Approximating Inter-modal Travel Cost Using a Hierarchical Accumulated Cost Surface Method

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Abstract
An essential component of spatial analysis travel is often inter-modal and any surface such as the ground, air or water can be a travel path depending on the travel mode. Current geospatial software, while offering various procedures for complex computation of travel costs based on different factors, can however become quite cumbersome, inflexible and limited in meeting a researcher's needs especially when dealing with inter-modal travel. To more realistically capture this ground truth, simulation models need fast and efficient methods that take into consideration available travel modes rather than simple networks. An innovative approach for computing and visualizing optimal paths in inter-modal travel is proposed in this paper. A modified Accumulated Cost Surface method is used with several travel cost surfaces created based on the underlying topography and available modes of travel. Preliminary tests demonstrated a high level of success in computing travel time on actual road network data. This paper discusses the effectiveness and limitations of this method. Current findings suggest that this method might provide a convenient way for computation and visualization that is suitable for use in Web-based planning support systems.

Keywords: path finding; accumulated cost surface; inter-modal travel; web-based planning support systems

1. Introduction
1.1 Path-finding computation in Planning
Path-finding and resource allocation are some of the most common and crucial procedures performed in socio-economic and environmental planning. They form an integral part in planning for transportation, energy supply, service access and disaster mitigation, etc. Travel cost and the search for the Optimal or Least Cost Path (LCP) from among available path options is a fundamental element in performing these procedures.

For a given origin and destination, there are usually multiple ways in which to travel. The mode of travel is usually the first thing to be considered before traveling. The mode determines the cost, be it in terms of time taken, money spent, comfort, environmental burden, etc. While the human brain can easily though maybe not accurately approximate the best course of action to take, modeling all these factors in a computer simulation can be a complicated process. These many factors to consider when deciding the way to travel create many options resulting in many paths or networks to be analyzed to obtain an optimal path. The travel options are also dependent on the available modes of travel which can also change depending on the person's current location. The networks generated by individual or a combination of available different modes of traveling are often complicated. Take for example a person traveling from their home to a shopping mall (Fig.1.). Depending on their priorities (time, money, health or environmental consciousness, etc), they might prefer to walk or drive or take a bus, a train, etc. In looking for a suitable site for a shopping mall, investors might want to know the number of customers in a service area when any one or a combination of available modes is considered. An analysis method considering all available travel modes can result in better judgment.

Fig.1. Abstract Example of Travel Options and Resulting Networks
this research involves the use of an algorithm that hierarchically computes inter-modal travel cost on a regular grid of cells that describe travel related conditions of the underlying surface. The initial data preparation is done using GIS. The algorithm can be implemented in spreadsheet software such as Microsoft Excel or by writing a simple program using any programming software. For the authors’ study, the algorithm is programmed in FORTRAN77 and runs independently which offers users the freedom to easily change computation parameters as well as flexibility to incorporate the program into any simulation model.

The proposed method demonstrated a high level of success in travel time computation using actual ground data. This paper also discusses its effectiveness and limitations, and, due to the favorable computation speeds and the ease with which data can be created or modified, it is suggested that the method might also provide a convenient way for path finding computations and visualization suitable for use in WebGIS-based planning support systems.

1.2 A note on LCP Algorithms

Most current geospatial software such as Geographical Information Systems (GIS) have functions and tools for computing optimal travel paths using LCP algorithms. These algorithms try to find the path of least resistance based on various impedance factors such as distance, time, monetary cost, slope or any other user-defined factor. LCP computation is usually done on either raster or vector format datasets. Many advanced studies in transportation research (e.g. Bell 2008, etc) focus on deriving more efficient and faster algorithms usually based on vector networks and have mostly found effective use in navigation systems as well as in the advanced vector-based functions or tools in GISs. However, these vector network-based tools and methods can become quite cumbersome, inflexible and limited in meeting a researcher's needs (Upchurch et al. 2004). It has been argued that the vector-based network models are suitable for analyzing precisely defined paths, such as roads and rivers or drainage canals. They are limited by their inability to deal effectively with what traditionally is termed as "off-network" areas forcing users to use simple methods such as buffers, thissen areas, etc, which do not fully consider the characteristics of the underlying surface (Fig.2.). Some of these simple approximation methods often give a rough and often misleading representation. The issue of correctly approximating travel cost in these "off-network" areas is important for a more wholesome spatial analytics.

It is important to note that travel is often inter-modal and any simulation that aims to more realistically capture the ground truth needs fast and efficient methods that must take into consideration available travel modes. Available travel modes will often dictate the available travel paths. This means that for the same origin and destination there exist at least as many different path networks as the available travel modes thus requiring a new definition for "on-network" and "off-network" areas. Representation of a surface as a network of all available travel modes in vector format can be a dauntingly difficult task and sometimes would require abstract judgment. Otherwise, the network generated might prove to be too large and complicated taking too much manual and computation time for practical use in simulation models that employ vector network-based optimal path computation algorithms. Drawing a walking path through an open space or park is a good example of a problem with infinite possible paths that would demand no-itional choices when creating a vector network. As an alternative solution, raster-based network models are better suited for computation over continuous surfaces where there are no specified paths or and various modes of travel are possible.

2. Review on Raster-Based LCP Computation

Raster-based procedures for path analysis, including routing or LCP computation and analyses, have been proposed, tested by various researchers and have become established in many geospatial and imaging applications. Smith et al. (2007) gives a brief concise description of these established raster-based approaches with introduction of commonly used terms such as Cost Distance, Accumulated Cost Surface (ACS), Distance Transform (DT), and other methods. Cost distance usually refers to the raster-based procedure for determining optimal paths across continuous grid surfaces considering various cost factors. These grid surfaces are called cost surfaces since each cell has attributes or weights describing the amount of resistance (cost of passage) to movement across the cell based on the given cost factors. ACS methods are the algorithms commonly used for computing cost distances. DT methods, which are similar to the ACS method but are commonly used in image processing have also found use in distance computation and navigation.

ACS algorithms are simple but efficient in finding optimal paths over cost surfaces. Advanced research on the use of the raster-based LCP computation methods includes among others studies by Hazel et al. (2008) for large datasets, Upchurch et al. (2004) for more realistic allocation of off-network areas, Yu et al. (2003) and Collischonn (2000) for use in road network development, and Feldman et al. (1995) for oil pipeline routing. An easy to understand explanation of the basics of ACS algorithms can be found in the Distance
Using ACS methods to calculate the LCP from the source(s) to destination(s) require (i) a source raster, (ii) a destination raster and (iii) a cost surface (raster). The ACS algorithm will iterate through the given set of source cells determining the least cost distance to the nearest neighboring cells. The process takes the form of a "wave spreading in all directions from the starting point" calculating and assigning to each grid cell it passes the lowest accumulated cost incurred. The output result is a raster with each cell in the study area assigned the lowest cost from the source cell and is normally referred to as the ACS raster. The ACS raster can then be used to compute the least cost (optimal) path by choosing the steepest downhill path from the destination to the source, or other methods such as the creation of a Least Cost Direction Surface (raster) at the same time as the ACS raster (refer to Collischonn, 2000). The ACS can also be used in other procedures such as in allocation of a cell to the nearest source.

When using ACS methods, creation of a Cost Surface that represents the actual conditions as closely as possible is an important step which will mainly determine the implication of the computed results. The Cost Surface can be created based on one or a combination of many different cost factors such as distance, speed, fuel cost, slope, land acquisition cost and obstacles et cetera. Basic ACS methods use Cost Surfaces modeled based on given average speeds of different classes of road networks. More advanced algorithms introduce other factors, for example Collischonn (2000) explores the use of slope and direction factors in an ACS algorithm to determine least cost routes for road and canal development. Upchurch et al. (2004) successfully overcomes the limitation of current vector network-based methods in dealing with off-network areas by modeling and using a Cost Surface with an ArcInfo based ACS algorithm to generate service areas in on-network and off-network travel. Atkinson (2005) in developing a multi-criteria model for use in determining a route for an arctic all-weather-road combined many factors including slope, land surface type, distance to streams, archeological and ecological sites, et cetera. All these studies show the flexibility with which ACS methods can be used with any modeled Cost Surface. Further studies, such as the pipeline routing study by Berry et al. (2004), and the Web-based consensus method for routing power transmission lines by Glasgow (2004) show the potential of using ACS methods in web-based planning support tools.

3. Applying ACS Methods to Inter-modal Travel

The authors see the flexibility of ACS methods as an attractive quality for modeling inter-modal travel. A Cost Surface for each mode of travel can be created and an ACS algorithm with some modifications to suit any special requirement can be used. This section looks at one possible way for using ACS methods in approximating inter-modal travel scenarios.

3.1 Modeling cost surfaces for Inter-modal travel

The data to be prepared are (i) a cost surface raster, (ii) a source/origin raster, and optionally (iii) a destination raster. Spatial data related to the mode of travel to be modeled for example road-network data, train network data, bus-network data, required source and destination data, as well as data for modeling other external factors that influence travel such as topographic data and obstacles, et cetera need to be collected and prepared in a GIS application. Usually, all these information need to be converted into raster-type data using GIS. This approach, however, would require time-consuming special preparation in GIS. For example, there would be a need to move the location of all origin and destination points to be on a network, there is the issue of keeping track of the map projection and coordinates, etc (Refer to Upchurch et al., 2004). To avoid these, the authors' technique involves the use of a regular grid of cells created within a GIS application to act as receptors of attributes that define the underlying topography and the networks formed by available modes of travel. The cells are actually regular square vector polygons and thus can be handled efficiently in a GIS environment just like any other vector data. Using GIS, each cell can be easily given all the attributes necessary thus making the process of cost surface modeling easier (Fig.3.).

3.2 Classification of travel modes

An important point in cost surface modeling for inter-modal travel is the classification of travel modes according to the expected network type. These network types can be broadly classified into three types which the authors have aptly named as 1) The continuous surface type, 2) Line-network type, and 3) Points type networks. For ease of explanation, let us consider walking, driving, bus travel and train travel. Walking can be considered a continuous surface network.
since it can be on any point on a surface except where obstacles such as water bodies, etc exist. Car travel follows established road networks including Expressways. However, Expressways have specific entry and exit points or interchanges (IC) that must be used to get on or off the Expressway. Therefore, driving on normal roads can be considered a line-network type network, but driving on an Expressway is a Point type network with the relationship between the ICs the points of focus. Likewise with bus and train travel, even though buses and trains follow established networks, they only stop at designated bus or railway stations thus making them point-type networks. Air travel shares the same point-type network qualities. Based on the above classification, four different cost surfaces for walking, driving, bus travel and train travel have to be prepared as shown in Table 1. and Fig.4.

### 3.3 The ACS algorithm and programming

The proposed algorithm is a modified form of basic ACS algorithm programmed and compiled in a FORTRAN77 compiler. The resulting program runs independently of any other application thus offering us the freedom to easily change computation parameters as well as flexibility to incorporate the program into any simulation model. The program follows the basic structure of the Dijkstra algorithm performing the LCP computation by spreading in all directions. The Dijkstra approach was taken over other LCP search approaches such as the A* algorithm due to the nature of the authors’ study case which deals with accessibility to facilities by users from unspecified origin points.

The program needs as input data i) Cost Surface files ii) Origin Points data, and optionally, iii) Destination Points data. These data are prepared in GIS (Ref. Fig.3.) and output in the form of separate text files. The origin and destination point files both contain the x and y coordinate values as well as the travel cost value (time taken to travel through a cell based on the set travel speeds) for each cell in the study area (Fig.5.). The unique ID is needed for linking all input and output text data with GIS vector data. The cost surface file can also contain other cost related factors such as the direction restriction factor, the slope factor, etc, or the travel costs for other modes.

<table>
<thead>
<tr>
<th>Travel Mode</th>
<th>(Cost Surface type)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Walking</td>
<td>(Continuous Surface type)</td>
<td>Any surface a person can walk on can be modeled and used in computation. Average walking speeds (or speeds modeled on walk ability of the surface under conditions such as slope, vegetation, etc) can be used. The origin or destination can be located anywhere.</td>
</tr>
<tr>
<td>b) Driving</td>
<td>(Line-network type)</td>
<td>The road network data excluding highways is used in computation. Travel is not allowed outside the network unless there is a mode change, e.g. to walking mode. Origin or destination points have to be located on the road network.</td>
</tr>
<tr>
<td>c) Driving</td>
<td>(Point type)</td>
<td>The Expressway interchange (IC) points are considered a kind of &quot;hop point&quot; with the cost of travel between them computed based on known time values provided for the Expressway.</td>
</tr>
<tr>
<td>d) Bus travel</td>
<td>(Point type)</td>
<td>Bus stations are considered a kind of &quot;hop point&quot; but with the cost of travel between them computed based on the bus schedule without need for considering the actual road network. If not computed combined with other modes such as walking, the origin and destination must be located in the bus station.</td>
</tr>
<tr>
<td>e) Train travel</td>
<td>(Point type)</td>
<td>Train stations are also considered a kind of &quot;hop point&quot; with the cost of travel between them computed based on the train schedule without need for considering the actual rail network. If not computed combined with other modes such as walking, the origin and destination must be located in the train station.</td>
</tr>
</tbody>
</table>

Table 1. Classification of Cost Surface Type for Each Travel Mode

![Fig.4. The Type of Cost Surface for Each Travel Mode](image-url)
The point type network is structured in such a way that each point has the travel cost to all the other points in the point network. For example, a cost surface for the abstract network shown on Fig.6. takes the form shown on the figure. This removes the need for repetitive unnecessary calculations saving computation time.

To initialize the computation process, the first step is for the user to select from the available modes the travel modes that can be used in the computation. A cost surface Selection Function then reads the coordinates and cost surface values for each selected travel mode and passes it on to the Spread Function. The Spread Function reads the coordinates of the given source(s) then creates an ACS file by computing the cost of traversing each cell for all given travel modes, comparing them and taking the smallest value as the least cost possible for travel from the origin to that particular cell. At this point if necessary, separate functions for tracking the spread transmission path and the mode of travel used at each cell can be called.

The spread transmission tracking is achieved within the spread function by sending the ID of the current cell to the next cell if the cost of travel to that cell is found to be the least. Tracking of the travel mode is also achieved by giving each cell an attribute (flag) that identifies the mode that was used to travel to it. Thus at the end of the process, it will be possible to know the modes of travel used to reach the destination. Now, this travel mode tracking can also be useful in situations when, for example, it might be cheaper/faster for someone to get out of a car and walk through a park rather than drive around it, but of course that would mean they have no car to drive once they reach the other side of the park and would incur more cost (e.g. time) to walk from there to their intended destination. Since the algorithm combines multiple travel modes which are sometimes thus intrinsically related, the tracking function could enable the computation process to use this kind of relationship and prevent for example someone from driving a non-existent car on the other side of the park. This functionality has not been tested in the authors' current algorithm but due to its important implications, they are planning to add it in their future study. Other mode changes, such as switching from car to train may also induce costs such as waiting time. Main public transport modes (buses, trains) are usually point-type networks, and therefore, dealing with such induced cost would involve giving each point in the network an impedance attribute, for example a value equal to the expected transfer or waiting time.

The output from the above process is an ACS text file with the unique ID, x and y coordinates for all the cells in the study area, the Accumulated Travel least Cost from the origin to each cell (ATC), the Nearest Neighbor Flag (NNF) for tracking the spread transmission path and the Travel Mode Flag (TMF) for tracking the mode of travel. The output information can then be used to optionally calculate the LCP to a given destination or to allocate each cell to its nearest source in case of multiple sources. The general flow diagram of the multi-mode computation algorithm is shown in Fig.7.

Examples of the computation steps followed to get the nearest source allocation map are shown below.

**Step 1:** Read available permitted travel modes from user input.

**Step 2:** Read the Origin Points file. Assign a cost value of zero to all Origin Point cells and an infinity value to all others cells.

**Step 3:** Mark all cells with Cost value greater or equal to zero but less than the infinity value assigned in Step 3 above with a "To-compute" flag. The flag shows the algorithm and which cells to use in the current cycle of computation.

**Step 4:** Sequentially select cells that are marked with a "To-compute" flag. At each selection, the selected cell will be termed as the current cell.

4a) Using each available permitted travel mode,
compute the cost to move from the current cell to each neighbor marked with the "Temporary" flag (For Point type Cost Surface, rather than considering the surrounding cells, directly connected cells in the point network are considered as neighbors). Compare costs incurred by each mode to travel to each cell. Take the lowest cost to travel to each cell and add it to the accumulated cost value of the current cell to obtain the accumulated cost to travel from the origin to that cell. If this new accumulated cost value to each cell is less than the value already recorded in each neighboring cell (initially a cost value of infinity is recorded and gradually updated as the computation process progresses):

4a-1) update each cell with the new ATC
4a-2) update each cell with TMF
4a-3) update each cell with NNF
4b) Mark the current cell with a "Computed" flag, which means that the computation of values in this cell has been finalized and will remain unchanged.
4c) Continue from Step 4 until there are no more cells marked with the "To-compute" flag.

Step 5: Repeat from step 3. End when all cells have been marked with a "Computed" flag.

4. Application Example

The proposed method was used in computation and visualization of changes in accessibility to services based on different scenarios of road improvement. The study area is the San-En-Nanshin region of Japan, which covers an area of about 5,700km² and has a total population of approximately 2,089,800 according to the 2000 census. Apart from the major cities found near the pacific coast, the area is mainly a mountainous region with settlements found mostly scattered over a wide area along river valleys with poor accessibility. There are several proposals for new road developments, including Expressways, aimed at improving the accessibility to these scattered settlements. In the application example, the required output to satisfy the research problem was the computed travel times to various public service provision points as well as to employment opportunities based on current future road conditions considering various improvement scenarios.

4.1 Creating the Cost Surface for the study area

For the authors' application example, two modes of travel, walking and driving, were considered. Three cost surfaces, 1) a continuous type cost surface for walking, 2) a Line-network-type cost surface for driving on normal roads and finally, 3) a point type cost surface for driving on Expressways. The cost surfaces for the whole study area are modeled using 500m cells. Walking speeds for each cell were set to the average walking speed of 4.5 km/h. The road data used are from the Digital Map 25000 Spatial Data Framework (DM25000) published the Geographical Survey Institute of Japan. For primary roads, driving speeds are set based on actual approximates provided by a research institute (Table 2.). Speeds for secondary and tertiary roads are set based on the classification scheme used in the DM25000 data as shown in Table 2. For cells in which multiple classes of roads exist, it is assumed that the fastest speed is taken as the traversing speed for the cell.

The location of relevant facility and employment opportunity points are prepared from various sources such as recent Public Facilities database and the Establishment and Enterprise Census database. The facilities considered include educational facilities (nursery: 143, elementary: 442, junior high: 201), public safety health and convenience facilities (Police: 322, fire stations: 131, hospitals: 143, post offices:

<table>
<thead>
<tr>
<th>Road Classification</th>
<th>Set speed (km/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Expressways (including 57 IC points)</td>
<td>Based on known average speeds (80-120km/h)</td>
</tr>
<tr>
<td>2. Primary roads</td>
<td>Based on known average speeds (25-60km/h)</td>
</tr>
<tr>
<td>3. Other road (Width &gt; 5.5 m)</td>
<td>15 km/h</td>
</tr>
<tr>
<td>4. Other road (Width = 3.0m ~ 5.5 m)</td>
<td>10 km/h</td>
</tr>
<tr>
<td>5. Other road (Width = 1.5m ~ 3.0mm)</td>
<td>5 km/h</td>
</tr>
<tr>
<td>6. Other road (Width &lt; 1.5 m)</td>
<td>1 km/h, 0km/h</td>
</tr>
</tbody>
</table>

Table 2. Road Classification and Speed Setting Scheme
460, gas stations: 162, Grocery Stores: 235), and job opportunity centers (large city centers and industrial zones: 12, etc). Fig.8.-1 is a general map showing the study area, and the collected data. Fig.8.-2 shows an example of a modeled cost surface for driving including use of Expressways.

4.2 Computed results and their accuracy

The accuracy of the modeled cost surface and the algorithm is further tuned using a commercially available road timetable. Taking a random section from the computed results, a comparison with the values shown in the road timetable confirmed the high accuracy in travel time computation (Fig.9.).

A lot of useful information can be gained from the computed results. For example, cells can be allocated to their nearest facility, and, since each cell in the study area has detailed values of time to the nearest facility, this gives a lot of flexibility in analysis of "service holes" based on some user defined criteria. For example, from the results of computation of travel time to the nearest hospital one can clearly see areas in need of improvement (Fig.10.-1). Fig.10.-2 shows islands of accessible areas due to the presence of an Expressway IC in an area while Fig.10.-3 shows an allocation map of municipal services to the nearest facility. The travel time results were computed using only the road distances and given speeds. A different way which can be implemented easily using this method is to look at accessibility in terms of monetary cost. This would give a different result from those shown in Fig.10. because in addition to the fuel costs, the Expressway toll fee among other cost factors would also need to be considered.

4.3 Strengths and Limitations of the ACS method

The ACS method described in this study shows great versatility for use in travel cost approximations. The ability to compute minute travel time information for all points in a study area as well as for each travel mode is a feature that cannot be easily imitated using vector networks. The ACS method has the potential to be programmed to closely portray actual ground conditions as it can easily accommodate factors such as direction, terrain condition e.g. slope and vegetation, travel mode relationship, etc. Moreover, due to the nature in which the data is constructed, the information can easily be linked to the original vector grid cells for visualization in GIS. The cells are actually regular square vector polygons and thus can be handled efficiently in a GIS environment just like any other vector data. The attributes of each cell can easily be modified in GIS making the process of cost surface modeling as well as linking with WebGIS databases easier. This makes it to easily integrate with WebGIS' enabling cost surface modeling over the web and thus widening possibilities for participatory planning.

One other quality of this method is the ability to compute travel time over continuous surfaces, along linear networks and by hopping from point to point. The hopping effect can be seen around Expressway ICs (Ref. Fig.10.-2). Even though only two travel modes (walking and driving) were considered in the authors' study example, the same technique can easily be expanded and used to simulate inter-modal travel that include any other mode of travel such as bus and train networks. Even with the large data set created for the whole study area (51357 cells), the program achieved impressive computation time. For the largest number of facilities (post offices, numbering 460), the time required for the program to compute the travel time and allocate all the cells to the nearest facility for the whole study area was less than 5 minutes on a dell notebook computer (Specs: Windows XP 2002, Intel®Pentium® M processor 1.73GHz, 1GB RAM). All these qualities hold big promise for application of ACS methods in any simple travel time calculation or if coupled into more complex uses such as in regional scale WebGIS based planning support systems.

The authors have been developing community scale WebGIS-based decision support systems coupled with simulation models such as fire spread and evacuation in crowded residential areas (Ohgai et al. 2006, Leleito et al. 2009). Based on the success of these systems in supporting participatory planning and increasing awareness among citizens on the community scale, the authors plan to expand these systems for use in supporting regional scale participatory planning processes through visualization and simulation. The travel time computation technique described in
this study can be easily coupled into these WebGIS systems and used as a basis for modeling regional scale planning issues such as road network improvement scenarios and facility accessibility, optimum location calculations, etc. For example, facility location issues such as finding the least impact method for closure of unsustainable facilities like schools or the optimum location for consolidation of multiple service facilities into one-stop service hubs is becoming an important issue for community sustainability in Japan where population is aging and rapidly decreasing. The technique introduced in this paper can play a core role in targeted service accessibility simulations based on travel modes of the potential facility users.

The method introduced here however has some drawbacks. For example, in this paper, 500m cells are used due to the big size of the study area. More refined input data can be achieved by using smaller cell sizes resulting in better approximations but with the expected computation time expense. Apart from increasing computer processing power, faster computation time can also be achieved by using pre-computed values for cases that do not change often, for example, the time taken to travel between expressway ICs does not need to be computed each time a simulation is run, but only when there are changes in the expressway conditions that affect the speed of travel. Use of large cell sizes can also create complexities and thus increase the effort needed to create the Cost Surface in GIS. An example is in the complex preparations that need to be made in modeling a Cost Surface for an area with a road along a river. When dealing with large cell sizes it is easily possible that the road would share a cell with the river and the spread function would go across the river at any point regardless of bridge absence. To prevent this, there would be a need for extra definitions of the manner in which the function spreads, for example by disallowing spread in certain directions as shown in Fig.11. below. This is a time consuming process.

5. Conclusions
The basic algorithm presented in this paper takes into account the inter-modal nature of travel. It provides a competent base on which to perform complex simulations of travel costs over an entire area without being limited by traditional networks. By following basic ACS procedures, the proposed method can be used to model Cost Surfaces to closely resemble real world scenarios. The data creation procedure which slightly deviates from traditional raster conversion techniques is an approach that not only reduces the task of modeling the cost surface, but also provides an easy way for linking the result to the original GIS database for visualization. The approach taken in programming the algorithm as a stand-alone program separate from the GIS or any other application makes it possible to easily integrate it into any simulation model. The excellent results obtained from the authors’ preliminary tests demonstrated a high level of success in computing travel cost on actual road network data in acceptable time. All these lead to the expectation that the method might provide a convenient way for computation and visualization that is suitable for use in WebGIS-based planning support systems. However, there is still a need to improve the algorithm to portray the intricately linked nature of inter-modal travel where current location in space together with past actions determines currently available travel modes.

References

Fig.11. Control of Spread Direction on a Road Along a River