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Road network analysis for timber transportation from a harvesting site to mills (Case study: Gorgan county – Iran)

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ABSTRACT: We summarized the results of the Road Network Analysis (RNA), when the shortest path to reduce travel time in the Gorgan city public road network, in Iran, was evaluated. The main objective was to determine whether by using a GIS-based new route approach it is possible to determine the shortest path from logging site to destination (mills). The results showed that by using the concept of travel time as a measure of the importance of nodes, the shortest path from origin to destination was found. A path with minimum links and lengths as well as maximum vehicle speed is the best. This dramatically reduced the search complexity in terms of routing.

Keywords: shortest path; travel time; GIS; origin and destination; public road; road network analysis

In forestry systems several types of secondary wood transportation can be used (Mendell et al. 2006). Forest logs may be carried by truck, train, ship and water either directly from landings to mills or indirectly to storage locations (Ichihara et al. 1996; Luppold et al. 1998). Forest transportation activities in the Hyrcanian zone of Iran include the log extraction from the stump to a depot and secondary transport by trucks on roads to a mill. This region requires a new and cost-effective approach to the management of road and transportation network. Road network planning and analysis are necessary to assure rapid, safe and cost-effective transportation and to predict new roads for future timber management. The transportation network accounts for a large proportion of total operational costs and thus it is important to manage it efficiently (Chou et al. 1998).

RNA is a GIS-based system which uses a range of data including the existing mills and transportation road network, enables the selection of a new path based on the shortest and quickest path and economic option (Anderson, Nelson 2004). The route solver of RNA has been extensively used in urban and industrial logistic applications (Murray 1998). Weiping and Chi (2015) showed that the urban road network plays an important role in the urban spatial structure. Ilayaraja (2013) determined the shortest path for three different scenarios between any two nodes within the road network using the shortest path algorithm in GIS. This dataset can be used for transport management by various organizations.

Harouff et al. (2008) used RNA with associated speed limits and mill locations to identify sawmill service areas based on drive times. In this study to increase the efficiency of harvested wood delivery from Gorgan city roadways to mills, a detailed analysis of the road network was performed using Geographic Information Systems (GIS). Most of the wood is transported from forest to mill by road including a portion of the trip on public roads. So the impacts of the truck traffic on pavement will be significant and severe. Douglas (2003) used RNA and GIS to predict the increases in heavy-truck traffic and changes in its distribution on public roads. This is useful to mitigate the impacts on pavement. Dijkstra's algorithm is also used by many researchers in routing. This algorithm finds the route with the lowest cost between that node and every other node (Dijkstra 1959; Kaufman, Smith 1993; Möhring et al. 2006).

The network is a system of interconnected elements, such as lines and nodes that represent a possible path from one location to another (Zhan, Noon 1998). The most common network analysis is finding the shortest path between two nodes. In

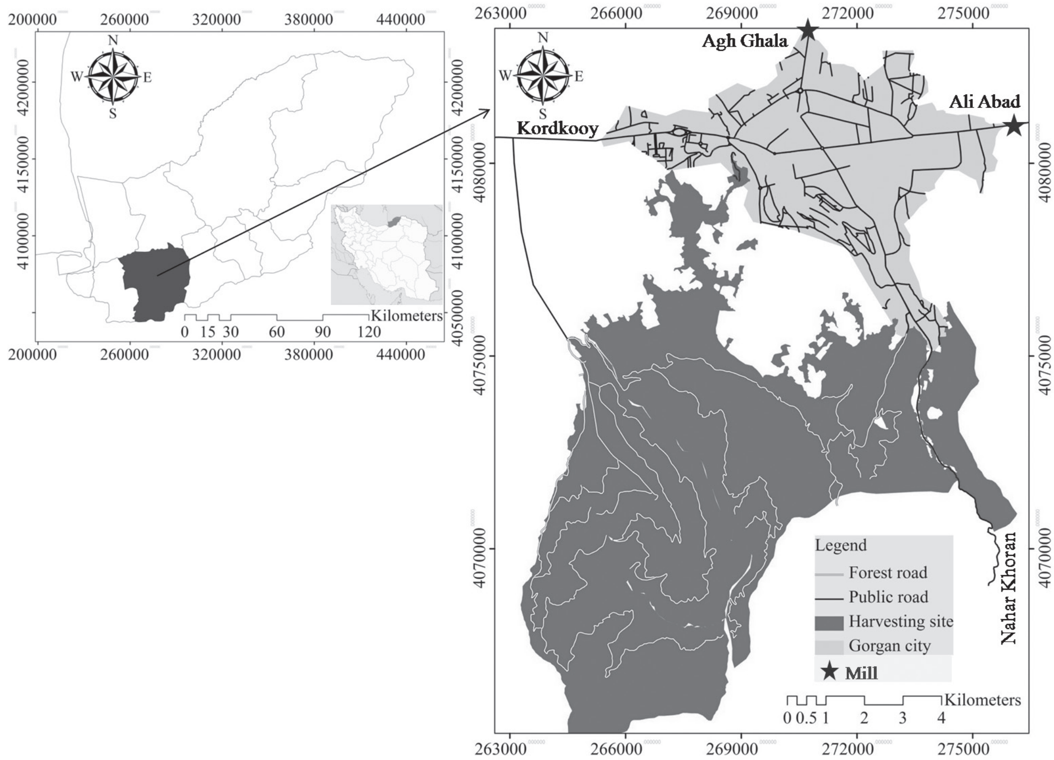

Fig. 1. Gorgan County and timber transportation network to mills

some forest-covered developing countries, log transportation from original node to mill is an economic challenge. The objectives of this study were to identify the most appropriate model for carrying out RNA in the study area and to find the shortest path from origin (harvesting site) to destination (mills) that minimizes the travel time.

MATERIAL AND MEHODS

The Gorgan County with an area of 1615.8 km^2 is located from 36°31' to 36°59' northern latitude and from 54°16' to 54°45' eastern longitude. The southern part of this county is covered by temperate deciduous forests, which can produce wood required by mills. Forests cover about 18% of the province. Gorgan has a temperate and Mediterranean climate with region types of warm and dry, temperate plains, cold mountain, forest cover and coastal area. Fig. 1 shows the harvesting site and forest roads linked to the city public transportation network.

The shortest path can be the quickest, economic, shortest and the most scenic route (Alazab et al. 2011).In the shortest path algorithm a network consists of a set of nodes and a set of links connecting the nodes. The travel time is assigned as the weight of each link. In order to provide the network database, transportation information of logging truck on each link was recorded based on three parameters: road length, average vehicle speed and travel time. The road length was measured by the Measure tool in ArcMap. The road types in the study area were divided into three classes of highway, main roads and secondary roads. The road conditions were good. Then the average vehicle speed was estimated based on road types and road conditions. The average vehicle speed on highway, main roads and secondary roads was 60, 50 and 30 km·h^{-1},

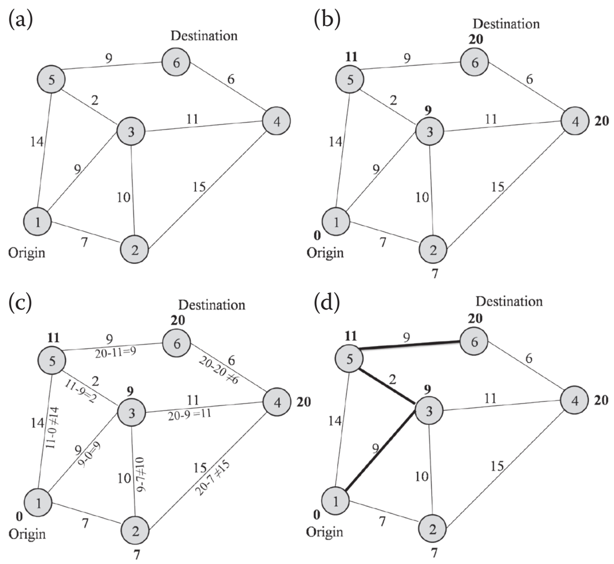

Fig. 2. Schematic of the shortest path algorithm

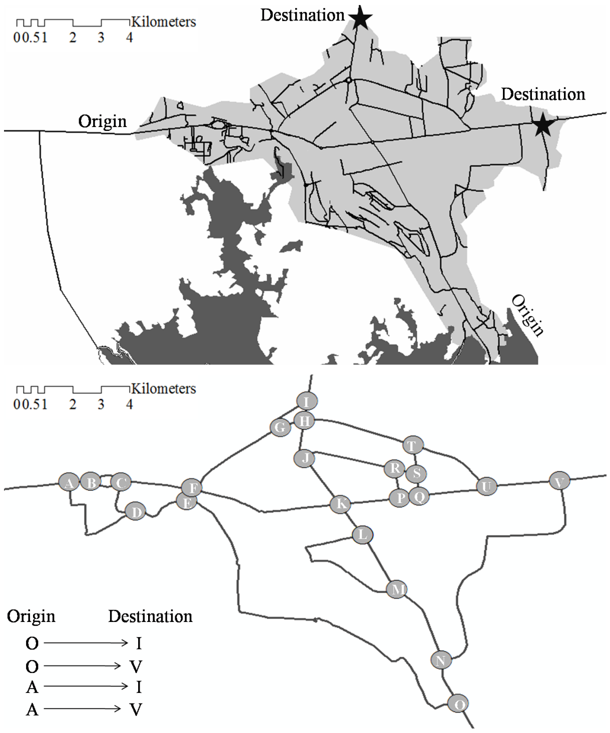

Fig. 3. Problem statement to find the shortest path from origin to destination in the study area

respectively (Akay, Haji Kakol 2014). The travel time of logging truck for each link was computed based on Equation (1):

$$T_{ij} = L_{ij}/V_{ij} \times 60 \quad (1)$$

where:

T_{ij} – travel time on road between two nodes i and j (min),
L_{ij} – length of road between two nodes i and j (km),
V_{ij} – vehicle speed between two nodes i and j (km·h^{-1}),
60 – coefficient to convert time from hours to minutes.

The shortest path to get from a harvesting site to mills was found by a new route approach of the network analyst tool extension in ArcGIS (ESRI, Redmont, USA)(Fig. 2). There were 22 candidate nodes to find the shortest path in our study area (Fig. 3). Statistical analysis was conducted in SPSS software.

RESULTS

Based on the shortest path algorithm O-N-V path with minimum nodes and links was acceptable to connect origin to destination in the present

Table 1. Basic parameters of the link-based generated paths in the study area

Some possible paths	
L_{ij} (km)	
O-N-V	0.82 + 4.78 = 5.60
O-N-M-L-K-P-Q-U-V	0.82 + 1.49 + 1.13 + 0.65 + 0.97 + 0.30 + 1.12 + 1.18 = 7.66
O-N-M-L-K-J-H-I	0.82 + 1.49 + 1.13 + 0.65 + 1.05 + 0.76 + 0.38 = 6.28
O-N-V-U-T-H-I	0.82 + 4.78 + 1.18 + 1.41 + 1.81 + 0.38 = 10.38
A-B-C-F-G-H-I	0.37 + 0.57 + 1.15 + 1.78 + 0.41 + 0.38 = 4.66
A-B-C-F-K-J-H-I	0.37 + 0.57 + 1.15 + 2.45 + 1.05 + 0.76 + 0.38 = 6.73
A-B-C-F-G-H-T-U-V	0.37 + 0.57 + 1.15 + 1.78 + 0.41 + 1.81 + 1.41 + 1.18 = 8.68
A-B-C-F-K-P-Q-U-V	0.37 + 0.57 + 1.15 + 2.45 + 0.97 + 0.30 + 1.12 + 1.18 = 8.11
V_{ij} (km·h^{-1})	
O-N-V	50 + 50
O-N-M-L-K-P-Q-U-V	50 + 30 + 30 + 30 + 30 + 30 + 50 + 60
O-N-M-L-K-J-H-I	50 + 30 + 30 + 30 + 30 + 30 + 30
O-N-V-U-T-H-I	50 + 50 + 60 + 60 + 60 + 30
A-B-C-F-G-H-I	30 + 30 + 50 + 60 + 50 + 30
A-B-C-F-K-J-H-I	30 + 30 + 50 + 30 + 30 + 30 + 30
A-B-C-F-G-H-T-U-V	30 + 30 + 50 + 60 + 50 + 60 + 60 + 60
A-B-C-F-K-P-Q-U-V	30 + 30 + 50 + 30 + 30 + 30 + 50 + 60
Σ T_{ij} (min)	
O-N-V	0.98 + 5.74 = 6.72
O-N-M-L-K-P-Q-U-V	0.98 + 2.98 + 2.26 + 1.30 + 1.94 + 0.60 + 1.34 + 1.18 = 12.59
O-N-M-L-K-J-H-I	0.98 + 2.98 + 2.26 + 1.30 + 2.10 + 1.52 + 0.76 = 11.90
O-N-V-U-T-H-I	0.98 + 5.74 + 1.18 + 1.41 + 1.81 + 0.76 = 11.88
A-B-C-F-G-H-I	0.74 + 1.14 + 1.38 + 1.78 + 0.49 + 0.76 = 6.29
A-B-C-F-K-J-H-I	0.74 + 1.14 + 1.38 + 4.90 + 2.10 + 1.52 + 0.76 = 12.54
A-B-C-F-G-H-T-U-V	0.74 + 1.14 + 1.38 + 1.78 + 0.49 + 1.81 + 1.41 + 1.18 = 9.93
A-B-C-F-K-P-Q-U-V	0.74 + 1.14 + 1.38 + 4.90 + 1.94 + 0.60 + 1.34 + 1.18 = 13.22

between two nodes i and j: L_{ij} – length of road, V_{ij} – vehicle speed, T_{ij} – travel time on road

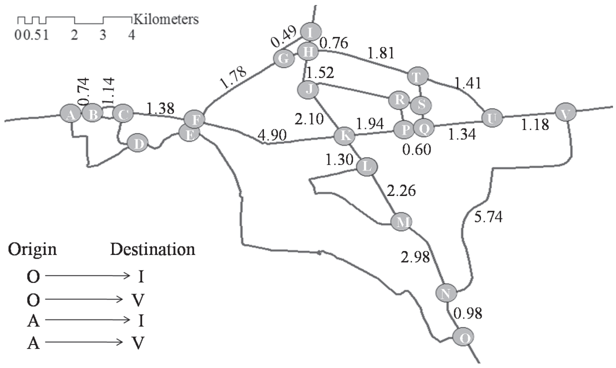

Fig. 4. Values of travel time on links of path

Table 2. Correlation analysis between the number of links and travel time (R = 0.695, P = 0.05)

Some possible paths	Number of links	Travel time (min)
O-N-V	2	6.72
O-N-M-L-K-P-Q-U-V	8	12.59
O-N-M-L-K-J-H-I	7	11.90
O-N-V-U-T-H-I	6	11.88
A-B-C-F-G-H-I	6	6.29
A-B-C-F-K-J-H-I	7	12.54
A-B-C-F-G-H-T-U-V	8	9.93
A-B-C-F-K-P-Q-U-V	8	13.22

study. Table 1 describes in detail the procedure for searching the shortest path from origin O and A to destination V and I. The path with minimum links and lengths as well as maximum vehicle speed is the best. Fig. 4 shows the values of travel time on the path and links on the path. In the first route (scenario) the O-N-V path was found as the shortest (best) path (Fig. 5a). The total length and the value of travel time on this path were found to be 5.60 km and 6.72, respectively (Table 1, Fig. 4).

In the second route (scenario) the shortest path from node O to I was found O-N-V-U-T-H-I (Fig. 5b). The total length and the value of travel time on the path were found to be 10.38 km and 11.88, respectively (Table 1, Fig. 4). According to the travel time equation the links among O-N-V-U-T-H-I were found as the path between O and I. In the third route (scenario), the links among A-B-C-F-G-H-I were the quickest path between A and I (Fig. 5c). The total length and the value of travel time on the path were found to be 4.66 km and 6.22, respectively (Table 1, Fig. 4). In the fourth route (scenario), the total length and the value of travel time on the path were found to be 6.68 km and 9.93, respectively (Table 1, Fig. 4). The quickest path from A to

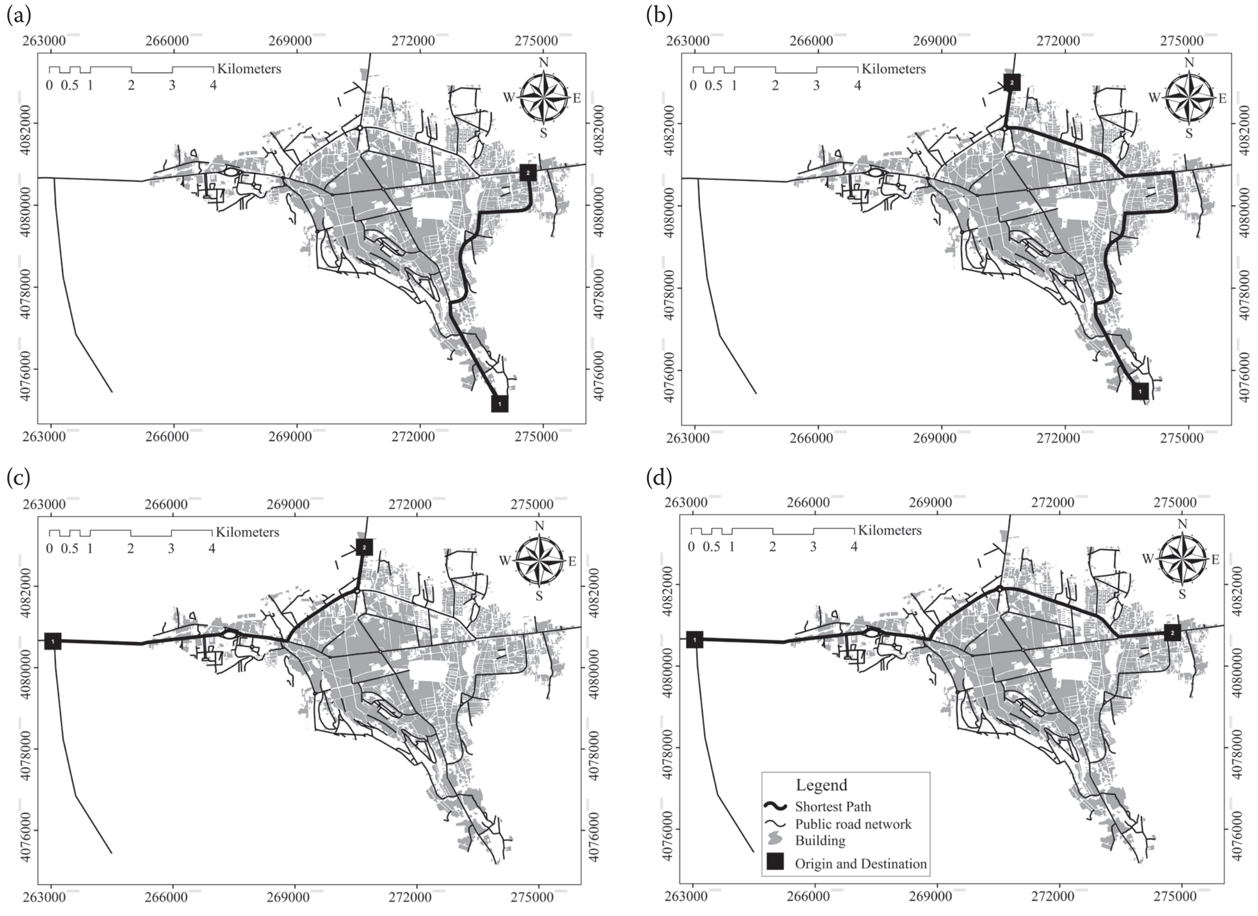

Fig. 5. Transit Node Routing from (a) Nahar Khoran (O) to Ali Abad (V); (b) Nahar Khoran (O) to Aq Qala (I); (c) Kordkooy (A) to Aq Qala (I); (d) Kordkooy (A) to Ali Abad (V)

V nodes was represented by links among A-B-C-F-G-H-T-U-V (Fig. 5d). There was a significant positive correlation between the number of links and travel time. Indeed, travel time decreased with the increasing number of links (Table 2).

DISCUSSION

This paper presents the GIS application of an optimization method for log transportation from the original place in a temperate deciduous forest to the woodworking plant. It is a contribution to operational and economic decisions of a wood haulier at truck transport. These techniques increased accessibility to the harvesting site and decreased the length of route. The shortest path algorithms are the theoretical analysis for finding a path with minimum travel time from one or more origins to one or more destinations on a transportation network (Kim 1998). In some cases it is not obvious which passage node to use for the mills, so the shortest path is required in such a situation (Newnham 1995). Yongtaek and Hyunmyung (2005) reported that a merit of the road graph is that it does not require any extra nodes and links for expanding the network. Therefore O-N-V path with minimum nodes and links is acceptable to connect origin to destination in the present study. Musliman et al. (2008) proposed a new function in 3D-GIS to find the shortest path on road networks or across terrain and visualize selected significant landmarks to improved map presentation. Findings showed that the travel time is affected by path length and vehicle speed (Akay, Haji Kakol 2014). As a result, the links among O-N-V nodes were found as the quickest path between O and V nodes.

Computing the shortest path between two locations in a road network is an important problem that finds various map services (Dial et al. 1980). Anderson and Nelson (2004) developed a model with the shortest path algorithm to project road networks that are suitable for strategic planning. The model produced a vector-based network that links to a harvest scheduling model and is used to assess trends in construction and maintenance associated with harvest. Karlsson et al. (2006) used a new GIS-based system called Road-Opt, designed to support forest road planning in Sweden. Similar to our study area the mills in Sweden forestry are situated far away from the harvesting site and the main distance to the mill corresponds to accessible public roads of high quality. To decrease the number of road links in the shortest path algorithm, the concept of passage nodes, typically a node where the road segment is reached, is introduced. From this node, the shortest or quickest path to the mill is used for transportation (Karlsson et al. 2006).

CONCLUSIONS

The Network Analyst extension of ArcGIS 10.1 software was used to find of quickest paths. O and A nodes as origins were located in a harvesting site and I and V nodes as destinations were located in mills. From the results of this study we concluded that the shortest path algorithm is efficient for finding several quickest paths to connect harvesting site to mills. By using the concept of travel time as a measure of the importance of nodes, we are able to find the shortest path. A path with minimum links and lengths as well as maximum vehicle speed is the best. This dramatically reduces the search complexity in terms of the transportation network. This study has also proved that a straight line link may not be the quickest path between origin and destination due to traffic and vehicle speed limitations. Indeed, in the New Route approach, the fastest and the safest access routes were evaluated in real time.

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