Article deals with the selection of suitable urban tolling system technology. In the paper, a lot of aspects, which have an influence on selection of particular technology in city conditions, were considered. For example: charging policy, user aspects, technical aspects and economic aspects. Although the analysis was not performed within specific conditions of a particular city, it was found out that in spite of general analysis, it is possible to form relevant and rather clear conclusions.

**Keywords:** Urban tolling system, tolling technology, on-board unit.

1. **Introduction**

Selection of technological solution is an important phase when deploying urban tolling system[1 - 4]. It is important to realise that selection of technology is not the first step of system deployment. In principle it applies that technology should not determine other aspects of objective system [5 - 7]. The reverse should be true. It means that technological solution should be a result of complex evaluation of many technical and non-technical requirements, objective and subjective requirements, aspects, parameters and criteria (often political ones, even at municipal level) [8 - 10].

Selection of technology itself should be preceded by the following phases (Table 1):
- identification of transport problems within city and its neighbourhood,
- selection of measures for solution of transport problems not only in context of city itself but within the whole agglomeration; one of these measures may be transport charging (maybe together with restriction) and then targets of charging (deployment of toll) have to be defined - the most frequent ones like traffic and environmental, or economic targets,
- defining pricing policy - especially setting the kind and form of charging, period of validity and so on,
- selection of organisational structure - mainly relates to selection of operation of urban tolling system (for example city itself, city organisation, commercial subject, PPP) and therefore indirectly with financial assurance of the project.

The selection of technological solution (in connection with the previous phases) is closely related to practical operation of system - with procedures and processes on the level of front office and back office levels as well.

| Order | Phase                                      |
|-------|--------------------------------------------|
| 1     | Identification of transport problems       |
| 2     | Selection of measures for solution of transport problems |
|       | Defining the objectives of charging        |
| 3     | Defining the pricing policy                |
| 4     | Selection of organisational structure      |
| 5     | Selection of technology                    |
| 6     | Elaboration of processes                   |
| 7     | System deployment                          |
|       | Pilot (testing) operation                  |
|       | Personnel training                         |
|       | Marketing – info campaign                  |
| 8     | Regular system operation                   |

From the above-mentioned steps, it is clear that several mentioned phases are interconnected.

2. **Aspects affecting technology selection**

Generally possible technological solutions for urban tolling system can be identified as follows [11]:
- non-technical solution (kiosks and terminals similar to ones for payment of parking fee),
- system with barriers,
2.1 Aspects of charging policy and user aspects

Among aspects determining single framework of charging we can include:
- object of charging,
- principle of charging,
- range of charging,
- charged unit,
- mode of individual types of participants,
while these aspects are hardly known and we can possibly presume that even in case of political decision (though at municipal level) on deployment of urban tolling system, these aspects will be an object of serious discussions and will probably underlie relatively frequent and considerable changes.

In terms of user, there are especially important aspects directly connected with one’s duties and restrictions. From this point of view an essential aspect is:
- suitability/simplicity with respect to participant who primary evaluates requirements on the user from point of view of processes and their complexity and possible demands on operation of technical devices (OBU, user terminals, ...),
while secondly this aspect includes even other aspects with relevant effect on participant.

From aspects of charging policy it is, for example:
- mode of particular types of users,
or from technical aspects the important ones are:
- user identification (especially obligatory OBU),
- payment means,
- affecting of traffic flow (especially if it is non-free flow system).

The question is which solution is the most suitable for specific conditions of a particular city.

The aspects (Table 2) [11] which affect selection of technological solution for urban tolling system can be divided into following groups:
- aspects of charging policy,
- user aspects,
- technological aspects,
- economical aspects.

It is not possible to describe and evaluate individual aspects while details of intention for deployment of tolling system are not known (e.g. in Bratislava conditions). Although the following analysis is in principle general, it is possible to deduce such outputs which are relevant for small or middle-sized cities.

| Aspect | Description |
|--------|-------------|
| 1      | Object of charging |
| 2      | Principle of charging |
| 3      | Range of charging |
| 4      | Charged unit |
| 5      | Number of charged units per time unit |
| 6      | User identification |
| 7      | Toll payment means |
| 8      | Mode of individual types of participants |
| 9      | Number of individual types of participants |
| 10     | Enforcement intensity |
| 11     | Toll system deployment costs |
| 12     | Toll system operational costs |
| 13     | Effectiveness of toll collection |
| 14     | Toll system deployment time |
| 15     | Flexibility of tolling system |
| 16     | Initial costs for participant |
| 17     | Suitability/simplicity in term of participant |
| 18     | Compatibility/interoperability |
| 19     | Practical aspect - technology maturity, experience with deployment and operation |
| 20     | Perspective |
| 21     | Support of added value services |
| 22     | Affecting of traffic flow |

The graph in Fig. 1 shows how individual solutions cope within four mentioned crucial elements.

From this graph, it is clear that ANPR is a suitable candidate for applied technology which meets the above mentioned elements (without OBU, detection of zone boundary and area, free flow).

In case that solution based on OBU is acceptable, solutions based on DSRC or GNSS/CN are also suitable (GNSS/CN technology maturity has to be proven in the real urban environment).

Solution based on odometer is specific, it is not verified in conditions of the city – only Swiss national tolling system is based on odometer; in this case interconnection of OBU with vehicle is
The implementation of a particular solution assumes processing aspects which can affect the effectiveness of toll collection, including:

- Time for deployment of tolling system, largely reflects the need for toll infrastructure establishment (so-called technological part) within the urban environment and related time requirements (including related bureaucracy).
- Flexibility of tolling system, it reflects the ability of the solution to adapt to variable conditions (mainly charging policy) in adequate time and with adequate costs.
- Compatibility/interoperability, it reflects if the solution is compatible or interoperable with other tolling systems. In conditions of Slovakia, only the national tolling system can be considered. However, in the future, there may be other urban tolling systems or city parking systems, even cross-border interoperability can be admitted, e.g., fictitiously Bratislava-Vienna.
- Technology maturity, experience, it characterizes experience with applied technology at least in the European context including the estimation of possible future mid-term development.
- Perspective, it evaluates technology in the framework of its expected deployment in defined time (in the framework of procurement procedure, such period is usually defined for 10-15 years) and its possible further use.
- Support of value-added services, it reflects the possibilities of technology to provide a wide variety of value-added services (using technical means or obtained data).

### Technological and Economic Aspects

Technological and economic aspects affecting the selection of technological solutions are:

- Identification of participant - defines the exactness of user identification, reliability of user determination or need to perform additional steps on this determination.
- Toll payment means - it is an aspect whether the solution enables/supports the broadest ways of toll payment including certain time freedom.
- Intensity of enforcement - it is being evaluated if the particular solution enables to reach required intensity of enforcement by adequate resources, or if some processes following from the basis of solution have essential effect on enforceability/effectiveness of enforcement.
- Costs on deployment of toll system reflect qualitative conception on investment demands.
- Operational costs - it reflects qualitative conception on operational costs including expected future technology renewal.
- Effectiveness of toll collection - typical standard for urban tolling systems is approximately within 90%-95% and in this case, accessibility of this standard is evaluated.

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**Fig. 1 Reviewing technological solutions in terms of essential aspects of charging policy and user aspects**
the experts further evaluated individual aspects according to the fact whether a particular solution fulfils given criteria in a standard way, if it is for solution fundamental or relevant drawback or advantage. Average weights and assessments of the individual aspects are shown in Table 3 (more accurate mentioned values are median ones).

With respect to meeting the requirements imposed by technical and economic aspects within the meaning of the following table, the most suitable solutions are offered by ANPR (as the only one without negative evaluation of any aspect) and GNSS/CN with similar evaluation. Following in the order is DSRC solution. As absolutely inappropriate solutions appear non-technical solutions and solutions based on the barriers.

3. Characteristics of technological solutions

Moreover, each of the mentioned options of urban tolling system is characterised by essential properties which can play an important role when selecting technological solution. In a nutshell, these features for all six solutions are mentioned in Table 4.

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### Table 3: Weight assigned to particular technical and economic aspects and their evaluation

| Aspect                                      | Weight [%] | Non-technical | ANPR | DRSC | GNSS/CN | Odometer |
|---------------------------------------------|------------|---------------|------|------|---------|----------|
| User identification                         | 9          | -3            | 2    | 2    | 3       | 3        |
| Toll payment means                          | 8          | -2            | 1    | 3    | 3       | 3        |
| Enforcement intensity                      | 10         | -2            | 0    | 3    | 3       | 3        |
| Costs on deployment of tolling system       | 9          | 3             | 2    | 1    | -2      | -1       |
| Tolling system operational costs            | 11         | 3             | 2    | 0    | -1      | -2       |
| Effectiveness of toll collecting            | 10         | -3            | 2    | 1    | 2       | 2        |
| Time for deployment of tolling system       | 4          | 3             | 2    | 1    | -1      | 0        |
| Flexibility of tolling system               | 5          | -2            | 1    | 0    | -1      | 3        |
| Compatibility/interoperability              | 3          | -3            | -3   | 0    | 1       | 2        |
| Technology maturity, experience             | 7          | -2            | -1   | 3    | 2       | 0        |
| Perspective                                 | 5          | -3            | -3   | 2    | 1       | 2        |
| Support of value added services             | 4          | -2            | -2   | 1    | 0       | 3        |
| Number of users, number of transactions per defined time period | 5          | 0             | -3   | 2    | 2       | 3        |
| Affecting the traffic flow                  | 10         | -1            | -3   | 3    | 3       | 3        |
| Weighted average                            | -0.87      | 0.15          | 1.7  | 1.25 | 1.58    | 0.96     |
| Overall ranking                             | 6          | 5             | 1    | 3    | 2       | 4        |

Legend:

-3 critical drawback
-2 relevant drawback
-1 drawback
0 neutral rating

- number of users, number of transactions per defined time period – it characterises system dimensioning, possibilities or restrictions of system to completely serve certain absolute number of participants or in defined time period (for example in traffic jam), including further extension,

- affecting the traffic flow – it reflects to what extent tolling system affects fluency of traffic flow (need to slow down vehicle, stop vehicle, need to use particular entrance/transit and so on); ideal solution does not affect traffic flow (so called free flow solution).

From the above mentioned, it is clear that if aspects of charging policy are not defined specifically, it is not possible to assess individual aspects for particular solutions either in qualitative or in quantitative way.

From this reason, the relatively complex technical aspects affecting the selection of technological solution of urban tolling system qualitatively are assessed by the following procedure [13]:

1. method of ‘survey among experts’ was used for qualitative assessment of individual aspects.
2. addressed experts assigned importance to individual aspects which characterises the seriousness of given aspect in complete interpretation.

3. the experts further evaluated individual aspects according to the fact whether a particular solution fulfils given criteria in a standard way, if it is for solution fundamental or relevant drawback or advantage.
Last solution which is appropriate, is the satellite-based solution whose basic disadvantage is its practical non-verification (except for realised pilot projects). Such solution still remains challenging and it can be expected that in close future such systems will not arise. They will probably get chance in medium-term horizon with EGNSS (Galileo) use and development of telematics within vehicles.

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