Title	Development of a Spatial Decision Support System (SDSS) for Route Costing Calculations within the Irish Timber Haulage Sector
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Publication date	2008
Publication information	Devlin, Ger, Kevin McDonnell, and Shane Ward. "Development of a Spatial Decision Support System (SDSS) for Route Costing Calculations within the Irish Timber Haulage Sector." American Society of Agricultural and Biological Engineers, 2008. https://doi.org/10.13031/2013.24368.
Publisher	American Society of Agricultural and Biological Engineers
Item record/more information	http://hdl.handle.net/10197/6102
Publisher's version (DOI)	10.13031/2013.24368

TECHNICAL NOTE:

DEVELOPMENT OF A SPATIAL DECISION SUPPORT SYSTEM (SDSS) FOR ROUTE COSTING CALCULATIONS WITHIN THE IRISH TIMBER HAULAGE SECTOR

G. J Devlin, K. McDonnell, S. Ward

ABSTRACT. *Since the 1970s, decision support systems (DSS) have become popular as computer technology has developed. A DSS aims to support the solving of specific problems with both human and computer techniques. The purpose of this research was to design and develop a DSS for application to cost and revenue calculations of contracted timber haulage in Ireland. The DSS allows the costs and revenue of timber haulage to be calculated on a daily basis and on a route-specific basis. This implies that the user interface allows certain criteria to be selected, such as truck configuration, truck model, engine size, horsepower, and design gross vehicle weight. Both the revenue and running costs are directly related to the payload weight and the distance traveled. To generate the routes traveled and provide a sophisticated interface for spatial road map information, a Geographic Information System (GIS) was used; ESRI's ArcView 8.3 provides its own application programming in the form of Visual Basic for Applications (VBA).*

Keywords. *Costs per km (CPK), GIS, SDSS, Timber haulage.*

The trend in routing systems in transport applications in general is to design and build a decision support system (DSS) around a geographical interface, where the user can interact with the problem, which leads to better decision support. For the spatial decision support system (SDSS) described in this article, interaction between the spatial road vector network of Ireland and other geographic data (cities, towns, *X* and *Y* coordinates of processing sawmill locations and timber harvesting sites, forest boundaries, and internal forest road network) are needed. Use of the Network Analyst Tool (NAT) in ArcView to select the routes between the origin and destination is also required before the DSS can be implemented and interacted with. Human intervention in the routing process can substantially improve the route generated based on local knowledge. With this SDSS, the 1:50,000-scale road network forms part of a geometric network from which a "cost-weighting" can be applied when using the NAT to predict the most likely and most cost-saving route to be taken by a timber hauler.

The growth of any SDSS depends on the availability of spatial data for Geographical Information Systems (GIS) software. In comparison to the U.S., the U.K., and continental Europe, Ireland's spatial data (both vector and raster) has generally been expensive and of poor quality. However, several private-sector companies (Mapflow, 2006; Fleetmatics, 2006) are now producing their own digital maps from satellite photography, remote sensing, and GPS surveys to provide improved GIS data for those who wish to work with it. It is estimated that up to 80% of the data needed for the activities of business and government is spatially related (Franklin, 1992).

In its most basic form, a routing problem involves traveling from origin to destination with a minimum of distance traveled. Within the GIS, "cost-weights" can be applied when using the NAT, which attempts to simulate the route to be taken in terms of the shortest distance, road class, speed limits, and the most probable route that the hauler would take (Devlin et al., 2007). Each route returns a total distance traveled, and the SDSS can then be used to determine the cost of traveling such a route and compare results for routes of varying cost-weights.

The potential production of roundwood from the forests of Ireland will reach 5 million m^3 per annum by the year 2015 (Gallagher and O'Carroll, 2001). Road transport will remain the most important mode of timber transport in Ireland, forming a substantial part of the timber industry's raw material costs and having a major influence on the sector's overall economic performance and competitiveness (Coillte, 2003). However, within the Irish forestry sector (both private plantations and state owned), there is a need to incorporate information technology (IT) into the timber haulage sector (Optilog, 2003). Information technology in this situation implies the use of GPS for tracking of timber trucks from forest harvesting sites to sawmill destinations and incorporating this positional technology with GIS to reference the timber trucks on a map. The GIS map is used to determine if a truck is located at the harvesting site, traveling on a national route, or unloading within a sawmill (Frisk and Ronnqvist, 2005). GPS and GIS technology have already been successfully implemented and utilized in many fleet management situations, such as the effective management of ambulances (Derekenaris et al., 2001), hazardous material truck routing (Frank et al., 2000;

Submitted for review in December 2006 as manuscript number IET 6805; approved for publication by Information & Electrical Technologies Division of ASABE in March 2008.

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  ISSN 0001–2351

Thill, 2000), milk collection (Butler et al., 2005), and real-time multivehicle truckload pick-up and delivery problems (Yang et al., 2004). Thus, this research is working towards a fully integrated pre-planning approach to timber haulage in an effort to optimize routes traveled in terms of haulage costs, distance, time, volume of timber transported, and savings from avoidance of empty return journeys, and to develop a flexible and cost-effective haulage control system for the Irish timber haulage sector.

Materials and Methods

Software and Data Used

A successfully implemented SDSS requires both the availability of appropriate road network vector data and software that can provide the relevant network representations. The software used for spatial analysis and representation of cartographic information was ArcView 8.3 (ArcCatalog, ArcToolbox, and ArcMap – ArcInfo versions). The development platform was Windows XP for PCs. Visual Basic for Applications (VBA) was used to design and create the DSS, while the GIS provides the spatial interface, database, and route modeling component. A DSS by definition is a combination of databases, user interfaces, and modeling components directed at solving a specific problem. For this specific problem, a GIS alone is not a DSS. However, the GIS and DSS together combine to create a spatial decision support system (SDSS) to extend the range of decision support through the SDSS's ability to define route selection using the NAT in ArcView 8.3, and the display of spatial road vector data for the user interface can greatly enhance the decision making process. The main tools used to create, manage, and edit the spatial geodatabase are found in ArcCatalog and ArcMap. ArcCatalog has the tools for creating and modifying the geodatabase schema, while ArcMap is used to analyze and edit the contents of the spatial geodatabase.

The digital road network used within the GIS was represented as a series of connections of arcs and nodes (arc-node topology). The nodes represent the road intersections, and the arcs represent homogeneous road segments. The road network consists of motorway, national primary, national secondary, regional, and third-class roads. This digital road network represents arc-node topology. The basic description of arc-node topology defines the vertices (X and Y pairs) as the shape of the arc, and the endpoint of each arc is termed a node. Arcs are only joined at nodes, and each arc has two nodes: a "from" node and a "to" node. The ability to store these topological rules efficiently in terms of a digital road network (or any other type of network such as water mains, power lines, etc.) is one of the essential functions of any GIS software. In ArcInfo 8.3, these types of networks are modeled with a geometric network.

Many routing systems that use GIS do so only to provide spatial map displays and take little advantage of the spatial processing capabilities of modern GIS software. The routing macro within the NAT automatically executes Dijsktra's routing algorithm (Frank et al., 2000; ESRI, 2003). To determine the shortest path, the algorithm scans the road network for all nodes adjacent to the origin node. All links to these nodes are assessed, and the shortest cumulative distance from the origin is selected at each node until the destination node is reached. However, while determining the shortest path to travel is useful, it does not always complete the routing problem. To manipulate the NAT further, a geometric network was built. Geometric networks are built in a GIS model to construct and maintain topological connectivity for the road data in order to allow path finding analysis. Geometric networks consist of edges and junctions that represent the arcs and nodes of the road network, respectively. In order to carry out an analysis of the road network, geometric networks must be built; in ArcInfo 8.3, the NAT cannot be used without a geometric network. Geometric networks can only be built in ArcInfo or ArcEditor. They are read-only in ArcView. From within the geometric network, varying cost-weights were applied to varying classes of the road network. These cost-weightings do not reflect the actual cost of road haulage or road weight restrictions.

In order to carry out the network analysis and identify the most logical route that would be taken by the hauler, we made some logical assumptions (Devlin et al., 2007). The values of the cost-weights imply that the routing algorithm will select the route starting at number one (or the next lowest number depending on the available network around the starting point). These cost-weightings were based on a Welsh model that has a similar road network to that of Ireland (Wales Timber Transport Group, 2005). This forces the algorithm to continuously select the route of higher classification until the destination node is met.

Calculating Vehicle Operating Costs

It is essential for any transport company to know its vehicle operating costs, whether it uses one or two vans, rigid trucks, or articulated trucks. Operating costs should be available in some form or another; however, it is how the costs are formulated that allows a full understanding of the transport costs. Transport costs cannot be just a measure of time and distance (km) related costs. Vehicle operating costs are a mixture of costs per day and cost per km, simply because time-related costs occur even when the truck is not in use, and distances vary considerably depending on the eventual destination. The DSS was designed to formulate transport costs based on the following criteria:

- Capital costs (truck + trailer + crane)
- Time-related costs (standing costs)
- Mileage-related costs (running costs).

Capital Costs

Capital costs include the initial purchase cost of the truck and trailer. The daily cost is calculated as 20% annual depreciation of the total initial cost over a five-year period. In this study, the truck was second-hand with a value of 35,000 euros. The trailer was also second-hand with a value of 10,000 euros.

Time-Related Costs

Time-related costs include:

- Wages: Employee's gross daily pay based on the time taken for the particular journey.
- Depreciation: Calculated as a percentage of the cost price over the depreciation period, normally five years.
- Insurance: Cost of insuring the vehicle and the goods in transit. Goods in transit insurance for hazardous chemicals is considerably more expensive.
- Tax: Goods vehicle road tax (based on the unladen weight of the truck). Trailer tax is also based on the unladen weight.

- License: National road freight carriers license (renewed every five years). The cost per truck is higher if the haulage license is international (for travel inside and outside of Ireland) as opposed to national (only within Ireland).
- Department of the Environment (DOE): Trucks and trailers must pass an annual road-worthiness test, known nationally as a DOE test. Without a road-worthiness certificate, no truck or trailer can be taxed, and it is illegal to travel on public roads in Ireland without the appropriate road tax.

Mileage-Related Costs

Mileage-related costs include:

- Fuel: Calculated from average km per liter, based on total km for the route driven (from GIS). Fuel consumption information can be retrieved from the truck using InfoMax software (see below). Cost per km (CPK) is the liters used per journey × average cost (cents) per liter.
- Tires: Calculated by dividing the average cost per tire by the total journey distance over a yearly period. In this DSS, the annual km traveled for the truck is approximately 100,000 to 120,000 km. This implies a daily distance of between 400 and 500 km per day, with approximately 250 working days per year. These figures comply with the readings of the tachometer on the truck.
- Maintenance: Calculated by dividing annual maintenance costs by total journey distance over a yearly period.
- Toll bridge: Some motorways in Ireland require a toll. The toll for a five-axle truck configuration is 5.60 euros.

For the purpose of this DSS, there are 250 working days in the year. Therefore, to calculate certain costs, such as tires and maintenance, on a daily distance basis, the annual cost is divided by the average distance traveled by the truck, which is approximately 100,000 km.

InfoMax Software

InfoMax is a software tool designed to optimize vehicle use and record engine performance. The software is installed on a laptop computer, and an adaptor cable is connected from the serial port of the laptop to the communication port on the truck. InfoMax extracts data recorded by the truck's fleet management system (FMS). Extraction is carried out at the end of each working day. It is not necessary, and not possible, to extract data in real-time. The truck must be switched off and stationary. Once the laptop is connected to the truck FMS with the adaptor cable, the ignition is switched on to proceed with the data extraction process. The extraction process consists of four stages:

- Preparation for communication: InfoMax checks the connection to the vehicle and identifies itself to the vehicle.
- Identification of the vehicle: InfoMax determines whether the vehicle has already been created in its database.
- If the vehicle is unknown in the database, then it must first be created in order to continue with the extraction.
- InfoMax then reads the diagnostic data stored in the FMS and saves it to the database.

GPS Tracking of Truck Routes Traveled

In order to test the SDSS based on the routes simulated within the GIS, an articulated truck was tracked with a GPS. The experimental articulated truck was a Renault Magnum 480 4×2 tractor unit (two wheels on the front axle and four wheels on the rear driving axle with road-friendly air suspension). The trailer was a Fruehauf tri-axle curtain-side trailer, measuring 13.6 m in length with a height of 4.2 m from the ground. The costs calculated through the SDSS could be compared with the costs calculated through the GPS tracking of the truck and the recording of variable factors such as distance traveled, liters of diesel fuel used, and journey time. These factors were extracted from the FMS on the truck using InfoMax version 4.0 software. This software is specific only to Euro 2 and Euro 3 Renault trucks. InfoMax 4.0 provides daily information on the engine diagnostics, including distance traveled, diesel fuel used, average consumption of fuel when moving and idling, average speed with engine running, and vehicle running time, as well as information on the cruise control, truck and trailer brakes, engine retarder, and percentage of transported mass. After the software was installed on the laptop, it was possible to connect to the truck's FMS using a DB-9 serial cable that was configured for the truck's communication port.

The GPS equipment used was a Trimble GeoXT handheld unit with sub-meter accuracy and external magnetic antenna, which was fitted to the roof of the truck cab. The GPS data were recorded through the ESRI ArcPAD software available on GeoXT. The data were recorded in World Geographic System 1984 (WGS84), i.e., the GPS reference system. Since the digital road map within the GIS is in the Irish National Grid, the GPS data had to be projected into the Irish National Grid reference frame. WGS84 is a global system, which implies that data are not defined as precisely as possible on a national or regional basis. Therefore, a projection onto the Irish National grid was necessary in order to eliminate alignment and accuracy errors when adding the layers of GPS route data for eventual analysis within the GIS (OSI, 1999). This projection of coordinate systems was carried out within ArcCatalog. The study area incorporated five varying routes from the haulage depot in the east of the country to five different destinations around the country (fig. 1). The GPS was set to record data every 20 seconds along each of the routes. Each route provided between 1200 and 1300 sample points, of which approximately 700 to 900 points were dynamic. There were on average seven satellites acquired for each of the sample points recorded. In three of the five routes, the number of satellites acquired reached as high as eleven. Considering that a minimum of four satellites is required to mark a position on earth, this indicates that the GPS antenna remained in continuous strong view of the sky and the orbiting satellites (Prisley and Carruth, 1995).

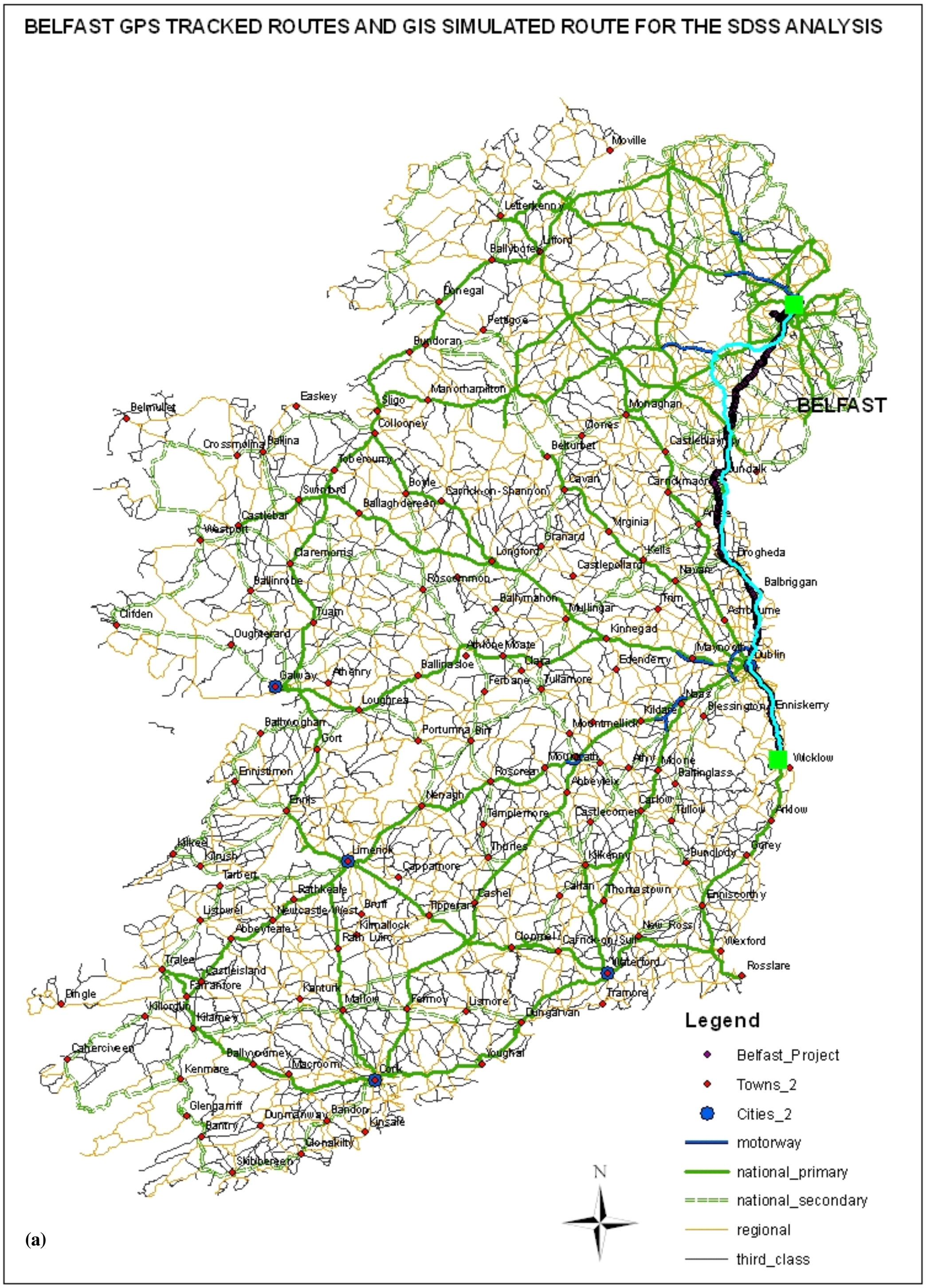


Figure 1. GIS maps of each GPS route (black line) and GIS route (light color line): (a) Belfast, (b) Cork, (c) Drogheda, (d) Limerick, and (e) Tipperary (continued on next page).

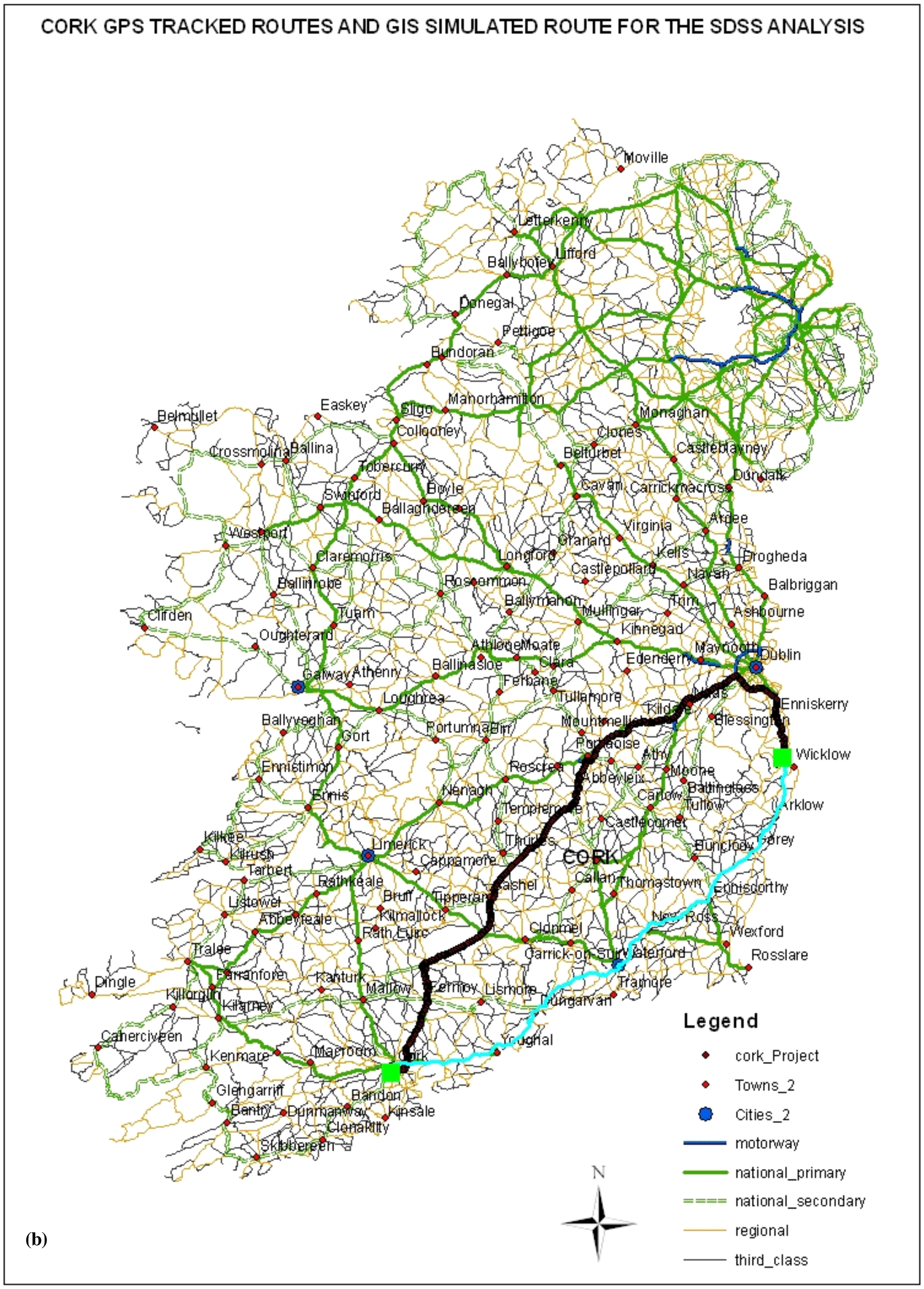
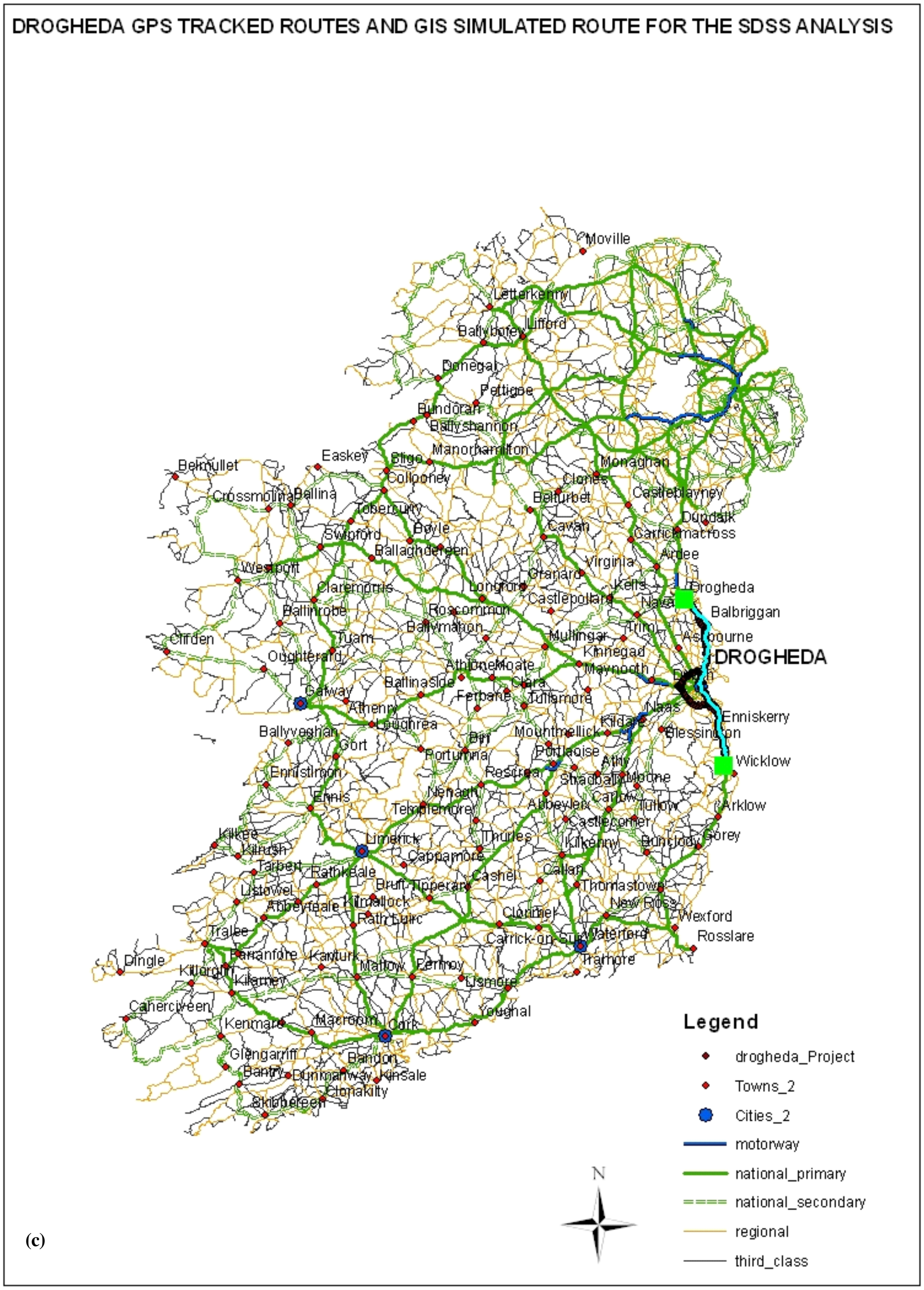


Figure 1 (continued from previous page). GIS maps of each GPS route (black line) and GIS route (light color line): (a) Belfast, (b) Cork, (c) Drogheda, (d) Limerick, and (e) Tipperary.



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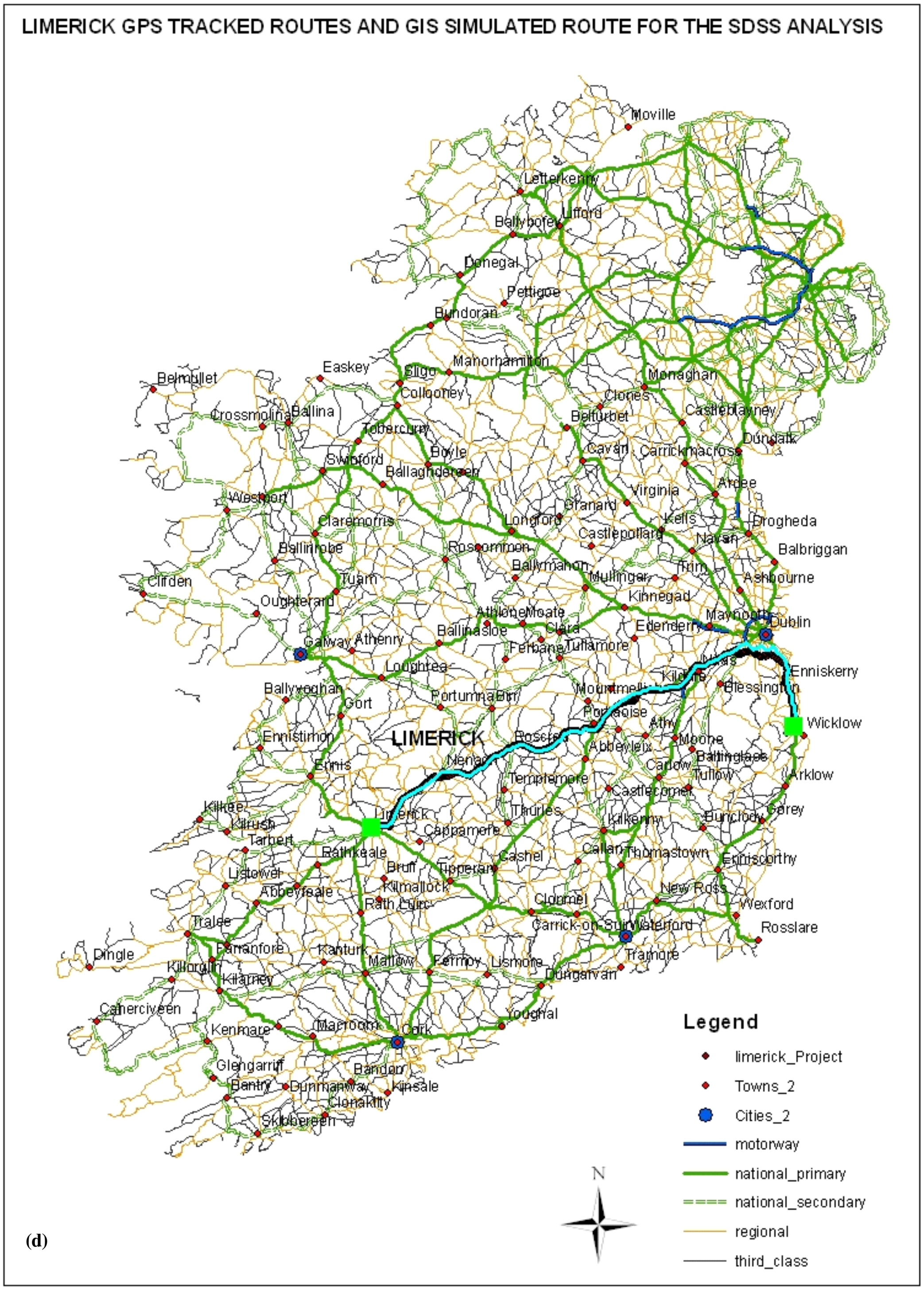

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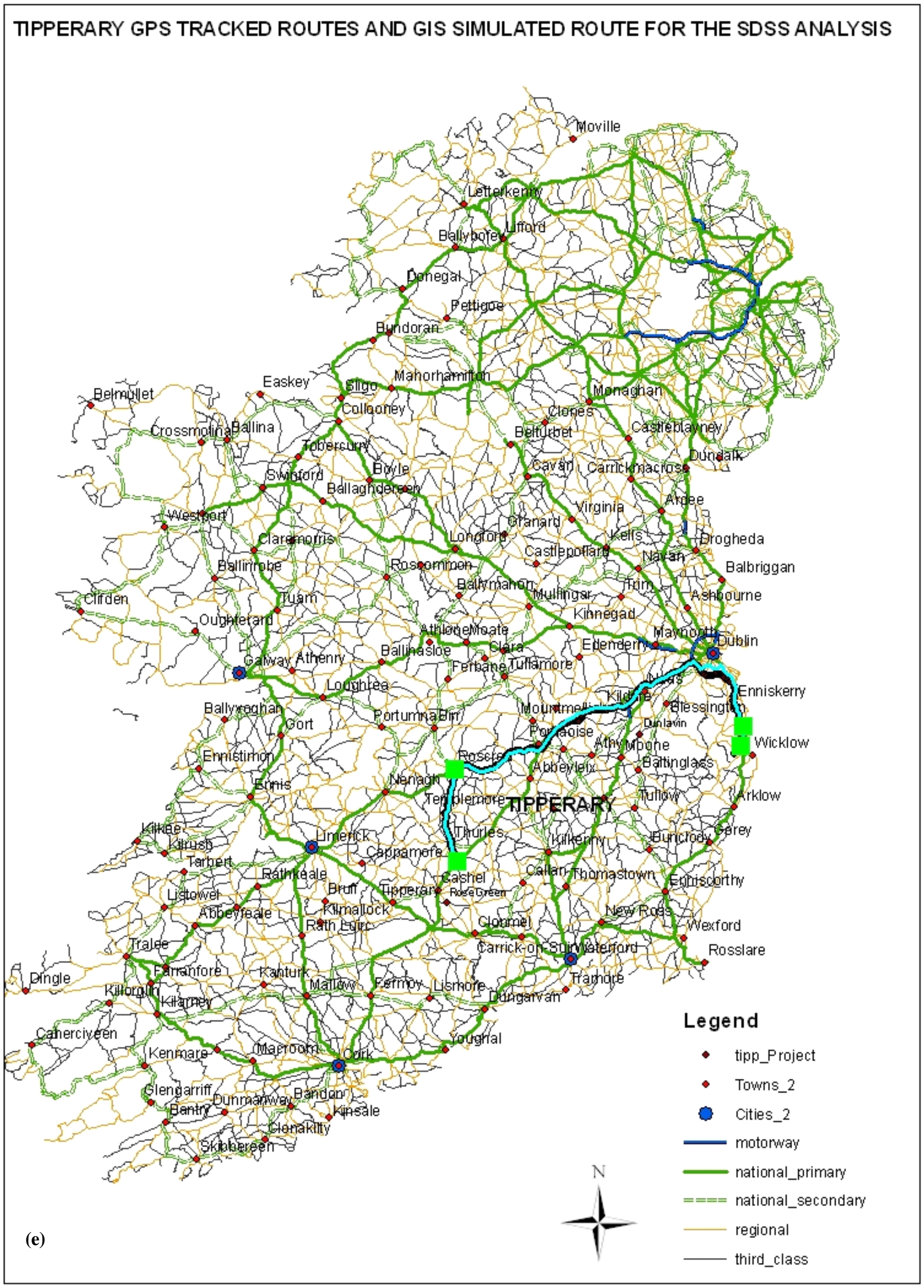

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Results and Discussions

The SDSS was used to calculate the costs of each of the five specific routes taken by the truck, i.e., how much it costs to travel a certain distance (fig. 2). The costs involved for each route were broken down into fixed and variable costs. The fixed costs relate to the capital costs of the truck and trailer. These values remain the same for each route cost calculation. The variable costs include both the mileage costs and driver costs for the time taken for the journey. These values change for each of the five routes traveled. The time taken for each journey, the exact traveling distance, and the distance (km) per liter of fuel are data that can be extracted using the InfoMax software. These data are used to calculate the variable costs. Table 1 shows the related costs for each GPS route based on the distance extracted using the InfoMax software.

Table 2 shows the corresponding costs for the distance extracted from the GIS. This distance reflects the most probable

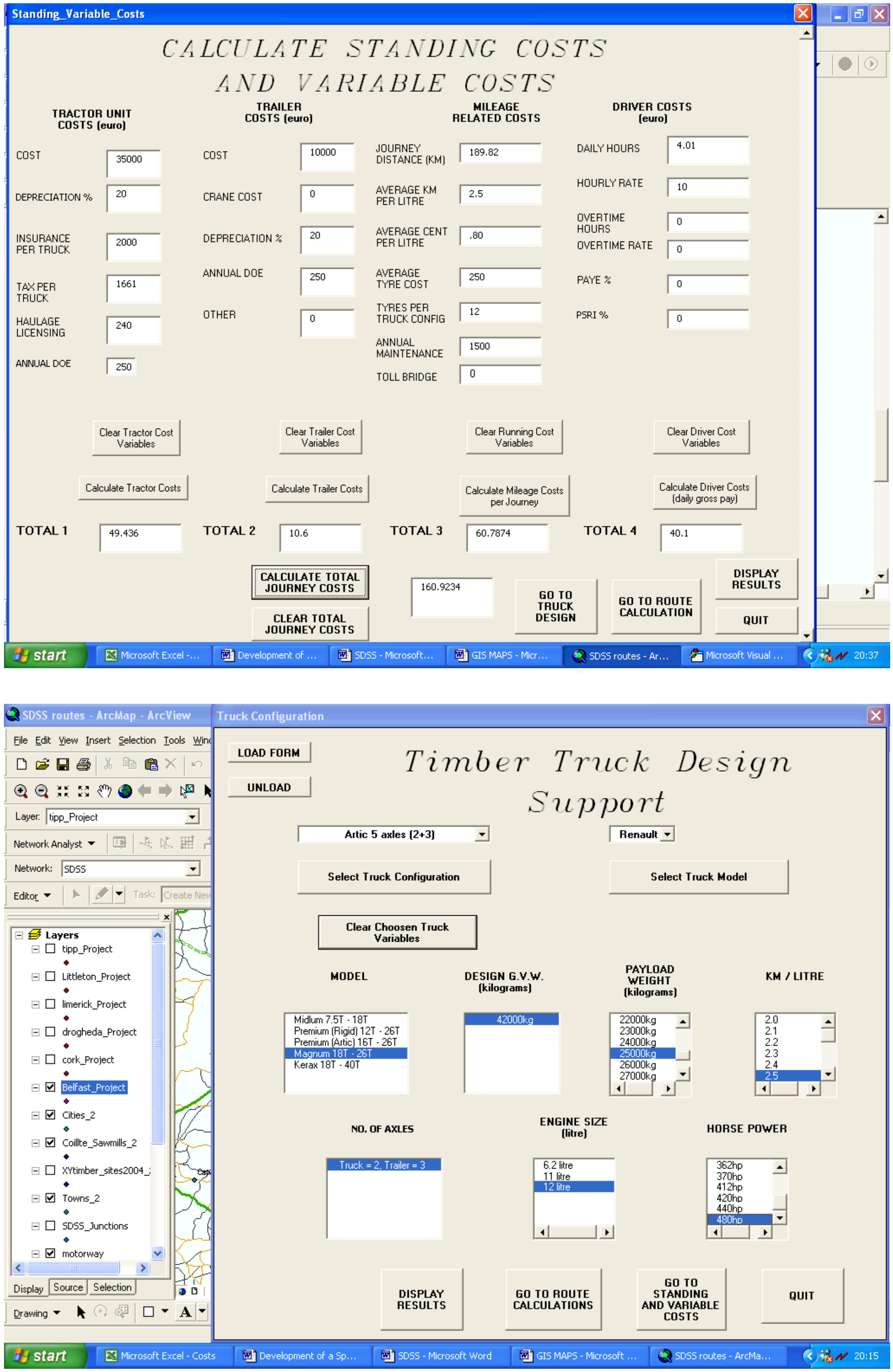

Figure 2. Screen shots of the DSS used to calculate the standing and variable costs and select the truck configuration.

Table 1. Details of the GPS routes.

	InfoMax Route				
	Belfast	Cork	Drogheda	Limerick	Tipperary
InfoMax distance (km)	490.10	565.90	235.40	545.30	406.00
Kilometer (km) / liter	2.50	2.60	2.50	2.30	2.30
Journey time (h)	8.50	8.15	4.96	8.56	7.00
Journey costs (euros)	162.48	174.17	80.97	189.71	141.26
Driver costs (euros)	85.00	81.50	49.60	85.60	70.00
Tractor unit costs (euros)	49.44	49.44	49.44	49.44	49.44
Trailer costs (euros)	10.60	10.60	10.60	10.60	10.60
Total costs (euros)	307.52	315.71	190.61	335.35	271.30
InfoMax CPK (euros)	0.63	0.56	0.81	0.61	0.67

Table 2. Details of the GIS routes.

	GIS Route				
	Belfast	Cork	Drogheda	Limerick	Tipperary
GIS distance (km)	456.64	517.08	189.82	537.50	405.46
Kilometer (km) / liter	2.50	2.60	2.50	2.30	2.30
Average speed (km/h)	57.60	69.40	47.30	63.60	57.90
Journey time (h)	7.92	7.45	4.01	8.45	7.00
Journey costs (euros)	146.17	159.15	60.79	187.00	141.07
Driver costs (euros)	79.20	74.50	40.10	84.50	70.00
Tractor unit costs (euros)	49.44	49.44	49.44	49.44	49.44
Trailer costs (euros)	10.60	10.60	10.60	10.60	10.60
Total costs (euros)	285.41	293.69	160.93	331.54	271.11
GIS CPK (euros)	0.63	0.57	0.84	0.62	0.67

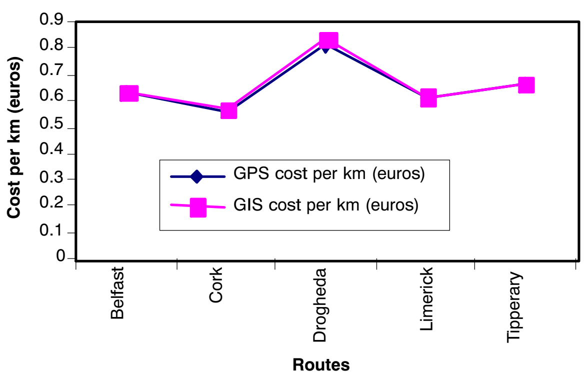

Figure 3. Graph of CPK for GPS vs. GIS routes.

route that is defined within the geometric network. Graphically, the routes look very similar, and indeed they are, except for small differences in the actual distance. In an effort to reflect the actual time taken for the GIS routes to be traveled, the average speed (km/h) was extracted from the InfoMax software. This value for each route was used to estimate the approximate traveling time based on the formula: speed = distance / time.

In the Cork route (fig. 1b), it can be seen that the GIS defined an entirely different route from the GPS route that was traveled, with a difference in distance of 48.82 km. The actual difference in CPK was in fact negligible, at 0.57 euros for GIS and 0.56 euros for GPS. An important point to note here is that the GPS tracked the truck on the return journey using the same route defined by the GIS.

Another point to note is the route defined by the GIS for the Drogheda journey (fig. 1c). This route travels through Dublin city and returns by this route. The truck traveled through the city early in the morning simply because there was no traffic congestion at that period of the day. The GIS route is shorter than the GPS return route, offering the added bonus of avoiding the toll on the M50 ring road around Dublin City. The reason for the GPS route traveling the ring road is that it provides a faster journey time than driving through the city in the afternoon. This is in fact the normal traveling procedure for the truck driver when traveling to the north of Ireland and leaving the depot early in the morning, usually around 4:00 a.m. As shown in table 1, the CPK for the GPS Drogheda route was 0.81 euros, while the CPK for the GIS route through the city was higher at 0.84 euros. This proves that by avoiding the city on the return trip, the CPK is decreased, even with the added charge of 5.60 euros for the toll bridge for the five-axle truck configuration. In addition, city driving can be full of stopping and starting, gear changing, and braking, all of which can lead to an increase in CPK despite the shorter distance traveled. The Belfast route (fig. 1a) was a similar situation regarding the use of the toll bridge, but the CPK remained consistent at 0.63 euros. Figure 3 shows a graphical representation of the CPK for each of the GIS and GPS routes.

As of February 2007, new legislation has come into effect in Ireland that will no longer permit heavy goods vehicles (HGV) to travel through Dublin City between the hours of 7:00 a.m. and 7:00 p.m. All trucks must use the outer ring road (the M50) or the new Dublin Port tunnel. All HGVs that work in Dublin Port must use the tunnel to avoid traveling in the city. The tunnel is 4.5 km long and takes approximately 6 minutes to travel through, joining Dublin Port with the M50 outer ring road, which provides convenient access to all other major national routes. The tunnel is toll-free for trucks. It is estimated that the tunnel will remove approximately 6,000 trucks a day from Dublin City. This newly constructed tunnel under Dublin City is the longest urban tunnel in Europe and opened on 20 December 2006 at a cost of 751 million euros to the Irish economy (DOT, 2006).

CONCLUSION

The introduction of IT into the Irish forestry sector is increasing. During the clearfell in Sweden in January 2005, Irish timber harvesters and haulers traveled to Sweden to aid in the recovery effort. The Irish workers saw the impressive use of IT in the Swedish forestry industry at first hand. There is a strong belief now that the same technology can be implemented in the Irish forestry sector for an increase in efficiency in harvesting and haulage operations. This article is another step into the overall integration of IT into the Irish forestry sector. The SDSS described here can be used to calculate the CPK associated with timber haulage. It works in conjunction with a GIS road map and the Network Analyst Tool (NAT) in ArcView. The NAT is used to define the most probable routes for the timber hauler, and the DSS can then analyze the CPK associated with these routes. Routes were verified through GPS tracking of a truck. The CPKs of the GPS route and the GIS-simulated route were compared. The results of the study discovered some interesting facts. For example, the GIS Drogheda route through Dublin City had a higher CPK of 0.84 euros compared to the GPS route. Even though the GPS route was longer and traveled the ring road around Dublin City, at an extra cost of 5.60 euros, the GPS route returned a lower CPK of 0.81 euros. All of the other GPS routes were longer in distance than the GIS routes, but the differences in CPK were only approximately 0.01 euros.

To take this study further, funding has just been secured to analyze the movements of the truck on the internal forest road network. The project aims to use the SDSS to define CPK on the forest roads and combine these values with the CPK on the public roads. The truck will be GPS tracked, and its positional accuracy will be quantified within the more difficult terrain of the forest canopy, as opposed to the almost open-sky conditions while traveling on public roads. It is well documented that GPS performance becomes degraded in forest environments. For this reason, it is predicted that other GPS services, such as differential GPS and the European Geostationary Navigation Overlay Service (EGNOS), will be used to optimize the GPS performance while tracking the truck.

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