APPROXIMATE SOLUTIONS OF THE MACROECONOMIC TRANSPORT PROBLEM AND MODELLING OF THE ECONOMIC STRATEGY IN TRANSPORT

By

K. Kádas

Department for Transport and Building Economics, Polytechnical University, Budapest
(Received December 29, 1967)

1. The traditional transport problem and its macroeconomic variations in socialist transport

The transport problem of operation research concerns in its already traditional form the optimal solution of the transportation of identical commodities or of properly interchangeable articles from several forwarding places — usually — to even more destinations on the condition (so-called secondary condition) that in the transportation period in question every place of destination should receive at least as many goods as intended to be sent to it, and also that the amount of goods planned to be forwarded from the forwarding places should not exceed their forwarding capacity. By optimality is usually meant the minimum magnitude of the total costs of the whole handling of goods. The problem can be easily solved by means of the model of linear programming in accordance with the rules of matrix algebra if the mentioned inequalities of the secondary conditions, or perhaps their equalities are linear in the transported quantities of relations (relations of the route of transport between forwarding place and destination) signifying the variable (parameter of action) of the problem, and if the efficiency function or objective function expressing the total transport cost in function of the variables is also linear. Inasmuch as the latter is quadratic — as it often is —, generally the problem can be also solved by means of the so-called quadratic programming.

The transport problem outlined in the foregoing usually arises during the economic activity of microeconomic units. In fact, the point in question is the formation of an optimal variation of the division of labour of transport. Namely, in what *cast* the transporting apparatuses of the relations should connect the forwarding places and the places of destination so that the optimal criterion under the given conditions (to which the non negative transported amount of goods of the relations also belongs) is fulfilled.

The above-mentioned cast, or the question of *traffic division* is raised in a more comprehensive form within the framework of the national economy. For example, which branch of transport (railway or motor lorry) should transport the given categories of goods from the sender to the place of destination in geographically determined directions, so that this entire activity of the distribution of goods should be the most favourable for the national economy.

This formulation of the transport problem is already macroeconomic, and it raises the very complex question of the optimal division of traffic among the railway, motor vehicle and the full range of transport branches. At the same time, it raises the question of "transport competition" developing in the "market" of transport performances and the question of the so-called market equilibrium. It is just this extension of the problem that suggests the application of the models of economic strategy for the case of certain simpler variations of the macroeconomic problem. Prior to this, however, it is necessary to attempt the clarification of some intermediate questions, so that this central task can be at least approached.

2. The interpretation of the decision preference function from the point of view of transport and the derivation of the parameter matrix

In its introduction, some questions arising already in the microeconomic forms of appearance of the transport problem have to be clarified. Such a question is first of all how the preference system of the decision maker, or more concretely its optimal criterion of decision influences the determination of the elements of the parameter matrix of importance for the model of linear programming. Generally, it directly governs two main factors: a) the linearity of the objective function, b) its economic, or more exactly national economic acceptability. As we shall see it later, in case of certain optimal criteria the linearity of the efficiency function is ensured, it does not involve such high "price" that would compromise the serviceability of the optimal criterion for the national economy. In other cases, unfortunately, the "price" involved may risk to loose even the seriousness of the programming. The case is even worse if neither the linearity, nor the serviceability of the model for the national economy is guaranteed any longer. Unfortunately, even such programming experiments have occurred. Their findings have not been used for practical planning.

In the new system of economic management the enterprises are entitled — between certain limits — to build up their optimal activities and optimal decisions so as they consider proper and practicable. With the transport tariffs applied as elements of the cost matrix, the programming dilemma detailed in the following arises. The question becomes more complicated if the transporting enterprises grant tariff reductions with a view to acquire markets, and they even compete with these. Then the problem becomes that of macroeconomic transport as a rule, for the solution of which the otherwise very useful model of linear programming no longer provides enough support, and it might be necessary to make use of some models of mathematical game theory.

3. The programming of the "transporter" and the derivation of the elements of the cost matrix

The elements of the cost matrix in the solution of the problems of operative and long-range traffic division. The related microeconomic problems.

We have seen that the derivation of the elements of the parameter matrix develops according to the preference system of the programmer. And the preference system, the optimal criterion of efficiency is often determined in dependence of who are the decision maker and the programmer, respectively. Inasmuch as — as it is often the case — the *transporter* is the *transporting enterprise* (e.g. the Hungarian State Railways), it is obvious that the transportations, i.e. the locomotive operations of the railways should be programmed on the basis of the minimization of total operating costs. In operative conditions it is obvious that the programming should be based on the average variable costs, perhaps on the so-called arc-marginal costs. In long-range planning, when in fact the enterprise possesses a great many action parameters, it is conducive to base the programming on total specific costs. Both types of cost have the great advantage that they may be differentiated according to relations, and the programming can be based on the concrete costs of the relations, which is in the last analysis the "ideal" programming case.

However, this pleasure is soon marred by the microeconomic cost law that the magnitude of the unit costs (of both total and marginal costs) is not independent of the load, or of the traffic density of the relations, of the line. As a matter of fact, that embarrassing case ensues when the elements of the parameter matrix depend on the corresponding elements of the transport matrix and of the combination matrix, consequently on the variables of the problem.

Fortunately, this relationship is such that its total cost function involves quadratic variables. So, the quadratic programming may still render us help.

The transporter, however, may use other allocation concepts in the programming as well, so, for example, the route length, the running time, etc.

4. The programming of the "sender" and the forwarder and the derivation of the tariff matrix

In this case, the cost of transportation develops linearly with the tariffs, and the sender has to consider it from this aspect. The operating transport costs of the transporting enterprise are unknown to him, and they are of no interest to him either because his calculations are debited with the tariff items. The cost matrix of the linear transport programming is transformed into a so-called tariff matrix. Yet, this would not make difficulties in itself, in fact, however, transport tariffs in the given commodity groups — and in that type of transport — depend only on the distance of transportation, but they no longer depend on the load of the relations. It is a practice accepted almost all over the world (perhaps France is an exception) that tariff unit rates are uniform on a nation-wide basis, while actual transport costs are differentiated, at least according to the load of relations, but obviously according to the magnitude of resistances of transport dynamics as well, which greatly depend on the line management of the relation. The matter is made more complicated by the fact that tariff costs do not differ equally from the transport operating costs of the relations in the different branches of transport.

An even more complex case ensues if the sender is interested in the *c.i.f.* cost, when he will carry out a combined production and transport programming. Namely, the price of the product (goods) might not reflect the regional social production cost of the commodity in its geographical differentiation.

5. The order of magnitude of the differences between the results of the programming of the transporter and the sender

The instructive results of recent Soviet experiments relating to the subject.

From the foregoing it is clear that the cost matrix and the tariff matrix brought to the level of the same prices or costs, resp., will not be identical. More exactly: the ensuing situation may be characterized by the fact that the programming (objective function) results of the transporter and of the sender (considering the question on the level of prices, or on the level of operating costs) will considerably differ. It is also evident that it is the programming based on the tariff matrix which gives higher costs. In given cases, the difference, i.e. the extra cost may have considerable values. The Ukrainian Academy of Sciences recently carried out experimental programming for sugar-beet — just in order to determine this difference (quoted by Professor Khanukov in his latest study). Accordingly, this extra cost may be as high as 20 per cent. The fact that the suboptimum differs from the actual optimum to such a great extent, warns to caution in choosing the preference and the optimal criterion, otherwise — even with the most precise mathematical programming — the national economy might suffer considerable, unintentional losses.

6. The programming of the senders if the transporters may grant tariff reductions in order to influence the distribution of traffic, with special regard to the magnitudes and variations of the tariff elasticities of the transport demand

The programming of the sender may be considered feasible only if the elements of the cost matrix (e.g. transport charges) are given for him. This is evident in case of fixed tariffs. What happens, however, if e.g. the transporters compete by means of tariff reductions in order to secure the transport demand of the senders, or a part of it. In such cases the development of the outcome of the competition and the corresponding market balance have precedence over the actual transport problem. A reasonable competition (as outlined) e.g. between the railway and the motor vehicles, might lead to considerable reductions of the tariff level if the tariff elasticity of the transport demand $|\varepsilon| > 1$, so long as during the reduction of the tariff level $|\varepsilon| > 1$. As soon as $|\varepsilon| < 1$ (usually with very low tariffs), there is no reason for continuing the competition. Considering that e.g. in the competition of the two duopolists, the railway and the motor car, the case of programming occurs under quite uncertain circumstances for both, the models of economic strategy can mostly be applied succesfully to determine the state of equilibrium of the competition, consequently to determine the market situation the most favourable for both of them.

7. The equilibrium of the market of transport performances in case of a duopoly developing on the side of transport (supply of transport performance)

The introduction of the goods traffic "allocation matrix" as the concept of the analogy of the payoff matrix of the models of economic strategy, with special regard to the differentiation of goods traffic from the viewpoint of transport technique.

It is conducive to start with the simplest competition situation (omitting the ideal-free competition) namely when there are only two competitors in the market of transport performances, on the supply side. Let them be — for the sake of further simplification — the organization of railway transport (e.g. the Hungarian State Railways) and that of the commercial vehicle transport (e.g. the Enterprise for Truck Transportation). According to our supposition, the competition consists in tariff reductions, consequently there is a so-called price competition. Since (within given categories of goods) the railway comes into consideration as a competitor beyond a certain distance of transportation only [1], the competition is only for longer transportations than this (Fig. 1). As much as the motor car acquires in the course of the competition (expressed by the weight of goods, Q), just as much is lost by the railway. Well, the motor car takes away the traffic from it. In fact, the struggle of the competition can be considered as a game of economic strategy between two

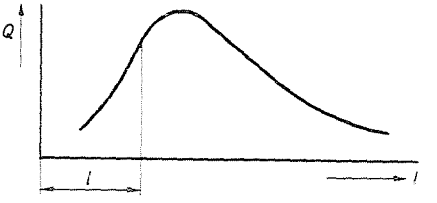

Fig. 1

persons where the rules of the game are given by the modes of tariff reduction. This may be stepwise. In such a case a game consisting of a finite number of strategies totalling zero comes into being. The tariff reduction — in principle — may be carried out by infinitely small values, consequently it is continuous in principle, when the set of the competition strategies is infinite. This is the so-called infinite game.

The elements of payoff matrix, or those of the game matrix included in the game theory represent the delivered or received allocated quantities of goods, or perhaps the pertaining tariff incomes. For this very reason this is called allocation matrix. By this technical means of mathematical game theory, primarily in case of duopoly, the optimum of traffic division and the minimum of corresponding tariff levels can be determined by means of suitable assumptions. Fortunately, in the competition on land, in a socialist economy this situation is near.

8. The expected perspective formation of the equilibrium of traffic division in case of pure traffic allocation strategies

In case of duopoly and in the application of so-called pure (this time, for the sake of simplicity, finite) strategies the elements of the payoff matrix and of the traffic division matrix are relatively easy to determine by means of the points of intersection of the tariff lines expressed in the function of the distance of railway and motor vehicle transport. By tariff lines are meant, of course, the curves brought about by reductions of tariff levels, and their point of intersection is considered. In this case the traffic division matrix is the following (Table 1), taking into consideration that with a low tariff level the value of the price income is greatly reduced. The elements of the matrix

Table 1

railway / motor vehicle		degrees of tariff reduction				
		0	I	II	III	IV
degrees of tariff reduction	I	3	0.5	0.1	0	—0.2
	II	4	2	0.4	0.1	0
	III	5	4	1.5	0.5	0.5
	IV	4	3	1	0.3	0.2

contain acquired and lost tariff incomes, respectively. For the sake of simplicity, the elements of the matrix reflect orders of magnitudes. It can be seen from the matrix that the saddle point to be expected in the region of degree III is — on the basis of the principle of minimax or of maximin — a market equilibrium and a corresponding tariff level. On this basis the senders can already carry out the programming. It is the question, however, to what extent the tariff levels developing in this manner correspond to the social costs of transportation, or how differentiated they show these relation-bound costs.

It can be concluded from the preliminary investigations according to articles that in some cases a saddle point will appear already at a III—III pair of strategy. In other cases this cannot be expected. Naturally, these situations develop according to what the transport demand curve of the article in question is like.

9. The expected formation of the equilibrium of traffic division in case of mixed traffic allocation strategies

If in the case of the application of pure maximin-minimax strategies no saddle point develops, the game totalling zero for two persons can still be solved. This is made possible by the application of the so-called mixed strategy, when the individual competitors assert their individual strategies with a determined relative frequency and probability, each. The total amount of the relative frequency of the application of the individual strategies is, of course, equal to the unit. By the methods of matrix calculation — by means of rather lengthy arithmetical operations — a mixed strategy can be determined that suits the maximin-minimax principle, consequently both parties.

10. The problems and the possibilities of traffic division equilibrium in case of oligopolistic formations of the transport market

In fact, there may be more than two competitors in the market. The so-called oligopolistic market is brought about in this manner. In such a case traffic division may be much more complicated. To my knowledge, there are no strategic models available yet for this case that could be handled for practical purposes as well. It seems that the equilibrium model of price theory elaborated earlier for the case of a limited competition is suitable for this purpose. The problem becomes even more complicated, if the products can be hardly substituted.

11. A comparison of the formation of the social costs of transportations in case of different traffic division programmes, with special regard to the possibilities of combined production-transport programmings

Bearing in mind the foregoing, the total transportations can be effected most economically for the national economy only if their programme is elaborated on the basis of the social costs of relations. In case of programming on the basis of transport tariffs, already 10 to 20 per cent or even 30 per cent extra costs may occur, even if these tariffs are so-called competition tariffs, simply because tariffs generally pay no regard e.g. to the load of relations.

The situation is different if the sender performs a combined production-transport programming. In such a case the objective is a common minimum of production and transport costs.

It is obvious that this common minimum generally does not coincide with the minimum of transport costs. That is, in case of the combined production-transport programming the social economic cost of transportations will be also higher than for a programming based on the relation costs. Investigations carried out so far indicate that this difference is generally of the order of 5 to 10 per cent. The outlined phenomenon belonging to the sphere of the reduction of costs of a compensating character manifests itself in an even more complex form in production-storage-transport programmings.

Summary

The macroeconomic version of the traditional microeconomic transport problem i raised by the distribution of transport tasks among the transport branches. The optimur solution depends considerably on the kind of optimum criterion applied in programmin on the existence of a competition among the transport branches and on the character of th latter. Thus, programming on the basis of the costs of transportation of relations gives bett results from the point of view of the national economy than programming on the basis tariffs because these are less differentiated territorially. In case of a duopolistic competiti between the transport branches, the market equilibrium can be obtained by means of mod of economic strategy in case of both pure and mixed strategies. In case of an oligopolis competition this is more problematic.

Prof. Dr. Kálmán KÁDAS; Budapest, IX., Kinizsi u. 1—7. Hungary