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Dynamic Modeling of Complex City Intersections for Transport Flow Problems

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Abstract

The purpose of this paper is to develop and study algorithms for interaction of Software Agents in group decision making support systems intended for logistic problems of control of transport flows on complex city intersections.

The paper regards the problem of modeling and solution of the problem of minimization of transportation costs and idle time of vehicles for the chosen version of the route and schedule at multiple intersections.

The authors offer a generalized algorithm for solution of the problem of drawing up an optimum schedule for traffic through multiple city intersections with the use of Software Agents and dynamic computer models of transport flows. It is also supposed that modeling software can detect formation of problematic situations, change the duration of one-type operations on separate processors and interact in search of the best solution.

The modeling program is controlling intersections under consideration, while the data collection and analysis program interacts with relational database and makes the optimum processors' operating schedule with the help of a group decision making support system. The processor is the traffic lights of the intersection, and the operation is handling of a transport flow to an assigned direction and time.
KEY WORDS: *Software Agent, Logistics.*

1. Introduction

With the help of the developed algorithm from a set of cars for particular intersection applying the Monte-Carlo method we select a certain vehicle. Its parameters are specified in the model: intersection, flow, vehicle ID, its velocity, acceleration, distance to the traffic lights and nearby obstacles, estimated braking distance and the time left until a prohibiting signal of the traffic lights. On the basis of the distance to the traffic lights and obstacles and the braking distance a conclusion on possibility to stop before or on a line at the signal of the traffic lights can be made.

Optimum data about the intersection processors' operating schedule received from the model are passed on by the Software Agents interacting with the database management system, recorded in previously prepared database table and displayed on the screen for users of a group decision making support system.

2. Mathematical Statement of the Research Problem

The following variables will be introduced:

$C = (c_1, c_2, \ldots, c_j, \ldots, c_m)$ – set of considered crossroads; where $c \in C$, i is an index of a crossroad;
$H = (h_1, h_2, \ldots, h_i, \ldots, h_k)$ – set of the given *vehicles* flow; where $h \in H$, i is an index of a car;
$R = (r_1, r_2, \ldots, r_j, \ldots, r_m)$, $r \in R$ – the number of traffic lanes in one direction; where j is an index of a flow;
$v_{i(t)}$ – speed of i vehicle at the time moment t;
sl_i – distance of i vehicle till k-th traffic light at the time moment t;
a_i – acceleration of i vehicle at the time moment t;
t_i – time;
b_i – braking distance of I vehicle till k-th traffic light at the time moment t;
x_i, y_i – position data of i vehicle at time moment t;
sp_i – distance of i vehicle at the time moment t till a car behind;
sa_i – distance of i vehicle at the time moment t till a car nearby;
sn_i – distance of i vehicle at the time moment t till a car in front of it;
TLk_i – duration of operation of L section for k traffic light;
V_{max} – maximum permissible value of speed on j traffic lane for vehicles;
V_{min} – minimum permissible value of speed on j traffic lane for vehicles.

The elements of modern graph theory, maximum flow function, can be used in modelling of vehicles flows.

We will consider the function which is defined for oriented graph $G = (V, E)$ in the following way:

1. each curve $e \in E$ is confered with positive rational quantity $c(e) \geq 0$ — its carrying capacity,
2. there is one top point v_0 — source $\Gamma_{v0}^{-1} = \varnothing$,

3. there is one top point v_z — flow $\Gamma_{vz} = \varnothing$.

Then oriented graph G is called a transport network and marked as $G(T)$.

Let us define flow function $\varphi(e)$ in transport network $G(T)$ as a curve function with the following features:

1. $\psi(e) \geq 0$,
2. $\psi(e) \leq c(e)$,
3. for all $e \in E$: $\sum_{e \in E_v^-} \psi(e) = \sum_{e \in E_v^+} \psi(e)$, where $v \neq V_0$; $v \neq v_z$; $v \in V$; E_v^- is at the top point v set of input curves and E_v^+ is set of output curves.

At each top point v the sum of input flows is equal to the sum of output flows.

We are interested in the maximum value of flow function

$$\max \sum_{e \in E_v^-} \psi(e) = \max \sum_{e \in E_v^+} \psi(e) = \psi_z .$$

We will mark with A transport network's $G(T) = (V, E)$ set of top points $A \subset V$, which contains top point v_z ($v_z \in A$), and does not contain top point v_0 ($v_0 \notin A$). As a section in transport network $G(T)$ we will call curve set E^-_A, which goes to set of top points A. This notion differs from the considered before notion of section in an oriented graph. The section in the previous meaning contains also curves, which go from set of top points A.

The sum of all section curves carrying capacity is called carrying capacity $c(E_A^-)$ of section E_A^-, e.g.,

$$c\left(E_A^-\right) = \sum_{e \in E_A^-} c(e).$$

In the same way we can define also the value of flow $\psi(E_A^-)$ in section E_A^-:

$$\psi\left(E_A^-\right) = \sum_{e \in E_A^-} \psi(e).$$

As flow ψ in each curve e does not exceed its carrying capacity $\psi(e) \leq c(e)$, then there the following dependence is valid

$$\psi\left(E_A^-\right) \leq c\left(E_A^-\right).$$

The let us consider Ford (L. R.)–Fulkerson (D. R.) method for maximum flow defining $G(T)$. It was elaborated in the middle of 50s. The method consists of two parts: in the first part we will define the top points, in the second one we will increase flow function ψ, if top point v_z is defined. If top point v_z has not got a definition, then maximum flow ψ_z in the given transport network $G(T)$ is obtained.

The top point definition is a pair, where the first element is top point, from which the first element gets its definition, and the second one indicates its increasing (at the beginning it is 0).

The defining of top points is made in two ways. The top point v_0 is defined ($-$, $\varepsilon(v_0) = \infty$), which is not changed. We will choose top point v_i defined as (v, $\varepsilon(v_i)$), then all top points $v_{j1}, v_{j2}, \ldots, v_{je}$, which correspond to the restrictions

$$\psi(v_{jk}) = \min\,[\varepsilon(v_i);\ c(v_i, v_{jk}) - \psi(v_i, v_{jk})].$$

The second way to define top points $v_{j1}, v_{j2}, \ldots, v_{jl}$, which correspond to the restrictions $\psi(v_{jk}, v_i) > 0$, is the following: choose designation

$$(v_i^-, \varepsilon(v_{jk})),\ k = 1, 2, \ldots, l;$$

where

$$\varepsilon(v_{jk}) = \min\,[\varepsilon(v_i);\ \psi(v_{jk}, v_i)].$$

If top point v_z is defined as $(v^+_{i1}, \varepsilon(v_z))$ and flow $\psi(v_{i1}, v_z)$, then curve of a new flow (v_{i1}, v_z) is $\psi(v_{i1}, v_z) + \varepsilon(v_z)$ and transition to other curve flows is changed.

If top point v_{i1} is defined as $(v^+_{i2}, \varepsilon(v_{i1}))$, then curve (v_{i2}, v_{i1}) with flow $\psi(v_{i2}, v_{i1})$ is increased for $\varepsilon(v_z)$ and new flow is

$$\psi(v_{i2}, v_{i1}) + \varepsilon(v_z).$$

If top point v_{i1} is defined as $(v^{-}_{i2}, \varepsilon(v_{i1}))$, then curve (v_{i2}, v_{i1}) flow is decreased for $\varepsilon(v_z)$ and new flow is

$$\psi(v_{i2}, v_{i1}) - \varepsilon(v_z).$$

It is continued while top point v_0 is reached, then flow function ψ is increased for value $\varepsilon(v_z)$. The definings of all top points are canceled except v_0, and top point are started to be confered with new definitions. If we can not confer top point v_z with a definition then flow function can not be increased.

The first value $v^{\pm}$ of definition pair shows the shorten curve way from top point v_z to v_0. The second value ε shows possible flow increasing. Let us start with flow $\psi = 0$ for all $G(T)$ curves.

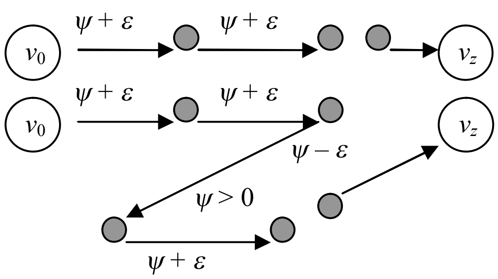

Fig. 1 Both cases of flow increasing

The considered graph theory method is applied in this article to solve the task of transport flow modelling.

It is considering the task of such t, lk, V_{max}, V_{min} defining, when H is maximum. The following algorithm is offered to solve this task.

3. Algorithm of Problem Solution

Step 1. Traffic Department Manager on the client-side (K) enters an inquiry for solution of this complicated problem, using interface (Wr) and information function f Kr:

Step 2. Supra program agent divides this problem into several subproblems

Step 3. To solve multi-criteria assignment problem, when the client has to choose the roads, and the criteria are both quality and quantity criteria, using the server (Fig. 1).

Step 4. Supra agent starts inquiry processing with interface (Wr) using information function (procedure) f Kr: If it receives the answer from server it can move to the next step. If the answer is not received, it has to search it in other server; otherwise the solution does not exist.

Step 5. Server (Wd) starts receiving an answer from data base (Dp) using function (procedure) $f$dp.

Step 6. Server (Wd) starts receiving client's task solution (Pd) using function $f$pd.

Step 7. Server (Wd) starts sending client's task solution to the server (Wr) using function $f$dr.

Step 8. Server (Wr) starts sending client's task solution to Supra program agent SPa that makes solution (s) analysis.

Step 9. To make up a schedule, Algorithm Steps analogue 3-8 are carried out.

Step 10. To analyze and evaluate made up traffic lights' work schedule.

Step 11. Server (Wr) starts sending client's task solution to Supra program agent SPa that makes solution (s) analysis to offer the client only the best task solution using function frSPa.

Supra agent (SPa) offers to the client (K) the best solution using function fSPaK.

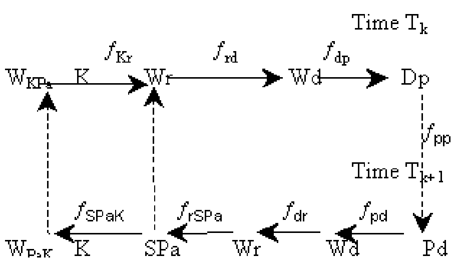

Fig. 2 Fragment of task solution algorithm

4. Role of Supra Agent

After solving one logistics task it is necessary to solve a new one. Supra agent coordinates the task of program agent that has to find an optimal solution for all sub problems.

5. Supra Agent Algorithm for Fixing on Data About Flow in Database

Step 1. Supra agent connects to the database of crossroad *Dp*.
Step 2. All variables of the flow for i = 1 till N about vehicles are set to the the current values.
Step 3. Preparation of SQL query.
Step 4. Execution of the query, writing into data base for the further calculations.

6. Results of Experimental Approbation of the Model

This part considers the results of the experimental approbation of the model. Fig. 3 demonstrates a moment of transport flow in the crossroads area. The main goal of the experiment was to check whether it is possible for vehicles data (speed, acceleration, braking distance and time and possibility to stop it in front of the crossroad) to be put into a specially developed data base.

Later on, the captured data can be applied in the mentioned above mathematic models of transport flows as well as for evaluation of different variants of possible urban transport flow organization, for example public transport zone, arrangement of new traffic lights and highway striping and consequence of these measures.

Fig. 3 There is participants of the flow: two cars, which have reached the traffic lights at the intermediary moment of time

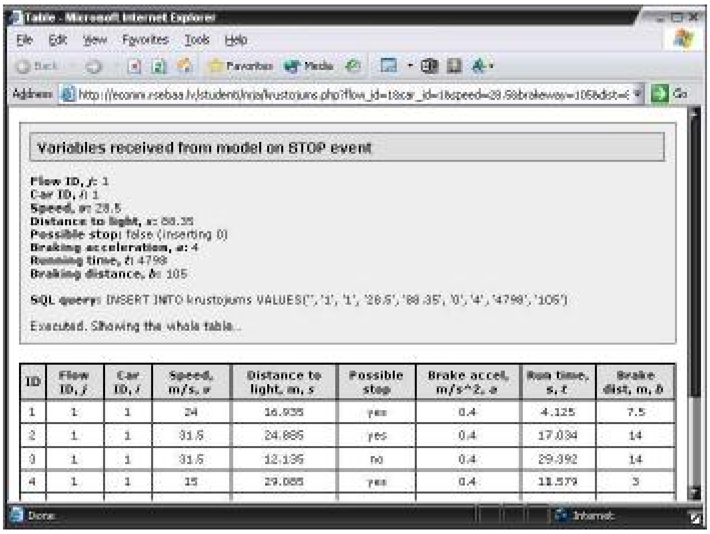

Fig. 4 Fragment of a specially developed data base, which keeps necessary data on vehicles participating in the flow. These data are input with pushing the button “Save current data in DB”

7. Conclusion

The problem of transport flow in modern cities under the condition of hard crossroads is becoming more important taking into account the increasing density transport flow and limited carrying capacity of the streets.

As this work demonstrates the mathematical and real transport flow modeling results do not correspond enough to the real situation because of quite many assumptions and restrictions, thus the transport flow control finds its application quite seldom.

Some progress in this field could be achieved applying the program of visual dynamic modeling of transport flow developed in this work. The program can be input with parameters of transport flows and crossroads characteristics, which allow bringing the developed model near the real situation of a hard crossroad zone.

One of the possible variants to apply data base is using of the algorithm published before [4].

The work demonstrates the principal possibility for visual modeling of transport and pedestrians flow at crossroads and urban transport stops, that proves the validity of the model.

We assume that after some improvement it could be successfully applied for automatization of urban transport or in automatically regulated systems with a correspondent material and technical basis and crossroads accessories.

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