Choosing an appropriate technology for guided surface transit systems: a comparative analysis of 6 surface transit systems

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Abstract

Comparison of different transit systems is a complex and uneasy work, especially for guided surface transit systems that offer almost equivalent services for users. So, careful analyzers should take into account not only some advantageous aspects of systems separately but also combination of every evaluation criteria under systemic approach in order to recognize better differences between one system and another ones. However, we find this kind of analysis hard to achieve for the reason of veiled information even if this step is indispensable to select appropriate systems at the moment of transport planning.

In this paper, we compare 6 guided surface transit systems (e.g. tramway on tyres and on steel wheels, trolleybus and other intermediate transport systems) to better understand their different characteristics and, furthermore, to better implement them at any urban context. This is also a reflection on our daily public transport problems for decision makers to make an harmonious decision with other stakeholders for complex transport projects.

The key innovation of this paper is the use of real data and the comparison of whole spans of surface transit systems now being in vogue under the currently more deteriorated environmental and economical circumstances. On using the ELECTRE method of multi-criteria analysis (MCA) with information obtained from transport authorities and operators of certain cities, we carry out our research as objective as possible vis-à-vis diverse local contexts in order to find reasonable and acceptable results.

This paper first presents a general panorama of guided surface transit. After that, we carry out a comparative analysis of these 6 surface transit systems using ELECTRE method. In conclusion, we establish some recommendations for suitable and sustainable public transport system.

Keywords: Guided surface transit system, MCA, ELECTRE, capital and operating costs, comparative analysis, public transport

The need for profound knowledge of public transit systems is an ongoing issue since the first birth of these systems in order to choose and implement an (sometimes several) appropriate one. This issue has become by no means more crucial considering today's financial, economical and environmental concerns being repeatedly mentioned. Therefore, the reasonable and consensual comparison for public transit systems now being continually progressed and highly desired has become more complicated and painful than before.

Our research is in the same line of this attempt to find more comprehensive understanding of public transit systems especially guided ones from bus-based to rail-based vehicle so that it allows us to choose an adequate transit system for our cities.

1. Six transit systems to study

In this section we will briefly present the transit systems we study including capacity, guidance technology, capital and operating costs. Moreover, we examine different constraints especially concerning the development of surface transit systems: the Right-of-Way width, physical infrastructure characteristics (slope, curve radii, type of pavement, etc.), and aspect of urbanism.

The six systems we now will study are surface guided transit systems which can be seen easily in our daily life although we don't recognize them well.

- 'Modern' Tramway on rail[1]: this is a classical streetcar but with many modernized material like development of more efficient electric supply and low-floor vehicles, now becomes one of the modern urban transit system.
- Tramway on tyre (Translohr): this is a new type of transit system made by Lohr Industrie. This uses a guidance system originated from rail-based system and a rubber-tyred traction system from road-based vehicle. So we call it tramway on tyre.
- TVR (Transport sur Voie Réservée: Transport on reserved route): this is a system invented by Brugeoise & Nivelles and then bought by Bombardier, which can be said a kind of bus with several cars and with a physical guidance system at the bottom of vehicle using one rail.
- CIVIS: this is a bus system with an optical guidance situated at the up front of the bus. This was invented by Irisbus and Siemens, and now is available as an option for several urban bus vehicles (not only for the Irisbus).
- Trolley: this is a kind of bus but using overhead energy supply system coupling with electric engine more powerful and less pollutant.
- Bus: this is a well-known road vehicle designed to carry passengers and widely used in public transportation field.

1.1. <u>'Modern' Tramway on rail</u>

The typical electrical tramway, also said streetcar, from its introduction in the late 1880s up to World War I, was a short, 2-axle, wooden-body vehicle operated by a driver. Four-axle vehicles, 12 to 16 m long, made their first appearance during the 1890s, mainly on American inter-urban lines.

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[1] A formal definition was adopted in 1989 and placed in the TRB's Urban Public Transportation Glossary: "A metropolitan electric railway system characterized by its ability to operate single cars or short trains along exclusive ROW at ground level, on aerial structures, in subways, or occasionally, in streets and to board and discharge passengers at track or car floor level."

During the 1920s and early 1930s competition with the private automobile began to make a significant impact on tramway ridership including congestion. Improving operation quality in congested streets and avoiding the track maintenance cost, operators began to convert tramway lines to buses.

In 1930, a Presidents' Conference Committee (PCC) was set up to examine the problem and supervise a development program for a modern tramway vehicle that would incorporate the most advanced technology available at that time. This effort produces the PCC car which is, in many respects, far more advanced than any of its predecessors. An extremely quiet vehicle with soft suspension was able to accelerate and brake rapidly, thanks to sophisticated indirect motor control. By 1952 about 6000 PCC cars had been produced in the United States. Modified versions of PCC cars have continued to be produced in Europe, e.g. Belgium (Brugeoise & Nivelles) and Czechoslovakia (Tatra).

The PCC car helped to improve the competitive position of transit systems vis-à-vis the private automobile and slowed down the moving from tramway to buses. But, due to the absence of other support – particularly separate Right-of-way implemented generally by city authorities was not available – the PCC car was not able to assure long-term stability neither for the tramway mode, nor for transit role in cities.

The decisive progress of tramway technology and applications came during the 1950s when a German manufacturer (Düsseldorf Wagen DÜWAG) produced a new model of articulated cars, far superior to all earlier articulated cars, including European and U.S. models. The wide application of these cars upgraded tramway networks along with the separated R/W, priority treatments, and other technological and organizational advances resulted in the creation of light rail transit – a rail system that is, by its performance, more similar to rapid transit than to simple tramway operating in mixed street traffic.

Countries where tramways have survived from the massive closure of the 50s and 60s, e.g. Germany, Switzerland, Belgium, have modernized and upgrade their tramway network and may now called "light rail systems".

Many other countries, where tramways had disappeared from the streets, have developed completely new systems since the mid-70s. This is the case in North America, in the Asia-Pacific area and in a few European countries such as the United Kingdom and France.

Tramway vehicles operate, in general, both in street traffic and on their own track of different types at a high average commercial speed with enhanced quality of service: A 32-meter tramway can transport 3000-4000 passengers per hour per direction depending on the headways (3 or 4 minute) with the commercial speed around 20 km/h under different Right-of-Way categories.

1.2. Tramway on tyre (Translohr)

The tramway on tyre with a central V-shaped rail guidance named Translohr is developed by the Lohr-Industrie located in Alsace, France. A single centrally embedded rail guides the vehicle on a guide way. Every axle is equipped with a guidance device composed of two rollers in V fixed on a swivelling arm. Each axle of the vehicle is oriented by using two arms, each having two rollers. The guidance system, mounted on all axles, is mechanically locked with the rail, and thus guarantees the precision of the trajectory and the perfect docking at the stations without any effort on the rail. A bandage with composite material has been using to avoid direct contact iron-iron. According to the manufacturer, there is no possibility of derailment including with much deteriorated grip conditions. The rail does not suffer wear, only the rollers bear it.

The first prototype of this system has also been tested in the first quarter of 2001 on RATP's Trans Val-de-Marne site, located on the southern suburb of Paris.

Clermont-Ferrand has been the first city to employ this system to passenger service through the operator SMTC from 2006. There are several versions of Translohr with three, four and five car sets from 25 m to 39 m length and 2.20 m gauge width. These vehicles are easily accessible thanks to its 250 mm height low-floor body and permanently guided having an electric traction system by catenaries.

A 32-meter Translohr (STE4) can carry 2250-3400 passengers per hour per direction according to the headway under the exclusive R/W (category B) and the commercial speed is nearly same as that of tramway while it requires less space to implement and less capital cost than tramway.

1.3. TVR

For the beginning, La Brugeoise & Nivelles (BN) in Brugge, Belgium demonstrated a stranger device initially running on a short track in Brussel. This named GLT (Guided Light Transit) was a rubber-tyred articulated bus (3 car sets) for a dual-modal system guided by a central rail. Each vehicle could be coupled as train-like ones, maximum 3 cars, of 76 m long, with a capacity of 600 passengers (6 standees/m^2). Each of the 4 axles could be put into guiding mode of which the minimum radius is 12.5 m.

In the early 1990s, a third prototype was given bogies and ran as a tram in Bruxelles, but these high-floor vehicles were soon disappeared by the arrival of low-floor trams (and later buses). Besides that, there was a significant problem which was excessive noise caused by the oscillation of the wheel in the guideway.

In 1989, the Bombardier Transports acquired the "Ateliers de Nord de la France (ANF-Industrie) and Brugeoise & Nivelles (Belgium)". This was a change to further develop the Belgian GLT (Guided Light Transit) concept with Spie-Enertrans. In the mean while, nothing happened, but in France, the Bombardier salesmen were able to convince French people to implement this system by proposing an "half-price tramway" and at the same time the French Ministry of Transportation wanted to have its own segregated surface transit system.

The Guided Light Transit or TVR guided by a single central rail has been developed by Bombardier and tested on an experimental site, the Trans-Val-de-Marne, in the southern suburb of Paris, in 1998. This system has been chosen for the future Separate ROW Public Transport of Caen and Nancy where the new system has been under operation from September 2001.

Nancy was the first city where implemented TVR and also the city where bi-modal trolley existed at that time. The city of Nancy wished to provide a heavy-duty transport solution for their important routes, but it was argued that, according to the Transit Authority, conventional trams would not be possible to climb the steep gradients on the route in all weathers. Nancy also wished to keep the expensive electrical installations of the trolley, so an electrically powered mode of transport was desirable. The TVR seemed to be an ideal solution (but later it turned into a bad answer result from the technical problems due to its bimodality of guidance system). Major works were carried out to install guide rails and stations and reorganize traffic flows in the city, and the system was inaugurated open in 2001. TVR is the name that the city of Nancy named.

Bi-articulated bus of 24 m long, TVR vehicles are shorter than most modern tramways, but quite long compared to regular buses. They are designed to look much like tramways, although they are unidirectional and have bus-like rear-view mirrors. TVR is a real dual mode transit system in terms of guidance technology cause it runs on guided part and non-guided part, and in terms of traction technology with 2 types of traction motors: ICE[2] and electric motor.

The TVR can carry approximately 2600 passengers per hour per direction thanks to his 24-meter length, but the commercial speed on the exclusive R/W section is not as high as the tramway or Translohr due to technical problems highly linked to the guidance system.

1.4. <u>CIVIS</u>

Civis is originated from the cooperation between Irisbus and Siemens companies. Irisbus provided the vehicle and Siemens was in charged of the optical guidance system. The result has been a bus-like vehicle with electric motor wheels, being able to circulate in non-guided mode and in guided mode.

The guidance system of CIVIS is based on the principle of image processing and path recognition. A video camera, located on the top of the vehicle, detects the position of the vehicle compared with a double painted stripe[3] beaconing on the pavement. Data are processed by an electronic central unit which acts automatically on the steering column, by the intermediate of an electric motor, so that the vehicle follows the reference path. The system being intangible, the driver can take back the driving in a manual mode at every moment if it is necessary for the reason of safety or operating, without slowing down the vehicle.

It is important to note that the optical guidance system concerns only the front axle; the rear axle being not guided, the vehicle is not a single-track.

The optical guidance only helps a docking in the station reducing the gap between the platform and the vehicle less than 50 mm width; this system is not validated between the stations. This system was tried and tested In Rouen and Clermont-Ferrand and now under operation in Rouen.

This Civis can carry around 2100 passengers per hour per direction on the exclusive R/W with less operating cost than the systems mentioned before. The DKE[4] of Civis is larger than these systems because of the lack of the physical guidance while this gives the flexibility of service when any interruption happens.

1.5. <u>Trolley</u>

Trolley or trolleybus is a bus mode which uses the electric supply system and electric motor. Characteristics and performances of trolley are almost same as those of bus except one thing, the energy supply, as mentioned before.

This system has many advantages. This is silent and doesn't make air pollution. However, the power supply system using the aerial contact line makes it less flexible in terms of route and exceptionally could become a hazard for road traffic due to the proximity of the wires and the bodies by touching it.

However, new generation trolleys are bi-traction, electrical and diesel/electrical, which give them a better operating flexibility. The new generation trolleybuses also take advantage of

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[2] ICE : Internal Combustion Engine

[3] Two parallel dashed stripes having that dash length: 50 cm; dash width: 10 cm; distance between dashes: 50 cm; width between dashes: 10 cm.

[4] DKE: Dynamic Kinetic Envelop.

an integral low floor body and an increased habitability (wide corridors) thanks to motor wheels adapted to this system. For example, the trolleybus named Cristalis is a new generation trolleybus made by Irisbus.

Trolley can carry as many passengers as Civis. However its layout is limited since it uses the electric power supplied by overhead catenaries reducing local pollution and noise.

1.6. Bus

The bus is the most common road vehicle, which is operating on the urban transit network. There are a standard version (12 m long) and an articulated version (18 m long) under operation in France[5]. Numerous improvements have been carried out on this mode, especially in accessibility terms with the appearance of low floors and with traction motors.

Concerning the image of vehicles, important progresses have been realized these last years, giving a new attractiveness and a new boost to this urban transit mode. At the same time as the comfort improvement of vehicles, noise emissions were reduced and numerous elements were redone, e.g. exterior, new headlights, lateral faces, windows, high-beam unit, etc.

The big bus makers propose several bus versions presenting innovating and attractive characteristics. For example, some bus makers offer a kneeling system allowing buses to reduce the vertical gap between vehicle and platform and an access slope with an electrical control to make an easy access for the persons with reduced mobility.

Its unit and hourly capacity is same as Civis and Trolley. However, if bus doesn't use exclusive bus lanes, the traffic perturbation occurs randomly and the quality of service will be going down rapidly.

The technical characteristics of 6 transit systems we will study are as follows:

Transit system	Unit	Tramway: Citadis 302	Tramway on tyre: Translohr	TVR	CIVIS	Trolley	Bus
Power		750 D/C	750 D/C	750 D/C & ICE	ICE[6]	750 D/C	ICE
Height	m	3.20	2.89	3.22	3.22	2.90	2.90
Width	m	2.40	2.20	2.50	2.55	2.50	2.50
Floor level	mm	320	250	290	320	320	340
Min. radius	m	25	11.80	12	12.50	12.50	12.50
Max. gradient	%	10	13	13	13	13	13
DKE[7]	m	5.85	5.46	6.14[8]	6.80	6.80	6.80
Overall length	m	32-33	32	24.50	18	18	18
Unit capacity	4 p/m^2	200	170	130	105	105	105

Table 1: Technical characteristics of 6 transit systems

[5] We can see 24 to 27 meter long articulated buses under operation in Curitiba and Bogota, which means that generally in South America where urban rail transits are not fully developed.
[6] ICE: Internal Combustion Engine.
[7] DKE: Dynamic Kinetic Envelop (Source: SYSTRA, EREA, Ingérop, LACUB (2005)) and this could be varied depending on the context.
[8] With the guidance.

2. Methodology: ELECTRE III

Multi-criteria analysis is widely used in selecting the alternatives to meet given objectives from a finite set of decision alternatives with respect to multiple, usually conflicting criteria. Transit system choice process is a multi-objective task in nature; maximize transport offers under limited cost and environmental constraints encircling many stakeholders. In addition, as it doesn't exist unique solution for a transport project but several compromises, decision makers only choose one solution among these compromises. So it is obvious to use multi-criteria analysis to assess transit systems among different alternatives.

In this research, we use one of multi-criteria analysis methods which called ELECTRE III to compare 6 surface guided public transit systems. The ELECTRE III method is a highly developed multi-criteria analysis method, which takes into account the "reality" such as uncertainty and hesitation by introducing a notion of "flou" (vagueness, unclearness) generally explained by pseudo-criterion. ELECTRE III method, therefore, allows us to do a comparison considering every intermediate outranking is possible (Roy 1985). The pseudo-criterion is associated with the criterion function g and two threshold functions:

p : Preference threshold,

q : Indifference threshold.

And, for not ignoring incomparability or misleadingly-obtained expression of relation, this method also introduces a veto threshold, v. Using these functions, 4 binary relations between each pair of actions can be found.

P : Strong preference,

Q : Weak preference,

I : Indifference,

R : Incomparability.

ELECTRE III method rests on the following steps (Maystre, Pictet et al. 1994).

2.1. Calculation of the global concordance indice

The concordance indice c_j, assert to what extent the action a_i is at least as good as action a_k for the criterion j. And then using this indice, we obtain the global concordance indice which assert to what extent a concordance exists with the hypothesis "action a_i outrank action a_k" and defined as follows:

$$C_{ik} = \frac{\sum_{j=1}^{m} P_j \cdot c_j(a_i, a_k)}{\sum_{j=1}^{m} P_j}$$

where:

C_{ik} : Concordance indice,

P_j : Weight of each criterion,

$$C_j(a_i,a_k)=0 \Leftrightarrow p_j < g_j(a_k)-g_j(a_i),$$

$$0 < C_j(a_i,a_k) < 1 \Leftrightarrow q_j < g_j(a_k)-g_j(a_i) \le p_j,$$

which means that : $C_j(a_i,a_k)=\dfrac{g_j(a_i)-g_j(a_k)+p_j}{p_j-q_j}$

$$C_j(a_i,a_k)=1 \Leftrightarrow g_j(a_k)-g_j(a_i) \le q_j$$

2.2. <u>Calculation of the disconcordance indice</u>

The relationship of concordance defined above must be weakened by a notion of disconcordance expressed by the veto threshold. The veto threshold for criterion j, written as v_j, is, by definition, the value of the difference $g_j(a_k)-g_j(a_i)$ from which it appears reasonable to refuse any credibility that outranks action a_k over a_i, even if all other criteria are consistent with this outranking.

We calculate the disconcordance indice d_j, with using this order $q_j < p_j < v_j$:

$$d_j(a_i,a_k)=1 \Leftrightarrow v_j < g_j(a_k)-g_j(a_i),$$

$$0 < d_j(a_i,a_k) < 1 \Leftrightarrow p_j < g_j(a_k)-g_j(a_i) \le v_j,$$

which means that : $C_j(a_i,a_k)=\dfrac{g_j(a_k)-p_j-g_j(a_i)}{v_j-p_j}$

$$d_j(a_i,a_k)=0 \Leftrightarrow g_j(a_k)-g_j(a_i) \le p_j$$

We can formulate these two indices simply like this:

$$C_j(a_i,a_k)=Min\left\{1,Max\left(0,\frac{g_j(a_i)-g_j(a_k)+p_j}{p_j-q_j}\right)\right\},$$

$$d_j(a_i,a_k)=Min\left\{1,Max\left(0,\frac{g_j(a_k)-g_j(a_i)-p_j}{v_j-p_\mathbf{j}}\right)\right\}$$

2.3. <u>Calculation of the credibility indice</u>

In ELECTRE III, there is always an outranking relation established between two potential actions, but this relationship is unclear as there are couples seem to be unarguable and very unconvincing. This “credibility” that varies from couple to couple and also influences the final ranking. So it is important to take this credibility into account, which called the credibility indice and defined as follows:

$$\delta_{ik}=C_{ik}\cdot\prod_{j\in\overline{F}}\frac{1-d_j(a_i,a_k)}{1-C_{ik}}$$

where:

$$\overline{F} = \left\{ j \middle| j \in F, d_j(a_i, a_k) > C_{ik} \right\} \text{ and } F \supset \overline{F}$$

This outranking relationship is used to classify actions in pre-order. The first relation is obtained from the top-down method, selecting the best action and other actions by ranking the best to worst, it is called distillation downward. The second is from the bottom-up method, by first choosing the wrong action, and by classifying the worst to the best action, it is called distillation upward.

The construction of two pre-orders based initially on using the discrimination threshold, $s(\lambda)$ and this leads us to a net outranking, $S_A^{\lambda_1}$:

$$a_i S_A^{\lambda_1} a_k \Leftrightarrow \begin{cases} \delta_{ik} > \lambda_1 \quad and \\ \delta_{ik} > \delta_{ki} + s(\delta_{ik}) \end{cases}$$

where:

$$\lambda \in [0,1]$$
$$\lambda_0 = \max(\delta_{ik})$$
$$\lambda_1 = \lambda_0 - s(\lambda_0)$$

After having done these steps, we can obtain a final ranking order which could be a good compromise among the actions. But before concluding, it is necessary to check the "subjectivity" of deciders. The determination of the importance coefficient is a function of the decision makers' preferences. For this reason, the application of a multi-criteria model should be followed by a sensitivity (robustness) analysis of the final outranking order by varying the preference, indifference and veto thresholds, as well as the weight of criterion (Papadopoulos and Karagiannidis 2008).

3. Data collection

The data we are using have been obtained and collected entirely from French cities: Clermont-Ferrand, Grenoble, Limoges, Lyon, Le Mans, Nancy, and Rouen. **Table 2** shows the data information concerning transit systems and cities where these data come from. The figures we are going to use are the average for the transit system data from several cities and the representative value for the transit data from just one city.

Transit systems	Cities
Tramway	Grenoble, Le Mans, Lyon
Tramway on tyre (Translohr)	Clermont-Ferrand
TVR	Nancy
CIVIS	Rouen
Trolley	Lyon, Limoges
Bus	Clermont-Ferrand, Grenoble, Lyon

Table 2: Sources of Data

4. Criteria selection

We have divided criteria into 3 parts in this research: performance/service, costs and environmental terms. This division can be generally accepted without critical objection and clearly represent different characteristics of surface guided transit systems. Before we start, it is indispensable to note that bus system in this research is not BRT[9] but an ordinary bus service with articulated bus. If someone wants to upgrade this conventional bus service to BRT or BHLS[10], it is required to use higher R/W category better than C. This upgrade absolutely improves bus service and then allows us to promote bus system. TVR and Civis are generally considered as BHLS.

4.1. Performance and service Criteria: technical characteristics

We have chosen some criteria concerning performance in regard to offered service that can be measured, as we do generally, for example, using the category of Right of Way, capacity, comfort and etc. This is much linked to technical aspect of each transit so we can call it technical characteristics. The criteria concerning performance we have chosen are shown **Table 3** below:

	Unit	Tramway: Citadis 302	Tramway on tyre: Translohr	TVR	CIVIS	Trolley	Bus
Hourly capacity[11]	passengers/hour/direction	3000	2550	2600	2100	2100	2100
Level of Service[12]	Categories of R/W	A or B	B	B or C	B or C	C	C
	Comfort(positive/negative)	+++++	++++	+++	+++	++	++
	0-10	**9**	**8**	**5**	**6**	**4**	**4**

Table 3: Characteristics concerning performance and service

For this outcome, we use 4 persons/m^2 to make an harmony between rail-based and road-based transits since these two fields generally use different methods for capacity calculation: 4 p/m^2 and 6 p/m^2. Moreover, we have used hourly capacity as pessimistic regard as possible in order to give more comfort to passengers that is contrary to the engineering view point which emphasizes only offered seats: “the more passengers we transport means the better transport systems we have.”

This hourly capacity is therefore, measured by using the headway at peak-hour: 4 minutes for rail-based transits such as tramway and Translohr and 3 minutes for other road-based systems to reflect a practical transport condition not a theoretical maximum one.

[9] BRT: Bus Rapid Transit.

[10] BHLS: Bus with the High Level of Service. The European term of BRT which emphasizes the service level more than the speed.

[11] 4 p/m^2

[12] LOS : Level of Service. It is noted that this is not a LOS generally used to define traffic condition but just a scale introduce by authors for a convenient reason.

4.2. Cost Criteria

This criterion is one of the most important factors when we are involved in choosing a transit system. Costs used in order to achieve a transit project directly reflect the efficiency of public budget allocation. If a same or equivalent result is obtained with less money expense, it is considered very efficient and good for our society. While cost factor is a well-known and easily-accepted criterion, there is a kind of culture that veils 'real' cost of transit systems, especially the operating cost. So it is not easy task to find operating costs of each system that we will just use already treated data given by operators or the Transportation Authorities.

Moreover, there exist so many other aspects we cannot measure as monetary value like environmental impact, amelioration of life style and image of city. We should pay attention to this disadvantage when selecting a transit system and must not take cost as an 'absolute' or 'supreme' criterion, which gives a preference to any transit system. We should use cost issue with special care and attention.

Year of 2007	Unit	Tramway: Citadis 302	Tramway on tyre: Translohr	TVR	CIVIS	Trolley	Bus
Capital costs	M€/km[13]	23.8	21.9	17.1	7.2	8.7	6.0
Operating costs	€/km	7.15	6.9	6.2	5.7	5.7	5.53

Table 4: Costs of 6 transit systems

We have taken into account costs for the 6 systems including just the necessary infrastructures in order to operate the system on separate R/W without special civil engineering like bridges, tunnels, and etc.

4.3. Criteria concerning environmental aspects

Environment is not a criterion only concerning to the Nature but also to the atmosphere of human beings that influences our daily social life. In this research, we consider the environmental criteria as context that can be significant to give a different transit perception to transit users such as accessibility and urban changes due to an implementation of new transit system.

	Unit	Tramway: Citadis 302	Tramway on tyre: Translohr	TVR	CIVIS	Trolley	Bus
Accessibility	floor height in mm	320	250	290	320	320	340
Impact on urban change	positive/negative	++++	++++	+++	+++	++	+
Synthesis	**0-10**	**8**	**8**	**6**	**6**	**4**	**2**

Table 5: Criteria concerning environmental aspects

Table 5 presents these environmental criteria considering that if level boarding is available, there is no substantial difference for the accessibility. This is the way we have got the numbers in synthesis cells.

[13] Million euros per kilometer

5. Application

Now we start to make a comparison of different transit systems we selected and mentioned before by using ELECTRE III method. The criteria we have finally chosen and their 'performance records' are shown in **Table 6**. One thing to keep in mind is that we have tried to use as minimum criteria as possible because this study concerning, firstly, reviewing every surface guided transit system under operation in France and secondly selecting an appropriate system which means that the selected system should be invariable whether we add another criteria or not, provided that our criteria selection method is pertinent. So, in this research as just a first step for transit system comparison, we have used only five criteria judged pertinent by authors and will gradually ameliorate our criteria selection and method as well for the future study. **Table 6** shows every criterion we have selected and other criteria necessary to apply ELECTRE III method: weight and 3 different thresholds.

	Hourly capacity (p/h/d)	**LOS[14] (0-10)**	**Capital costs (M€/km)**	**Operating costs (€/km)**	**Environmental aspects (0-10)**
Tramway	3000	9	23.8	7.15	8
Translohr	2550	8	21.9	6.9	8
TVR	2600	5	17.1	6.2	6
CIVIS	2100	6	7.2	5.7	6
Trolley	2100	4	8.7	5.7	4
Bus	2100	4	6.0	5.53	2
Weight	25	20	20	25	10
Indifference threshold	5%	1	20%	10%	2
Preference threshold	30%	3	40%	20%	4
Veto threshold	50%	5	90%	50%	

Table 6: Performance matrix as reference

The final ranking of 6 transit systems after applying the ELECTRE III method is shown in **Table 7** before sensitivity analysis. Tramway and Translohr seem to be the most pertinent systems at first look under our research context.

Ranking	**Transit systems**
1	Tramway, Translohr
2	CIVIS
3	Trolley, Bus
4	TVR

Table 7: Final ranking of 6 transit systems

It is, therefore, required the verification of this result that examines it in detail whether it is invariable or not by carrying out a sensitivity analysis.

[14] LOS : Level of Service. It is noted that this is not a LOS generally used to define traffic condition but just a scale introduce by authors for a convenient reason.

5.1. Sensitivity analysis

Now we will do a sensitivity analysis to check our final result with the rank above. It is noted that, in this test, we are much interested in the weight change that could be relatively sensible and subjective at any project decision process than other threshold criteria. In addition, these thresholds we have chosen represented well the different features of decision makers' subjectivity and did not seem to be variable when we change them. Consequently, we will just look into the weight change.

5.1.1. Changing the weight of capacity

The weight of hourly capacity doesn't change our final ranking if it is situated between 14 and 30. Generally, the capacity factor is not greater than 25-30% of the importance so that our decision of the capacity weight 25 remains convincing. Further more, although we put the capacity weight less than 14 and more than 30, the final ranking remains valid because the first best option doesn't change.

	Hourly capacity	**LOS**	**Capital costs**	**Operating costs**	**Environmental aspects**
Weight	**14-30**	20	20	25	10
Indifference threshold	5%	1	20%	10%	2
Preference threshold	30%	3	40%	20%	4
Veto threshold	50%	5	90%	50%	

When hourly capacity is under 13

Ranking	**Transit systems**
1	Tramway, Translohr
2	CIVIS
3	Bus
4	Trolley
5	TVR

When hourly capacity is over 31

Ranking	**Transit systems**
1	Tramway, Translohr
2	CIVIS, Trolley, Bus
3	TVR

Table 8: Weight change of hourly capacity

There is another thing to be noted: even if we change the capacity weight the worst option remains invariable. Civis, bus and Trolley can be same solutions as we emphasize the capacity more than other criteria, which is absolutely logic provided that they have same capacity.

5.1.2. Changing the weight of reliability: LOS

The weight of reliability is more sensitive than capacity one. Between 15-23, there is not a change of final ranking, however, under 14, Translohr and Civis become a second best option, which indicates that it is favorable to Civis but not to Translohr. If we emphasize the reliability more than 23, Civis goes down and becomes as same level as Trolley and bus. This means that in certain range of reliability, Translohr and Civis would be a same level, but Translohr is generally situated on the upper level than road-based transit system. Tramway always remains the best option.

	Hourly capacity	LOS	Capital costs	Operating costs	Environmental aspects
Weight	25	**15-23**	20	25	10
Indifference threshold	5%	1	20%	10%	2
Preference threshold	30%	3	40%	20%	4
Veto threshold	50%	5	90%	50%	

When LOS is under 14

Ranking	Transit systems
1	Tramway
2	Translohr, CIVIS
3	Bus, Trolley
4	TVR

When LOS is over 24

Ranking	Transit systems
1	Tramway, Translohr
2	CIVIS, Trolley, Bus
3	TVR

Table 9: Weight change of LOS

5.1.3. Changing the weight of capital cost

The result of this change illustrates that if we do not highlight the capital cost over than 30% of total importance, Tramway and Translohr remain the best solution. Besides, the less we emphasize the capital cost, the less the difference between transit systems becomes blured.

	Hourly capacity	LOS	Capital costs	Operating costs	Environmental aspects
Weight	25	20	**18-30**	25	10
Indifference threshold	5%	1	20%	10%	2
Preference threshold	30%	3	40%	20%	4
Veto threshold	50%	5	90%	50%	

When capital cost is under 17

Ranking	Transit systems
1	Tramway, Translohr
2	CIVIS, Trolley, Bus
3	TVR

When capital cost is over 31

Ranking	Transit systems
1	Tramway, Translohr
2	CIVIS
3	Bus
4	Trolley
5	TVR

Table 10: Weight change of capital costs

The capital cost weight change has an effect on the final ranking contrarily as the capacity weight change does while the worst option is same. We could also say that the capital cost influences more the road-based transit systems than rail-based ones: rail-based transits are unvarying between the weight 18 and 30.

5.1.4. *Changing the weight of operating cost*

The operating cost weight has exactly the same characteristic as capital cost factor except for having a little bit more importance.

	Hourly capacity	LOS	Capital costs	Operating costs	Environmental aspects
Weight	25	20	20	**23-35**	10
Indifference threshold	5%	1	20%	10%	2
Preference threshold	30%	3	40%	20%	4
Veto threshold	50%	5	90%	50%	

When operating cost is under 22

Ranking	Transit systems
1	Tramway, Translohr
2	CIVIS, Trolley, Bus
3	TVR

When operating cost is over 36

Ranking	Transit systems
1	Tramway, Translohr
2	CIVIS
3	Bus
4	Trolley
5	TVR

Table 11: Weight change of operating costs

5.1.5. *Changing the weight of environmental aspects*

The weight of environmental aspects has the same quality as the capacity weight and the final result doesn't change: Tramway and Translohr are the best option. If we put more emphasis on the environmental aspects, the road-based transit systems become same options. The worst option always remains invariable.

	Hourly capacity	LOS	Capital costs	Operating costs	Environmental aspects
Weight	25	20	20	25	**3-13**
Indifference threshold	5%	1	20%	10%	2
Preference threshold	30%	3	40%	20%	4
Veto threshold	50%	5	90%	50%	

When env. aspect is under 3

Ranking	Transit systems
1	Tramway, Translohr
2	CIVIS
3	Bus
4	Trolley
5	TVR

When env. aspect is over 13

Ranking	Transit systems
1	Tramway, Translohr
2	CIVIS, Trolley, Bus
3	TVR

Table 12: Weight change of environmental aspects

5.2. Results of the application after sensitivity analysis

Tramway and Translohr have become more appropriate transit mode with any regard. If we emphasize capacity factors more, bus seems to become more competitive mode but neither than tramway not Translohr.

The weight of reliability is more sensitive than other criteria. With reliability criterion change, we can have the same raking of Translohr and Civis. In addition to this, it is possible to obtain the same ranking of Civis, trolley and bus. Even so, Translohr is generally situated on the upper level than road-based transit systems and Civis could be the best option amongst road-based transits. Tramway always remains the best option.

We have also observed that if we underline cost weights, the ranking of bus goes up and could be considered as more adaptable system but Tramway and Translohr remains the best option.

Ranking	**Transit systems**
1	Tramway, Translohr
2	CIVIS
3	Bus
4	Trolley
5	TVR

Transit systems
Tramway
Translohr, CIVIS
Bus, Trolley
TVR

Transit systems	**Ranking**
Tramway, Translohr	**1**
CIVIS, Trolley, Bus	**2**
TVR	**3**

Table 13: Ranking changes

The orders of other systems called road-based transits are not actually changed even though we modify any criterion, which points out that the ranking of 4 road-based transit systems could be Civis -> bus -> Trolley -> TVR in one case and Civis/bus/trolley -> TVR in another case, but TVR is always the last option to choose.

6. Conclusion

With the respect to the result obtained, we can conclude that when there is an urban transit project to offer a capacity between 2000 and 3000 passenger per hour per direction, Tramway and Translohr would be the best solution, Civis the second and then bus/trolley. In any case it is reasonable to consider firstly Tramway and Translohr as transit system.

We could also find that the Civis considered as a BHLS could be a better solution than conventional bus services at some context because it improves considerably the service reliability by using exclusive R/W and level boarding owing to the optical guidance system.

This study is just a first step of Ph.D. dissertation and so more detailed results will be published in near future.

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