INVESTIGATION OF EFFECTS OF CONSTANT TIME-PROGRAMMED TRAFFIC CONTROL LIGHTS

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1. Interconnection between the characteristics of traffic flow and time losses in urban centres

The purpose of the general and comprehensive complex control of the heterogeneous town traffic is, besides the most advantageous use of capacities, — particularly in the relatively ever narrower transportation area capacities — to maximally fulfil the safety and economical requirements and to deduce the traffic flows by fully taking into account their objective features, laws and continuity.

Accordingly, the most important partial tasks of the traffic control are as follows [3]:

a) increase of safety in road traffic, particularly as concerns the pedestrian traffic,
b) highest utilization and increase of the capacity of routes and centres,
c) control of the flow conditions in centres in such a way as to minimize the delay (loss of time) and to increase economy in traffic flow as much as possible,
d) controlling the order of waiting (parking) of vehicles on roads and squares.

By taking into account also those said from the capacity and utilization of centres, in establishing the control and time schedule of the traffic and in determining the periods and phase times, one should endeavour to arrange the traffic flows according to their nature, quantities and qualities with a minimum of constraint, restriction and disturbance, and one should take for starting principle the optimum use of the capacity of the centre, the continuous flow, as high cruising speed (i.e., the shortest, still tolerable detention) as possible.

In the system of traffic control with light signals in a given centre, on a road or road network — i.e., in a controlled system — it is occasionally inevitable to break the continuity of the traffic flow or to stop running vehicles or to prescribe speed restrictions inconvenient for them. Thus, the vehicles covering a certain distance will be delayed. This delay is composed the deceleration, stop and acceleration of some of the vehicles, and should be averaged with respect to all of the vehicles traversing the cross section. Thus, the detention suffered by a part of the vehicles will be referred to their entity a number characterizing the system [8].

The delay caused in centres may be investigated according to phases and so may be the whole loss of time in centres. In a route or network system in reference to the traffic flow serving for basis for the comparison, in the centres comprised by the system, the total delay suffered all together should be taken into account. That arrangement of systems is the optimum where the sum of delays is minimum. By minimizing the delays also the operating expenses will decrease and also the nerve strain on the drivers lessens and so does the harmful ecological effect of the transportation.

Numerous relationships exist for determining the traffic delay. All of them try to find interdependence between the characteristics of traffic control lights, the intensity of the traffic flow and the anticipated delay. An adequately precise relationship has the important advantage to help predicting the involved traffic delay in case of an adjustment of the traffic control light system or determining the divergence of the equipment in use from the optimum. Accordingly, the adjustment causing the least delay possible might be found. It should be noted that recently, the exact relationships have been replaced by simulation methods reckoning with the local conditions and parameters.

From among all of the delay relationships investigated [1, 2, 3] formula by WEBSTER, NORDQUIST, MILLER, STEIERWALD the delay model by WEBSTER is the most realistic approximation, taking local conditions best of all into consideration. It is noteworthy that the results of our measurements are somewhat lower than those calculated by the formula referred to above. The delay formula concerns a particular centre controlled by a fixed-program light signal system.

Anyhow, practically no unambiguous relationship of universal validity, based on the findings of delay measurements on certain centres can be established. Regression equations established from measurements are only valid at the given centre and only under given circumstances.

Webster's theoretical model has been produced on a digital computer by a simulation, with the assumption that in the effective green phase a saturated flow of traffic took place

Webster's delay formula is as follows:

$$\delta = \underset{\text{I.}}{\frac{Z(1-\lambda)^2}{2(1-\lambda)}} + \underset{\text{II.}}{\frac{x^2}{2q(1-x)}} - \underset{\text{III.}}{0{,}65\left(\frac{Z}{q^2}\right)^{1/3}} \cdot x^{(2+5\lambda}$$

where δ = average loss of time (delay) per vehicle

Z = period

λ = ratio of green phase to period
x = degree of utilization
q = flow intensity in each direction.

The first term of the formula yields the loss of time for the case of on uniformly distribut arrival of vehicles. The second and third terms take the random distribution of the arrival of vehicles into account. For practical use, the formula may be given in a better ordered form (the involved constants being tabulated):

$$\delta = \left(Z \cdot A + \frac{B}{q}\right)\left(\frac{100 - C}{100}\right).$$

It may be pointed out that up to a flow intensity of about 400 E/h the term I of the formula gives a sufficiently close approximation; at 800 E/h, there is a 100 per cent difference between the values yielded by the linear and the entire formula. The relationship permits to determine for different flow-intensity values the cycle to which the minimum delay is co-ordinated. The divergence from this cycle value involves economical effects, related to the increase of delay. The optimum adjustment of the traffic light signals can also economically be evaluated and its optimum efficiency numerically pointed out [6].

2. Analysis method

The basic principle of the economical investigation method presented below is to compare the numerically in evaluable active and passive effects to be characterized by index numbers found at centres both operated by optimized control light signals and by optimum program operated traffic control light signals. It can be pointed out that the numerical values are always suitable to evaluate one or another signalling program and to compare control systems realized at different centres.

The strength of the active effects and their calculation method is influenced by numerous local conditions and parameters, for example, the ratio of the mass to private transportation passing through the centre; number of routes joining the centre; ratio of utilization of the capacity of the centre; the cycle and time schedule of the control light system, etc. The suggested method endeavoured to take all of the important influencing factors into account, therefore a computation method based on the principle of "modular construction" has been established which is applicable by ignoring the undesirable or unexistent factors. In case of great many variables, the model is expediently handled by a computer.

The following headings "active effects" and "passive effects" recapitulate the advantageous economical factors the expenses of the signal light optimization, respectively.

2.1 *Active effects of the optimization*

2.11 *Numerically expressible active effects*

1. The vehicles of mass transportation (tramway, bus, trolleybus) cross the centre without stop, detention, hence at a minimum loss of time. Accordingly:

- turn-over time of the vehicles will be shorter, the same passenger transportation is performed by less vehicles, thus equipment expenses may be reduced;
- work time of drivers will be shortened, use of fewer vehicles means a saving in labour and wages;
- passengers' travel time will be reduced.

2. Rapid, unhindered traversing of freight vehicles permits them to perform a higher conveying performance in the same time, adding to the benefit.

3. In the private motor-car traffic, travelling time and expenses may be saved and the public passenger vehicles may rise the passenger transportation performances.

4. Considering the total number of vehicles, the number of decelerations, accelerations and stops will be reduced and so will be the fuel consumption, brake and tyre wear.

5. Time schedule of the optimum program may be better adjusted to traffic requirements, therefore, the transmittance of the centre is better utilized than in case of a non-optimized program.

2.12 *Numerically not expressible active effects*

1. The optimum control light program more suitable to the requirements of the traffic technique better satisfies the safety requirements in centres and reduces the risk of accidents.

2. A uniform, rythmical movement of vehicles comes about within the centre.

3. Noise level will be reduced.

4. Air pollution will be diminished.

5. Nerve strain of the persons partaking in traffic decreases.

6. Maintenance costs of road surfaces will be reduced.

2.2 *Passive effects of optimization*

1. Optimization may be realized only in constant knowledge of the traffic characteristics. Therefore, in each centre, systematical traffic surveys should be carried out. For this purpose, extra wages or traffic recording equipment are needed.

2. Interaction of several factors can only successfully analyzed by means of a computer. Expenses of the production of the computer program and running time are charged on the active effects.

2.3 *Optimum criteria*

The analysis of the above mentioned active and passive criteria might be carried out by taking different optimum criteria separately or together into account. In economically analyzing a particular centre with more than four branches, the consideration of the following five optimum criteria is advisable:

1. period,
2. number of phases,
3. phase program,
4. phase sequence,
5. distribution of green time.

Besides, several other optimum conditions may be prescribed, more of optimization purposes, however, significantly increase the number of varieties to be calculated and the benefit would not be proportionate to the calculation expenses. (Even in case of five constraints, more than 30 cases should be analyzed.)

Advantage of the proposed method is to involve also the economical effects of separate optimization of each factor. Besides, the method permits to widen the choice on the criteria.

The length of the period effects the length of the waiting time and utilization. In case of short cycle, but a few vehicles can pass through the centre in each direction, a long queue of vehicles remains waiting; in turnin case of a long cycle, direction will seldom change this is why the waiting time will be lengthened. The cycle time may be defined as a function of the load per track.

Although increase in phase number contributes to realizing an undisturbed flow of traffic and improves safety of passing through the centre-augmentation of the number of phases lengthens waiting time and reduces the capacity of the centre. The advantage of simultaneous use of both should be utilized.

A phase program might be established in several ways. An optimum program equalizes the charges of introductions into the centre. Between different transport facilities equalizing charges, the basis of comparison should be selected at a particular care.

The phase sequence is important in case of more than two phases. Alteration of order of succession of phases changes expenditure factors of the same traffic.

Distribution of the green time is instrumental in realizing economy. A little careful establishment of green time increases the loss of time. This, in turn, changes the capacity and the whole time requirement of passing through the centre.

3. Numerical determination of active effects

In analysing the costs, the differences in vehicle-operating costs, time-cost of passengers and freight might be calculated in case of a traffic control light system differing in any of the optimization factors from that of optimum cycle, green light phase distribution, phase number, program and sequence. An optimum traffic control light program decreases the continuous costs of vehicles crossing the centre. The change in optimum costs is highly influenced by the composition of the traffic which, besides, also effects the establishment of the traffic control light program, therefore, it is advisable to calculate the savings according to types of vehicle.

Cost analysis for a given centre, at a given time and under given traffic condition will be spent an optimum program, established by simulation on the basis of the above viewpoints.

3.1 *Public bus*

Let the centre be crossed by a number N of buses per hour. The row of vehicles lining up in front of the centre will contain ratios band in cases of buses and optimum control-light programs, respectively. The delays differ by $(\tau_a = \tau_a')$ vehicle between the two cases, where τ_a' and τ_a are specific waiting delays belonging to the optimum, and non-optimum programs, respectively. From this difference a time saving

$$N(\tau_a - \tau_a')(b - b') \qquad (\text{sec/h})$$

is obtained.

Time saving may be calculated as an optimization factor, and its final value is the sum of the part values. This circumstance permits to consider separately the cases where not all of the factors are optimum. Thus, altogether 32 cases might be analysed:

$$\left[\binom{5}{0} + \binom{5}{1} + \binom{5}{2} + \binom{5}{3} + \binom{5}{4} + \binom{5}{5}\right] = 32$$

in a combinatorical way of thinking.

Providing the optimization criteria with codes (i), the formula can be built up according to these codes.

Thus, the time saving at the centre is:

$$T = \sum_{i=1}^{k} N(b - b')(\tau_a - \tau_a')_i \quad \text{(sec/h)}$$

where $i = 1, \ldots, k$ is the code of optimization coefficient. For example:

code of optimum cycle . . .	1
code of optimum phase number . . .	2
code of optimum phase program . . .	3
code of optimum phase sequence . . .	4
code of optimum green-time distribution . . .	5
⋮	
optimum	k.

Can be calculated vehicle turn-round time saving shortening which in case of the original turn-round time T_F will have a more favourable value T'_F:

$$T'_F = T_F - \sum_{i=1}^{k} (\tau_a - \tau_a') \quad \text{(sec)} .$$

In case of an invariable passenger traffic and starting interval (S) the following inequality is true:

$$\frac{T'_F}{S} < \frac{T_F}{S} \quad \text{(vehicles)},$$

which shows savings in vehicles of the given route. In this case savings in investment will be

$$Be = \frac{B \sum_{i=1}^{k} (\tau_a - \tau_a')}{S} \text{ [Forint]},$$

where B(Ft) = investment rate of a vehicle. The rate for a year may be calculated in the knowledge of the specific efficiency coefficient. Also the yearly operation cost might involve savings of similar structure (K_e):

$$K_e = \frac{K' \sum_{i=1}^{k} (\tau_a - \tau_a')_i}{S} \text{ [Forint/year]},$$

where K'(Ft/year) is the operation cost per year before adoption of the optimum control-light program. Besides savings in vehicles, also labour saving can expressed by money.

In the case of a non-optimized program of light control, the stop delay of the vehicles before the centre is higher, incidentally, they have to stop several times before passing through the centre. Deceleration, acceleration and idle running consume more fuel, and wear in vehicle is increased. Denoteine the costs of stop, starting and acceleration by a, the savings in operating expenses (Δ Kü) in case of γ operating hours/year are:

$$\Delta \text{ Kü} = \gamma \sum_{i=1}^{k} [N(b - b')a]_i \text{ [Forint/year]}.$$

Besides savings in operating expenses, there are also passenger-time-cost savings (ΔK_{ui}). Denotine the average number of passengers in a bus by β, the wages per hour per person (passenger) by d [Ft/h/Passenger], we have:

$$\Delta K_{ui} = \frac{d \cdot \gamma}{3600} \sum_{i=1}^{k} [N(b - b')\beta(\tau_a - \tau_a')] \quad \text{[Ft/year]}.$$

3.2 *Tramway*

The structure and calculation course of the method is the same as in case of public bus transportation.

Let a number V of tramways pass through the centre per hour [in trains/hour]. The hourly number of vehicles waiting for passing through the centre will contain tramways in proportions v and v' and optimum control light programs, respectively. In the two cases, the delay difference per train being $(\tau_v - \tau_v')$ sec/train, where τ_v and τ_v' are specific stop delays belonging to and non-optimum programs, saving in time at the centre is:

$$\Delta T = \sum_{i=1}^{k} [V(\tau_v - \tau_v')(v - v')] \text{ [sec/h]}.$$

Savings in investment expenses:

$$B_e = \frac{B \sum_{i=1}^{k} (\tau_v - \tau_v')_i}{S} \text{ [Forint]}.$$

Saving in expenses per year:

$$K_e = \frac{K' \sum_{i=1}^{k} (\tau_v - \tau_v')_i}{S} \text{ [Forint/year]}.$$

Savings in operation expenses in case of service hours ω:

$$\Delta K_{\ddot{u}} = \omega \sum_{i=1}^{k} [V(v - v')a]_i \quad [\text{Forint/year}] .$$

Saving in passenger-time costs referred to passenger/train:

$$\Delta K_{ui} = \frac{d \cdot \omega}{3600} \sum_{i=1}^{k} [V(v - v')\zeta(\tau_v - \tau_v')]_i \quad [\text{Forint/year}] .$$

3.3 *Lorry*

A convenient control light program results savings in the work hours of drivers and driver's mate which efficiently can be made use of, and which, at the same time means increase in traffic speed. Be the given traffic centre crossed by lorries in per hourly proportions of c and c' included in the line of waiting trains in case of a non-optimum and an optimum traffic control light program, respectively then, the savings per vehicle resulting from the right adjusted program are $(\tau_t - \tau_t')$ sec:

$$\Delta T = \frac{1}{3600} \sum_{i=1}^{k} [L(c - c')(\tau_t - \tau_t')] \quad [\text{driver hours/hour}] .$$

Amussing operating the performance excess in conveyance during these economised hours, hours per year results in an income excess per year of:

$$\Delta K_{ai} = \frac{e \cdot \varepsilon}{3600} \sum_{i=1}^{k} [L(c - c')(\tau_t - \tau_t')] \quad [\text{Forint/year}].$$

Also savings are made in operating expenses for the lorries comprised in the waiting line of vehicles before the control light signal:

$$K_{\ddot{u}} = \sum_{i=1}^{k} [L(c - c')a]_i \quad [\text{Forint/year}].$$

3.4 *Passenger car*

Both savings in time expenses and in operating costs may be calculated; in analyzing actual conditions, the savings for public and for private cars and are to be separated.

For a number of vehicles passing through the centre controlled by signal light [passenger cars/hour], before establishment of an optimum control light program, a proportion p vehicles were lining up before the control light signal; in case of an optimum signal program this proportion will be p'. The difference in stop delays per vehicle is $(\tau_s - \tau_s')$ vehicle [sec]. Assuming a number of passengers ϱ per vehicle, during given service hours σ, the passenger-time cost saving will be:

$$\Delta K_{ui} = \frac{d \cdot \sigma}{3600} \sum_{i=1}^{k} [M(p - p')\varrho(\tau_s - \tau_s')]_i \text{ [Forint/year]}.$$

Savings in the operation costs:

$$\Delta K_{\ddot{u}} = \sum_{i=1}^{k} [M(p - p')a]_i \text{ [Forint/year]}.$$

The savings at the centre investigated ΔK [Forint/year] composed of the operating, freight and passenger-time costs, as well as of the investment savings are

$$K = \sum_{j=1}^{n} \Delta K_{\ddot{u}} + \sum_{j=1}^{n} K_{ui} + \sum_{j=1}^{n} K_{\acute{a}i} \text{ [Forint/year]}$$

where $j = 1, 2, \ldots, n$ (types of vehicles).

4. The non-measurable active (useful) effects

A certain part of these effects cannot be numerically evaluated concerning their influence on costs and although a certain amount of their effect on costs may be expressed numerically, it is impossible to define unambiguously the share of traffic control. No definite values can be assumed for the noise effects and for nervous system train. Although the cost impacts accidents can be evaluated, the shares of deficiencies of traffic control and of inattention and tiredness of traffic participants cannot precisely be evaluated. Nevertheless, no doubt, these effects outgrow in significance numerically calculable the effects, and they are increasingly involved in the evaluation of the effects of accidents.

The operation of the control lights in conformity with the traffic requirements is of great significance for increasing the traffic safety. According to the accident statistics, a great part of the road accidents occur in centres, resulting mainly from the omission of the obligatory precedence yielding, non-observance of control signals and collision due to overtaking. Therefore, it is necessary to supply busy centres with control light system and time programs of controlling, permiting vehicles to pass through centres possibly without stops.

The *ecological effects* are hardly expressible in numbers. Townsmen are heavily paying for the comfort of urban life in terms of rapidly worsening, harmful environmental effects. The conditions are growing unfavourable with the increase of the number of vehicles. Therefore, one should use every means to try to decrease the effects of the two environmental damages: air and noise pollution.

With the rapid development of motor transportation, the level of air pollution increases not only linearly with the number of motor vehicles but exponentially, due to the saturation of the roads and centres and the imadegnete control system, the ever increasing number of stops in front of the traffic control lights and the idling of motors. These operating conditions are worse than continuous running with respect to the increased amount and harmful composition of the exhaust gases. In 1971 the Scientific Research Institute of Road Traffic measured the air pollution at several busy points of Budapest [3]. Meanwhile also traffic surveys had been performed, offering an opportunity to the investigation of the relation between air pollution and traffic density. Although the air pollution depends also on meteorological conditions, composition of the traffic, operating way of the engines, air pollution from other causes so that the difference of values measured at different points of the town may be attributed to different causes comparison of pollution values from a column of vehicles running steadily and occasionally accumulating at a centre may be highly instructive. Evidently, the stopping vehicles caused a higher level of air pollution.

Pollution components measured during 20 minutes	Measuring points in Budapest		
	Crossing of Krisztina boulevard and Mészáros street	Crossing of Rákóczi avenue and Lenin boulevard	Népköztársaság Avenue in front of the Opera
SO_2 mg/m^3	0.22	0.18	0.16
NO_2 mg/m^3	0.19	0.19	0.08
Formaldehyde mg/m^3	0.00	0.14	0.03
CO mg/m^3	5.70	4.00	3.00
Number of vehicles passing through the measuring points	736	700	659

From environmental aspects, also the *increase of noise is harmful*. Damaging physiological and psychological effects are caused mainly by the intensity of noise, however, neither the duration of the noise effect is indifferent. Intensity of the noise increases at the starting of vehicles, and the duration of the noise making is proportionate to the average speed of the vehicles.

It may be pointed out that the introduction of the optimum control light programs is also efficient for reducing both air pollution and noise damage.

Nervous overstrain of persons partaking in road traffic is a harmful phenomenon of our age. Lengthening of travel time, congestions of vehicles, slow progression, etc., cause unnecessary strain on nerves. Experienced drivers are known to become impatient in such situations and often infringe the regulations. A similar phenomenon occurs with pedestrians and individuals in mass transportation. It has a significant though non-measurable advantageous effect to reduce or prevent such nervous strains.

Also delayed *wear of road surfaces* may result from reducing the frequency of stops of vehicles. This may hardly be numerically expressed because surface wear occurs not only traffic control system conditions. Nevertheless, it is experienced that, in general, the road surface requires more repairing work at centres than elsewhere.

5. Evaluation of the passive (disadvantageous) effects

The expanses of developing optimum traffic control programs (traffic survey or automatic recording, use of computers) belong to the disadvantageous effects. However, these expenses are likely to be neglegible in amount in comparison to the expected savings and even in case of the adaption of a simple time programming the supervision of the programs is necessary. Besides, the findings from systematic traffic surveys may be utilized for other design purposes.

6. Summary

In the development of urbanization an traffic motorization, traffic controlling by signal lights must not be dispensed with. It is an important requirement to adopt such a traffic control requiring the least of sacrifices both from the part of traffic and persons partaking in urban traffic. In general, several constant time programs can be applied, practically, however, traffic lights only operated with one or two programs. The described evaluation method verifies that even in case of non-measurable active (advantageous) effects, the benefits from optimum traffic control may be determined in terms of money. The system is the more valuable as its advantages can be realized without any investment, rebuilding, and traffic disturbance. AT a slight modification, the system is suitable for the evaluation of a co-ordinated traffic control system consisting of several signal lights.

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