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HUMAN ENERGY EXPENDITURE IN DIFFERENT MODES:
IMPLICATIONS FOR TOWN PLANNING

Hermann Knoflacher
Department of Traffic Safety
Vienna, Austria

Abstract

The disproportionally strong resistance to walking distances and the decision to use the private car as a means of transport may be explained by taking into account the energy expenditure involved in walking or using various transportation systems. Raising the travelling speed of public transport, as well as imposing limits on the parking space available at the destination, unfortunately, are not adequate instruments for making a reasonable choice of some means of transport if "equality of opportunity" is not provided at the point of origin, i.e., in residential areas. This equality can be brought about only if the subjectively assessed travel-time components, i.e., the walking distances to public means of transport, do not become longer than those to the parked vehicle. This would lead to a type of town with limited-traffic pedestrian catchment areas in residential districts and central car parks or garages near the stops of public transport. The results of this study are in line with empirical efforts aimed at reducing the traffic in most European towns.

Introduction: The Problem

Classical urban planners and road builders make assumptions about human behavior which have not been tested for the very simple reason that people working in these fields have technical backgrounds. There are density model data pertaining to transit stops indicating that whereas a value of 300 meters distance between transit stops is acceptable in the town center, in suburbs as much as 800 meters is acceptable. However, these data do not stand up to critical examination. The density model data would suggest that if the people in the center city were to change places with the people in suburbs, behavior (and attitudes) would change correspondingly. This suggestion is in error.

The primary technical planning error is based on the assumption that objectively measureable data can be processed objectively by human beings. According to this assumption, time and distance are accurately experienced by human beings in the same way as they are measured by a watch or measuring tape. This is very doubtful. Not even organisms as simple as insects "work" in this way, as Frisch showed in his works on the behavior of bees.[1]

To bees, distances are interpreted as different degrees of resistance. For example, Frisch demonstrated that bees communicate walking distances of 3-4 meters as equivalent to flying distances of 60-80 meters. The assumption is made that if people in the suburbs were exchanged for people in the center city, behavior would change as place of residence changes. This assumption is in error.

This information, which has been available for some 50 years, would seem to indicate that even more complicated organisms such as human beings perceive quantities that appear easy to measure physically--such as time or distance--not in a physical but in a subjective way. If so, ignoring this information may give rise to serious mistakes in our planning.

In 1972, for example, it was shown in Hamburg[2] that with a linear increase in walking distances the resistance to such distances increases disproportionately. Another study done in Berlin[3] revealed that the same transportation system is perceived (subjectively) to be slower by people who have to walk long distances than by people who live in close proximity to a stop. Both studies suggest the existence of certain subjective transformation mechanisms. (Figure 1)

Man as a Measuring Device in the Traffic System

If the physical effort involved in two types of movement:

1. walking[4] and
2. driving[5]

is compared, the pulse frequency represented by the heart rate ratio (HRR), may be used as a first approximation of the physical achievement. For a walker this ratio is about 1.5 and for a driver 1.1--1.2.

If this measure is used to calculate the difference in energy consumption in the two different types of movement, a quadratic increase in resistance over time can be seen. (Figure 2)

This quadratic equation approximates closely the results of earlier empirical studies. This means that there is a quadratic increase, over time, in resistance to walking distances as compared with driving.

If they are experienced subconsciously, time delays which lead to a deviation from the expected expenditure of time also are subjectively experienced disproportionately.[6] With increasing disturbance this subconscious overestimation of time loss penetrates into consciousness and from then on times are measured relatively accurately. (Figure 3)

Presumably these relationships do not show an absolute distributional function (for all areas) but depend on various conditions: the rider's mental state and the overall character of the transportation system (calibration by system). This approach only shows that, in measuring time and distance, man does not feel and react in accordance with physical laws solely, but also transforms objectively measurable quantities into subjective modes of behavior.

Influence on the Modal Split

Considering the non-linear transformation of time and distance, the foregoing discussion suggests that urban density models which are public transport preference oriented have to be questioned in their present form.

Thus every road user subjectively compares the various traffic system available according to:

a. the objectively measurable time Tj_k, where k denotes the traffic system, and

b. a certain subjective time assessment factor derived from the total of the individual travel time components in the respective system.

If public transport and individual traffic are taken as options and differentiated by the subjective time components, the results are:

$$y = \frac{F_{ijp}}{F_{iji}} = \left\{ k \left[\frac{T_{iji} \cdot f_i}{T_{ijp} \cdot f_p} \right]^{\alpha} \right\}_P$$

y = modal split

T_{iji} = travel time in individual traffic

T_{ijp} = travel time in public transport

where

$f_i = f\,(t'_1)$

$f_p = f\,(t'_2)$ are subjective assessment factors

$$\frac{\partial y}{\partial t'_1} = k \left[\frac{T_{iji}}{T_{ijp}} \right]^{\alpha} \left[\frac{f_i\,(t'_1)^{\alpha-1}}{f_p\,(t'_2)^{\alpha}} \cdot \frac{\partial f_i\,(t'_1)}{\partial t'_1} \right]$$

$$= k \left[\frac{T_{iji}}{T_{ijp}} \right]^{\alpha} \left| \frac{f_i\,(t'_1)}{f_p\,(t'_2)} \right|^{\alpha-1} \cdot \frac{1}{f_p\,(t'_2)} \cdot \frac{f_i\,(t'_1)}{t'_1}$$

change of modal split according to subjective components of individual traffic

$$\frac{\partial y}{\partial t'_2} = k \left[\frac{T_{iji}}{T_{ijp}} \right]^{\alpha} \left[\frac{f_i\,(t'_1)^{\alpha}}{f_p\,(t'_2)^{\alpha+1}} \cdot \frac{\partial f_p\,(t'_2)}{\partial t'_2} \right]$$

$$= k \left[\frac{T_{iji}}{T_{ijp}} \right]^{\alpha} \left[\frac{f_i\,(t'_1)}{f_p\,(t'_2)} \right]^{\alpha-1} \cdot \frac{1}{f_p\,(t'_2)} \cdot \boxed{\frac{f_i\,(t'_1)}{f_p\,(t'_2)}} \cdot \frac{\partial f_p\,(t'_2)}{\partial t'_2}$$

change of modal split according to subjective components of public transport

It can be seen from these formulae that the sensitivity of the modal split to public transport t_2 is proportional to the sensitivity to individual traffic multiplied by a factor constituting the ratio of subjectively assessed travel times in individual traffic and in public transport. With today's urban pattern this factor will always be smaller than 1.

Therefore, an improvement of the modal split through the acceleration of public transport will be connected with this damping factor. For practical examples of equal travel time but with different compositions of the individual time components, see Figures 4-6 which show the effects on modal splits for 4 different examples.

This makes it clear why the public transport acceleration measures carried out in most European countries and aimed at increasing travelling speed have had little effect on ridership rates. Restrictive measures, such as parking fees and limited parking zones at destination points, also show relatively little effect because equality of opportunity for various means of transport gets lost from the start. Therefore, it is important to have this equality of opportunity at the point of departure and not at the destination point. A key element is the walking distance to the respective means of transport.

Conclusions for New Urban Models

Due to advertising, high convenience and safer operation, man shows a strong propensity towards individual car use, and this fact has serious unfavorable consequences in conurbations. The present organization of different traffic systems and activities in the environment does not allow equality of opportunity between individual and public transport (considering man's subjective mechanisms of transformation). The disproportionate resistance to walking distances to public transport stops cannot be compensated for by accelerating public transport. In order to readjust the balance of the "organism of conurbations," adequate resistance to individual traffic has to be built into the system, that is, equal walking distance (energy consumption) to the parking space. In practice, this means that collective parking garages will have to be constructed near public transport stops, even in residential areas; individual traffic in the form of stationary vehicles will have to be eliminated from residential areas, and demands for low-traffic zones and areas of communication will have to be considered. For certain purposes (but not for parking), these zones may of course be used by individual traffic. With this type of town both groups of road users are forced to use common ways, and this would help to prevent the isolation which exists today and which is aggravated by the traffic system. (Figure 7)

The need for these changes results from observing actual human behavior in which physical quantities such as time and distance are transformed subjectively in different ways. Since subjective resistance to certain journeys is dominated by the walking distance, urban planners who focus on people's needs will have to consider, more carefully than before the requirements of pedestrian traffic. In land-use planning, quantitative proof of equal accessibility by public and private means of transport will have to be furnished in order to find locations for all activities. In practice, this will be tantamount to shifting parking spaces away from apartments and, as a result, creating areas free from individual traffic. This applies to suburban areas, central areas, and to the region as a whole.

These measures will not only lead to an improvement in the modal split but also to a more critical attitude on the part of public-transport users.

Disregarding the subjective mechanisms of transformation, which can be explained from ergonomic studies, the planning of towns and traffic systems will lead, in spite of formal planning rules, to a further destruction of the environment and to unresolved traffic problems.

Planning for human beings is possible only if their behavioral mechanisms, within the given technological system, are actually known. The connections derived in this paper constitute a first step towards a better understanding of the phenomena described herein, and they call for a complete departure from the existing patterns, encouraged by contemporary and urban models.

FIGURE 1

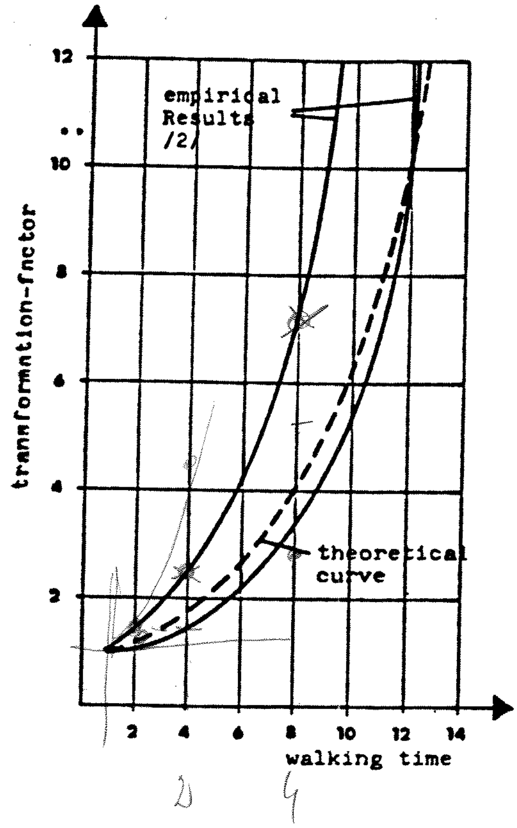
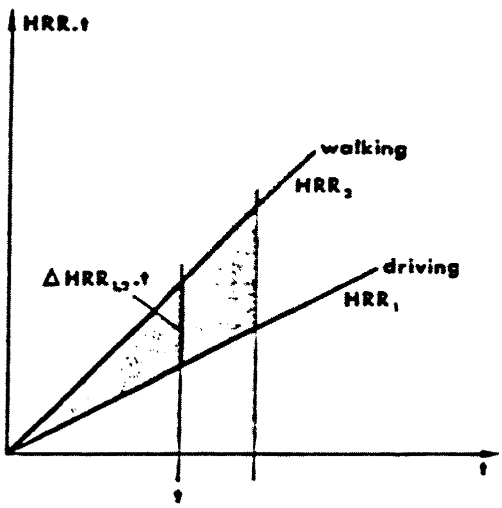


FIGURE 2



$$E = \int_0^t \Delta HRR(t) \cdot t \, dt$$

and if ΔHRR is constant this gives

$$E = C\frac{\Delta HRR \cdot t^2}{2} = W$$

FIGURE 3

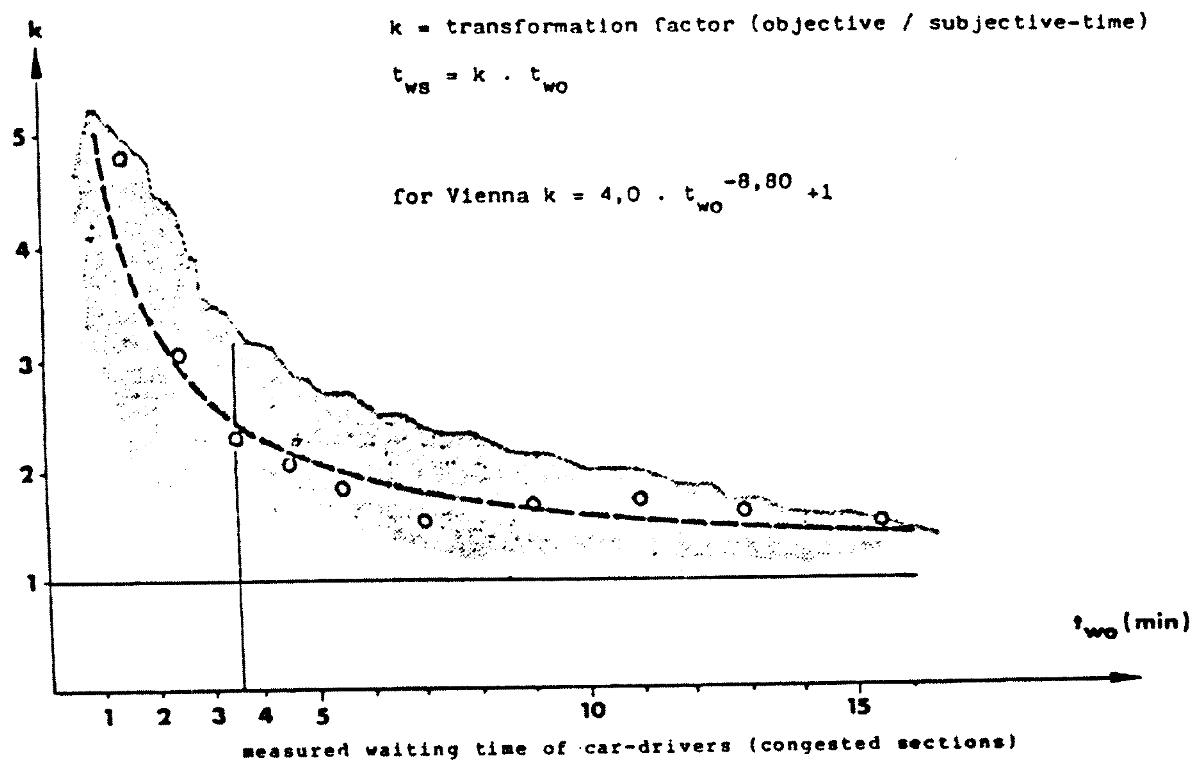


FIGURE 4

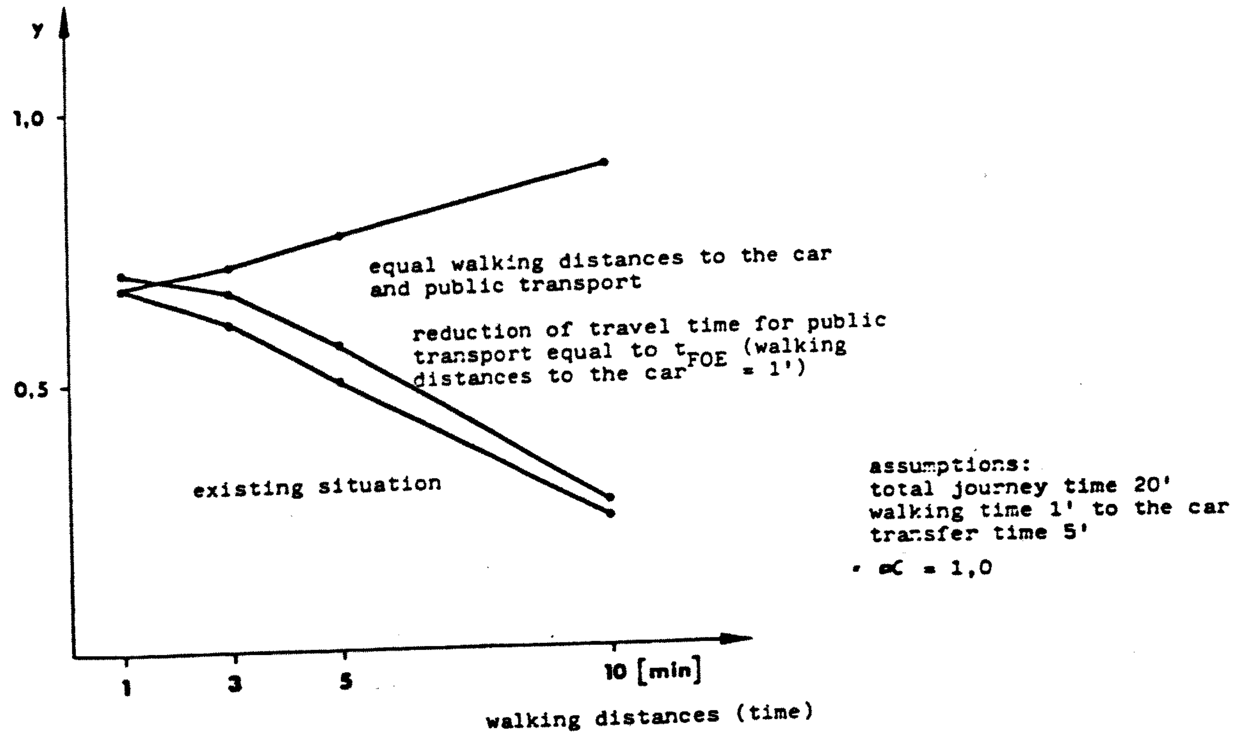
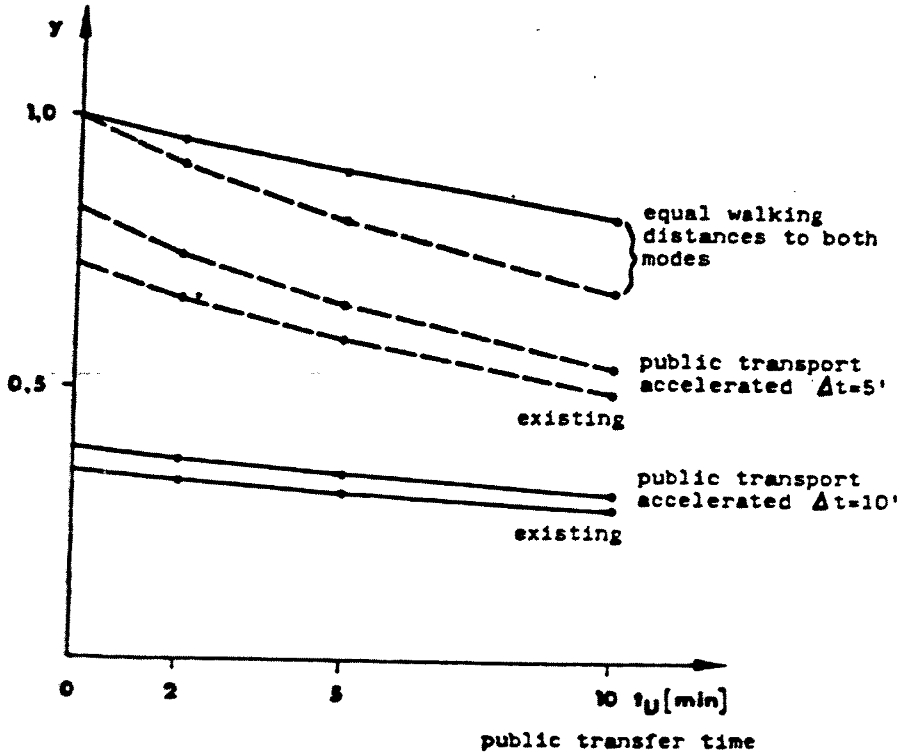


FIGURE 5

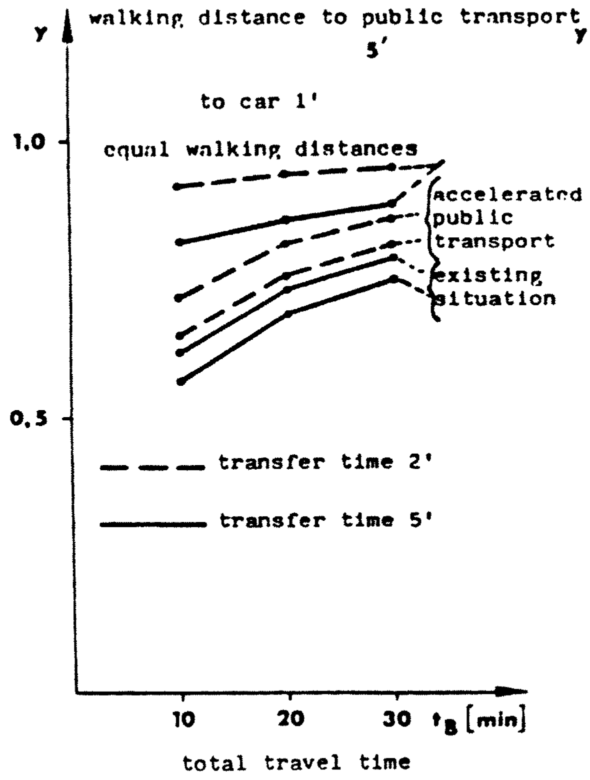


assumptions:
total travel time 30'

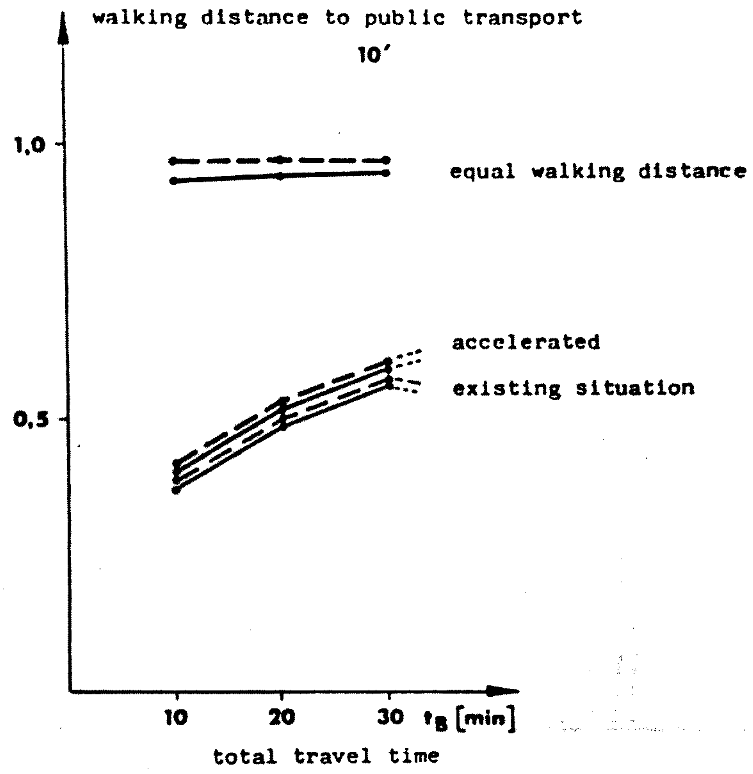
- - - - - - walking distances to public transport 5'
———— walking distances to public transport 10'

1' walking distances to the car

FIGURE 6



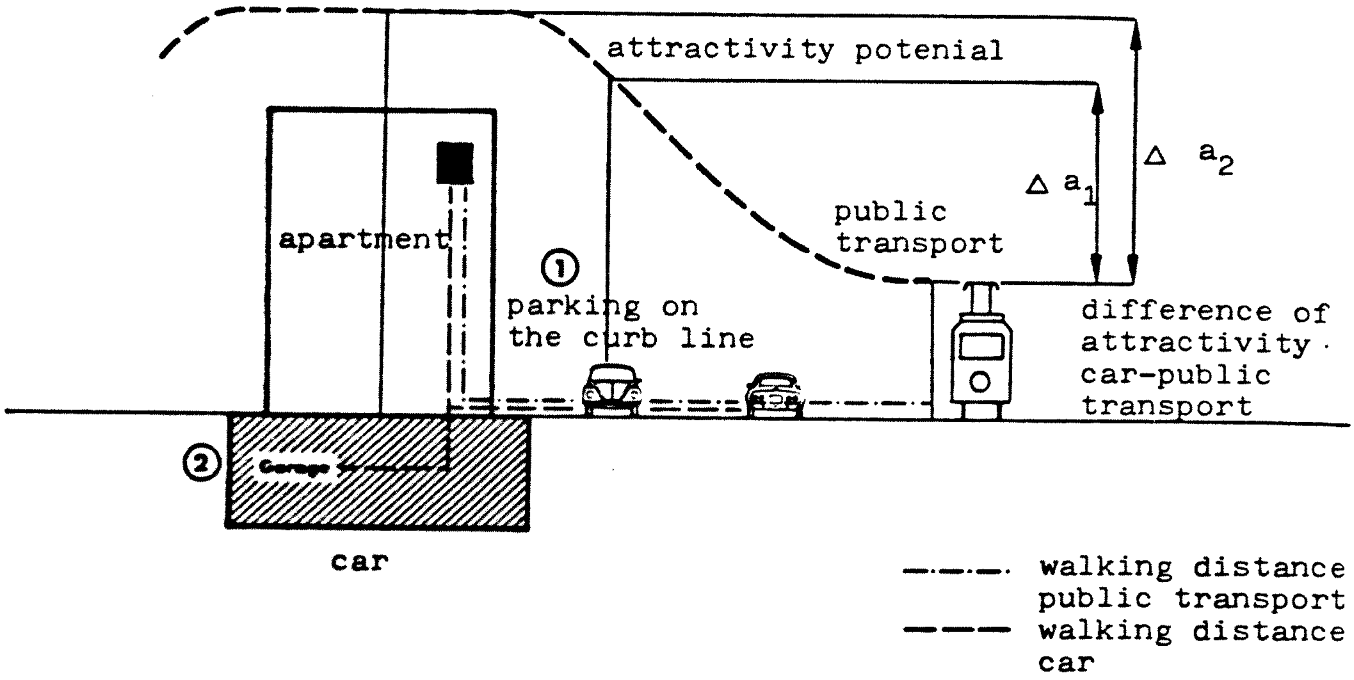
y
walking distance to public transport
5'
y
to car 1'
1,0
equal walking distances
accelerated
public
transport
existing
situation
0,5
transfer time 2'
transfer time 5'
10
20
30
t_B [min]
total travel time



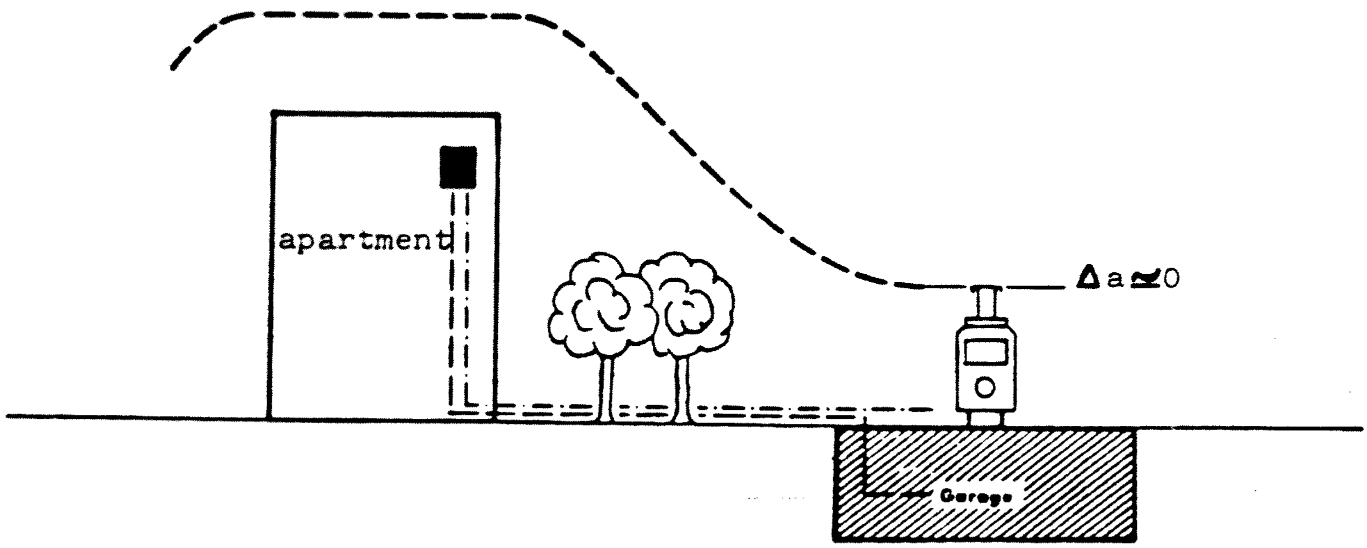
walking distance to public transport
10'
1,0
equal walking distance
accelerated
existing situation
0,5
10
20
30
t_B [min]
total travel time

FIGURE 7

Existing Situation



Proposed System



NOTES

1. K.V. Frisch, Aus dem Leben der Bienen, Springer-Verlag, Berlin, Heidelberg, New York, 1927 and 1977.

2. K. Walther, "Die Fahrzeitaquivalente Reisezeit im offentlichen Personennahverkehr," Verkehr und Technik 28, no. 7 (1975): 271-275.

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4. R.N. Das and S. Gangulis, Preliminary Observations on Parameters of Human Location 22, no. 11 (1979): 1231-1243.

5. B. Friedel, "Belastung und Beanspruchung im Strassenverker," Arzt u. Auto, 56, Jq.H., 10 Oktober 1980, S. 11-29.

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