Analysis of flexibility on the FTS

László Erdei *PhD student*
Institute of Logistics, University of Miskolc, Hungary

Prof. Béla Illés
Institute of Logistics, University of Miskolc, Hungary

Péter Tamás *associate professor*
Institute of Logistics, University of Miskolc, Hungary

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Abstract
Mobility is an important societal issue, and one that COVID-19 has touched on to a large extent. The epidemic situation is slowly recovering, but the use of flexible transport systems is not widespread. I will present the need to examine the approach to DRT and the competitive deployment of flexible transport systems from the perspective of mobility as a service. For the effective design and deployment of flexible transport systems, it is necessary to collect the parameters that can be qualified and to establish the methods to analyse their effectiveness. The parameters to be analysed need to be established for each FTS categorical operational concept. Appropriate flexibility indicators for flexible transport network variants. The context in which the indicator can adequately qualify flexible transport systems is debated. The outcome of this research is to establish resilience parameters (for A-FTS) and describe operational concepts (for A-B-C-FTSs) based on preliminary research.

1. Introduction
Mobility is an essential part of our lives, which is reflected in the use of private and public transport. Walking can be considered as a private mode of transport, but it is extremely limited in terms of spatial and temporal mobility. Furthermore, walking and cycling can be influenced by hectic factors such as the weather, which can influence the decision of the passenger to use mobility devices [1]. The car is the most accurate personal transport vehicle to meet travel needs, but it has several negative impacts on travel culture and it is expensive and has a high specific environmental impact [2]. Classic public passenger transport modes, such as buses and trains, offer a satisfactory service in terms of time coverage at a generally low fare, but are very limited in terms of spatial coverage.
Nowadays, it is fashionable to look at personal mobility equipment in terms of whether it is owned or hired by the passenger. This is the approach of MaaS (Mobility as a Service) [3], which is the provision of a mobility service by autonomous vehicles, including the use of personal transport available to members of the community, which is in effect a rental system. A sustainability approach can be seen between the two theories, shifting in the direction of minimising private ownership. All the while, the car's using/parking ratio of off-road transport should be higher.
Demand Responsive Transportation (DRT) and Flexible Transportation Systems (FTS) are the same concept in several research studies. Flexible transport systems include all passenger transport services available to the community that differ in their spatial and temporal demands from a service with a fixed stop and a fixed route [4]. In this context, demand responsive transport systems are a subset of flexible transport systems. A more detailed overview is therefore recommended and will be analysed in more detail in the following chapters.

2. Modes of mobility
There are micro- and macro-level mobilities. The major variants of these have been mostly described in the previous chapters. It is worth examining the spatial/temporal flexibility of each mode of travel as a function of capital requirements. The Figure 1 illustrates this. The cost of transport modes is very different for each type of travel options. The usage of private cars is a high-cost form of travel to meet mobility needs but can perform mobility needs at a high level. However, it is limited due to several factors: (i) congested roads [5], (ii) limited parking spaces [6], (iii) poor air quality [7], (iv) noise pollution [8].
Environment-friendly mobility modes, such as walking and cycling, require minimal investment and have a positive impact on health, but depend on spatial, temporal and weather parameters.

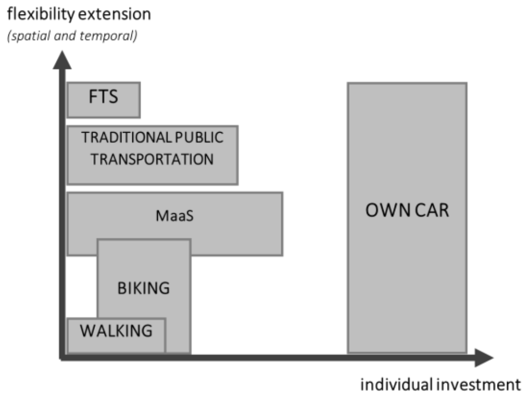


Figure 1: Flexibility opportunities (spatial and temporal) as a function of individual investment

Mobility as a service has made available the possibility for individual users to use private transport that is not economically viable and/or not available to them. Examples of such services are carsharing, carpooling, bike-sharing, etc. The investment cost is not borne by the user, so use is possible at a rental fee, but no other cost is involved. The mobility in space and time for these solutions can be local, interurban or even long-distance. The deployment of such systems has spread and is operating competitively in places with high average population densities. The disadvantage of MaaS systems is therefore their accessibility in countryside.
Flexible transportation systems can be organised and designed to manage individual and collective travel needs. Flexible transport systems can thus meet a wide range of mobility needs at low investment costs. In the remainder of the paper, flexible transport systems will be examined as a result of the literature review of FTS and DRT systems, and thus their characterisation will be examined in the subsequent chapters.

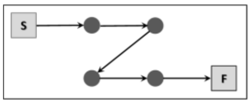
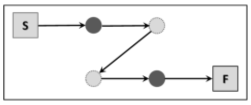
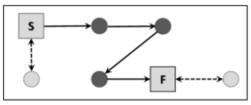
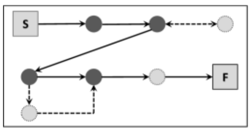
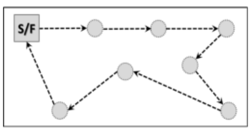
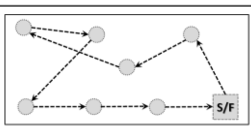
3. Flexible Transportation Systems

Several schematic network figures have summarized in the previous literature research on demand-responsive (DRT) and flexible transport systems (FTS). Detailed source and literature research can be found in [9]. The result of that research is 6 DRT and FTS design samples and several flexible elements have been identified according to the transport network design.
The 6 DRT and FTS design samples can see in Table 1. (I-II-III-IV-V-VI. types) where a transition between the 0-1 elasticity measure can be observed. The Roman numerals also correspond to the numerals in the first column of Table 1., where further analysis requires further narrowing down the network elements for new grouping purposes (last column). For the theoretical and practical studies, the 6 schematic network diagrams had to be further narrowed down by applying a method and approach. In the following chapters, the flexible categories A-B-C are presented in detail. Furthermore, the flexible parameters relevant for public transportation planning are identified.

Some major research questions (FTS):

- Which areas can each type of FTS be used?
- What operational parameters can be used to qualify a given type of FTS service?
- What is the possible size of the service area for different types of FTS?
- When is an FTS journey optimal?
- When is an FTS journey optimal?
- etc.

Table 1: Literature and new network categories

Network from previous literature review [9]: Name (network with …)			New FTS category
I.		fixed route and stops	A-FTS
II.		fixed route with some optional stop(s)	
III.		route extension from start or ending stop(s)	B-FTS
IV.		extension with back-and-fort and by-pass	
V.		fixed start/ending points and route/tour is flexible	C-FTS
VI.		fully demand responsive route	

3.1. A-FTS category

The A category flexible transport system the A-FTS, is not very different from classical public transportation modes, as its network elements include a fixed route and fixed and/or optional stops. This category can be extended to public transport by rail in addition to passenger transport by bus and coach. The logic is that the vehicle stops at the stops indicated in the schedule only if there is a need to alight and/or board. With this option, a fixed route service can be provided to meet actual travel demand.

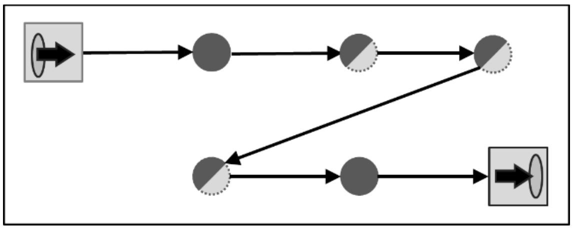


Figure 2: Network of A-FTS

In terms of flexibility, it provides minimal and only time flexibility to the transport system. Currently, the bus just stops at bus stop where if there any demand but is rarely used in rail transport. However, it is wasteful of energy and time for a vehicle to stop at a stop or station where there are no passengers alighting and/or boarding. In this case, it is not only time that can be saved in the case of a journey, as energy can also be saved by skipping unnecessary deceleration and acceleration phases. Moreover, in a similar application, a reduction in brake wear between two services can be demonstrated. At the same time, this flexibility has positive implications for operations. For passengers travelling between origin and destination, a long-distance train can arrive at their destination more than 10 minutes earlier by continuing without stopping at each stop.

Even for the use of A-FTS, it is essential to use a digitalisation system to register take-on and take-off requests and to predict the expected arrival/departure time window depending on the existing demand. The system would provide a time window moving within a pre-defined framework as information. The maximum travel time between the two endpoints would be the travel time calculated by stopping at the take-on and take-off points. The minimum travel time is the travel time between the two endpoints without stopping.

$$T_{min} \leq T_{real} \leq T_{max} \quad (1)$$

Equation 1 means the time window for the whole journey, but this time window may change at the time of departure of the journey and during real-time data processing. The travel time should not fall outside the maximum and minimum journey times only in case of an accident or an emergency.

In the case of bus transportation in Hungary, it is well known that this system works on the logic that the vehicle stops only when needed. However, due to the time overrun caused by missed stops, the departure time indicated in the timetable at later stops can lead to misleading and unsuccessful journeys. A continuous information system is therefore an essential part of an efficient service.

It can be seen that this category only provides time flexibility by using existing interconnected infrastructures. It may have a viable application in macro-regional road and rail passenger transport, such as trams or suburban railways, as well as in regional and long-distance transport.

3.2. B-FTS category

The B category flexible transport system the B-FTS, is a vision that can complement the classic public bus transport network with flexible elements for example extension with back-and-fort and by-pass, D2D etc.

The B-FTS contains significantly different types of flexible network elements compared to the previous category, which can affect the flexibility of the system. This network has a fixed backbone on the route, which is almost always traversed by the transport vehicle. The conditional mode of the previous sentence will be explained in the next paragraph (iii). The stops on the backbone can be fixed or optional. In addition, there are optional stops which are not located on the backbone. They will only be served by the transport vehicle if the need exists. Where stops outside the backbone are accessed, they may be approached by a predefined route, which is an optional route.

The different optional routes can be: (i) a detour from the starting or endpoint, which is considered as a shortcut route without special claim; (ii) branches off the ridge, which branch off at the same point on the backbone and return at the same point; (iii) a by-pass where the departure and return from the backbone point do not coincide; (iv) door-to-door passenger services from the backbone by means of a detour, which are not a predefined service function but are in any case optional.

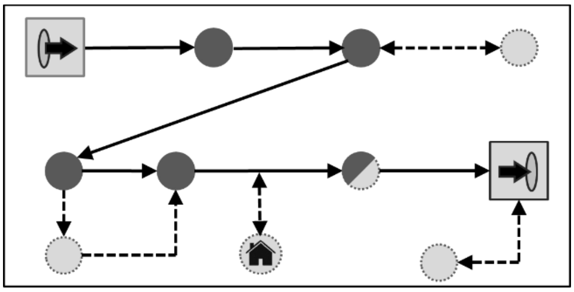


Figure 3: Network of B-FTS

The flexible transport category B-FTS cannot be used for fixed-route passenger transport. However, it is widely useable in public bus transportation. A flexible element can be served by high-capacity buses and minibus if the infrastructure for passengers to and from the bus and minibus is adapted to the conditions of classical bus transportation. However, smaller capacity vehicles can also be used, as it is not necessary to have a higher capacity in off-peak periods, which is a fraction of the nominal traffic. A smaller vehicle can efficiently carry out the door-to-door service during off-peak periods, unlike a large capacity vehicle.

Depending on the previous ideas, the B-FTS category can be divided into three transport management tasks. The first is where stops are defined to serve an area and are served by a route schedule that includes optional routes, other than fixed ones, according to various parameters. If there is no demand for travel at the points covered by the optional routes, passenger transport is shorter in terms of route and faster in terms of journey time for the whole journey. The scope may also include interurban services, for example in small rural areas or on suburban bus routes. The concept as described can operate throughout the day. The second case is when door-to-door passenger transport needs can be met on a transport network with fixed and optional elements. This level offers greater potential for category B-FTS, which can meet maximum travel mobility needs. Again, of course, a travel demand processing/information system is essential for efficient operation. D2D travel needs cannot be fully served by such a flexible public transport system. In most cases, these needs can be served more efficiently in the early morning or evening hours, as extra by-pass trips would lead to a large increase in travel time and distance. It is known that the less demand a mode must satisfy, the more flexible it can operate, and therefore the better the D2D demand can be met during off-peak periods. Individual needs, such as door-to-door passenger transport, may be available to passengers at an extra cost. This is possible on urban and suburban lines, mostly during off-peak periods.

3.3. C-FTS category

The C category flexible transport system the C-FTS, in which the route is adapted to the full travel demand. Individual needs determine the pick-up or drop-off points involved in a route.

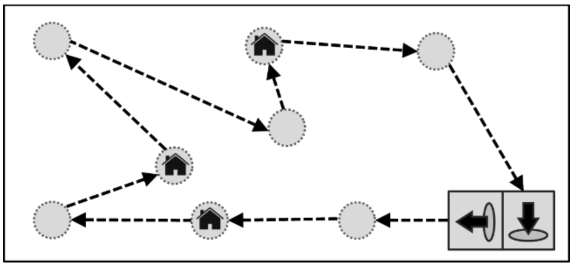


Figure 4: Network of C-FTS

The classic case is where the system origin and destination are at the same location, through which it provides a distribution and/or collection to serve, for example, an intermodal hub. However, this category does not only correspond to a flexible roundtrip. Self-organising service structures can be included in this category. Taxi, airport transfer belongs to this level of system when the travel demand draws the route as in a pulling system. The case of a taxi, which is completely unbounded from a network point of view, so that it can satisfy D2D demands efficiently, since the system does not contain fixed network elements. This option operates at a relatively expensive fare, so it should also aim to design for the C-FTS category based on public transport criteria.
Providing optimal operating conditions and keeping fares at an economical level can make this level of service available to everyone.
In the introduction, the relationship between the concepts of FTS and DRT was explained. For this category, it is shown that a demand responsive transportation systems structure is also available for self-organised services and round trips. A 100% transport flexibility for individual mobility needs cannot really be achieved by public transport. Conditions for planning and optimisation need to be set up and considered.

4. Flexibility definition and parameters

As a result of the characterisation of the basic FTS categories, it can be concluded that these A-FTS, B-FTS and C-FTS categories are associated with several mobility problems. From various macro-regional transport systems to passenger transport services serving local mobility needs, applicable proposals are included in the category descriptions presented in Chapter 3.
About flexible transport systems, there are several different parameters to be considered between design and practical implementation.

4.1. A-FTS Flexibility parameters

In order to quantify the flexibility that can be defined in A-FTS, it is necessary to collect the parameters that influence the service flexibility of each category.
One of the measurable parameters of service flexibility is the rate of the number of fixed stops (n_f) and the number of optional stops (n_o).

$$e_{fo} = \frac{n_f}{n_o} \qquad (2)$$

Equation 2 is a ratio that can provide a basis for comparison of two A-FTS options. However, this ratio is not sufficient for a set of rating indicators, but additional specific parameters and ratios are needed to compare operational characteristics.
Such an indicator could be the difference of maximum and minimum destination and arrival times. This difference is a T_{win}^{stop}. This parameter cannot be longer than the maximum waiting time window ($T_{max}^{wait}; T_{win}^{max}$).

$$T_{win}^{stop} = t_{arrive}^{max} - t_{dep}^{min} \leq T_{max}^{wait} = T_{win}^{max} \qquad (3)$$

In the case where several regional nodes have fixed departure times in their time windows, the route has to be fragmented several travel sections for the purpose of calculating flexibility. The parameters described above are then examined for each section and a comparable value is obtained by averaging the results.
The indicators calculated from the number of passengers carried are not relevant for the A-FTS category, as they can be used in transport areas (rail, bus) where the number of passengers is high.

However, the rate of passengers alighting (N_{alig}^{pass}) and/or boarding (N_{board}^{pass}) can be used to classify fixed and optional types of stops.

$$e_{qual}^{stop} = \frac{N_{board}^{pass}}{N_{alig}^{pass}} \quad \begin{cases} \text{if } e_{qual} < \vartheta \rightarrow option. \\ \text{if } e_{qual} \geq \vartheta \rightarrow fix. \end{cases} \quad (4)$$

If the value of Equation 3 is greater than or equal to the value of ϑ, it should be treated as a fixed stop in the A-FTS design, and if it is less, it should be treated as an optional stop.
These data can be used to identify which sections and destinations are frequented and subject to high congestion.

4.2. B-FTS Flexibility parameters

When analysing B-FTS, the backbone and the flexible elements should be considered separately. The analysis of the backbone is similar to that for A-FTS, with the difference that the travel times will be influenced by the types of flexible elements in the system (sub-chapter 3.2) and their quantities. Each type of flexible element should be considered separately, as each element in the system may have a different impact on the variation of travel time and distance. Each elastic element can be classified at network level by the time, distance and number of optional stops affected by the by-pass trip.
On the practical side, the number of passengers carried will be essential for qualification. Need to select those types separately. It is possible for a passenger to board at a flexible stop on the backbone and travel to the destination, or to travel to a stop other than the backbone. Therefore, all the possible options need to be considered and the network elements can be classified as a result. For this flexible transport mode, not only the share of flexible elements is an important influencing parameter, but also the movements between fixed and optional network elements and the travel demand linking them. The application of B-FTS can be considered and applied effectively already for interurban and local trips. The size and capacity of a transport vehicle can have a significant impact on the quality of a flexible transport service, such as D2D passenger demand. Which can be effectively complemented by off-peak and low-capacity vehicles for passenger transport.

4.3. C-FTS Flexibility parameters

The C-FTS can no longer be characterised by the number of flexible elements. The mandatory network element may be the origin and the destination point, which are always located at the same physical location. This is a round trip-based concept, which can be studied using several logistical studies [10] [11] on round trip planning and service. In the design, it is necessary to define constraints on the size of the area served. A flexible transport system cannot cater for many trips on a single route/vehicle at the same time, as this would compromise the quality of the passenger service. These are specific parameters and have a major impact on the fare structure, the digital system for processing the demand and the service area. A similar problem is the separation of two types of activity for round services: collection and distribution. Time as an influencing parameter plays a limiting role in determining the volume of travel demand that can be served by a single service. On the other hand, for distribution and distribution services, the service quality indicator is the ratio between the number of trips carried and the number of trips collected. Which is not the same at different times of the day.

5. Further reaserch directions definition

As a result of processing the literature on the network elements involved in flexible transport systems, it was possible to outline structures that can be examined at a higher level and to establish them from a technical point of view. A large number of further research milestones and exploitations can be identified: (i) more detailed elaboration of the A-B-C-FTS categories from a research point of view; (ii) identification of the conditions for optimal planning of routes; (iii) development of a time-of-day dependent pairing strategy for a given transport system; (iv) development of decision-making relations for efficient organisation in public transport planning.

6. Conclusion

Mobility is an essential part of everyday life, which takes up a lot of time. Therefore, the study of travel chains is an important area of research and a key issue is to investigate the flexibility of mobility solutions. The efficiency of travel chains is strongly influenced using flexible and semi-flexible systems. Another advantage is that the use of flexible transport systems can identify latent mobility needs that are currently unknown.
To this end, this paper presents the parameters that influence the resilience of the established FTS categories.

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