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Jet-Set: Jeu Educatif en Transport/Simulation for Education in Transportation—Synthesis

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ABSTRACT

JET-SET has been prepared to serve as a management training tool for professionals in the interurban passenger transportation industry. It is a computerized game in which six transportation companies owned and managed by players or teams of players compete in a simulated market environment. The simulation program is composed of four principal components: an operation model, a transportation model, a fleet model and a budget model. The current version of JET-SET operates on the APPLE II E Microcomputer and a second version will soon be available on the IBM-PC.

I. INTRODUCTION

The interurban passenger transportation industry plays a major economic and social role, both at the provincial and at the national or international levels. This industry now more than ever constitutes the back bone of a diversity of professional, commercial, industrial, scientific and social activities that require individuals to travel. As with many other sectors, this industry suffers from the current economic situation and several companies are now facing severe problems.

While some of these problems are explained by the economic situation, many other explanations can be proposed, which very often correspond to contradictory opinions: poor management, too low or too high governmental involvement, severe competition or effect of monopolies, cost of labour, etc. The transport companies are thus facing multiple problems. The overall and detailed comprehension of the complex environment in which they operate represents a challenge. The decision making process relates to different levels: from medium to long term planning to strategic management and short term operational procedures.

The managers work with very few tools to analyse their particular situation and to make decisions. Research in the passenger interurban transportation area has been quite weak. Mathematical models are available to simulate and predict the transportation demands aggregated by mode between different city pairs. However, these models are not very useful to the transportation companies when the time comes to decide about the level of service they should offer between city pairs, to plan the purchase or lease of vehicles, to request loans, to initiate promotion campaigns, to predict and evaluate the strategies of competing companies in a sensible market place in constant evolution, to adapt to the variation in the price of oil, etc.

This paper presents a computerized system prepared for teaching individuals to operate in complex situations like the one previously summarized. The program, named JET-SET (Jeu Educatif en Transport/Simulation for Educaton in Transportation), has been prepared as a game to help familiarize participants to the internal dynamic behaviour of the interurban passenger market. It will also allow the players to experiment on the effects of their decisions and that of their competitors. JET-SET has been designed for the specialized training of planners or managers in the field of interurban passenger transportation and for the training of students interested in this area.

JET-SET has been developed by the Centre de recherche sur les transports de l'Université de Montréal, under the direction of Christian Lardinois. The development was realized for the George A. Scott Centre of Transport Canada, with the collaboration of the Transportation Development Centre of the same ministry.

The next section presents the basic but essential issues that guided the development of JET-SET; these issues are related to the decision making process in interurban passenger transportation and to the environment in which companies operate when making these decisions. The following sections present the objectives of the game, its functions and the structure of the software. Then the simulation program and the transportation model are described, detailing the route choice and assignment procedure. The conclusion briefly describes the initial user trial, resulting improvements and its potential uses.

II. THE DECISION MAKING PROCESS AND ITS ENVIRONMENT

As in many other industrial sectors[1], decision making in an interurban passenger transportation company is characterized by:

— the multiplicity and diversity of decisions;
— the necessity to make decisions at different levels;
the high level of interaction between all the decisions;
— the necessity to work in a complex environment which has direct and indirect impacts on decision making.

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Figure 1 illustrates this situation. Decisions apply in the first place on the definition of a supply policy, that is the network configuration, the types of services between each city pair, the frequencies, etc. This network design must take into consideration the state of the market, the demographic trend, the transportation demand, the position of each mode and each company, etc. It should also consider the economic context (cost of energy, inflation rate, labour cost, . . .), the government context (transportation policies, support to some modes in particular, regulation, . . .) and the financial status of the company.

The orientation and choices adopted at this level must be taken for long, medium and short terms and must be related to the planning activities for the development of the company. This procedure will enable the company to introduce services that it desires to offer now as well as others in the coming years. Analyses are necessary at this level to plan he development or the replacement of the vehicle fleet, the hiring or training of personnel, etc.

However, it is mainly at an operational and more tactical level that questions are raised regarding the availability and allocation of human and material resources for the company. This level of tactical decisions is the one at which the company decides in detail the level of service to offer between city pairs, and consequently organizes its multiple operations taking in consideration the seasonal weekly and daily variations of the transportation demand. The schedules and the capacities assigned to these schedules are defined; the routing and scheduling procedures are outlined; the assignment of each vehicle category and the personnel for these services is managed; the maintenance activities are organized; the tariffs are chosen, etc. All these actions are made, while taking into consideration the government's regulations and the competition that other modes or companies exert. These decisions interact with each other; they all influence human and material resources required to ensure the services and vice versa.

The company must evaluate the financial implications on the one hand and the possible effects on the market on the other hand, before choosing its levels of service. The financial implications relate to the operating costs but also to the investments required for the potential acquisition of new equipment. While forecasting, the company must also consider marketing strategies and competing mechanisms that rule the market behaviour.

Lastly, considering its investments, operating costs and operating revenues, the company must manage a budget which often also includes other categories of revenue and expense, for example government subsidies, revenues related to sales on board of vehicles, taxes, R&D expenses. In addition, the company has access to financial tools such as loans that must be planned in parallel with its investments and its obligations to balance its budget. However, these tools are limited as they are governed by the financial market (interest rates, credit limit, . . .).

The process illustrated in Figure 1 is continuous and reiterates from one year to another within each company. The company is operating in a market environment which is determined by the other companies' strategies, but also determined, as mentioned earlier, by the economical context and the government policies and regulations. In order to plan and manage its activities, each company relies in part on its own historical development; in general, the evolution of its position in each market segment procures a good indication on potentially interesting adjustments of the service to be offered. The company can also use, but less frequently, information systems and performance indicators in order to account and control several components of its operating costs and revenues, o evaluate profits and costs of its investments and to prepare more detailed forecasts.

Managers and planners in the interurban passenger transportation industry (including government managers in charge of policies and regulations) have an arduous task in an environment where they possess few tools with which to grasp the multiple effects of their decisions, apart from their own personal experience. No method or instrument exists to analyze and forecast, in a completely integrated and detailed manner, the correlated effects of all decisions, of the economical contingency and of the regulation on the market behaviour, on the companies productivity/competitiveness and on the financial health of these companies.

III. JET-SET; ITS PHILOSOPHY AND ITS OBJECTIVES

Decision making in interurban passenger transportation represents a difficult task which is considered by many people to require more sensibility to the social and political context than scientific and rational considerations. However, the question that remains to be answered is how to train individuals in order to help them make better decisions in complex situations.

This question was the starting point of the research project devoted to the conception and development of the computerized management training game presented in this paper.

The objective of the JET-SET package is to create game situations that:

- reproduce, to a greater extent, the complexity of the situations in which the interurban passenger transportation companies have to evolve;
- enable the participants to make diverse and interrelated decisions as the ones encountered in practice;
- enable the participants to experiment progressively with the effect of their decisions, the effect of those taken by their competitors and the effect of the economical and regulative environments;
- sensitize the participants with regard to the underlying market dynamics of interurban passenger transportation, and particularly to the interactions between competing modes and companies, as well as to the mechanisms that determine the equilibrium between transportation supply and demand.

The current version of the game considers most of the mechanisms and interactions illustrated in Figure 1. Simplifications have been made to the detailed management of operations; in particular, routing and scheduling issues are not examined in JET-SET[1].

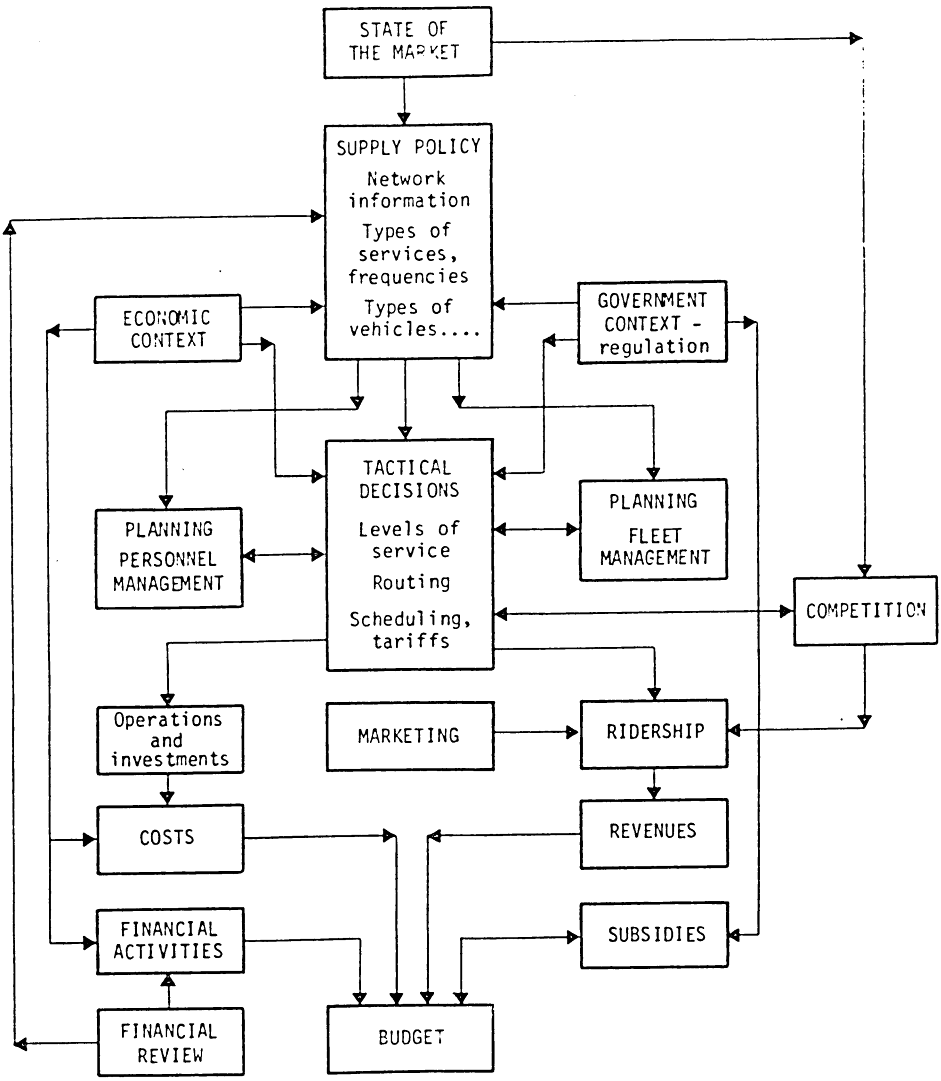

Figure 1: The Decision Making Process in Inter-urban Passenger Transportation

IV. FUNCTIONS OF THE GAME

JET-SET is a computerized game in which six transportation companies compete: one conventional train company, one rapid train company, two traditional bus companies and two air companies one offering STOL services.

At the beginning of a match, each company is in a predetermined financial situation and owns a fleet of vehicles with given techno-economical characteristics (price, capacity, operating costs, life-span . . .). Each company has a specific market share between each city pair that it serves. The complete network includes seven cities, each company has a direct service between 6 of the 21 city pairs.

Each player (or team of players) owns one of these six companies and manages it individually.(2) In this regard, the player is required to make several decisions concerning his company: level of service offered between each city pair (frequencies and fares), purchases or leases of vehicles to enlarge the fleet or to replace old vehicles, loans or debts repayments . . . . The player can also decide to initiate special projects, such as promotional campaigns or market studies. Each player must make these decisions at the beginning of each year, using the information contained in the activity report that he receives at the end of the previous year (see Figure 2).

The information contained in these reports concern the company: its operations during the year that is terminating, the composition of the vehicle fleet, its ridership, its operating costs and revenues, the load factor of the vehicles in operation, the costs of its investments and of its banking activities, its financial situation, its credit limit, the number of vehicles on order, etc. Other information is also presented in the report illustrating the economic, demographic and financial context: population per city, interest rate, variations in salary and energy costs, taxation rate, subsidy rate, etc. Information from regulatory agencies impose constraints on permitted variations in the levels of service. Additional information is given to the players who have requested special projects. All this information constitutes a means for a player to analyse in more detail the state of its company and its environment, and consequently this information helps the player to make decisions for the following year.

A seventh character, as important as the six players intervenes in JET-SET. This is the "game master" who plays the role of the government with the power to influence the evolution of the economic, financial, regulatory and demographic(3) context.

The game master receives, at the end of each year, a report informing him of the status of the transportation network, the market shares of each company, their respective performance, etc. On the basis of this information, the master will make decisions to vary some indicators such as the demographic growth rate, the salaries and energy costs, the government subsidy rates, the interest rate, etc. The game master also regulates the permitted variations in the levels of service.

The players and game master's decisions are then used as input into the computer program, which creates an evolving artificial environment, within which the six companies are simultaneously present (as well as the car which is always present in JET-SET). The program simulates the multimodal and multicompany transportation network as well as the behaviour of the users of this network. The program also represents the companies' operation, simulates the evolution of their vehicle fleet and determines their annual budget in relation to their financial status updating.

Each execution of the computerized program simulates one year of activity for all the companies, representing the consequences and interactions of the players' decisions and the choices made by the

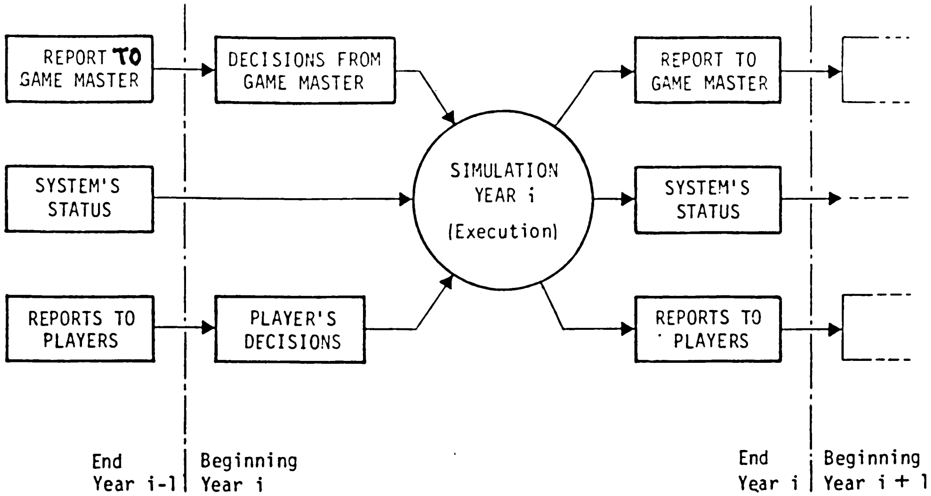

Figure 2: Functions of the Game

game master. After the execution of the program, the companies face a new situation which corresponds to the status of the system a year later, which is a new equilibrium between transportation supply and demand. New reports are handed out to the players and the master, and so forth. A complete game covers a series of simulated years in such a manner that the evolution of each company depends directly on the decisions taken by the player that manages it but also, indirectly by the decisions taken by other companies as well as by the game master. Each layer works with the objective of gradually enhancing his decision making capability while experimenting with the dynamic mechanisms of the market.

V. SOFTWARE COMPONENTS

As illustrated in Figure 3, the software is composed of three major elements:

- A data bank grouping several files containing all the information which describes the system's status at the beginning of a match, as well as the status as it evolves.
- A simulation program that solves mathematical models, following a well defined procedure. These models describe the relationships between all the system's variables including the complete transportation network on one hand and the individual company's on the other hand.
- An interface between the user and the data bank, that is a "user friendly" interactive program that enables an easy dialogue between the user and the software for the collection of the players' and the master's decisions, for the updating of the data files and for the editing of the output reports. This interactive program also allows the simulation program execution to be controlled.

The software is implanted on an APPLE II E microcomputer, and has been written in Pascal. In the near future a version will be prepared for the IBM-PC.

The interface between the user and the software constitutes a key element that characterises the facility and the flexibility of utilizing JET-SET. The presentation of this interface would be too tedious in the context of this paper but the simulation program, particularly the transportation model, needs to be detailed.

VI. THE SIMULATION PROGRAM

The series of operations executed in order to simulate one year of activities for all the companies is schematized in Figure 4. This simulation program is made up of four major components.

The operation model is the simplest of all four. Using the techno-economic characteristics of vehicles and the offered levels of service, it accounts for the physical operations of the companies and evaluates their costs. It should be noted that for similar services from one year to another, these costs can vary as functions of the energy and manpower unit costs.

The transportation model, detailed in the following section, is the heart of the program. It simulates the complete network, the transportation demand, and the behaviour of passengers on the network, in order to obtain the ridership of each company between each city pair and, consequently, the vehicles load factors, the detailed market structure and the operating revenues.

The fleet model has four major functions. The first function is to proceed to an annual adjustment of each vehicle fleet, to increase the age of all vehicles by one, to shelve the vehicles that attained the retiring age, and at the same time to introduce new purchased or rented vehicles in the fleet; the

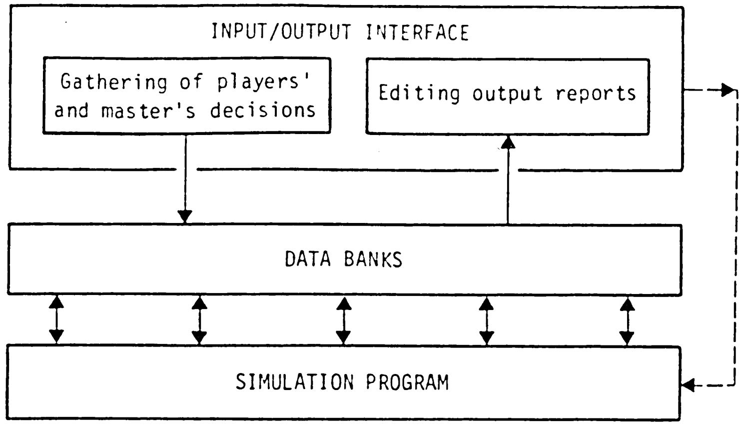

Figure 3: Main Components of the Software

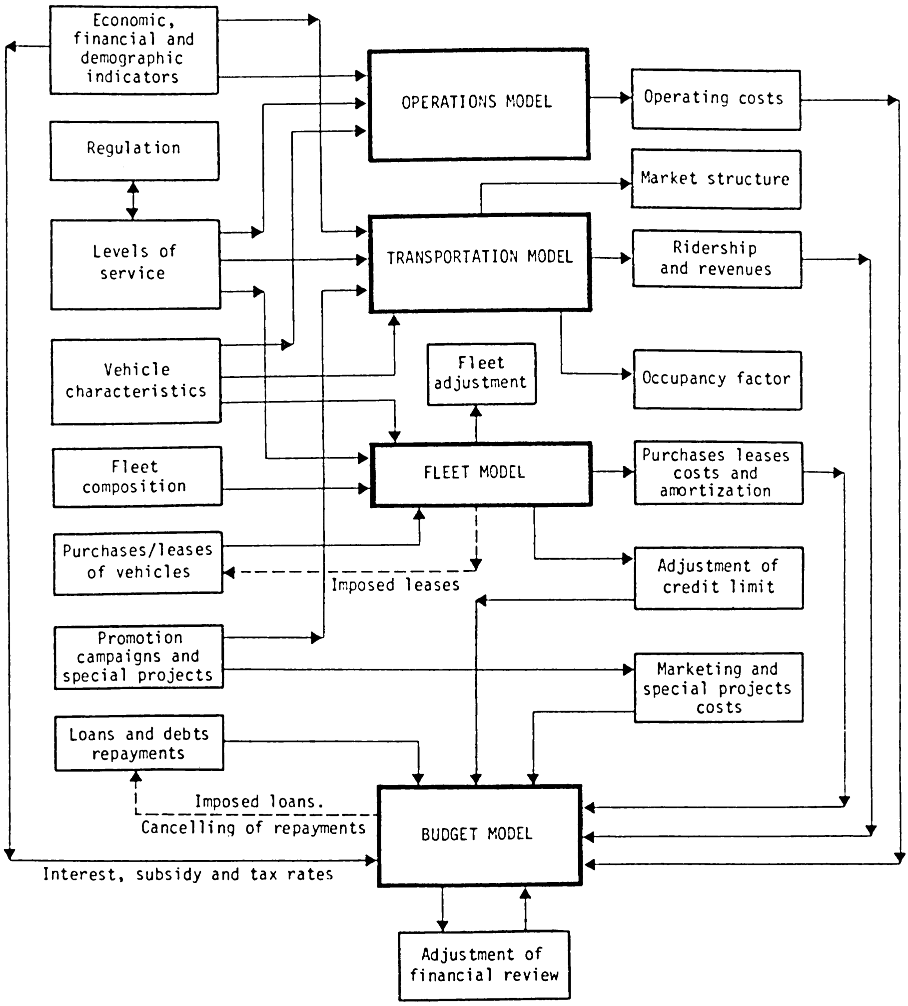

Figure 4: Schematic of the Simulation Program Structure

introduction of new vehicles includes those that were ordered previously but for which the delivery was delayed. The second essential function of the fleet model is to verify the compatibility between the fleet size and the offered services: if a company does not have a sufficient number of vehicles to ensure the services that it offers[4], the program automatically applies the "imposed leases" policy, forcing the company to lease additional vehicles with a financial penalty. The third function is to update the credit limit of the companies on the assumption that the banks determine these limits as a function of the value of the fleets. The fourth function is the registering of the costs of all purchases and leases of vehicles, as well as the amortization which is calculated over the vehicles life-span.

The budget model is a simulation procedure of the financial activities of each company at the beginning and at the end of each year. At the beginning of the year, when companies proceed with purchases, leases, loans and/or debt repayments, the program verifies if the companies are capable of doing such operations considering their financial situation; if it is not the case, the program will impose additional loans on some companies (at a higher rate than the regular loan rate) and/or postpone repayments. This "imposed loan" rate also applies to companies that want to borrow beyond their credit limit. The program is then used to prepare the budget of each company at the end of a year. All other costs and revenues are then assembled: operating costs, interest to pay, marketing campaigns and special project costs, operating revenues, government subsidies and interests received; the taxes to pay are computed (after deduction of amortization) and companies that do not dispose of sufficient financial resources to pay all the expenses are forced again to make an "imposed loan" and/or cancel repayments.

VII. THE TRANSPORTATION MODEL

The transportation model is made up of two parts (refer to Figure 5): a demand model which determines the transportation demand between each city pair, and a route choice and trip assignment model which simulates passenger behaviour on the network while considering the restrictions imposed by the offered capacity.

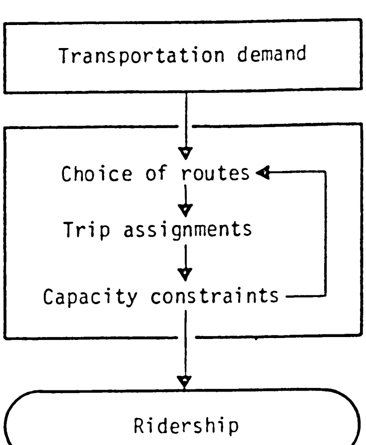

Figure 5: Transportation Model's Structure

The demand model and the route choice component of the second model have mathematical formulations that originate from the linear log forms of total demand models and market share models discussed by Gaudry and Wills[2]. The essential difference relies on the replacement of the concept of "mode choice" by the one of "route choice"[5].

A. The Demand Model

The transportation demand T_{ij} between two cities i and j is estimated with a gravity model that has the following form:

$$T_{ij} = \alpha_0 (P_i P_j)^{\alpha_1} \cdot L_{ij}^{\alpha_2} \cdot S_{ij}^{\alpha_3}$$

$$\text{with } \alpha_0, \alpha_1, \alpha_2, \text{ and } \alpha_3 > 0 \qquad \text{(Eq. 1)}$$

where α_0, α_1, α_2, and α_3 are parameters,

P_i and P_j are the populations of cities i and j, L_{ij} is the linguistic index that measures the linguistic homogeneity of cities i and j, and S_{ij} is a measure of the level of service offered between i and j; this measure is defined as follows:

$$S_{ij} = \sum_{k \in \Lambda^*_{ij}} U_{ijk}$$

$$\text{with } \Lambda^*_{ij} \quad \Lambda_{ij} \text{ and } U_{ijk} = \gamma_{ijk} \cdot C_{ijk}^{\beta_1} \cdot D_{ijk}^{\beta_2} \cdot F_{ijk}^{\beta_3}$$

$$\text{with } \beta_1, \beta_2 < 0 \text{ and } \beta_3 > 0 \qquad \text{(Eq. 2)}$$

where U_{ijk} is defined as the utility[6] of the path k between i and j, Λ_{ij} is the set of all "possible" paths k between i and j, Λ^*_{ij} is the sub-set of four paths that have the greatest utilities, C_{ijk} is the transportation cost between i and j by the path k, D_{ijk} is the travelling time[7] characterizing the path (i,j,k), F_{ijk} is the frequency of service on that same path, and β_1, β_2, β_3 are three parameters determining the utility elasticities regarding cost, time and frequency. γ_{ijk} is a constant which characterizes the company (or the companies) serving the path (i,j,k). The measure S_{ij} is defined over the subset Λ^*_{ij} in order to be based on a common scale for all city pairs.

It should be understood that "possible" paths are the ones that satisfy certain criteria of plausibility; in particular, all paths that require more than one transfer from a service to another are excluded, but we consider several paths that require one transfer, for example, from i to s using company X, then from s to j using company Y. There is a total of over 400 paths considered throughout our network of 21 city pairs. It should also be understood that for paths with a transfer, the transfer costs and the transfer times from a service to another are taken into consideration in the variables C_{ijk} and D_{ijk}.

In order to avoid an unrealistic increase of the demand T_{ij} when companies raise very significantly their levels of service, the gravity relation presented previously (Eq 1) has been restricted asymptotically for large increases of S_{ij}.

B. Route Choice and Trip Assignment Model

In the absence of congestion (supposing that there are no problems relating to capacity constraints), the transportation demand T_{ijk} related to each possible path k between two cities i and j is presented in the following relation:

$$T_{ijk} = (U_{ijk}/U_{ij}) \cdot T_{ij} \qquad \text{(Eq. 3)}$$

$$\text{with} \quad U_{ij} = \sum_{k \in \Lambda ij} U_{ij}$$

where U_{ij} is defined as being the "aggregated utility" of the set of possible paths to travel between i and j. (U_{ijk}, T_{ij} and Λ_{ij} are defined in section A.

It should be noted that if a company (or the companies) operating on a path k between i and j reduces considerably its tariff[8], the utility U_{ijk} of that path can become very large, to such an extent that the company can dominate almost the whole market between i and j; such a situation, even though not probable, is not impossible. On the other hand, if the frequency of service is augmented considerably for one reason or another, there is a limit to the attractiveness of such an increase on the public; consequently, the relation that defines the utility U_{ijk} (Eq 2) has been restricted asymptotically for all large increases of frequency F_{ijk}.

Equation 3 solves the problem of simulating the route choice when the network is not congested. It expresses that travellers try to utilize possible paths as a function of their respective utilities. The transportation demand d_a on each arc a of the network[9] is presented in the following assignment formulation:

$$d_a = \sum_{ijk} T_{ijk} \cdot \Theta^a_{ijk} \qquad \text{(Eq.4)}$$

where $\Theta^a_{ijk} = 1$ or 0 depending if the arc a belongs or not to the path k between i and j. This assignment procedure does not account for capacity constraints $d_a \leqslant \rho_a$, where ρ_a represents the offered capacity on arc a. In other words, this procedure does not account for the fact that some passengers can be turned down due to lack of space on the arcs that compose the path that they want to use. To solve this problem, we utilize a route choice and assignment procedure that is iterative and that can be summarized as follows:

- *Step 0:* For each arc a, v_a = accepted volume on arc a = 0.
- *Step 1:* Knowing the demands T_{ij}, we simulate the route choice (Eq 3) and we assign the resulting flows T_{ijk} on the network (Eq 4), thus obtaining values d_a of the "additional" demands. The demand assigned on each arc a is $D_a = v_a + d_a$.
- *Step 2:* On each arc a where the demand D_a is greater than the capacity ρ_a, we determine the proportion of the additional demand d_a that is excessive. This proportion is

$$f_a = (D_a - \rho_a)/d_a = (D_a - \rho_a)/(D_a - v_a)$$

- *Step 3:* We make the hypothesis that the probability to be rejected on an arc is the same for all travellers that want to use that arc, whatever path (i,j,k) each traveller wishes to use. This hypothesis enables the model to calculate the number of travellers E^a_{ijk} on a path (i,j,k) that are in excess on that path due to a lack of capacity on the arc a; we have:

$$E^a_{ijk} = T_{ijk} \cdot f_a \cdot \Theta^a_{ijk}$$

- *Step 4:* We determine the number of travellers E_{ijk} exceeding the capacity of each path (i,j,k). If this path is composed of two arcs a and b, we have[10]:

$$E_{ijk} = \text{Max}\ (E^a_{ijk}; E^b_{ijk}) = T_{ijk}\ \text{Max}\ (f_a; f_b) \qquad \text{(Eq. 5)}$$

because if the arcs a and b take on $T_{ijk} - E^a_{ijk}$ and $T_{ijk} - E^b_{ijk}$ respectively, this means that together they take on a number of passengers equal to:

$$\text{Min}\ (T_{ijk} - E^a_{ijk}; T_{ijk} - E^b_{ijk})$$

that is T_{ijk} − Max $(E^a_{ijk}; E^b_{ijk})$ passengers. Obviously, if the path is composed of a single arc a, we have:

$$E_{ijk} = E^a_{ijk}.$$

- *Step 5:* On each path, passengers are rejected when in excess. We obtain the flow v_a accepted on each arc a:

$$v_a = D_a - \sum_{ijk} E_{ijk} \cdot \Theta^a_{ijk} \qquad \text{(Eq. 6)}$$

The transportation demand that "exceeds" between each city pair is given by:

$$E_{ij} = \sum_{k \in \Lambda ij} E_{ijk}$$

This "exceeding" demand is a demand that needs to be redistributed in the network after eliminating all paths including arcs that are saturated, i.e. arcs where the capacities ρ_a are exactly attained.[11] After those eliminations, we repeat all the procedures starting with step 1 where we make $T_{ij} = E_{ij}$, and so on.

Note: To prove the convergence of this algorithm, it is sufficient to prove that at step 5, there is always at least one arc a on which the exact offered capacity is reached, after subtracting all exceeding flows. The demonstration follows.

Among all the arcs on which there are exceeding flows (see step 2), there is always at least one arc a on which the exceeding proportion f_a is superior to the proportions f_e calculated on other arcs e. In other words, there is always an arc a such that:

$$f_a \geqslant f_e \text{ for any arc e.}$$

For that arc a, we have (see Eq. 5):

$E_{ijk} = E^a_{ijk} = T_{ijk} \cdot f_a$ for any path (ijk) including that arc.

Equation 6 becomes:

$$V_a = D_a - \sum_{ijk} T_{ijk} \cdot f_a \cdot \Theta^a_{ijk}$$

$$= D_a - f_a \cdot \sum_{ijk} T_{ijk} \Theta^a_{ijk}$$

$$= D_a - f_a \cdot d_a = \rho_a.$$

VIII. CONCLUSION

The multiplicity and diversity of decisions made in order to manage interurban passenger transportation companies render the managers' tasks extremely arduous, especially as the effects of decisions interact between each other. This complex process is a continuous and iterative process that repeats itself in a market environment determined by the strategies of other companies and/or other modes, but is also determined by the socio-economical and political context and by regulations.

The computerized management training game JET-SET presented in this paper enables the learning of these complex situations that characterize the interurban passenger transportation industry. It is aimed at training transportation planners and managers, as well as students interested in this area.

A preliminary version of the program was run experimentally during the fall of 1984, at the George A. Scott Institute of Transport Canada, during a senior transportation management course. This first trial was excellent although the program presented a few weaknesses. The transportation professionals that participated in this course were in general satisfied with the didactic and technical qualities of the system. Their criticisms enabled us to better orient our subsequent developments that brought us to this current version.

In a context where planners and managers of transportation companies do not have any choice but to enhance the competitiveness and the productivity of their company, the use of such specialized techniques seems very suitable and desirable. This applies equally in a governmental context where there is a requirement for adequate knowledge of the transportation market in order to generate adequate policies. Using the scientific qualities of transportation models together with didactic capabilities of micro-computers, tools like JET-SET are a step in the right direction.

ACKNOWLEDGEMENT

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ENDNOTES

1. However, a simplified notion of scheduling is implicit, and players have to take it into consideration.
2. The number of players may be less than 6. In such a case, companies which are not represented by a player stay inert during the match.
3. through immigration policies, for example.
4. The required number of vehicles is based on hypothesis regarding the daily peak period of the transportation demand.
5. This substitution and the specific data characterizing the particular configuration of our network required adjustment to the parameters estimated by Gaudry & Wills.
6. U_{ijk} can be interpreted as the inverse of a generalized cost of transportation.
7. This travelling time includes access and egress time.
8. At the limit, in JET-SET, a company can offer some free services.
9. An arc is defined by two extremities (two cities) and by a company that serves directly those two cities. For example, the arc a = (u,w,x) is the arc of the network that represents the service offered by the company x between cities u and w.
10. We suppose that all paths formed of more than two successive arcs are not "possible" paths.
11. We suppose that vehicles are saturated at 90% of their capacity.

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