Integrating GIS-Technology for Modelling Origin-Destination Trip in Multimodal Transportation Networks

Hicham Mouncif, Azedine Boulmakoul, and Mohamed Chala
Department of Computer and Sciences, University Hassan II-Mohammadia, Morocco

Abstract: *This paper presents a system proposing a solution to the problem of Origin-Destination (OD) trip modelling for Multimodal Transportation Networks (MTN) using GIS tools. An efficient method for the handling of travel information within the MTN consists of dealing with an optimal multimodal routing of travellers from a point of origin to point of destination. Furthermore, the multimodal travelling alternative offers the promise of efficiency, safety and flexibility. It allows taking advantage of all modalities by using each transportation mode for the part of the journey to which it is best suited. Our aim is to propose an effective design for the multimodal path computation within the MTN. The goal is to provide a travel model that can aid to improve the user's path decision, where travelling might involve different combination of rail, and route. Travellers can access information about all modes of public transportation and ridesharing available in their area, learn more about emissionless forms of transportation and find the fastest, safest routes to their destinations. GIS was invaluable in the cost-effective construction and maintenance of this work and the subsequent validation of mode sequences and paths selections.*

Keywords: *GIS, multimodal transportation networks, multimodal graph, spatial networks.*

Received March 21, 2004; accepted May 232005

1. Introduction

Actual transportation networks are increasingly characterised by several noises: Traffic jam, accidents, air pollution, etc. Hence, limitation of indivi dual accessibility is currently one of the important factors affecting the quality of the daily life. The integration between public and private transport services, with the aim of encouraging the use of public transportation modes with respect to private mode, is a research topic of growing interest.

In this context, Multimodal Transportation Networks (MTN) presents complex topology and restrictions, hence the design of them is a hard task. The question of how to model the MTN, that may include several transportation modes (e. g, bus, metro, car, etc) operating through various information systems is of primary concern.

The GIS-technology facilitates the modelling of spatial networks (e. g., rail and road networks), offering tools to query and analyse them. The GIS-based system can maintain and integrate spatial transportation data from several sources and constitutes a significant decision support. Many advantages are issued from the integration of GIS in transportation modelling (Anderson [1], Niemeier [16]). The primary advantages include analytical capabilities, visual power, efficiency of data storage, integration of spatial databases, and capabilities for spatial analysis (Franklin [7], Muller [15]).

This paper describes the development of a system offering a solution to the problem of modelling passengers' travel paths and transit durations for MTN. The MTN manages the distribution of transportation related information and the coordination of transportation zones for the profit of the travellers. Travellers need enhanced means to access information on alternative transport modes and problems affecting their journeys. The efficient management of MTN in order to achieve fast, safe and comfort transportation of travellers to the appropriate destinations is a vital aspect of the quality of their daily life. In an urban area usually, it is not easy to travel from the working place to the home by only one transportation mode, because the road network is increasingly affected by traffic jam and is not easy to find place in parking and the rail network is scattered and it does not covered all places. The multimodal mobility offers the promise of lowering overall transportation costs by allowing each mode to be used for a suitable appropriate part of the OD trip and thereby reducing congestion and the burden on overstressed networks. Hence, an OD trip may be accomplished using distinct modalities. For instance, an OD trip might require driving a car to a metro station or to bus stop, with possibility of additional transfers within or among modes to complete the trip.

As its name implies, the trip planning module generates shortest multimodal paths for travelers. By providing travelers, especially regular commuters, with traffic and transportation service information prior to embarking on their trips, travelers can make the most informed choices of modes and routings.

One of the purposes of this study is to integrate the developed trip planning module and GIS-technology. We design the MTN, using two views: Geometric view and logical view. The geometric view maintains the spatial networks of the MTN (see section 2). The logical view represents the MTN by a multimodal graph (see section 4). The multimodal graph is comprised of mono-modal sub graphs, where each one models a corresponding mode network of the MTN. The mono-modal sub graphs are interconnected among them by virtual arcs that represent modal transfers. Our goal is to deal with a system offering tools to model and evaluate multimodal optimal path and compute travel times for each individual OD trip within the MTN. It is based on the integration of Geographic Information System (*MapObjects 2.2*, ESRI product). The optimal multimodal OD trip finding module is a main component of the GIS-System (see section 5), informing and assisting travelers in choosing the best path to reach their destination in terms of transit modes, transit routes, accessible transit stations, modal transfers, schedules.

The remainder of this paper is structured as follows. Section 2 describes the MTN object model. In section 3, we present the MTN solver model. Section 4 is devoted to the description of the multimodal graph and the design of the time-dependent multimodal viable optimum routing. Section 5 deals with the GIS System and gives its key functions. Finally, the concluding remarks appear in section 6.

2. MTN Object Model

This section presents a main objects in the MTN object model. Each object is described in the terms of its purpose. The MTN depiction represents the network objects (e. g. stations, roads, etc.) using simplified and conventional topological objects with specific roles. We deal with two views to model the MTN, that are geometric and logical views. The geometric view describes the geographic aspect of the MTN. In geometric view, a network is comprised of linear features through which commodities flow. A network also contains point features where transfers of commodities occur, such as from roads to stations, or from one road to another. In logical network, a network is comprised of edges and junctions. Commodities flow through edges, and edges connect together at junctions, where flow from one edge is transferred to another. Thus, the class *Node* is the most basic element of the object model. It can represent street intersections, railroad switches, bus stops or other point features. Between two point features, a link may be defined to store spatial information. The class *Link* represents connection between two nodes. Two relationships between the class *Node* and the class *Link* specify the limiting nodes of a link. The direction of the traffic flow, for instance, may be defined by appropriate entities, relationships or attributes.

According to *TransModel* (Roach [18]), the physical network represents physical infrastructure, such as streets and their intersections and railroad tracks. It is composed of the road network and rail network. The journeys scheduled during the planning stage are supposed to run along this physical network. The basic classes of the physical network are *TransportArc* and *TransportNode* The road network represents all routes available for vehicles such as a bus route. Two classes: *RoadLink* and *RoadNode* are basic elements of the road network. According to *GDF* (Heres *et al.* [9]), road junction may be located: At intersections of two (or more) road centrelines, at the end of dead end roads, at the intersection of a road element and an *Enclosed Traffic Area* (a two-dimensional level-1 feature in *GDF*), at the intersection of a road segment and a rail segment, at places where the validity of any significant information changes along the road (for instance the width or the number of lanes). The class *Turn* is a specific junction describing possible movements of vehicles at road intersection between specific road segments. Each one is used to model turn restrictions in road network and for detailed road intersection delays. The class *TrafficLightControl* is defined to simulate the operations of traffic light control encountered in intersections of roads. In similarity, the description of the rail network is meant to be a model of the track network along which vehicles (or trains) can physically proceed. Railway aspects are developed in this data model for reference purposes and not for control functions. The rail network is modelled by two classes *RailArc* (track along which metro or train can physically proceed) and *RailNode* (located at switches).

We design the public transit network as a set of mode transit lines in which vehicles served passengers at time points. Hence, we introduce the class *TransitLine* to represent one mode transit line (bus line, metro line, etc.). Since each mode transit line is assigned an itinerary (a designed path in the transit network), we define the class *Itinerary* as a sequence of stations and legs, where a leg is a segment of an itinerary between two successive stations and the class *Station* as a basic element in the public transit network. The class *TransferStation* is a station where passengers can transfer to another mode transit line. Furthermore, each mode transit line is assigned a time table informing about departure and arrival times at time points. The class *TimeTable* provides a efficient method of modelling time table information. The class *TimePattern* defines driving times between stations. It is used to take into account the traffic conditions between two successive stations of the itinerary, specifically in the rush hours. The class *Course* represents a run of the transport service from one departure station to one terminal station at one departure time.

3. MTN Solver Model

In this section we give the spatio-temporal concepts integrated to the GIS-System to deal with the travel data within the MTN. The information related to the trips made by individuals are considered as an important data source for transportation research. This information may describe detailed activities at the individual level. It offers a useful data to derive important statistical information of trip characteristics (e. g., trip length, trip frequency, etc.) and opportunities to gain a better understanding of individual's travel patterns and travel behaviour (Wang and Cheng [20]). Each person normally records the origin location, destination location, starting time, ending time, trip purpose, and travel mode of each trip. The trip information contains spatial, temporal, and attribute information about individual trips and the people who made these trips. The GIS-System organize trip records based on the space-time path concept of time geography, which was first proposed by Hägerstrand [8] and consolidated by himself and his collaborators at a later time (Wachowicz, [19]), suggests concepts that are applicable to handling travel information as trip sequences with spatio-temporal characteristics.

In the GIS-System, we implement the spatio-temporal concept as the techniques performed by (Yu H. and Shaw S. L [21]). Therefore, the entity *Person*, represents the information about individual persons, such as age, gender, and occupation of a person. The entity *Travel information* is composed of trip information, including the origin/destination, starting/ending time of a trip, trip purpose, person who takes this trip, etc., and the entity *Location List* is a list containing location information (e. g., address, name, description) of the origin/destination of trips. The entities: *Location*, *Trip*, *Space-Time Path*, *Snapshot*, and *ST Trip* are objects with explicit geometric representations (i. e., Feature Classes). Among them, *Space-Time Path*, *Snapshot*, and *ST Trip* are spatio-temporal features. A spatio-temporal feature contains not only geometric shape but also temporal information, in which spatio-temporal information is represented as either a set of triplet ({<*x, y, t*>}) for a point feature or a sequence of triplet sets ({<*x0, y0, t0*>, <*x1, y1, t1*>, … }) for a line feature.

MTN solver model use a logical network to perform the path evaluation problem based on the algorithmic approach proposed in the section 4. Our strategy is to provide a network oriented operator that addresses the efficient evaluation of paths within GIS-System (see section 5). The path evaluation operator is one of the most important operators in GIS (Boulmakoul *et al.* [3]). Networks are modelled with graphs, a set of labelled nodes and labelled arcs. This evaluation is applied on huge graphs since the data set associated with a whole network is very large.

4. Description and Design

In this section, we develop a model of the MTN which captures all the possible modalities and the interconnection among them. MTN is composed of mode networks, where each mode network is associated with one transport mode. The modal transfers enable the linking between the mode networks. Then, we represent the MTN by a multimodal graph, where each node represents a place where one has to select between continuing with the current mode or changing it. Arcs correspond to the modal connections between the nodes. We have two kinds of arcs: Transport arc and transfer arc. Transport arc models a linking between two nodes by only one transport mode. A transfer arc represents a commutation from one modality to another. One and only one mode is associated with each arc.

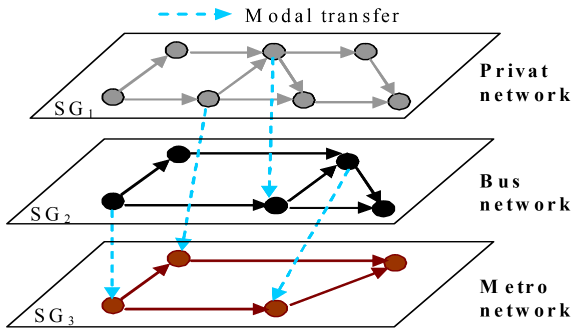

Figure 1. A multimodal graph *G* and its mono-modal sub graphs.

Definition 4.1: A multimodal graph is a triplet G = (N, E, M), where N is the nodes set, E is the edges set and M is the transport modes associated with the arcs.

We assume that each network is modelled by one mono-modal sub graph $SG = (N_r, E_r)$, where N_r is the set of nodes and E_r is the ser of arcs, $r \in M$. The multimodal graph $G = (N, E, M)$ is partitioned to a set of mono-modal sub graphs: SG_{r1} (N_{r1}, E_{r1}), SG_{r2} (N_{r2}, E_{r2}), …, SG_{rq} (N_{rq}, E_{rq}), (e. g., see Figure 1) such that:

$$N = N_{r1} \cup N_{r2} \cup \ldots \cup N_{rq}, N_{ri} \cap N_{rj} = \varnothing,$$

$$E_{r1} \cup E_{r2} \cup \ldots \cup E_{rq} \subset E, \quad E_{ri} \cap E_{rj} = \varnothing, \text{ wehere } i \neq j \text{ and } r_i \in M, \text{ for } 1 \leq i \leq q.$$

Let *Ts* be the set of modal transfers between the different modalities, then the elements of *Ts* are the transfer arcs, and we have the following:

$$E = E_{r1} \cup E_{r2} \cup \ldots \cup E_{rq} \cup Ts$$

4.1. Multimodal Viable Path Description

Now, we are interested to find the multimodal shortest path from the node origin to the node destination, that respects the set of constraints on its sequences of used modes and includes an acceptable number of modal transfers, on the multimodal graph $G = (N, E, M)$.

A path Π_{xy} between the node x and y is an alternating sequence of nodes and arcs of the form $(z_1, z_2, \ldots, z_m)$, in which: $z_1 = x$ and $z_m = y$. In a multimodal context we find two types of paths: The mono-modal path and the multimodal path.

Definition 4.1.1: A mono-modal path is a path accomplished by only one mode $r \in M$. Hence, the path $\Pi_{xy} = (z_1, z_2, \ldots, z_m)$ is mono-modal, if $z_i \in N_r$, $r \in M$, $\forall\, i \in \{1, \ldots, m\}$.

Definition 4.1.2: A multimodal path is a path accomplished by using several modes. Hence, the path $\Pi_{xy} = (z_1, z_2, \ldots, z_m)$ is multimodal, if the nodes z_i , $\forall$ i $\in \{1, \ldots, m\}$, belongs to distinct nodes set.

In Transportation Networks System, it is not easy to use the private vehicle down town because the private network suffers of traffic jam and also the parking space is not enough, rail network is scattered and it does not arrive everywhere, but surface network is thick and arrives almost everywhere. Since rail network is connected and its transfers are made easier to user, then a user takes it long as possible in her/his path.

Several models have been proposed on shortest paths on multimodal networks: Fernandez *et al*. [6], studied the shortest path on bimodal networks. Pallottino and Scutellà [17] considered the number of modal transfers in a path as an attribute in the multicriteria shortest path. Modesti P. and Sciomachen A. [13] presented a utility measure for finding multiobjective shortest paths in urban multimodal transportation networks. Miller and Storm [12], created a modal transfer arc for representing each modal change. Ziliaskopoulos and Wardell [22] studied time-dependent least time paths on multimodal networks, without explicitly expanding the network. Crainic and Rousseau [5] included a node to represent a set of operations done in terminal, and generated a limited number of ‘‘best’’ itineraries to reduce costs and delays, and improve the quality of service. Few research has been introduced the definition of viable path in multimodal transit (Battista *et al*. [2], A. Lozano and G. Storchi [10, 11], Mouncif and Boulamkoul [14]).

A characteristic of viable path is the use of distinct modes of transportation. The traveller has a set of several modes for travelling, but he/she not disposed to undertake too many modal transfers. Coherent with the works (Storchi *et al*. [11], Sciomachen *et al*. [13]), we assume that no modal transfer allows to transfer from public modes to private mode since it is implicitly assumed that once path is not started with private modality, it is not possible anymore to take it for reaching the destination. For this reasons an *OD* feasible path that uses the private mode, it takes it at the origin node *O*. In the following, the private mode and the rail mode are considered as constraint modes. Then, the viable path is a path that respect the following constraints:

- The number of modal transfer of the path must respect the maximum that the user is able to establish.
- If the path uses the rail mode, it must include only one consecutive sequence of rail mode.
- If the path uses the private mode, it must include only one consecutive sequence of private mode with initial node *O*.

In order to deal with the formulation of the multimodal viable path, we introduce the definitions of some notations that will be used in the rest of the paper. Let *(v, u, w)* denote a node-triplet on the multimodal graph *G*. By the notation *Transit (v, u, w)* we mean, the transit from the node *v* through the node *u* to the node *w*.

Definition 4.1.3: Let (v, u, w) be a triplet nodes on the graph G. Transit (v, u, w) is Monomodal, if the arcs (v, u) and (u, w) are associated with the same mode $r \in M$.

Definition 4.1.4: Let (v, u, w) be a triplet nodes on the graph G. Transit (v, u, w) is Begin_ModalTransfer, if the arc (v, u) is a transport arc, and the arc (u, w) is a transferarc.

Definition 4.1.5: Let (v, u, w) be a triplet nodes on the graph G. Transit (v, u, w) is End_ModalTransfer, if the arc (v, u) is a transfer arc, and the arc (u, w) is a transport arc.

Figure 2 illustrates examples for the definitions 4.1.3, 4.1.4 and 4.1.5.

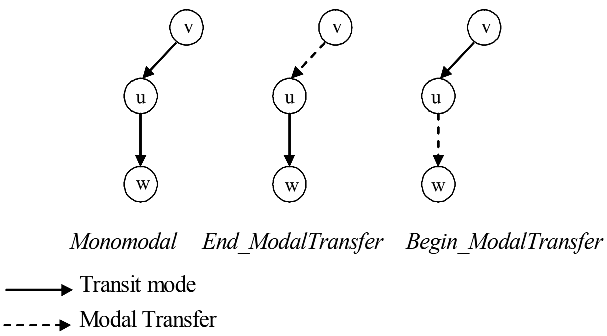

Figure 2. Transit type illustration.

Let *(v, u, w)* be a node triplet on the graph *G*. As a consequence from above discussions, we have the following results:

- If *Transit (v, u, w)* is *Monomodal*, then the *Transit (v, u, w)* is viable.

- If *Transit (v, u, w)* is *End_ModalTransfer*, then the viability of the transit from node *v* through node *u* to node *w*, must be controlled.
- Finally, if *Transit (v, u, w)* is *Begin_ModalTransfer*, then the number of modal transfers is incremented and tested if not superior of the maximum transfer given by the user.

Dealing with the previous assumptions of the viable path, we define the procedure used for determining the viability of the *Transit (v, u, w)*. We assume that the path Π_{OD} from the nodes *O* to *D* is comprised of sequence of *Transit (v, u, w)*. We consider the set of transit modes *M = {Private vehicle (P), Bus (S), Metro (R)}*. Each arc *(v, u)* is associated with one mode, denoted by *mode (v, u)*. In this case, we consider the modal transfer as a mode. The notations *Mod (v, u)* and *Transf_Number(v, u)* represents the set of modes and the number of modal transfers respectively, in the current path Π_{Ou} from the origin node *O* to the node *u* through the arc *(v, u)*. If *Transit (v, u, w)* is a *End_ModalTransfer*, we use the following procedure.

```
Switch (mode (u, w))
  Begin
       Case (Private):
         If (Mod (v, u) = O or Mod (v, u) =P)
            Transit (v, u, w) is viable and Mod (u, w) = P
       Break;
       Case (Rail mode):
         If (Mod (v, u) = O, US, UP, or R)
            Transit (v, u, w) is viable and Mod (u, w) = R
       Break;
       Default:
       Case (Surface mode):
          If (Mod (v, u) = O)
             Transit (v, u, w) is viable and
              Mod (u, w) = S
          Else
             Transit (v, u, w) is viable and Mod (u, w) =
             Mod (v, u)
       Break;
  End
```

To allow entering a node origin, we introduce a virtual arc *(0, O)* in the beginning of the trip. It is associated with *Mod (0, O) = O*. Furthermore, Leaving one transit mode $m \in M$, in the current path Π is denoted by *Um*, it means that the transit mode *m* was used in the current path Π.

In the case where the *Transit (v, u, w)* is a *Begin_ModalTransfer*, we need to confirm if the number of modal transfers associated with the arc *(v, u)* is not superior than the maximum of transfers given by the user (*Max_transfer*), then the number of modal transfer performed on the current path to arrive at the node *w* is incremented, and marked that the transit mode of the arc *(v, u)* it was used to arrive at the node *w*. Those steps are defined in follows:

```
If (Transit (v, u, w) is Begin_ModalTransfer)
Begin
   If (Mod (v, u) ≠ O and Transf_Numbe(v, u) <
       Max_transfer )
     Begin
        If (Mod (v, u) = UR, US, or UP)
           Mod (u, w) = Mod (v, u) and
           Transf_Numbe (u, w) = Transf_Numbe (v,
                                             u) + 1
           Transit (v, u, w) is
           viable_Begin_ModalTransfer
        Else
          Mod (u, w) = Concatenation (U, Mod (v,
                      u)) and Transf_Numbe (u,
                      w) = Transf_Numbe (v, u) +1
         Transit (v, u, w) is
         viable_Begin_ModalTransfer
     End
End
```

4.2. Time Constrained

In MTN, schedule transit mode lines serve several stations, and each one is associated with related scheduled departures. Then, our goal is to deal with efficient schedule model, where each station has a set of scheduled departures serving next stations. A node on the graph *G* can modelled station, parking, light control, and more.

From the above, we assume that each station *u* is associated with a set of scheduled departures list denoted by $DL(u) = \{D_{0,w,}, D_{1,w}, \ldots, D_{r,w}\}$, where *w* is one successor of the node *u* and $D_{i,w}$ represents the i^{th} scheduled departure serving the arc *(u, w)*. Let *(v, u, w)* be a node triplet on the graph *G*. We denote by $Time_m$ *(v, u)* the time required to travel from node *v* to node *u* on mode $m \in M \cup Ts$. *Delay (v, u, w)* denoted the delay at node *u*, when traveling from node *v* through node *u* to node *w*.

- In the case where *Transit (v, u, w)* is *Monomodal*, *Delay (v, u, w)* may represented the time penalties associated with the turning movement delay.
- If *Transit (v, u, w)* is *End_ModalTransfer*, then *Delay (v, u, w)* is the waiting time until the coming scheduled departure.
- Finally, if *Transit (v, u, w)* is *Begin_ModalTransfer*, we assume that leaving one transit mode associated with the arc *(v, u)* is accomplished without delays.

For each node *u*, we define the following labels: Arr_m *(v, u)* is the arrived time at node *u* through an arc *(v, u)* on mode $m \in M \cup Ts$, and $Dep_{m,n}$ *(v, u, w)* is the departure time from node *u*, provided that we visit it through arc *(v, u)* on mode *m* and the next arc to travel on mode *n* is *(u, w)*, where $m, n \in M \cup Ts$. Figure 3 illustrates the arrived time, the departure time, the delays and the travel time associated with a *End_ModalTransfer*.

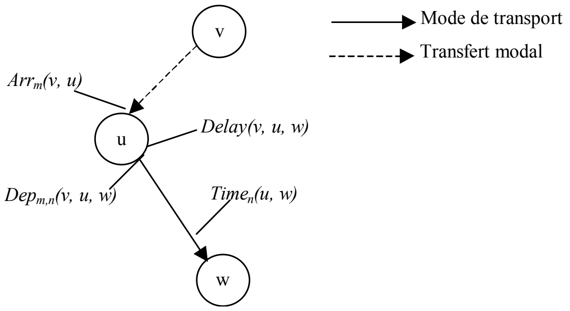

Figure 3. Representation of labels associated with *End_ModalTransfer*.

Now we define a strategy to calculate $Dep_{m,n}(v, u, w)$ and $Delay(v, u, w)$, in the case where $Transit(v, u, w)$ is ***End_ModalTransfer***, where $m \in Ts$, $n \in M \setminus \{P\}$, and $Arr_m(v, u)$ is the arrived time at node u on mode m. Let $DL(u) = \{D_{0,w}, D_{1,w}, \ldots, D_{r,w}\}$ be a list of scheduled departures associated with the transit mode station u and serving the arc (u, w). The procedure is done as follows:

Consider the time intervals $([D_{i-1,w}, D_{i,w}])_{1 \le i \le r}$.
If $(Arr_m(v, u) < D_{0,w})$ *then*
  $Dep_{m,n}(v, u, w) = D_{0,w}$ *and* $Delay(v, u, w) = D_{0,w} - Arr_m(v, u)$
Else
  If $(Arr_m(v, u) > D_{r,w})$ *then*
    $Dep_{m,n}(v, u, w) = \infty$ *and* $Delay(v, u, w) = \infty$
  Else
    Find integer i such that $Arr_m(v, u) \in [D_{i-1,w}, D_{i,w}]$.
    If $(Arr_m(v, u) = D_{i-1,w}$ *or* $Arr_m(v, u) = D_{i,w})$ *then*
      $Dep_{m,n}(v, u, w) = Arr_m(v, u)$ *and* $Delay(v, u, w) = 0$
    Else
      If $(Arr_m(v, u) > D_{i-1}$ *and* $Arr_m(v, u) < D_{i,w})$ *then*
        $Dep_{m,n}(v, u, w) = D_i$ *and* $Delay(v, u, w) = D_{i,w} - Arr_m(v, u)$
      End if
    End if
  End if
End if

This procedure can be done in time $O(\log r)$ by binary search, where r is the number of scheduled departures.

4.3. Design of the Multimodal Shortest Viable Path Procedure

The algorithm proposed is a version modified of our K-shortest path algorithm [14] to which we integrated the new design of the multimodal viable path in order to define an efficient solution for multimodal shortest viable path problem.

Algorithm:

1. Initialization: $Arr_m(0, O) = 0$; $Arr_m(v, u) = \infty$; $\forall (v, u) \in E$; $m \in M \cup Ts$; Insert the values $Arr_m(v, u)$ into the set X;
2. Find and remove the minimum value $Arr_m(v, u)$ from X;
3. For each arc (u, w) emanating from node u do
   If (Transit (v, u, w) is viable) then
     $Dep_{m,n}(v, u, w) = Arr_m(v, u) + Delay(v, u, w)$;
     $Temp(u, w) = Dep_{m,n}(v, u, w) + Time_n(u, w)$;
     If $(Temp(u, w) < Arr_m(u, w))$ *then*
       $Arr_n(u, w) = Temp(u, w)$;
       Update the value $Arr_n(u, w)$ *in X;*

   Else
     If (Transit (v, u, w) is viable_Begin_ModalTransfer) then
       $Dep_{m,n}(v, u, w) = Arr_m(v, u)$;
       $Temp(u, w) = Dep_{m,n}(v, u, w) + Time_n(u, w)$;
       If $(Temp(u, w) < Arr_m(u, w))$ *then*
         $Arr_n(u, w) = Temp(u, w)$;
         Update the value $Arr_n(u, w)$ *in X;*
4. *If X is not empty then go to step 2, else stop the algorithm.*

Proposition 4.3.1: The algorithm with a Fibonacci heap as a storage data structure has computational complexity $O(|E| * |N|)$.

Proof: To obtain the time complexity of the algorithm, recall that it involves operations if initialization (step 1) is $O(|E|)$, take one node and remove it from the scanning set (step 2) is $O(|E| * \log(|E|))$. Two operations: Viability tests and decrease-values jointly determine the complexity of step 3. As far as decrease-value is concerned, we need to examine $|N|$ nodes each with at most $|E|$ arcs to update the associated labels. In each examination of one arc, we need to compute the departure time and delay by calling the appropriate procedure done in $O(\log r)$.

It is clear that the step 3 determines the major complexity of the algorithm. We need to examine $|N|$ nodes each with at most $|E|$ arcs, i. e., $|E|$ values to update. Thus, the complexity of the algorithm is $O(|E| * |N|)$. □

5. GIS-System Environment

To facilitate the interaction between decision makers with a complex transportation model, we constructed a stand-alone *Graphical User Interface (GUI)* (see figures 4 and 5). The *GUI* is designed to include all computational steps in the transportation systems analysis process and to present the computational results in various formats such as graphs, tables and maps. To implement this *GUI* system we employed the following software elements: 1) *Microsoft Visual C++* (version 6.0) for *GUI* development, 2) *ESRI's MapObjects* (version 2.2) as a mapping tool and 3) *Oracle 9i* for data management. Here, it should be remarked that all computational procedures (or modules) described in the previous section were coded in C++. The modules were then converted to the *Dynamic Link Library (DLL)* using the *Component Object Models (COM)* Builder toolbox so that *Visual C++* can refer them. *MapObjects* is employed to represent diverse computational results in a series of color maps with proper scales and legends. The data model describing in previous is integrated into a general object model frame for a broad range of objects dealing with the topological networks.

In general, network development is an integrated process of building links and nodes. Links represent road and rail segments. Nodes represent intersections. These form the framework for building other features. A network is not only a representation of physical alignment or location of a roadway and transit system, but more importantly, it is a representation of a transportation system supply, such as, capacity, speed, area type, length, intersection delay and turn prohibitions, as well as how travel demand can be loaded on transportation networks. In addition, three kinds of data are required by the GIS-system: MTN description, traffic control plans and traffic conditions.

The traffic conditions may be input as the turning proportions at junctions plus the input distribution of vehicles. The MTN description includes the spatial networks (i. e., the geometry of networks), turning movements, link and junction features, location of detectors along the networks, transit vehicles, transit lines and transit segments. The traffic control plans are composed of the description of stages and their durations for signal controlled junctions. The traffic networks are modelling as a set of links connected to each other through nodes. The links are composed of section entities which correspond to lanes, and nodes are made up of node entities which connect input and output entities and define the turning movement. An entity link, is defined by a set of attributes whose values are specified through a dialogue window. The node description consists of node identifier, spatial coordinates, and labels. The description of one link may include several attributes: Direction (i. e., the start node and the terminal node), list of modes allowed on the link, link type, number of lanes, maximum speed, capacity and a user attribute. The notion of road traffic is incorporated in terms of traffic occupancy. In many real-time applications, traffic volume is measured in vehicles/h with the help of sensors.

An important feature of the software that allows for the modelling to be done correctly is the ability to assign a delay codes for turning movements. A turn delay is an impedance associated with travelling from one link to another, and it's primary use is to model intersections. Turns were performed in two ways. During path building whenever the path went from a walking mode to a transit mode, there was a delay that account for waiting times and differences in headways. Leaving one transit mode to a walking mode did not require a delay. Going from a transit mode to another transit mode is a transfer modal and one transfer modal must be added to the path. Adding turn delays then made sure that the paths that were determined did not unrealistically include numerous changes of route or getting off and on the transit mode without some penalty.

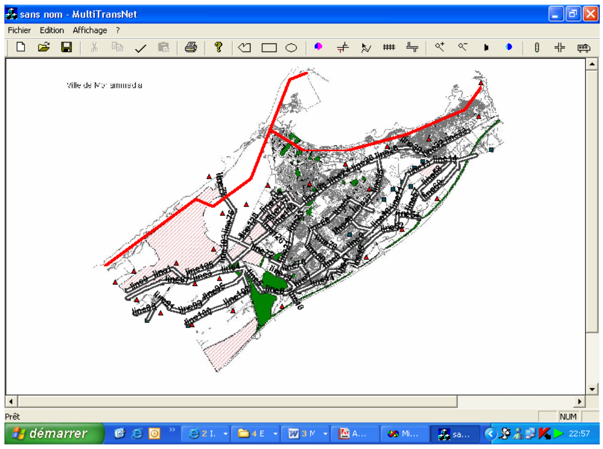

Figure 4. Illustration of MTN design.

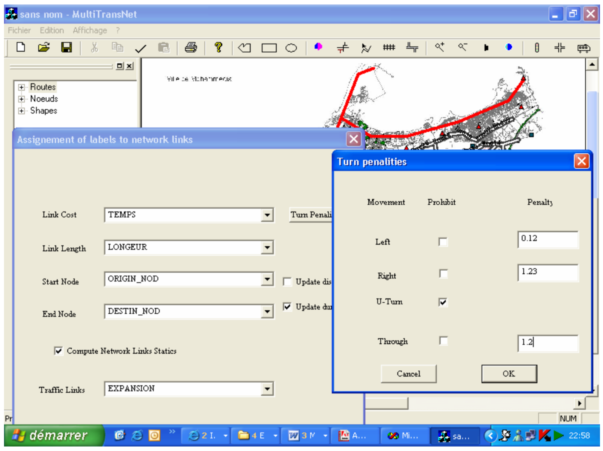

Figure 5. Procedure to update link's labels and turns impedance.

6. Conclusions and Future Work

In this paper, we have described a modelling procedure to evaluate optimal path and to compute travel times for each multimodal OD trip. Furthermore, the GIS-System developed, offers a solution to the problem of modelling an *OD* trip for the Multimodal Transportation Networks (MTN). Its purpose is to enhance the evaluation of multimodal transportation demand and to permit geographical analysis of traveller's behaviour. We have modelled the MTN by a multimodal graph, where each mode network is represented by one mono-modal sub graph. This graph model provide a efficient formal framework for structuring the MTN, enable to speed up the computation of the multimodal shortest viable path and also to performed a new design for the multimodal path finding. The proposed approach algorithmic add more aspects of the integration of the path evaluation operator into the GIS-analysis. The users can define the number of modal transfers and the mode of transport he/she preferred to reach his/her destination. The complexity of the approach algorithmic is done in $O(|E| * |N|)$.

An important extension suggested of our work, is the integration of the spatio-temporal modelling and querying of mobile objects (Brinkhoff [4]) (e. g., vehicle, persons, etc.) to deal with travel information collected basing on the new technologies, such as Global Positioning System (GPS) and Global System for Mobile communication (GSM).

References

[1] Anderson L. D., "Applying Geographical Information Systems to Transportation Planning," *Transportation Record*, no. 1305, pp. 113-117, 1991.

[2] Battista M. G., Lucertini C. M. and Simeone B., "Path Composition and Multiple Choice in a Bimodal Transportation Network," *in Proceeding of theSeventh WCTR* , Sydney, Australia, 1999.

[3] Boulmakoul A., Laurini R. Mouncif H., and Taqafi G., "Path-Finding Operators for Fuzzy Multimodal Spatial Networks and Their Integration in Mobile-GIS," *in Proceedings of 2nd IEEE International Symposium on Signal Processing and Information Technology (ISSPIT)*, Marrakech, Morocco, pp. 51-56, 2002.

[4] Brinkhoff T., "A Framework for Generating Network-Based Moving Objects," *GeoInformatica Journal*, vol. 6, no. 2, pp. 153-180, 2002.

[5] Crainic T. G. and Rousseau J. M., "Multicommodity, Multimode Freight Transportation: A General Modelling and Algorithmic Framework for the Service Network Design Problem," *Transportation Research*, Part vol. B-20, no. 3, pp. 225-242, 1986.

[6] Fernandez E., DeCea J., Florian M., and Cabrera E., "Network Equilibrium Models with Combined Modes," *Transportation Science,* vol. 28, no. 3, pp. 182-193, 1994.

[7] Franklin C., "An Introduction to Geographic Information Systems: Linking Maps to Databases," *Database*, vol. 15, no. 2, pp. 12-21, 1992.

[8] Hägerstrand T., "What About People in Regional Science?," *Papers of the Regional Science Association*, vol. 24, pp. 7-21, 1970.

[9] Heres L., Lahajie P., Claussen H., Lichtner W., and Sielbold J., "*GDF*: A Proposed Standard for Digital Road Maps to be Used in Car Navigations Systems," *Rapport Technique*, Philips CE/CIS-Lab, Eindhoven, Holland, 1993.

[10] Lozano A. and Storchi G., "Shortest Viable Hyperpath in Multimodal Networks," *Transportation Research*, Part B-36, pp. 853-874, 2002.

[11] Lozano A. and Storchi G., "Shortest Viable Path Algorithm in Multimodal Networks," *Transportation Research*, Part A-35, pp. 225-241, 2001.

[12] Miller H. J., Storm J. D., "Geographic Information System Design for Networks Equilibrium-Based Travel Demand Models," *Transportation Research*, Part C-4, pp. 373-389, 1996.

[13] Modesti P. and Sciomachen A., "A Utility Measure for Finding Multiobjective Shortest Paths in Urban Multimodal Transportation Networks," *European Journal of Operational Research,* vol. 111, no. 3, pp. 495-508, 1998.

[14] Mouncif H. and Boulmakoul A., "Multimodal Transportation Networks: Object Modelling and K-Multimodal Shortest Path," *in the Proceedings of the International Conference on Information Systems and Engineering*, pp. 75-80, Montreal, Canada, 2003.

[15] Muller J. C., "Latest Developments in GIS/LIS," *International Journal of Geographic Information Systems,* vol. 7, no. 4, pp. 293-303, 1993.

[16] Niemeier-Debbie A. and Kate-Beard M., "GIS and Transportation Planning: A Case Study," *Computers Environment and Urban Systems*, vol. 17, no. 1, pp. 31-43, 1993.

[17] Pallottino S. and Scutellà M. G., "Shortest Path Algorithms in Transportation Models: Classical and Innovative Aspects," *Technical Report*: *TR-97-06*, Universita Di Pisa, Dipartimento Di Infomatica, 1997.

[18] Roach H., "*EUROBUS*/ Transmodel Project: Public Transport Data Modeling," *Technical Report of Advanced Transport Telematics*, *EEC* DG XIII, Bruxelle, Belgium, March 1993.

[19] Wachowicz M., *Object-Oriented Design for Temporal GIS*, Taylor & Francis, London, 1999.

[20] Wang D. and Cheng T., "A Spatio-Temporal Data Model for Activity-based Transport Demand Modeling," *International Journal of Geographical Information Science,* vol. 15, no. 6, pp. 561-585, 2001.

[21] Yu H. and Shaw S. L., "Representing and Visualizing Travel Diary Data: A Spatio-Temporal GIS Approach," *in Proceedings of the ESRI User Conference Proceedings*, pp. 1-13, 2004.

[22] Ziliaskopoulos A. and Wardell W., "An Intermodal Optimum Path Algorithm for Multimodal Networks With Dynamic Arc Travel

Times and Switching Delays," *European Journal of Operational Research*, vol. 125, no. 3 pp. 486-502, 2000.

Hicham Mouncif received his BS degree in mathematical & computer science from the Faculty of Sciences and Techniques BeniMellal in 1999, and the MS degree in mathematical & computer science from the University of Ben Msick, Casa-Blanca in 2001. He received his PhD in computer science from the Faculty of Sciences and Techniques Mohammadia (FSTM), Morocco in 2005. His research interests include spatial databases, intelligent transportation systems, algorithms & applications, and mobile-GIS.

Azedine Boulmakoul received his PhD in computer engineering and his diploma in research supervisor from the Claude Bernard University Lyon-I, France, in 1990 and 1994, respectively. In 1987, he was an assistant professor at the INSA of Lyon. In 1988, he joined the National Institute of Research on Transportation and their Safety (INRETS-Paris) as a researcher. He participated intensively in European programs DRIVE (I+II) during the period 1987 till 1994. Currently, he is a professor in Faculty of Sciences and Techniques Mohammadia (FSTM), Morocco. He received with his team of INRETS the sphere of the "Mécénat" 1991, a prize discerned by the French Academy of Science. In 1999, he received the 3rd prize of the innovation of R&D Morocco. His research interests include reactive intelligent system development.

Mohamed Chala received his BS degree in computer science from the FSTM in 2002 and the MS degree from Higher School of Technology, Fes, Morocco in 2004. He is a PhD candidate in computer science, Department of Computer Science, FSTM. His research interests include mobile databases, location based services and GIS-Mobile, and telegeomonitoring systems.