A study of travel times and distances for haulage routes in Ireland using GPS and GIS.

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Abstract

Since the late 1980s, GIS (geographical information systems) have evolved to fully enable the range of capabilities needed in transportation routing, research and management. However, little work has been carried out integrating the potential of both GIS and GPS (global positioning systems) into the transport networks of general haulage in Ireland from collection point to delivery point. The objective of this paper was to analyse the designation of articulated haulage routes from one central depot to various destinations around the country of Ireland in terms of road class, distance, speed and travel time and compare the results with simulated routes within the GIS. The analysis incorporated a digitised road map of Ireland, where the GPS routes could be overlayed, together with ESRI's (Environmental Systems Research Institute Inc., CA) Arcview GIS software. The ArcInfo network analyst program was used to compare routes generated by Dijkstra's routing algorithm with the actual GPS routes in terms of road classifications, distance, speed and journey time of the route selected i.e. '<u>destination planning</u>', a term used here to describe the shortest optimum route based on road class, road length, road speed and route journey time. Results showed that the shortest path, (in terms of distance) determined by the network analyst program did not replicate the actual GPS routes. However, when the network analyst was manipulated and used to determine the routes based on road classes i.e. routing to higher classes of roads and not distance (by applying a cost weighting within the geometric network), then the GPS routes were over 90% similar with what was modelled within the GIS. This may allow the GIS alone to be used in the network analysis of truck routing and in particular, timber truck routing from forest harvesting site to destination timber mill in Ireland and incorporate the use of GPS for other advantages such as real – time tracking.

Keywords: GIS, GPS, route planning, model truck flows, truck travel times.

1. Introduction

The rising amount of timber transported on the public road network across Ireland will present major challenges to the Irish road network in the coming years. The potential production of roundwood from the forests of Ireland will reach 5 million m^3 per annum by the year 2015 (Coford, 2001). The majority of this harvested timber will be softwood. Coillte (Irish Forestry Board) will remain the dominant supplier, but it is predicted that their market share will drop from 84% in 2001 to 66% by the year 2015. The private forest sector market share will rise to 23% and the Northern Ireland forest sector will remain constant at 11% (Coillte, 2003). 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).

The introduction of new legal weight limits of 40 / 44 tonnes gross vehicle weight (g.v.w.) set by the Irish Department of Transportation (IFIC, 2004) is to try and help reduce the effect of heavy timber haulage on the forest roads but this has not agreed well with the hauliers. Fear of an economic downturn in timber sales forces the hauliers to maximise their payload, which in turn continues the accelerated deterioration of the access forest roads, which in time will reduce or even permit further service and accessibility (Martin et al, 1999).

Examination of timber haulage weight records showed that 20% of all loads are in excess of 20 tonnes and 60% are exceeding the 44 tonne g.v.w. For example, in Scotland, it is recognised that the rapidly increasing timber harvest is going to have significant impact on the rural road network, namely regional and third class roads. As a result of this the Scottish Forestry Commission and a number of local authorities have developed agreed routes, which are selected to keep timber traffic off the most vulnerable roads by directing it along stronger and safer routes (UK timber transport forum, 2005). Scotland has a timber production forecast of 2.95 million m^3 for the year April 2004 to March 2005, compared with 3.25 million m^3 for Ireland in the same period. Scotland has a forest cover of 1.33 million hectares compared to Ireland's 0.659 million hectares, yet the amount of harvested timber transported on Irish roads is far greater than that of Scotland. Coillte in conjunction with every Local County Council have also developed and agreed routes for timber extraction in an effort to reduce the cost of road repair and maintenance. These designated extraction routes do not always agree economically with the movement of the hauliers in terms journey time, journey distance, revenue per mile and cost per mile. It is for these reasons that work is being currently undertaken within the Irish forestry sector to analyse and determine the effectiveness of incorporating GPS and GIS technology to 1) Monitor timber truck movements (through a PC and web browser) as to whether they are travelling these agreed routes or not and thus enforce any necessary penalties (such as suspension of the haulage contract) if they are avoiding these agreed routes.

2) Monitor the truck from the point of view that it is travelling to the correct sawmill destination and not some other destination and removing some of the timber from the load (for personal gain) before continuing on to its proper destination, thus providing an added security for the volume of timber transported. 3) If the opportunity of a backload arises throughout the working day, then the forest manager can decide which truck is closest to the pick-up point and divert it accordingly.

Several research projects have been undertaken in an attempt to optimise the timber extraction routes over a sample road network so that timber transportation could be routed to the nearest higher class roads to minimise the damage to the peat based forest access roads. This would effectively reduce the expenses of road maintenance (Owende et al. 1999). Martin et al. 2001 incorporated GIS technology to research the evaluation of timber extraction routes. The results found that the maintenance costs of the optimum routes of 10,969 $ / km was in fact higher than the maintenance costs of the actual travelled haulage routes by 332 $ / km. This would suggest that the transport of timber should be routed towards the higher class of roads and not necessarily to the optimum route (shortest route), to minimise the road maintenance costs.

A similar type of routing model has been developed in Wales (UK Timber Transport Forum). This project is attempting to model the flows of timber from Welsh forests across the road network from now until 2015 and try to predict any changes in the movement of timber across different classes of roads. The project uses ESRI Arcview GIS software for mapping both the Welsh public road network and forest road network. The utility Network Analyst extension is also used to model and predict the movement of the trucks.

GIS technology has already successfully been incorporated into the Irish forest industry dealing with the inventory mapping, harvest scheduling and planning. However, little work has been undertaken concerning the pre – planning and scheduling within the haulage sector in Ireland as well as the GPS tracking of the actual timber haulage trucks. Within this paper it is attempting to show that when a "cost weighting" are applied to the Irish road network within the GIS, the resulting simulated routes agree well with the GPS movements of an articulated truck across certain routes in Ireland. Routes are then classified as 1) Actual GPS route (actual truck movements), 2) GIS simulated route based on routing to higher classes of roads and 3) GIS simulated route based on shortest possible distance (optimum route). Each of the routes are compared in terms of road class, distance, speed and travel time. The movement of the articulated truck was based entirely on commercial destinations from one central pick – up depot i.e. the normal working day.

2. Materials and Methods

2.1. Software and data used

The GIS used in this research is ESRI's Arcview 8.3 (ArcCatalog, ArcToolbox and ArcMap) to explore, query and analyse the data geographically. The development platform was Windows XP for PC's. The main tools used to create, manage and edit the geodatabase are found in ArcCatalog and ArcMap. ArcCatalog has the tools for creating and modifying the geodatabase schema while ArcMap is used to analyse and edit the contents of the geodatabase.

The GPS equipment used was a Trimble GeoXT handheld with sub-metre accuracy and external magnetic antenna, which was fitted to the roof of the cab of the truck. The GPS data was recorded through the ESRI ArcPAD software available on the GeoXT. The data was recorded in the 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 is 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. This projection of co-ordinate systems was carried out within ArcCatalog.

The structure and relationships of the data is important in creating the database for a GIS model. A necessary procedure is to identify the functions of the proposed model, (model the user’s view). In this case, to model the flow of a general haulage truck on the Irish road network using a GPS and comparing the recorded routes with that simulated within the GIS model based on road classes, distance, average travelling speeds and route journey time.

2.3.Data collection procedure

The study area incorporated four distinct routes from the haulage depot in the east of the country to four destinations in the south, southwest, west and northwest of the country. The GPS was set to record data every thirty seconds along the route. Each route provided approximately 1000 sample points, of which 500 points were dynamic. There was on average seven satellites acquired for each sample point recorded. 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 et al. 1995).

A digital road network of Ireland was used within the GIS. This comprised of motorway, national primary, national secondary, regional and third class roads. The road network was represented as connections of 5917 nodes and 8941 links. The nodes represent the road intersections and the links represent homogeneous road segments. Geometric networks are built in the GIS model to construct and maintain topological connectivity for the road data in order to allow the path finding analysis to be possible.

2.4. Data analysis

The first route selection (Dist A) shown in the tables two to five below was determined by the GPS and gives road classes travelled, distances on each road class, average speeds on each road class and finally the total travel time on each road class. The simulated path finding between origin and destinations (o – d pairs), were carried out using the network utility analyst within ArcInfo. The routing macro automatically executes Dijkstra's routing algorithm, which scans the road network for all nodes adjacent to the origin node (Frank et al. 2000, ESRI UK, 2003). All links to these adjacent nodes are assessed and the shortest cumulative distance from the origin is selected at each node until the destination node is reached. This determines the shortest optimum path based on distance. These are labelled as Dist C in table's two to five.

The route selection (Dist B) involves applying weights to each of the five classes of roads. These weights force Dijkstra's routing algorithm to scan the road network the same as above except the roads are selected based on the highest class (not on distance) connected to the origin node and then in descending road class until the destination node is reached. This is done by simply adding weights to the classes of roads when building the geometric network as defined in table 1. 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 haulier, some logical assumptions were made in conjunction with the co – authors. 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 the Welsh model which have similar road network to that of Ireland. This forces the algorithm to continuously select the route of higher classification until the destination node is met.

INSERT TABLE 1 HERE

The simulated routes from within the GIS are then compared with the GPS route for each o-d pair based on road class selection, distance and total journey time.
This approach introduces the idea of routing timber across Ireland's road network by avoiding lower classes of roads, firstly in terms of distance and time of each route (Tietoenator, 2002). The transportation component of timber harvesting accounts for significant costs and can therefore provide opportunities for savings through increased efficiency with GIS network analysis of the haulage routes (Arvidsson, 2002). Burke (1995) designed a hydraulically independent power driven trailer, equipped with a crane and used in conjunction with suitably power driven tractor with a load carrying capacity of 15 - 20 tonnes. This was used to transport (pre-haul) timber from forest areas to suitable loading bays as close to higher classes of road as possible, for eventual transport by timber haulage trucks to eliminate 1) the movement of at most

44 tonne g.v.w. timber trucks travelling across sensitive forest access roads and 2) the need of costly forest and public road maintenance. This also aids in keeping the timber trucks routed to the higher classes of roads for optimum timber transport based on journey time and distance (Carlsson et al. 1999, Martin et al. 2001). Burke concluded that the pre-haulage would reduce the cost of timber extraction by up to 41%.

Annually, Coillte must inform the respective Local Authorities of the sites that they intend to harvest during the coming year and the roads that they intend to use as an access route. Planning permission is then needed before any timber extraction can be carried out. Depending on their location, public roads are the responsibility of the National Roads Authority (NRA) or the Local Authorities. It is an offence to damage public roads under the Road Act 1993 (Irish Department of Transport, 2005). This research's objective is to incorporate the model for pre-planning of timber truck flows as far as the timber harvest forecast allows, which is up until 2015 (Frisk, 2003, Tarantilis et al. 2002). This pre-planning approach to timber haulage would be carried out annually in conjunction with the designation of timber harvesting sites (Optilog, 2003, Mapflow Presentation Summary, 2002).

3. Results and Discussions

The collected GPS data is shown in table's two to five. Each point recorded was sampled every thirty seconds from starting point to delivery point. The results show data for a one way and fully loaded trip on each of the four trips providing over twenty hours of actual travelling time and approximately 4 000 sampling points. Each table identifies the GPS data in terms of 1) road classes travelled, 2) the distance travelled on each road class, 3) the average speed on these road classes and finally 4) the overall travelling time (Prisley et al. 1995, Quiroga et al. 1998).

INSERT TABLES 2 – 5 HERE.

Dist B and Dist C and their corresponding travelling times, Time B and Time C, reflect the results generated from Dijkstra's routing algorithm within the GIS in terms of road class (Dist B) and shortest distance (Dist C).

Dist A and Time A are determined from the GPS data. The GPS unit recorded time, speed, position and the amount of satellites used at each sampling point as part of its overall recording of data. Dist B and Dist C are extracted from the GIS statistics once the routing algorithm is performed. Time B and Time C are determined by the formula; Speed = Distance / Time.

The speed is recorded from the GPS datalog and tabulated as Average Speed (kph). For road classes where the GPS did not travel, but the other simulated routes did, the truck speed limit for that road class was used in the calculation (tabulated as Truck Speed Limits (kph)).

Figure 1 shows the comparison of each route in terms of Distance Vs Road Class. Figure 2 shows the comparisons of each route in terms of Time Vs Road Class.

At present in Ireland speed limits and distances on all road classes have changed from miles per hour (mph) to kilometres per hour (kph), under the Road Traffic Act 2004, effective from 20th January 2005 (Irish Department of Transport, 2005). As a result of this, the speed limits of 91% of the country's lower classes of roads will decrease and 9% of higher classes and safer roads will increase in speed limit. The results of this paper have been determined in accordance with this new legislation.

INSERT FIGURE 1 AND FIGURE 2 HERE

Results show that despite Dist C being the shortest distance over all of the routes the travel times increase significantly over the regional and third class roads. Table 4 shows the greatest extra travel time of 2hrs 01mins 53secs for the Cork route, but with a shorter distance of only 48.75 km. A time of 1hr 59mins 04secs for the Westport route was calculated with a shorter distance of 11.98 km (table 5). The Tralee route (table 2) shows a time difference between route A and route C of 1hr 21mins 49secs while Dist C is only shorter than Dist A by 28.7km. The Ballinrobe route (table 3) shows the smallest difference in journey time of 00hr 26mins 38secs with a corresponding shorter distance of 66.87km. These lack of similarities between route A and route C are due to the fact that the truck must travel at much slower speeds on the lower classes of roads as opposed to travelling at higher speeds on the higher classes of roads as is the case with Dist A and Dist B. This is exactly the problem that is trying to be tackled as regards the haulage of timber in Ireland. Coillte are in fact adopting the approach of paying their contracted hauliers based on mileage bands. This will add incentive to the hauliers in terms revenue per mile while at the same time reduce the effect of road deterioration of the lower class of roads. If the designated extraction routes are also adhered to, then this will automatically lead to a reduction in the cost of road repair and maintenance.

The GPS route (Dist A), is simulated the best by the modelled route Dist B. The route selection between the two routes for each journey has similarities as high as 96.6% for Tralee (Fig. 3), 95.6% for Westport and 93.4% for Cork. The route to Ballinrobe has the least similar route at 90.8% of the GPS route (Fig. 4). These percentages are calculated based on the distance values of Dist A and Dist B.

INSERT FIGURE 3 AND FIGURE 4 HERE.

Results show that with this high level of percentage agreement between the GPS route (Dist A) and the simulated route (Dist B), it could be possible to use the routing algorithm within the GIS, in a manipulated manner, to model real-life truck movements across the Irish road network with quite a high degree of accuracy (Butler et al. 2005). The results indicate that while journey distance may increase, the actual journey time can in fact be less. In terms of transportation costs, time is much more crucial than distance (Yang et al. 2004). This automatically implies less driving time, better driving conditions across higher classes or roads, less wear and tear of trucks, less diesel and overall less expense for hauliers (Frisk, 2003).

4. Conclusion

This study has shown that truck haulage routes in Ireland can be modelled within a GIS by manipulating the routing algorithm with cost effective weights. The simulated route (Dist B) replicates the GPS route (Dist A) with similarities ranging from 96.6% for Wicklow to Tralee, to only 90.8% for Wicklow to Ballinrobe. From this, it may be possible to make full use of the manipulated routing algorithm to model truck flows throughout Ireland, namely timber truck routes, in terms of road class, road distance, road speeds and perhaps most importantly, road travelling time. Coillte and the Forest Industry Transport Group (FITG) have discussed the benefits of in-vehicle tracking devices and to gain experience in the use of tracking devices and reporting devices in the context of timber haulage. The new weight legislation is reducing the haulier’s income per pick-up and delivery. This demands the need to assess pre-planning and re-sequencing of pick-ups and deliveries within existing routes as a means of increasing the daily route revenue. Can attempting to decrease the cost per tonne bridge the loss in income as a result of the new weight limits? To do this, however, the cost associated with existing routes needs to be calculated as a base for future analysis and comparison.

Within the Irish forestry sector attempts are in progress to fully optimise the transportation of timber from forest to mill based on route planning and destination planning incorporating GPS and GIS (Optilog, 2003). It may allow for the GIS to be used in conjunction with the annual designation of timber harvest sites until 2015 and beyond, which is predicted in the report published by Coford (Coford, 2001).

Route optimisation involves pre-planning pick-ups and deliveries so that the cost per mile is decreased and the revenue per mile increased. This system requires developing a database geo-referencing the forest sites, haulier depots and mill locations of the site area. Route optimisation requires GPS and GIS technology to develop this geo-referenced database. By managing timber haulage in a green-field, pre-planned and efficient manner (i.e.) by knowing pick-ups an deliveries in advance, timber hauliers can attempt to fully optimise the earning potential of each truck.

To take the analysis and research developing a truck routing strategy further, we need to include all factors associated with the calculation of the haulier’s daily expenses. By creating this database for the participants involved we can then use as it as reference for future comparison and analysis with the revenue earned. Factors such as tax, insurance, fuel, cost of legal loading, road tolls, driver wages, operational and maintenance expenses, must all be included for an exact calculation to be carried out. Other factors to be incorporated into the calculating the haulier’s expenses would be the loading and unloading times. If for example, in the case of articulated tractor units, each truck had various trailers accessible to it, then a system could be developed to load trailers in advance of the pick-ups to reduce the time lost for the driver to load and unload. This in turn would lead to the possibility of introducing a backloading system. On average, trucks are unloaded for 50% of the journey. By increasing the amount of the journey time loaded would automatically lead to an increase in revenue per mile.

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Road Classes	Cost Weighting
Motorway	1 units/km
National Primary	3 units/km
National Secondary	5 units/km
Regional	8 units/km
Third Class	12 units/km

Table 1 - Weights applied to road classes in geometric network.

Road Classes	Dist A[a] (km)	Dist B[b] (km)	Dist C[c] (km)	Average Speed (kph)	Truck Speed limits (kph)	Time A (h:m:s)	Time B (h:m:s)	Time C (h:m:s)	Time A - Time B (h:m:s)	Time A – Time C (h:m:s)
Motorway	42.97	33.37	0	85.52	85	0:24:30	0:23:24	0	0:01:06	0:24:30
N.Primary	277.34	253.46	62.87	68.50	80	4:32:30	3:42:00	0:55:04	0:50:30	3:37:26
N.Secondary	0	8.46	28.61	0	64	0	0:07:55	0:26:49	-0:07:55	-0:26:49
Regional	3.11	23.06	123.74	52.60	56	0:03:00	0:26:18	2:21:08	-0:23:18	-2:18:08
Third Class	0	16.38	79.40	0	30	0	0:32:45	2:38:48	-0:32:45	-2:38:48
TOTAL	**323.39**	**334.73**	**294.72**			**5:00:00**	**5:12:22**	**6:21:49**	**0:12:12**	**1:21:49**

Table 2 – Routes A, B and C from Wicklow to Tralee.

Dist A [a] = actual GPS recorded route.

Dist B [b] = modelled route based on road class selection within GIS.

Dist C [c] = modelled route based on shortest distance within GIS.

Time A = Time recorded by GPS. This is not exactly equal to the theoretical value of Dist A / Average Speed. This is due to perhaps certain errors within the GPS such as multipath, atmospheric or Dilution of Precision. These induced errors cause the radio waves from the GPS satellite to become bent or refracted which changes the length of the path and thus the length of time it takes the signal to reach the GPS receiver (Prisley et al, 1995).

Time B = Dist B / Average Speed.

Time C = Dist C / Average Speed.

Road Classes	Dist A[a] (km)	Dist B[b] (km)	Dist C[c] (km)	Average Speed (kph)	Truck Speed limits (kph)	Time A (h:m:s)	Time B (h:m:s)	Time C (h:m:s)	Time A - Time B (h:m:s)	Time A - Time C (h:m:s)
Motorway	46.07	23.91	0	84.57	85	0:30:30	0:16:57	0	0:13:33	0:30:30
N.Primary	221.75	121.26	31.92	71.59	80	3:42:00	1:41:37	0:22:38	2:00:23	3:19:22
N.Secondary	14.95	91.62	15.45	48.95	64	0:18:00	1:52:30	0:18:56	-1:34:30	-0:00:56
Regional	33.74	40.78	138.33	53.85	56	0:26:30	0:37:59	2:34:12	-0:11:29	-2:07:42
Third Class	0	10.00	63.94	0	30	0	0:20:00	2:07:52	-0:20:00	-2:07:52
TOTAL	**316.51**	**287.57**	**249.64**			**4:57:00**	**4:49:03**	**5:23:38**	**0:07:57**	**0:26:38**

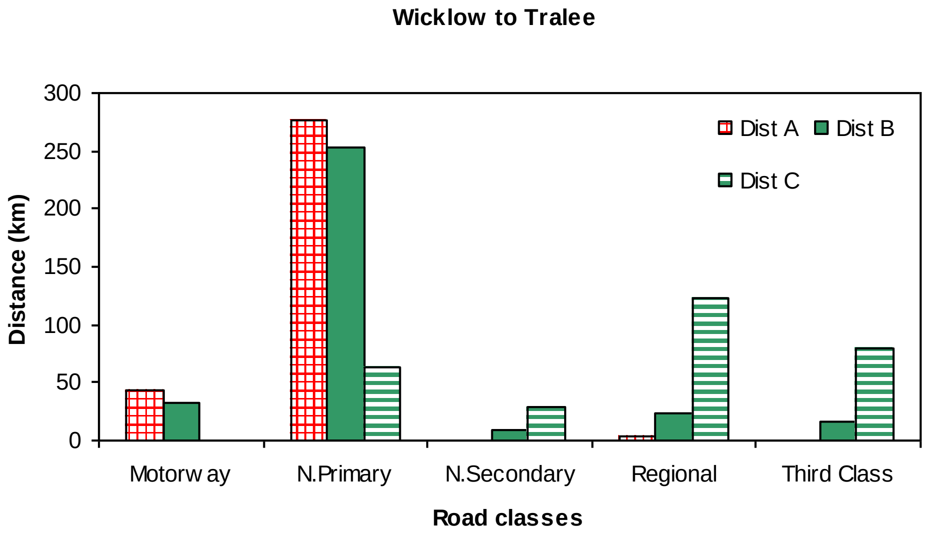
Table 3 – Routes A, B and C from Wicklow to Ballinrobe.

Road Classes	Dist A[a] (km)	Dist B[b] (km)	Dist C[c] (km)	Average Speed (kph)	Truck Speed limits (kph)	Time A (h:m:s)	Time B (h:m:s)	Time C (h:m:s)	Time A - Time B (h:m:s)	Time A– Time C (h:m:s)
Motorway	0	0	0	0	85	0:00:00	0:00:00	0:00:00	0:00:00	0:00:00
N.Primary	293.29	233.45	48.70	74.46	80	4:11:00	3:08:06	0:39:14	1:02:54	3:31:46
N.Secondary	32.92	31.94	54.94	75.01	64	0:28:00	0:25:32	0:43:56	0:02:28	-0:15:56
Regional	3.02	28.80	44.39	47.29	56	0:03:30	0:36:32	0:56:19	-0:33:02	-0:52:49
Third Class	0	13.30	132.45	0	30	0	0:26:26	4:24:54	-0:26:26	-4:24:54
TOTAL	**329.23**	**307.49**	**280.48**			**4:42:30**	**4:36:36**	**6:44:23**	**0:05:54**	**2:01:53**

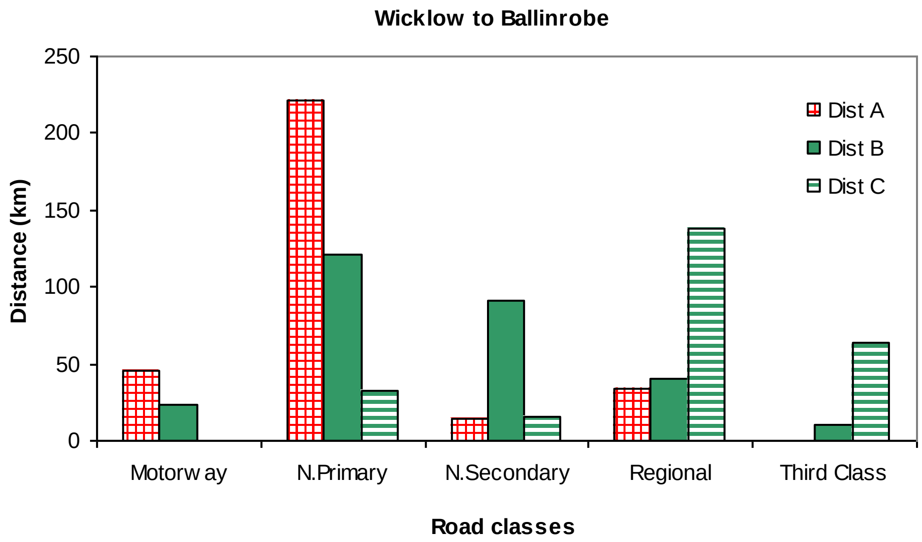
Table 4 – Routes A, B and C from Wicklow to Cork.

Road Classes	Dist A[a] (km)	Dist B[b] (km)	Dist C[c] (km)	Average Speed (kph)	Truck Speed limits (kph)	Time A (h:m:s)	Time B (h:m:s)	Time C (h:m:s)	Time A - Time B (h:m:s)	Time A – Time C (h:m:s)
Motorway	46.27	30.76	0	82.19	85	0:31:30	0:22:27	0	0:09:03	0:31:30
N.Primary	227.80	232.29	31.99	69.59	80	4:12:30	3:20:16	0:27:34	0:52:14	3:44:56
N.Secondary	17.04	21.97	21.80	38.26	64	0:26:00	0:34:27	0:34:11	-0:08:27	-0:08:11
Regional	3.02	21.83	143.14	42.75	56	0:04:00	0:30:38	3:20:53	-0:26:38	-3:16:53
Third Class	0	0	85.22	0	30	0	0	2:50:26	0:00:00	-2:50:26
TOTAL	**294.13**	**306.85**	**282.15**			**5:14:00**	**4:47:48**	**7:13:04**	**0:26:12**	**1:59:04**

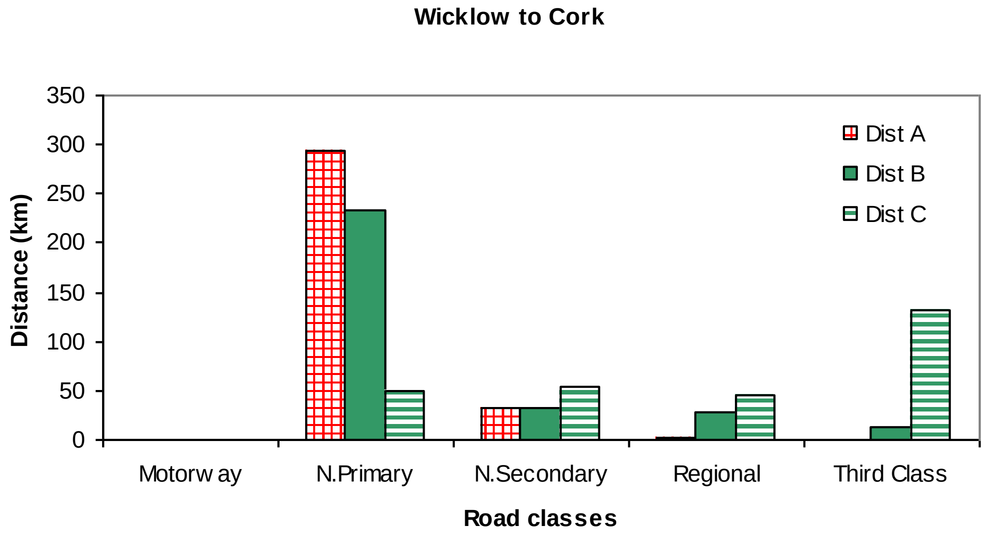
Table 5 – Routes A, B and C from Wicklow to Westport.


Wicklow to Tralee
Distance (km)
300
250
200
150
100
50
0
Dist A
Dist B
Dist C
Motorw ay
N.Primary
N.Secondary
Regional
Third Class
Road classes

506


Wicklow to Ballinrobe
Distance (km)
250
200
150
100
50
0
Dist A
Dist B
Dist C
Motorw ay
N.Primary
N.Secondary
Regional
Third Class
Road classes

507



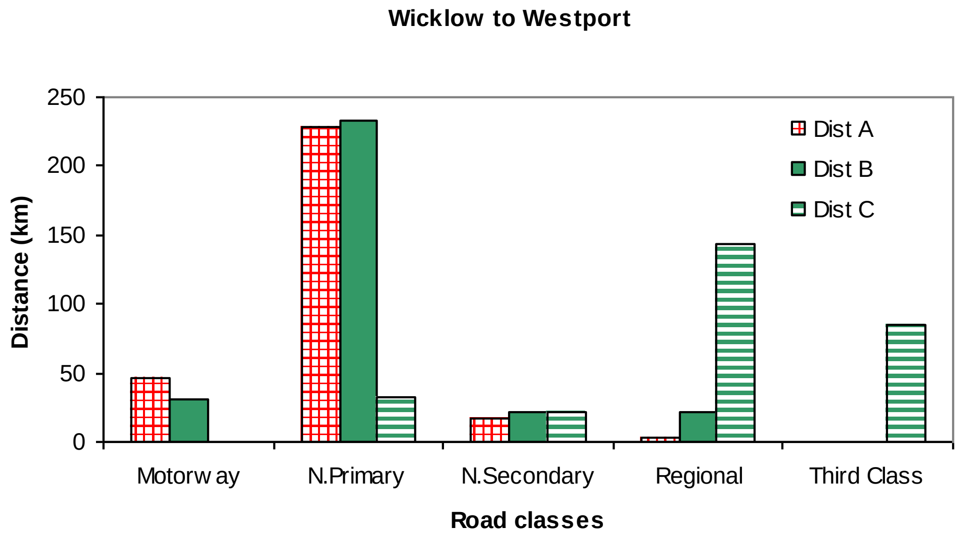
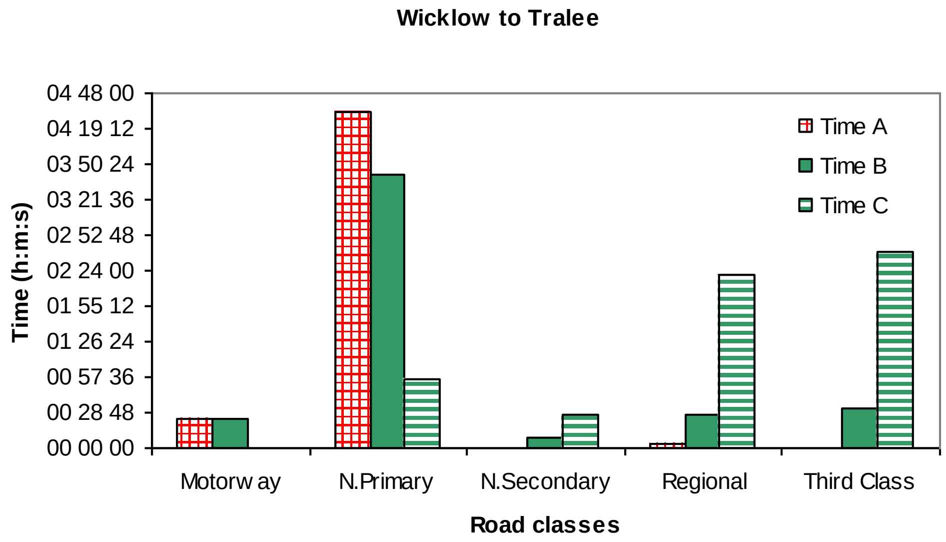
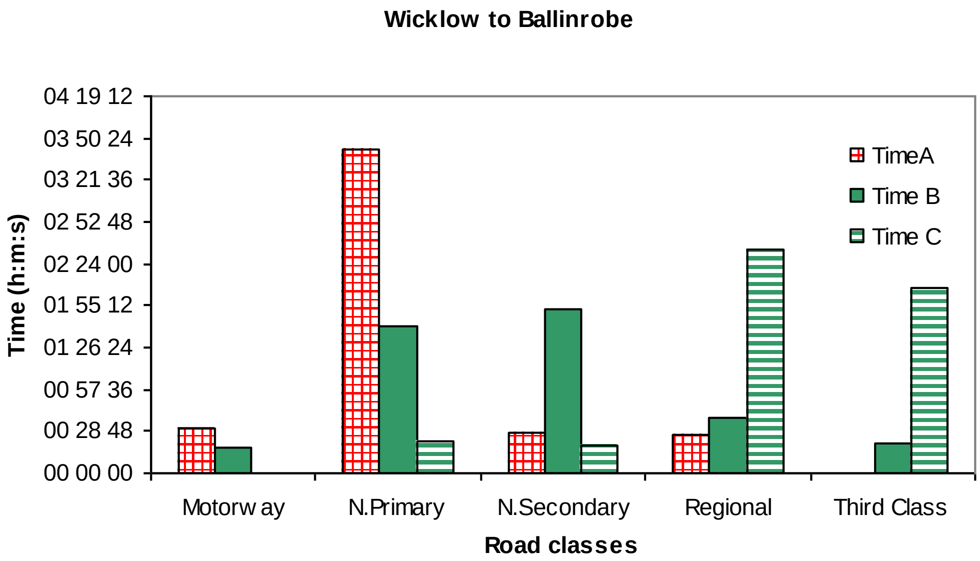
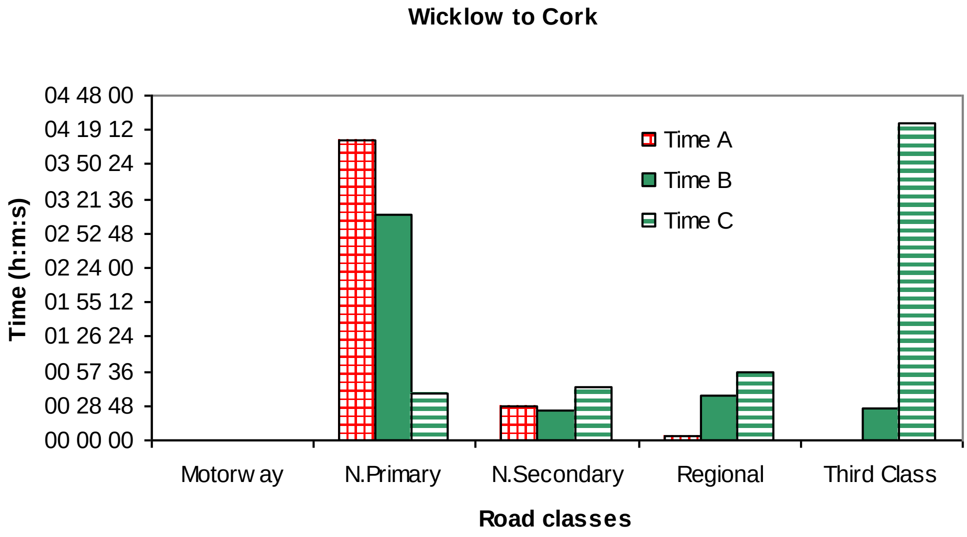


Figure 1. Distance Vs Road class for each of the 4 GPS routes recorded together with routes generated from the GIS.


Wicklow to Tralee
Time (h:m:s)
04 48 00
04 19 12
03 50 24
03 21 36
02 52 48
02 24 00
01 55 12
01 26 24
00 57 36
00 28 48
00 00 00
Time A
Time B
Time C
Motorw ay
N.Primary
N.Secondary
Regional
Third Class
Road classes


Wicklow to Ballinrobe
Time (h:m:s)
04 19 12
03 50 24
03 21 36
02 52 48
02 24 00
01 55 12
01 26 24
00 57 36
00 28 48
00 00 00
TimeA
Time B
Time C
Motorw ay
N.Primary
N.Secondary
Regional
Third Class
Road classes



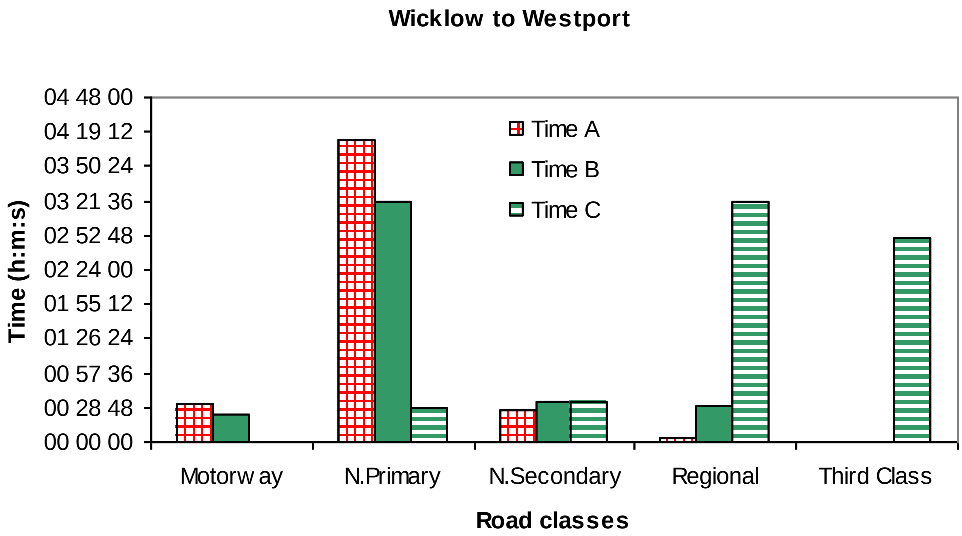


Figure 2. Time Vs Road class for each of the 4 GPS routes recorded (Time A) together with routes generated from the GIS (Time B and Time C).

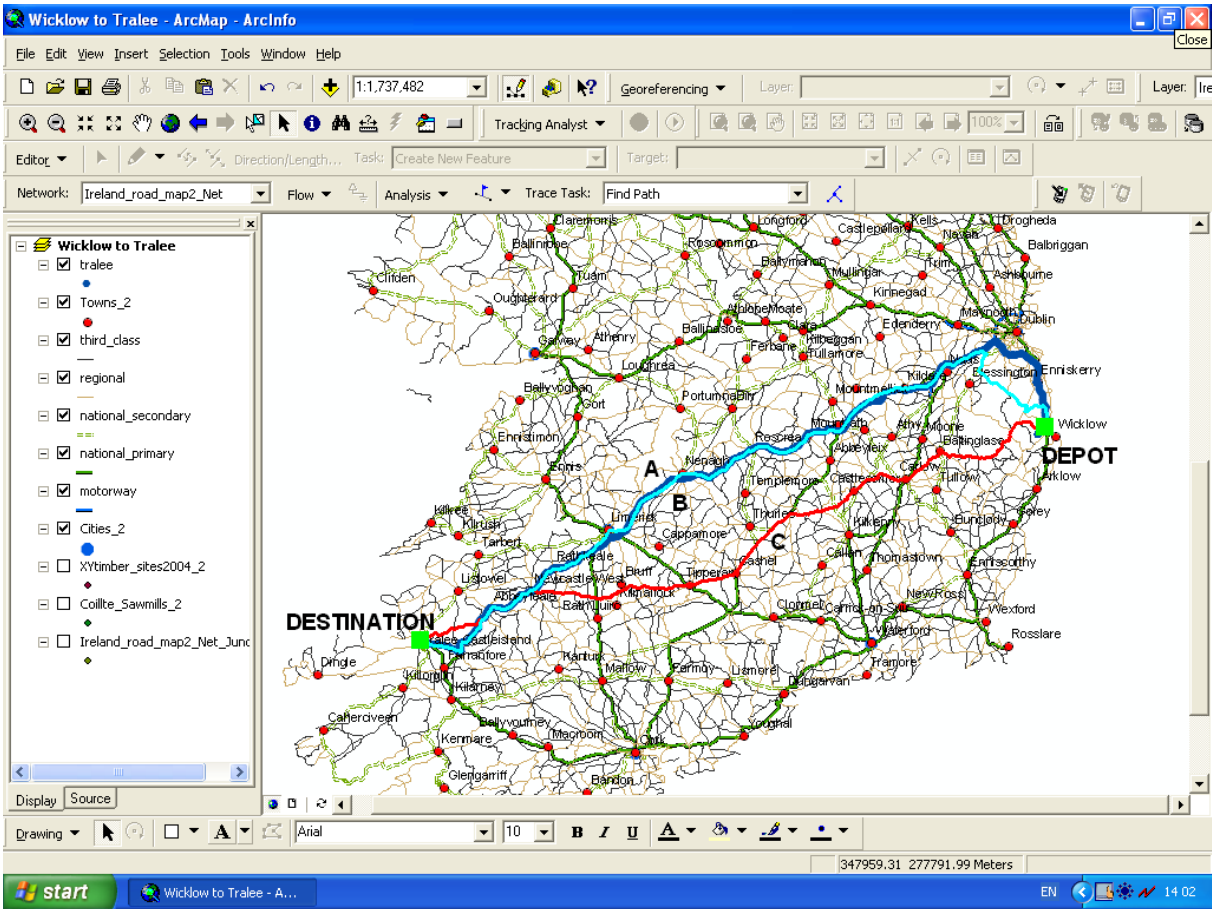


Figure 3. GIS map showing routes A (GPS), B (road class) and C (shortest) from Wicklow to Tralee.

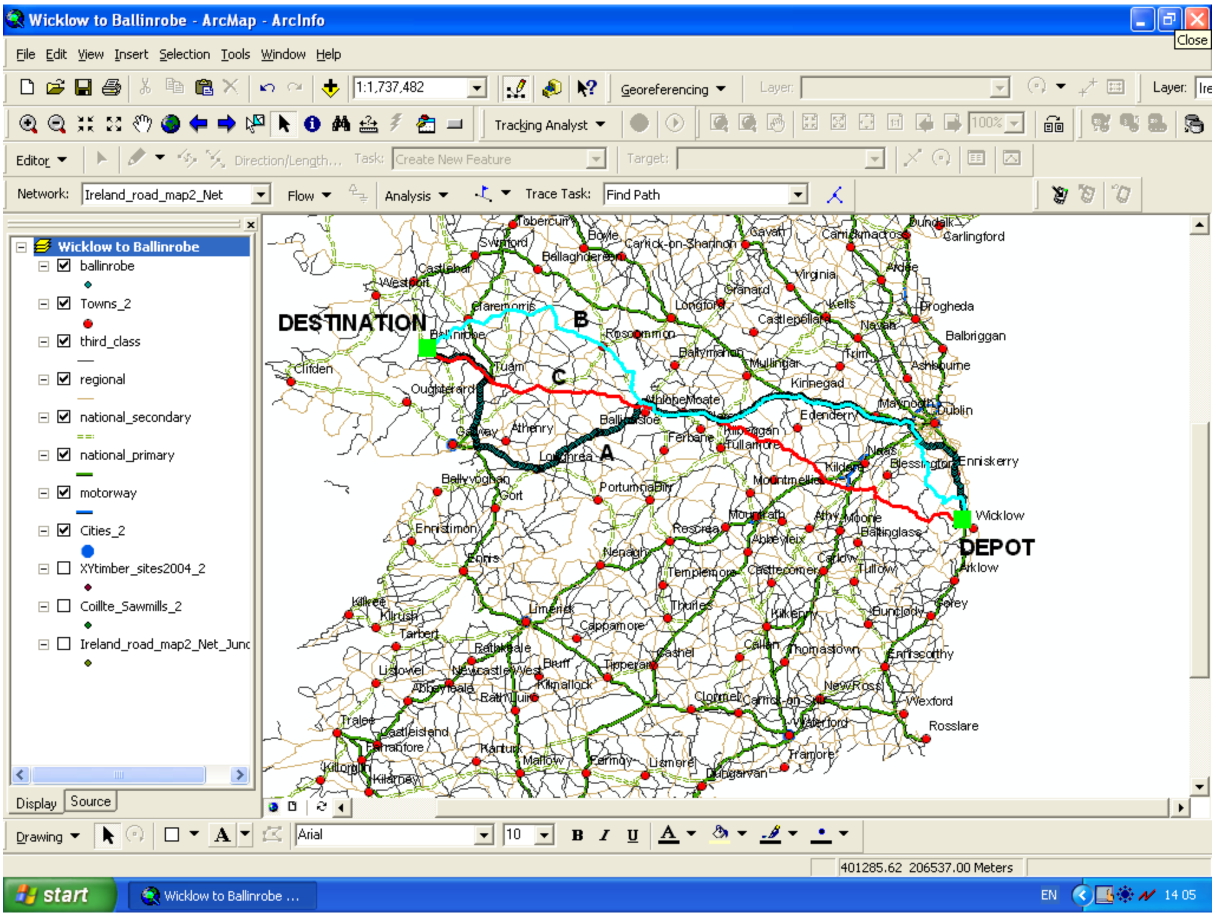


Figure 4. GIS map showing routes A (GPS), B (road class) and C (shortest) from Wicklow to Ballinrobe.