BLAŽ BOGOVIĆ, D.Sc.
Fakultet prometnih znanosti,
Vukelićeva 4, 10000 Zagreb, Republika Hrvatska
BOJAN KOVAČIĆ, B.Eng.
Srednjaci 23, 10000 Zagreb, Republika Hrvatska
VINKO JENIĆ, M.Sc.,
Fakultet prometnih znanosti,
Vukelićeva 4, 10000 Zagreb, Republika Hrvatska
e-mail: vinko.jenic@fpz.hr

Science in Traffic
Preliminary Communication
U. D. C.: 656.2:725.31.008
Accepted: Jun. 19, 02
Approved: Jan. 23, 03

COEFFICIENT OF RAILWAY STATION ACCESSIBILITY

ABSTRACT

In order to provide highest quality services to its users, railways need to pay attention not only to the standard qualitative and quantitative indicators, but also to other, seemingly less relevant ones. One of these may be the accessibility coefficient of a certain railway station. The paper analyses the formal mathematical model of its definition, and proposes a possible classification of accessibility. The considerations also expand briefly to the accessibility regarding gravitational zone of the respective railway station, mentioning also some problems related to the accessibility and the guidelines of their solutions.

KEY WORDS

coefficient, accessibility, railway station, organisation, technology

1. INTRODUCTION

In studying the organisation and technology of railway passenger transport attention is usually paid to the quantitative and qualitative indicators. The former include e.g. the number of transported passengers, passenger kilometres, wheelset kilometres of the passenger cars, etc. whereas the latter include e.g. passenger composition turnaround, average commercial, i.e. technical speed, etc. The objective of the analysis of relations of these values is primarily to maximally satisfy the requirements of passengers - users at minimal costs, to establish an optimal organisation, and to be competitive with other (road, air) carriers. In today's market competition, this is far from simple, since apart from the increased number of passenger cars, and the quality of transport provided by competitive carriers, there are also problems which occur regarding supply, such as obsolete rolling stock, obsolete infrastructure, etc., which cannot be optimally solved due to the lack of financial means. Thus, some of traditional advantages of railway, in particular safety and transport speed are slowly disappearing in the Republic of Croatia. However, the main advantages - possibility of mass transport and environmental protection still do remain. Nor should the present social and economic situation be neglected, because of which even commercial ventures (benefits, annual and monthly tickets, etc.) become a significant advantage. If one wants to survive and compete well on the market, almost nothing may be neglected, not even the seemingly less important things such as the look of the railway stations and stops, and the design of approach roads, cleanness of the trains, etc. This paper will analyse one such case: the accessibility of railway station / stop which may be taken as a criterion or measure of the railway technological advantage, that is, the level of its service. The considerations mainly include the passenger transport, although even the accessibility in cargo transport can be considered in principle. General criteria for ranking of railway station accessibility will be given, as well as a proposition to increase accessibility of those railway stations that are poorly ranked according to these criteria.

2. DEFINITION OF THE COEFFICIENT OF ACCESSIBILITY

First, an example will be used to briefly and intuitively consider what the term of accessibility of a facility means.

Example: The distance from place A to place B in which the railway station is located is 15 km. To travel this distance by car a person would need 20 minutes, and to walk this distance it would take 3 hours[1] (see Figure 1). If the person carried a certain load (e.g. a

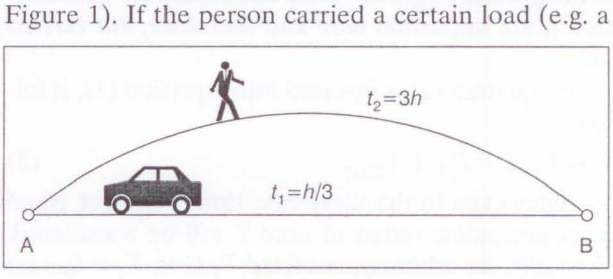

Figure 1

bag containing things of a total mass of m 10kg), the 3-hour walk with this load would represent substantial physical effort. Therefore, it may be claimed that to this person, this particular railway station is *accessible* by car, but *inaccessible* on foot.

Generally, the accessibility of a facility can be understood as a kind of a *measure of time* needed to reach the facility from a certain *origin*[2]. Therefore, the tendency is to express the accessibility precisely as a function of that time[3]. This function has to reflect inversely proportional values of accessibility and time, i.e. the shorter the time, the greater the accessibility, and vice versa. It should be mentioned immediately that due to inversely proportional values, this function cannot be linear, but the tendency is to make it (at least regarding form) as simple as possible.

For general consideration of the whole, we start with fixing an arbitrary origin, and taking for the destination the nearest railway station to this origin. It is intuitively considered acceptable to assume that the distance between the origin and the destination can be travelled on foot, by certain means of public transport (bus, tram[4]) or a combination of these. Consequently, the time T from starting from the origin to departure of the train from the railway station[5] can be (analytically) divided into time T_{arr} necessary to arrive at the destination (i.e. railway station) and time T_{wait} of waiting (at the railway station) until the departure of the train. This results in the equation:

$$T = T_{\text{arr}} + T_{\text{wait}}. \tag{1}$$

Time T_{arr} is a variable value and it will be considered in more detail further in the text. It should be emphasised that time T_{wait} is a relatively variable value depending on the frequency of trains. It would prove ideal if T_{wait} were a fixed value, but this would require adjusting of the train schedule, possible introduction of additional compositions, etc. which is not always feasible.

Time T_{arr} from equation (1) can be analytically divided into time T_{foot} spent on walking and time T_{pt} of public transport ride. Therefore, the following equation holds:

$$T_{\text{arr}} = T_{\text{foot}} + T_{\text{pt}}. \tag{2}$$

It should be mentioned that also the time T_{pt} can be divided if several public transport means are used in the process (e.g. bus – tram combination). This division is not important here and therefore, not carried out.

If equation (2) is inserted into equation (1), it follows:

$$T = T_{\text{foot}} + T_{\text{pt}} + T_{\text{wait}}. \tag{3}$$

Since even in the ideal case time T cannot equal zero, *acceptable values* of time T will be considered. Formally, for arbitrary, but fixed $T_1 \in \mathbf{R}$, $T_1 > 0$, *a set of acceptable values* V is defined as a semi-open interval $V := <0, T_1]$. Thus, if the total time from the beginning to the end of the process falls within the interval V, it may be considered that the process developed at a satisfactory speed, and that no additional improvements are necessary. The maximum element T_1 of this interval can be called *maximum acceptable time*.

The question is: Which value should be selected for T_1? Generally, $T_1 = 1$ hour (= 60 minutes) may be taken. However, no concrete values for T_1 will be taken here, but rather the generally maximal acceptable time T_{max}, and accordingly the interval $V = <0, T_{max}]$ will be taken for the set of acceptable values.

Using equation (3) and the previous considerations the following function can be defined:

Definition 1. Function δ: $<0, +\infty>^3 \rightarrow <0, +\infty>$ is defined with

$$\delta(T_{\text{foot}}, T_{\text{pt}}, T_{\text{wait}}) := T_{max} / T, \tag{4}$$

where T is the value determined by relation (3), is called the *function of accessibility*.

The function of accessibility δ is theoretically a function of three variables and can have an infinite number of values. However, this is not true in practice since this area of the function definition is in fact a Cartesian product[6] of three finite sets. The whole process, namely, is performed in real time, i.e. it takes a finite length of time. Also, all the three variables that occur in (4) are practically integers (integer number of minutes) since seconds, tenths of seconds etc. may be neglected. Therefore, each of the sets forming the Cartesian product is finite, and so is their product – the domain of the function of accessibility δ - a finite set. Direct consequence of this fact is the finiteness of the set which contains exactly all the values of function[7]. This set is called the *function image*[8] δ.

It is known in mathematics that every finite subset of a set of real numbers $\mathbf{R}$ has its minimal and maximal element (i.e. minimum and maximum) regarding the standard device in the set $\mathbf{R}$ of real numbers. Since the image of function δ is a finite subset of $\mathbf{R}$, the following definition has sense:

Definition 2. Maximum δ_{max} of function δ determined by relation (4) is called *coefficient of accessibility*.

Further in the text the coefficient of accessibility is denoted with δ (like the function defined with (4)).

The question is immediately raised here, why precisely this maximum was chosen and whether such choice is completely acceptable. The maximum was chosen, first of all, in order to consider the best possible case. If even the best possible case (according to criteria later analysed) is not good enough, then it is obvious that all the other cases are even worse. In other sciences as well (physics, chemistry, etc.) ideal models are considered first, and this approach has been applied here as well.

What are the properties of the coefficient δ? From (4) it may be seen that for $T \in V$ the following is true: δ

≥ 1, whereas for all the other T the following holds $\delta \in < 0, 1>$. This may be interpreted also in this way: [the smaller the coefficient δ, the less accessible the destination, and the greater the coefficient δ, the more accessible the destination. For simplicity, $\delta \in < 0, 1]$, will be taken, i.e. that the maximum possible value of the coefficient of accessibility equals 1[9].

Closely related to the coefficient of accessibility is the *coefficient of inaccessibility* η defined by relation

$$\eta = 1 - \delta. \qquad (5)$$

It is obvious that $\eta \in [0, 1>$, and it may be stated that the destination is less accessible the greater the coefficient η, i.e. more accessible the smaller the coefficient η.

Subject to discussion is the issue regarding which values of the coefficient of (in)accessibility are "good" (i.e. do not require improvements in organising transport), and which are "poor" (i.e. require searching for better solutions). One of the possible criteria is the following: accessibility can be considered poor if $\delta \leq 1/2$ (the process in that case takes at least double the maximally acceptable time), medium if $1/2 < \delta \leq 2/3$, good if $2/3 < \delta \leq 3/4$, very good if $3/4 < \delta < 1$ and excellent if $\delta = 1$[10].

It is also interesting to observe the difference $T - T_{max}$ in order to see the extent of deviation from the maximally acceptable time, i.e. the ratio p of the mentioned difference and time T_{max} (i.e. how many times the process is longer than would be acceptable) Using (4) and (5) the following equation is obtained:

$$p = \frac{T - T_{\max}}{T_{\max}} = \frac{1 - \delta}{\delta} = \frac{\eta}{\delta} \qquad (6)$$

The ideal case is when $p = 0$ and this occurs when $T \in V$. However, for the majority of origins this is not only greater than zero, but even greater than 1. This case occurs when the accessibility of railway stations is poor (according to the above criteria). If $p \geq 2$, the railway station can be considered practically inaccessible (the process takes at least three times longer than acceptable), and in practice, this represents a serious problem in organising traffic. The method for its solution will be generally studied in the next section.

Thus, theoretical starting points for further considerations regarding coefficient of accessibility have been given. The next section will briefly mention some problems related to accessibility, for the solution of which the coefficients of accessibility may be used.

3. SOME PROBLEMS RELATED TO ACCESSIBILITY

Regarding its purpose every railway station is oriented to one place only (*locus standi*). However, if one considers the places of residence of passengers who travel from this railway station because of necessity, a wider set of places is obtained. More precisely, we may speak of places that *gravitate*[11] to a certain railway station. In traffic technology, the term of gravitation zone (e.g. suburban traffic) has been known for a long time, and it is divided into individual zones in order to provide optimal organisation of train traffic, i.e. passenger transport related to daily migration of the population. Thus, one may speak here about a *gravitation zone* of a single railway station, understanding here a *set* of all those *origins* nearest to the given railway station, and consider the accessibility of the railway station regarding each of the origins from its gravitation zone.

Obviously, it is very unpractical to calculate the accessibility of a railway station regarding every potential origin in its gravitation zone. The coefficients of accessibility of a certain railway station regarding two adjacent houses in the same place are practically the same. Therefore, the gravitation zone may be divided into more sub-zones so that the railway station has practically the equal[12] coefficients of accessibility regarding all the potential origins within one zone. In this way the gravitation zone may be divided according to the coefficient of accessibility and it may be seen compared to which zones the railway station does have the same coefficient of accessibility, compared to which zones it has poor accessibility, etc. An example of one such division is given in Figure 2.

Special problem is the *periodical accessibility* related to non-uniform passenger flows in public transport during the day. Thus, e.g. it may occur that one

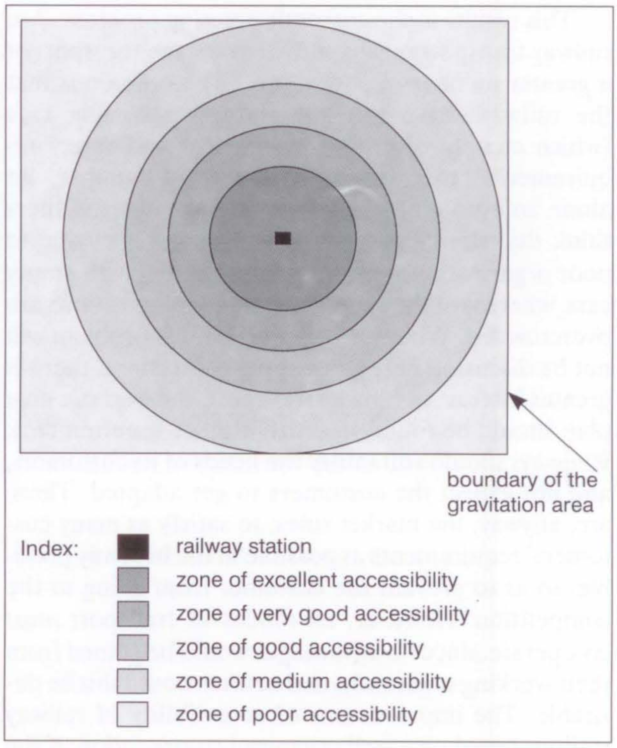

Figure 2

can reach place B where the railway station is located, from place A by public transport only during the morning hours, which automatically results in the issue of accessibility of that railway station regarding place A during the rest of the day. In other words, according to the criteria mentioned in the previous section, a railway station (with regard to a set of origins or even whole zones) at one time of the day can feature very good accessibility, and at another time of day poor accessibility. This results in the question: How to improve the accessibility of a railway station regarding a certain zone?

The main role in solving this problem must be provided in the commercial policy of the railways. First, a survey should be carried out among the population of each single zone about the interest in using the railway transport with special focus on the frequency of travelling and the time during the day (week, month, even a year) foreseen for this journey. If there is interest to travel during the time when the station accessibility regarding that zone is medium or poor, the railways should adjust its supply to the interest and organise the transport adequately. One of the possible methods is subcontracting transport operations with road carriers who may transport passengers to and from the station. If, however, the interest in one zone is such that this would prove unprofitable (e.g. according to the "cost-benefit" analysis), the tendency should be to improve the connections of the zones for which the station has medium or poor accessibility. Thus, it is possible for transport to be unprofitable regarding one zone, but profitable when several zones are included.

This results in the currently pressing problem: Are railway transport means sufficient for the transport of a greater number of passengers? The opinion is that the railways have not got enough passenger cars (which comply with all the technical and safety requirements) to transport the current number, let alone an even greater number of passengers. Others think that the means are sufficient, but that due to poor organisation some compositions run with empty cars, whereas at the same time other compositions are overcrowded. Whoever is right (and this problem will not be discussed here), one thing is certain: if there is greater interest in railway transport, the best possible plan should be found to satisfy the set requirements. Railways should still satisfy the needs of its customers, and not expect the customers to get adapted. These are, anyway, the market rules: to satisfy as many customers' requirements as possible in the best way possible, so as to prevent the customer from going to the competition. However, all modes of transport *must* co-operate, since no advantages would be gained from their working separately, and neither would this be desirable. The improvement of accessibility of railway stations based on a well organised co-operation of the public road carriers and the railways may prove to be the best example possible.

BLAŽ BOGOVIĆ, D.Sc.
Fakultet prometnih znanosti,
Vukelićeva 4, 10000 Zagreb, Republika Hrvatska
BOJAN KOVAČIĆ, B.Eng.
Srednjaci 23, 10000 Zagreb, Republika Hrvatska
VINKO JENIĆ, M.Sc.,
Fakultet prometnih znanosti,
Vukelićeva 4, 10000 Zagreb, Republika Hrvatska
e-mail: vinko.jenic@fpz.hr

SAŽETAK

KOEFICIJENT DOSTUPNOSTI ŽELJEZNIČKOGA KOLODVORA

Kako bi pružala što kvalitetnije usluge svojim korisnicima, željeznica treba obratiti pozornost ne samo na standardne kvalitativne i kvantitativne pokazatelje, nego i na druge, prividno manje relevantne pokazatelje. Jedan od njih može biti i koeficijent dostupnosti nekoga željezničkoga kolodvora. U radu je razrađen formalni matematički model njegova definiranja, te je predložena jedna moguća klasifikacija dostupnosti. Potom se razmatranja ukratko proširuju na dostupnost s obzirom na gravitacijsku zonu kolodvora, te se navode neki problemi vezani za dostupnost i smjernice njihova rješavanja.

KLJUČNE RIJEČI

koficijent, dostupnost, željeznički kolodvor, organizacija, tehnologija

REFERENCES

1. In both cases, as well as in further discussion, it is assumed that both movements are uniform linear.
2. Every *final travel* (that is, the result of one or more uniform linear movements that take a total of finite time) has its *origin* – the starting point (the place from which the travel starts) and *destination* – the end point (the place where the travel ends).
3. Accessibility can also be related to the distance between the origin and the destination. However, since it is assumed that all movements are uniform linear, then, because of the known formula $s = v \cdot t$ which connects distance, speed and time, i.e. direct proportionality of distance and time, it is more acceptable to establish a relationship between the accessibility and time, moreover, since different times are parameters of numerous formulae used in traffic organisation and technology.
4. Transport means such as passenger car, bicycle, etc. are not taken into consideration here since it cannot be assumed that at least one of these means is available to everybody.
5. Further in the text, the shorter term *process* will be used for all activities involved from the start from the origin to departure of the train from the railway station (walking

to the station, ride by public transport, waiting for the departure of the train).

6. *Cartesian* (according to the latinised surname *Cartesius* of the French mathematician, Rene Descartes) or *direct product* of two sets A and B is the set $A \times B := \{(x,y): x \in A, y \in B\}$.

7. The considerations here could theoretically be complicated only by the possibility of the existence of infinitely many lines of the public transport which may be used and an infinite number of trains whose departures may be waited for. However, no such possibility can be realistically true.

8. Formally, *function image* $f: A \to B$ is the set $Im\, f := \{y \in B : \exists x \in A, y = f(x)\}$.

9. Formally, thus, for $T \in V$ defines $\delta = 1$, regardless of the real value of δ_{max} calculated according to the definition 2.

10. Classification of the accessibility coefficient should be performed in a more detailed manner. Therefore, this could be a certain challenge for all the experts in the field of transport technology, especially the road and railway transport.

11. The word comes from the Latin word *gravitare* = gravitate, i.e. *gravitas* = weight (gravity), load.

12. For the needs of these observations two figures may be considered practically equal if the absolute value of their difference is less than 10^{-2}.

LITERATURE

[1] **B. Bogović**: *Organizacija željezničkoga prometa*, Fakultet prometnih znanosti, Zagreb, 1987.

[2] **B. Bogović, M. Luketić**: *Prijevoz robe, marketing, tehnologija, organizacija*, Fakultet prometnih znanosti, Zagreb, 1995

[3] **A. Stipetić**: *Infrastruktura željezničkoga prometa*, Fakultet prometnih znanosti, Zagreb, 1999.

[4] **S. Kurepa**: *Matematička analiza 1*, Školska knjiga, Zagreb, 1997.

WEB SITES

[5] http://irpud.raumplanung.uni-dortmund.de/ /irpud/pro/peri/ber53_kop2.pdf

[6] http://utel.kuciv.kyoto-u.ac.jp/research/00_cpis_2.pdf