours are performed thanks to the modularity of the rolling stock and to the full automatization of the system operation under the control of a disptaching realizing the network management (controls, protections, signalizations, monitoring). Complete system testing and endurance tests of the sybsystems have been performed at the TAU Tests Centre located in JUMET near CHARLEROI.

Keywords. Transportation system; train control; automation; urban system.

## THE PROBLEMS OF URBAN TRANSPORT

City centres are becoming increasingly congested due to the widespread use of private cars. Public transport vehicles that run on the surface, whether trams or buses, cannot provide a service of a satisfactory quality.

Indeed :

- during rush hours, these vehicles are in the thick of traffic jams and cannot guarantee satisfactory commercial speeds nor an adequate regularity,
- during off-peak hours, the operating companies reduce vehicle frequencies to limit operating personnel costs. This gives rise to waiting times that passengers often find unacceptable.

The usual solution to these problems takes the form of conventional underground rail systems.

However, the construction and equipment cost of such systems is extremely high, whilst the transport capacity they provide is excessive for medium-sized towns.

## THE OBJECTIVES OF TAU SYSTEM : An optimized system

Up to now, no effective solution had been found for the public transport in medium-sized towns. Between the street siting of buses and trams and the high capacity, "heavy" underground train, there exists a demand for a rush hour transport capacity between 5,000 and 20,000 passengers per hour and direction which is not covered.

This gap is the target area of the TAU, designed to be :

- the main network in medium-sized towns (100,000 to one million of inhabitants),
- the secondary network in big cities,
- the solution, in a simplified version, for special applications (airport or industrial estate services).

The question was simple : How to develop a transport system on private right-of-way, preferably underground to avoid the roads, involving only low infrastructure costs, economic in operation ... and yet attractive to the users ?

In response, the TAU system has to fulfil the following objectives :

- It must provide "metro" quality service (frequency, commercial speed and comfort) whilst limiting investment costs to 60 % of the expenses involved in a conventional metro,

- It must be possible to build the system into the urban infrastructure at low costs : the system will be constructed at a shallow depth along the street lines with direct access to the stations from the pavement. In order to avoid costly expropriations, the system will have curve radii of 10 m to enable the tunnels, at intersections, to follow street lines even when these are narrow.

- The vehicles must be of small overall size to allow them to run in small cross-section tunnels and compact stations.

- The tunnel sections must be limited to a minimum and the vehicles provided with a traction system allowing them to climb steep gradients (6 to 10 %) to reduce approach trench distances.

- Transport capacity must be adaptable to the varying demands of rush hours and slack periods, whilst maintaining a sufficiently high degree of train frequency to avoid prohibitive waiting times. Use must thus be made of a modular system that allows train capacity (number of vehicles) and frequency (headways) to be changed.

- To reduce operating costs, a fully automatic transport system must be used with no driver on the vehicle.

- As a direct consequence of the automation, but also essential to guarantee comfort and regularity, the system must entirely be built on its own right of way site.

- The system must provide a level of safety, reliability and availability higher than that obtained with conventional systems, high as this may already be.

## THE T.A.U. SYSTEM - A NEW OVERALL APPROACH TO URBAN TRANSPORT

Particularly well adapted to cities of 100,000 to one million of inhabitants, the TAU is a public transportation system, capable of the performances, the comfort and the service quality of a metro, but with high savings in investment and operating costs.

The TAU system, an integrated transportation system, presents the following highlights :

- A total automatization of the transport network with the unmanned driving of the vehicles and remote control of the complete network from the dispatching : basic criteria for the operating costs reduction.

- An easy integration within the urban network thanks to specific construction methods for the tunnels and the stations, to a new design of articulated bogie with four independent wheels and to small-profile vehicles : basic criteria for the construction works costs reduction.

The whole automatization enables to reduce notably the operating costs against those of usual transportation systems, for which the expenses for the operating personnel are high. The flexibility of adaptation to the transportation demand enables to manage optimally the park of vehicles, having also in mind the economy of energy.

The infrastructure costs, which represent nearly 3/4 of the investment costs of the existing transportation systems, have been minimized thanks to a specific design of the vehicles enabling to reduce largely the gauge of the civil engineer works and to the design of new methods of civil works using prefabricated units for the tunnel and stations realization.

The TAU system permanently realizes the adaptation of the transport capacity to the demand variable between off-peak hours and rush hours, by programmed control of the headways and the train compositions.

During rush hours, 2 or 3 coupled traction units will circulate with headways of 60 to 90 seconds (depending on line and station layout), while during off-peak hours, a single traction unit circulating every 3 minutes will enable to keep acceptable waiting times for passengers.

The short interval between off-peak trains is made economically feasible by the absence of on-board operating personnel and by the small dimensions of the traction units.

## PERFORMANCES, SAFETY, AVAILABILITY

T.A.U. is designed to operate on 6-% gradients. It can cope with 10-% banks with a reduced level of performance.

Commercial speed is 30 to 35 km/h on a line with stations spaced 500 to 750 m apart, the cruising speed being of 60 km/h (maximum speed 72 km/h).

T.A.U. is able to operate up to 60 seconds headways. The trains are unmanned and remotely operated from a central dispatching.

Safety

Designing a transport system with unmanned vehicles and stations entails a twofold obligation : to guarantee safety and to generate passenger assurance. In this respect, all the safety functions are triplicated, in the operation control centre, on board the vehicles and in the stations, using a configuration of computers with two out of three voting. Passenger safety is ensured by constant video monitoring of vehicles and stations.

Sliding platform doors prevent unauthorized access to the track.

Passenger assurance is obtained by modern communication facilities enabling passengers to keep in touch with the operating control centre.

Availability

The automatic systems have been carefully designed to ensure passenger safety combined with a very high degree of system availability, involving :

- full built-in redundancy of equipment, duplicated throughout and even triplicated for the "safety" functions, both on the ground and on board the vehicles,

- high-performance functions in degraded modes which are integrated and programmed within the system. This allows very quick restoration of normal traffic conditions following disturbances and minimizes the need for intervention by operating staff.

Availability has been fully reassessed to allow for driverless operation, involving :

- simple and reliable subsystems,
- greater quality assurance,
- function redundancy,
- degraded mode operating procedure.

QUALITY OF SERVICE

It is substantially improved by the automatization (headways as short as one minute). For the user, waiting time is reduced to the minimum. Additional trains may be inserted into the network through remote commands from the operation control centre, when required. Minimum waiting time, high commercial speed, operational flexibility all these contribute to the high quality of service.

SUBSYSTEMS OF THE T.A.U. SYSTEM

Compact advanced vehicles :

Of modular design, they can operate in trains of one or more units and are thus fully adaptable to the demand.

The basic traction unit consists of indivisible two-car trains. These will be 17.5 m long, 3.00 m high and 2.06 m wide. Each car has two sets of double sliding doors per side. A two-car train will seat 28 passengers and accomodate a further 90 standing passengers under crushload conditions (6 passengers per square meter) or 60 under normal conditions (4 passengers per $m^2$).

With headways of 3 minutes during off-peak hours and between 60 and 90 seconds during rush hours, the capacity of the TAU system is self-adapted to transportation demand between 500 and 20,000 passengers per hour in each direction.

A new design of articulated bogie with 4 independent wheels was patented. A pair of wheels, each integrated with its own independently-mounted DC motor, is linked by an articulated frame to a pair of wheels of much smaller diameter. This arrangement allows the train to negotiate 10 m radius curves, so that the system's insertion into the urban environment is easier, thus reducing significatly the necessary property expropriations.

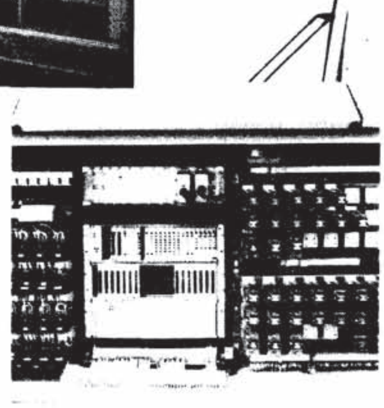
Passenger space has been carefully fitted to combine comfort and pleasing decor with ease of access and maintenance.

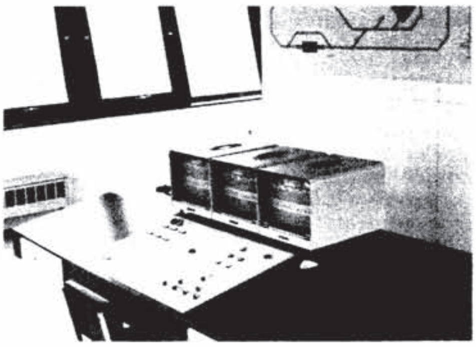
Maintenance is facilitated by the exclusive use of electricity to power the ancillary equipment and by the self-diagnosing systems.

Motors have separate excitation and are controlled by complete thyristor bridges.

Three-phase power and 950 V is collected by under-running shoes from a triple conductor rail assembly.
Dynamic and disc braking is augmented by electromagnetic track brakes.

Full automatization





The TAU is provided with full integrated automation that allows line operating costs to be reduced by 40 % in comparison with those of conventional "metro" systems, full automation meaning that the system can be operated by only half the number of staff employed in conventional transport systems.

Within the TAU system, the functions, usually performed by the operating personnel which highly burden the operating costs, are realized by automatisms : driving of vehicles, serving of stations, traffic management and control, selection of time tables and headways, depot and yard management, selection of routes, terminus handling, injection on line and returning to depot.

Regularized operation with short headways and keeping high frequencies during off-peak hours are performed thanks to the modularity of the rolling stock and to the full automatization of the system operation under the control of a dispatching realizing the network management (controls, protections, signalisations, monitoring).

The architecture of the automatisms is that of a computerized remote control network which is responsible for both safety and control functions. The vehicles are managed from the dispatching as remote controlled dependent stations. For that purpose, a single cable laid along the track ensures permanent track-to-train transmissions and enables the dialog between the computerized equipment located at the operation control centre and the computers located on the vehicles.

Moreover, the track cable enables the self-location of the vehicles and is used as a mark for the stops in the stations.

a) Automation architecture :

The architecture of the automation is that of a remote control data processing network, responsible for safety as well as for equipment and system operating functions. Vehicles and points are controlled from the operation control centre in the same way as remote stations from a master station.

This design philosophy enables track and station equipment to be reduced to a minimum, a factor that is particularly favourable with respect to system reliability and maintainability.

At the O.C.C., there are two hierarchical control levels :

- the operating and handling level, termed the upper hierarchical level, that comprises two redundant computers with one in standby. This level is responsible for all functions not associated with safety, such as traffic regulation, scheduling control, vehicle fleet, depot, etc, ...

- the safety level, termed the lower hierarchical level, comprises three redundant computers which operate simultaneously in parallel. A majority vote method enables the system to continue running with unimpaired safety and at full performance levels when one computer is defective. This architecture is also to be found on board the vehicles and in the stations.

b) The functions carried out by the automatisms:

On the basis of the self-location carried out by each vehicle and transmitted to the OCC, the latter draws up and continuously updates the position of each vehicle on the network, as well as its direction of travel.

The Operating Control Centre computers generates and transmits to each vehicle :

- the maximum speed, or the highest speed at which the vehicle may run, taking into account the track occupation and the line's configuration (presence of points, a sharp curve calling for a reduction in speed, etc, ...). The true speed of a vehicle is continuously compared with the maximum speed level by the safety processors responsible for continuous speed monitoring. Should a vehicle exceed this maximum speed level, its emergency brakes are automatically applied until it is at a complete standstill.

- the recommended speed, according to the operating program. This is processed by the processors responsible for the speed regulation and for the control of the automatic progress of the vehicle.

In order to provide fully automatic driving, other functions are also carried out :

- the control of door closure and train departure : The door closure instruction is automatically transmitted by the operation control centre as a function of prerecorded timetables and of the traffic regulation program. As soon as this signal is received on board, a sound signal warns the passengers that the doors are about to close. After a few seconds, the vehicle doors close in synchronism with the station platform doors, but departure is only authorized once the effective closure of all the doors has been recorded.

- the "on target" function, which provides for stopping in an exact position to allow the station sliding doors to be used.

- the door opening instruction once the vehicle is fully stopped.

- the continuous transmission of a health message by the vehicle, that enables the operation control centre computers to decide at all times whether the vehicle can continue to run or must be withdrawn from service.
These health messages are generated by the vehicle and processed at the operation control centre by an automatic fault monitoring system.

In order to allow for movements along the network's alternative routes and branch lines, as well as to the depot and to parking sidings, the system is provided with automatic vehicle and destination identification functions.

These functions also provide for automatic vehicle path monitoring according to the destination, and the display of the destination on the platforms and on board the vehicles for the benefit of the passengers.

c) Traffic and system control

The system operation computers (upper hierarchical level) are informed at all times of the position of the trains on the line (vehicle position monitoring program) and continuously compare the system's configuration with an idealized situation.

Right from the onset of a disturbance at some points of the network, they will restore the programmed schedules or a constant interval between trains as quickly as possible, so that the cumulative late-running effects should not be allowed to become any greater.

For this purpose, the computers instruct the vehicles to change their station stopping times or to travel between stations at speeds different to those corresponding to ideal running conditions.

When a rush hour is expected, the computers will also control the insertion of trains into the network and their withdrawal to the depot or to sidings as the rush hour comes to an end.

Operation Control Centre (OCC) (Dispatching)

The role of the OCC essentially involves :

- providing communication facilities between OCC operators and passengers,

- monitoring the vehicles, stations and permanent way equipment (electrical substations, points, ...),

- taking immediate action in emergency situations,

- managing the rolling stock park in the depot,

To perform these functions, it is provided with :

- TV and intercom systems,

- Regular information on the state of the various sub-assemblies by telemetry transmission,

- Processing logic enabling it to synthesize the above data, diagnose the condition of the various sub-assemblies and assess the consequences of any failure,

- Remote control facilities enabling OCC operators to take over from the automatics in an emergency requiring human intervention.

Tracks

The metric gauge track on the TAU transport system is similar to a conventional rail track. It is laid on special antivibration pads which improve sound insulation while reducing maintenance costs, making this type of layout extremely advantageous compared with the conventional sleeper and ballast track.

The points have flexible switch blades and the switch boxes are of the internal locking type. TAU vehicles are powered by three-phase 950 V supplied via new-design third rails running beside the track, and new-design current collectors which meet safety, reliability and economy requirements.

Stations

The low-depth stations provide ease of access. Designed for unmanned operation, the stations are equipped with facilities for ticket issuance and checking and for controlling passenger access to the platforms and vehicles.

Platforms are enclosed on the track side by walls provided with sliding platform doors. Passenger access between the train and the platform is effected by passing through the vehicle doors and the station doors, whose openings coincide.

This arrangement allows for full weather protection and complete safety of passengers.

A television/intercom system links the stations to the operation control centre enabling passengers to communicate directly with OCC operating staff.

The stations have specially been designed to meet requirements in terms of safety, comfort and ease of maintenance.

Passenger information

In a fully automated system, good communications are an essential requirement for passenger assurance. Firstly, passenger announcements are carried out automatically by voice synthesizers and moving visual indications in the vehicles and on the platforms. Secondly, a video intercom system enables any passenger to communicate with the operation control centre both from the platforms and inside the trains.

CIVIL ENGINEERING WORKS

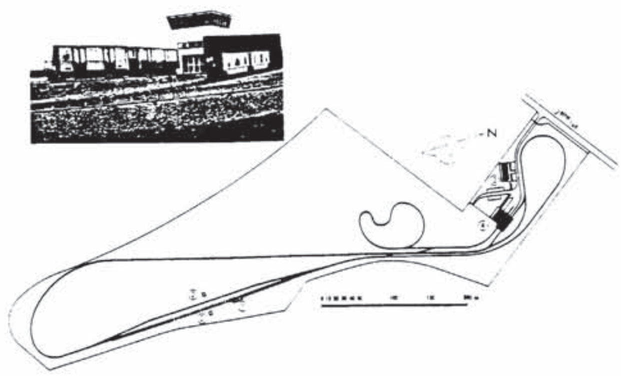
The implementation of new methods of civil works, based on the use of prefabricated units for the construction of tunnels installed at small depth enables important savings of the civil works costs (upto 50 % in comparison with usual methods) and reductions of the length and the duration of the works, which involve a reduction of the environmental disturbances.

The very short radius of turning circle of the vehicles makes it possible to tunnel under the existing road network, thus avoiding land expropriation.

The small dimensions of the vehicles facilitate the use of factory-made prefabricated components. Prefabrication and low-depth construction ensure rapid completion of the project.

A new construction technique resulting from the implementation of these special features of the TAU system has the advantage of eliminating the inconvenience of large working sites, considerably reducing the time and area of occupation of roadworks and drastically reducing the costs of civil engineering.

TEST NETWORK



The TAU system was developed as a result of in-depth research involving many innovations at subassembly level. It was therefore essential to undertake comprehensive trials and subject the constituent parts of the system to setting-up and endurance tests in order to establish the validity and credibility of the selected options.

Qualitification tests commenced in 1982 at the TAU Test Centre in JUMET. This facility, unique in EUROPE, has been designed to simulate the constraints and difficulties encountered both during the construction and operation of the system. The majority of the tests and trials were performed under the supervision of a Safety Commission with the participation of railway and metro experts. Once it goes into service, the TAU will be one of the most thoroughly and severely tested urban transport systems.

This Centre is equipped with the following facilities :

- A 2.5 km circular track with a 100 m-long tunnel, a 6-% gradient and a completely equipped and fitted station incorporating platform doors,
- A building including the dispatching for the operation management of the test network (traffic of vehicles, energy distribution), the computerized control, protection and monitoring equipment, a workshop-depot, the traction and auxiliaries supply substations. The testing facility also includes a depot and workshop.
- Two 2-car trains, the first one being an experimental one equipped with the traction and control equipment, the second one being totally coachful and fitted.

The initial tests in 1982 were conducted on the experimental vehicle.

The metric gauge track is equipped with rails and points similar to those used in conventional railways.

As the TAU vehicles are equipped with an original type of undercarriage (flexible bogie + traction motor), this has been tested over many thousands of kilometres on a secondary track, which has 10-metre radius curves and reverse-curves.

The TAU is supplied with three-phase 950 V by current collectors and third conductor rails of an entirely new design. The JUMET facility has made it possible to check the system for efficient operation and stability, to overcome problems of wear and on-going current collection, to try out different methods of securing the 3rd rail and to devise a system whereby the 3rd rail can be incorporated into the alighting platform.

All the TAU automatics, whether involved in vehicle propelling, traffic control or operation of station equipment, have undergone comprehensive trials in the testing facility, which also includes a complete operation control centre. It has therefore been possible to simulate all the operating conditions obtaining in an actual network.

A 100 m-long underground section was constructed according to a new technique, using prefabricated tunnel and station components based on an original method of assembly. The experimental site has made it possible to establish the validity, reduced overall dimensions and speedy construction of the system as a whole.

Antivibration supports for the tracks are being designed and tested at the JUMET facility to minimise noise.

A prototype underground station has been developed and equipped with sliding doors. This arrangement has made it possible to carry out research into volumes, to devise a functional organisation and to try out new developments and systems catering for passenger information, safety and comfort.

CONCLUSIONS

The technical feasibility of a fully computerized automated transport system, has been demonstrated by the trials carried out on the JUMET circuit. The system has implemented original solutions to both the structure of the vehicles and their drives, to the electronic data processing control and monitoring devices, as well as to the civil engineering aspect. The safety and reliability aspects were very thoroughly investigated and solutions guaranteeing the highest levels of performance in this respect were developed and fully tested. Improvements and endurance tests have been carried out on an experimental vehicle for two years.

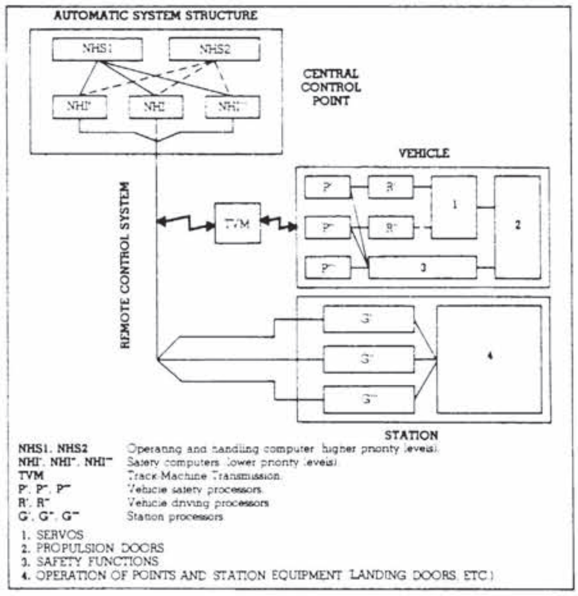
A second, fully finished vehicle - a prototype of subsequent operational vehicles - was brought into service at JUMET in April 1985.

Due to the advanced design of the vehicles and the implementation of new methods of tunnel and station construction, the layout of the TAU system is suitable for the existing urban infrastructures and the costly expropriations are reduced considerably.

The TAU system appeals to cities which do not consider rail transit because of the high capital cost. TAU's small-profile trains and automatic operation makes it cheaper to install and operate than conventional metros.

Its features meet the need for modern, attractive, reliable economic, rapid and comfortable public transport system. It has been designed to cater for a wide range of operating features and can be readily adapted to specific urban requirements. It is a modern transport system on private right-of-way ensuring high service frequency and fully automated operation.

It can easily be integrated within the existing urban context.




AUTOMATIC SYSTEM STRUCTURE