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32 was manipulated and used to determine the routes based on road classes i.e. routing to  
33 higher classes of roads and not distance (by applying a cost weighting within the  
34 geometric network), then the GPS routes were over 90% similar with what was  
35 modelled within the GIS. This may allow the GIS alone to be used in the network  
36 analysis of truck routing and in particular, timber truck routing from forest harvesting  
37 site to destination timber mill in Ireland and incorporate the use of GPS for other  
38 advantages such as real – time tracking.

39

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

41

## 42 **1. Introduction**

43 The rising amount of timber transported on the public road network across  
44 Ireland will present major challenges to the Irish road network in the coming years.  
45 The potential production of roundwood from the forests of Ireland will reach 5 million  
46 m<sup>3</sup> per annum by the year 2015 (Coford, 2001). The majority of this harvested timber  
47 will be softwood. Coillte (Irish Forestry Board) will remain the dominant supplier, but  
48 it is predicted that their market share will drop from 84% in 2001 to 66% by the year  
49 2015. The private forest sector market share will rise to 23% and the Northern Ireland  
50 forest sector will remain constant at 11% (Coillte, 2003). Road transport will remain  
51 the most important mode of timber transport in Ireland, forming a substantial part of  
52 the timber industry's raw material costs and having a major influence on the sector's  
53 overall economic performance and competitiveness (Coillte, 2003).

54 The introduction of new legal weight limits of 40 / 44 tonnes gross vehicle weight  
55 (g.v.w.) set by the Irish Department of Transportation (IFIC, 2004) is to try and help  
56 reduce the effect of heavy timber haulage on the forest roads but this has not agreed

57 well with the hauliers. Fear of an economic downturn in timber sales forces the  
58 hauliers to maximise their payload, which in turn continues the accelerated  
59 deterioration of the access forest roads, which in time will reduce or even permit  
60 further service and accessibility (Martin et al, 1999).

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

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

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

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

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

119

## 120 **2. Materials and Methods**

### 121 *2.1. Software and data used*

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

128 The GPS equipment used was a Trimble GeoXT handheld with sub-metre  
129 accuracy and external magnetic antenna, which was fitted to the roof of the cab of the  
130 truck. The GPS data was recorded through the ESRI ArcPAD software available on

131 the GeoXT. The data was recorded in the World Geographic System 1984 (WGS84)  
132 i.e. the GPS reference system. Since the digital road map within the GIS is in the Irish  
133 National Grid, the GPS data had to be projected into the Irish National Grid reference  
134 frame. WGS84 is a global system, which implies that data is not defined as precisely  
135 as possible on a national or regional basis, therefore a projection onto the Irish  
136 National grid was necessary in order to eliminate alignment and accuracy errors when  
137 adding the layers of GPS route data for eventual analysis within the GIS. This  
138 projection of co-ordinate systems was carried out within ArcCatalog.

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

145

### 146 *2.3.Data collection procedure*

147 The study area incorporated four distinct routes from the haulage depot in the east  
148 of the country to four destinations in the south, southwest, west and northwest of the  
149 country. The GPS was set to record data every thirty seconds along the route. Each  
150 route provided approximately 1000 sample points, of which 500 points were dynamic.  
151 There was on average seven satellites acquired for each sample point recorded.  
152 Considering that a minimum of four satellites is required to mark a position on earth,  
153 this indicates that the GPS antenna remained in continuous strong view of the sky and  
154 the orbiting satellites (Prisley et al. 1995).

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

162

#### 163 *2.4. Data analysis*

164 The first route selection (Dist A) shown in the tables two to five below was  
165 determined by the GPS and gives road classes travelled, distances on each road class,  
166 average speeds on each road class and finally the total travel time on each road class.

167 The simulated path finding between origin and destinations (o – d pairs), were carried  
168 out using the network utility analyst within ArcInfo. The routing macro automatically  
169 executes Dijkstra's routing algorithm, which scans the road network for all nodes  
170 adjacent to the origin node (Frank et al. 2000, ESRI UK, 2003). All links to these  
171 adjacent nodes are assessed and the shortest cumulative distance from the origin is  
172 selected at each node until the destination node is reached. This determines the  
173 shortest optimum path based on distance. These are labelled as Dist C in table's two  
174 to five.

175 The route selection (Dist B) involves applying weights to each of the five  
176 classes of roads. These weights force Dijkstra's routing algorithm to scan the road  
177 network the same as above except the roads are selected based on the highest class  
178 (not on distance) connected to the origin node and then in descending road class until  
179 the destination node is reached. This is done by simply adding weights to the classes

180 of roads when building the geometric network as defined in table 1. These “cost  
181 weightings” do not reflect the actual cost of road haulage or road weight restrictions.  
182 In order to carry out the network analysis and identify the most logical route that  
183 would be taken by the haulier, some logical assumptions were made in conjunction  
184 with the co – authors. The values of the cost weights imply that the routing algorithm  
185 will select the route starting at number one (or the next lowest number depending on  
186 the available network around the starting point). These “cost-weightings” were based  
187 on the Welsh model which have similar road network to that of Ireland. This forces  
188 the algorithm to continuously select the route of higher classification until the  
189 destination node is met.

190

191 INSERT TABLE 1 HERE

192

193 The simulated routes from within the GIS are then compared with the GPS  
194 route for each o-d pair based on road class selection, distance and total journey time.  
195 This approach introduces the idea of routing timber across Ireland’s road network by  
196 avoiding lower classes of roads, firstly in terms of distance and time of each route  
197 (Tietoenator, 2002). The transportation component of timber harvesting accounts for  
198 significant costs and can therefore provide opportunities for savings through increased  
199 efficiency with GIS network analysis of the haulage routes (Arvidsson, 2002). Burke  
200 (1995) designed a hydraulically independent power driven trailer, equipped with a  
201 crane and used in conjunction with suitably power driven tractor with a load carrying  
202 capacity of 15 - 20 tonnes. This was used to transport (pre-haul) timber from forest  
203 areas to suitable loading bays as close to higher classes of road as possible, for  
204 eventual transport by timber haulage trucks to eliminate 1) the movement of at most

205 44 tonne g.v.w. timber trucks travelling across sensitive forest access roads and 2) the  
206 need of costly forest and public road maintenance. This also aids in keeping the  
207 timber trucks routed to the higher classes of roads for optimum timber transport based  
208 on journey time and distance (Carlsson et al. 1999, Martin et al. 2001). Burke  
209 concluded that the pre-haulage would reduce the cost of timber extraction by up to  
210 41%.

211           Annually, Coillte must inform the respective Local Authorities of the sites that  
212 they intend to harvest during the coming year and the roads that they intend to use as  
213 an access route. Planning permission is then needed before any timber extraction can  
214 be carried out. Depending on their location, public roads are the responsibility of the  
215 National Roads Authority (NRA) or the Local Authorities. It is an offence to damage  
216 public roads under the Road Act 1993 (Irish Department of Transport, 2005). This  
217 research's objective is to incorporate the model for pre-planning of timber truck flows  
218 as far as the timber harvest forecast allows, which is up until 2015 (Frisk, 2003,  
219 Tarantilis et al. 2002). This pre-planning approach to timber haulage would be carried  
220 out annually in conjunction with the designation of timber harvesting sites (Optilog,  
221 2003, Mapflow Presentation Summary, 2002).

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### 230 3. Results and Discussions

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

238

239 INSERT TABLES 2 – 5 HERE.

240

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

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

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

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

255 At present in Ireland speed limits and distances on all road classes have changed from  
256 miles per hour (mph) to kilometres per hour (kph), under the Road Traffic Act 2004,  
257 effective from 20<sup>th</sup> January 2005 (Irish Department of Transport, 2005). As a result of  
258 this, the speed limits of 91% of the country's lower classes of roads will decrease and  
259 9% of higher classes and safer roads will increase in speed limit. The results of this  
260 paper have been determined in accordance with this new legislation.

261

262 INSERT FIGURE 1 AND FIGURE 2 HERE

263

264 Results show that despite Dist C being the shortest distance over all of the  
265 routes the travel times increase significantly over the regional and third class roads.  
266 Table 4 shows the greatest extra travel time of 2hrs 01mins 53secs for the Cork route,  
267 but with a shorter distance of only 48.75 km. A time of 1hr 59mins 04secs for the  
268 Westport route was calculated with a shorter distance of 11.98 km (table 5). The  
269 Tralee route (table 2) shows a time difference between route A and route C of 1hr  
270 21mins 49secs while Dist C is only shorter than Dist A by 28.7km. The Ballinrobe  
271 route (table 3) shows the smallest difference in journey time of 00hr 26mins 38secs  
272 with a corresponding shorter distance of 66.87km. These lack of similarities between  
273 route A and route C are due to the fact that the truck must travel at much slower  
274 speeds on the lower classes of roads as opposed to travelling at higher speeds on the  
275 higher classes of roads as is the case with Dist A and Dist B. This is exactly the  
276 problem that is trying to be tackled as regards the haulage of timber in Ireland. Coillte  
277 are in fact adopting the approach of paying their contracted hauliers based on mileage  
278 bands. This will add incentive to the hauliers in terms revenue per mile while at the  
279 same time reduce the effect of road deterioration of the lower class of roads. If the

280 designated extraction routes are also adhered to, then this will automatically lead to a  
281 reduction in the cost of road repair and maintenance.

282 The GPS route (Dist A), is simulated the best by the modelled route Dist B.  
283 The route selection between the two routes for each journey has similarities as high as  
284 96.6% for Tralee (Fig. 3), 95.6% for Westport and 93.4% for Cork. The route to  
285 Ballinrobe has the least similar route at 90.8% of the GPS route (Fig. 4). These  
286 percentages are calculated based on the distance values of Dist A and Dist B.

287

288 INSERT FIGURE 3 AND FIGURE 4 HERE.

289

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

299

#### 300 **4. Conclusion**

301 This study has shown that truck haulage routes in Ireland can be modelled  
302 within a GIS by manipulating the routing algorithm with cost effective weights. The  
303 simulated route (Dist B) replicates the GPS route (Dist A) with similarities ranging  
304 from 96.6% for Wicklow to Tralee, to only 90.8% for Wicklow to Ballinrobe. From

305 this, it may be possible to make full use of the manipulated routing algorithm to  
306 model truck flows throughout Ireland, namely timber truck routes, in terms of road  
307 class, road distance, road speeds and perhaps most importantly, road travelling time.

308 Coillte and the Forest Industry Transport Group (FITG) have discussed the benefits of  
309 in-vehicle tracking devices and to gain experience in the use of tracking devices and  
310 reporting devices in the context of timber haulage. The new weight legislation is  
311 reducing the haulier's income per pick-up and delivery. This demands the need to  
312 assess pre-planning and re-sequencing of pick-ups and deliveries within existing  
313 routes as a means of increasing the daily route revenue. Can attempting to decrease  
314 the cost per tonne bridge the loss in income as a result of the new weight limits? To  
315 do this, however, the cost associated with existing routes needs to be calculated as a  
316 base for future analysis and comparison.

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

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

329           To take the analysis and research developing a truck routing strategy further,  
330 we need to include all factors associated with the calculation of the haulier's daily  
331 expenses. By creating this database for the participants involved we can then use as it  
332 as reference for future comparison and analysis with the revenue earned. Factors such  
333 as tax, insurance, fuel, cost of legal loading, road tolls, driver wages, operational and  
334 maintenance expenses, must all be included for an exact calculation to be carried out.  
335 Other factors to be incorporated into the calculating the haulier's expenses would be  
336 the loading and unloading times. If for example, in the case of articulated tractor units,  
337 each truck had various trailers accessible to it, then a system could be developed to  
338 load trailers in advance of the pick-ups to reduce the time lost for the driver to load  
339 and unload. This in turn would lead to the possibility of introducing a backloading  
340 system. On average, trucks are unloaded for 50% of the journey. By increasing the  
341 amount of the journey time loaded would automatically lead to an increase in revenue  
342 per mile.  
343

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

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

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Road Classes	Dist A <sup>a</sup> (km)	Dist B <sup>b</sup> (km)	Dist C <sup>c</sup> (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
<b>TOTAL</b>	<b>323.39</b>	<b>334.73</b>	<b>294.72</b>			<b>5:00:00</b>	<b>5:12:22</b>	<b>6:21:49</b>	<b>0:12:12</b>	<b>1:21:49</b>

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

440 Dist A<sup>a</sup> = actual GPS recorded route.441 Dist B<sup>b</sup> = modelled route based on road class selection within GIS.442 Dist C<sup>c</sup> = modelled route based on shortest distance within GIS.

443 Time A = Time recorded by GPS. This is not exactly equal to the theoretical value of

444 Dist A / Average Speed. This is due to perhaps certain errors within the GPS such as

445 multipath, atmospheric or Dilution of Precision. These induced errors cause the radio

446 waves from the GPS satellite to become bent or refracted which changes the length of

447 the path and thus the length of time it takes the signal to reach the GPS receiver

448 (Prisley et al, 1995).

449 Time B = Dist B / Average Speed.

450 Time C = Dist C / Average Speed.

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

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

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

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

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

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

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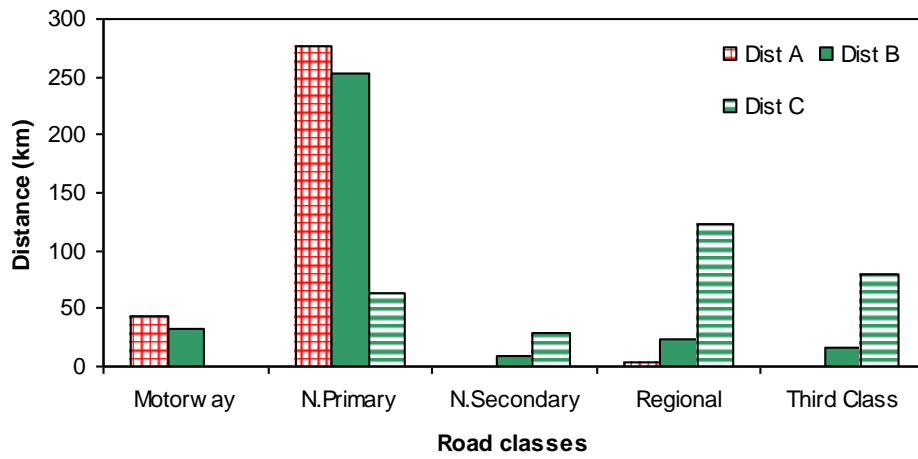
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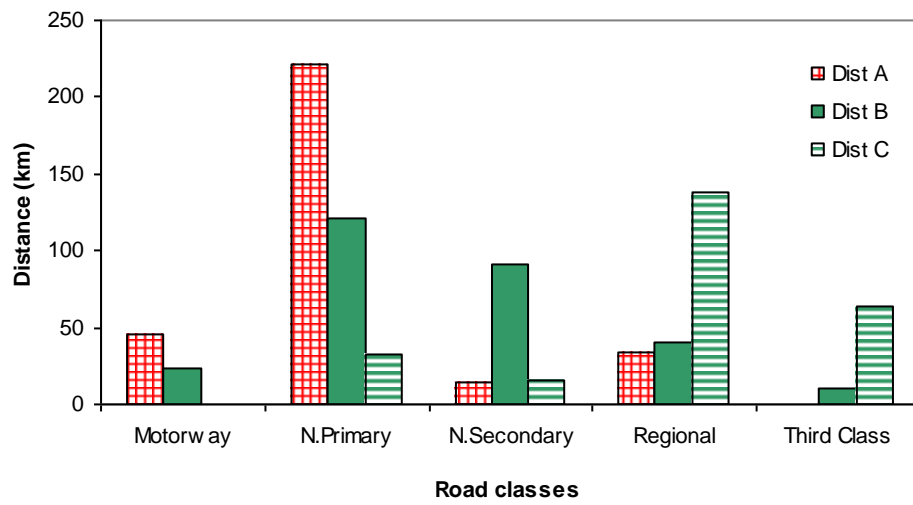
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Wicklow to Tralee

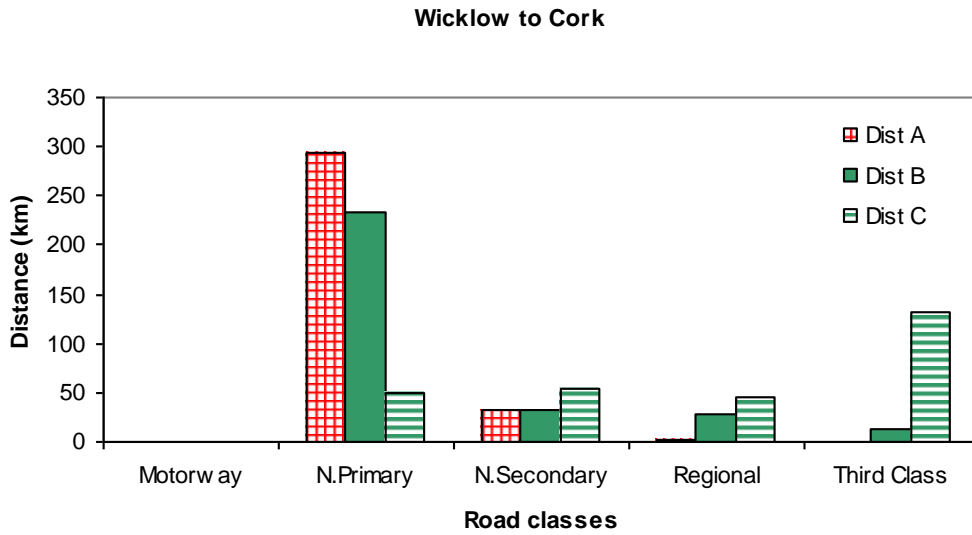


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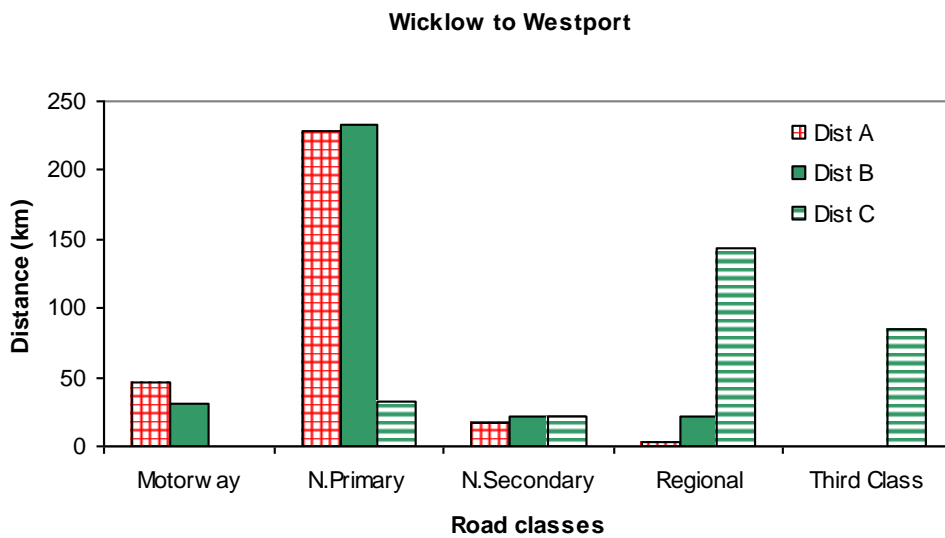
Wicklow to Ballinrobe



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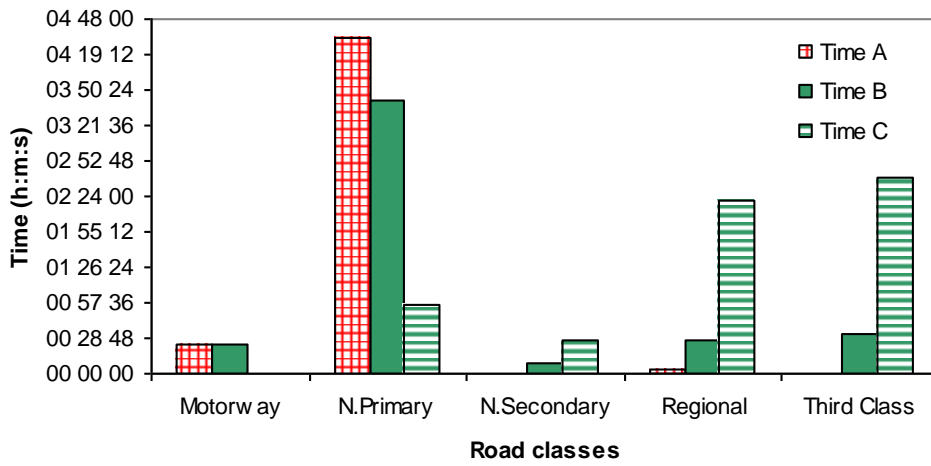
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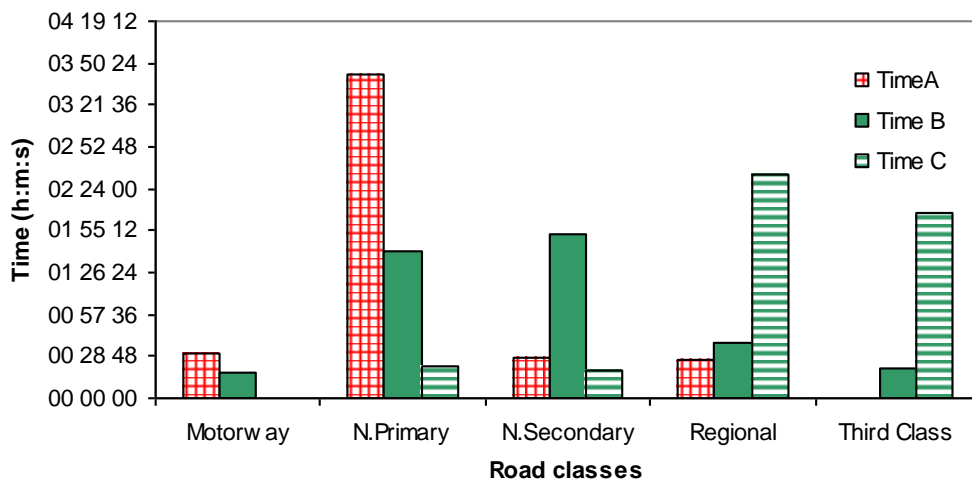
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Wicklow to Tralee

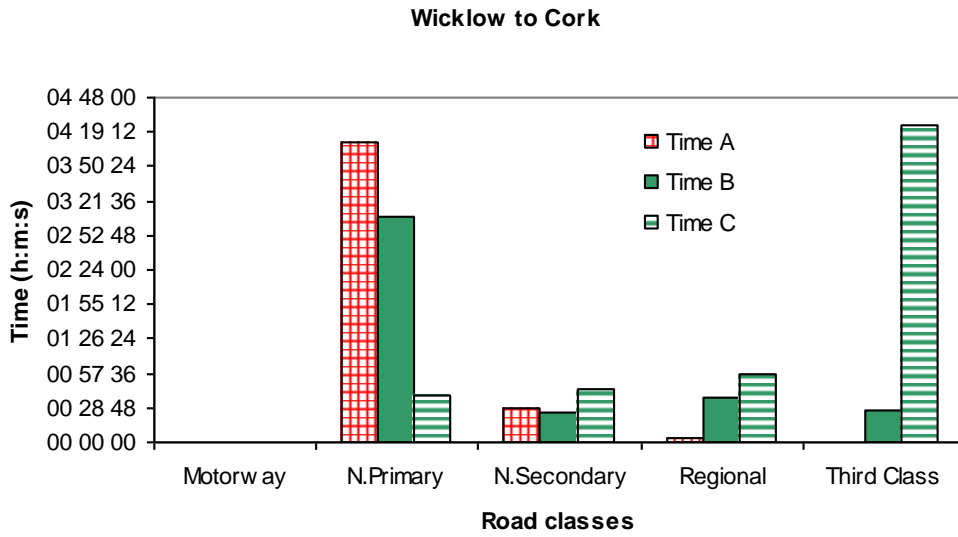


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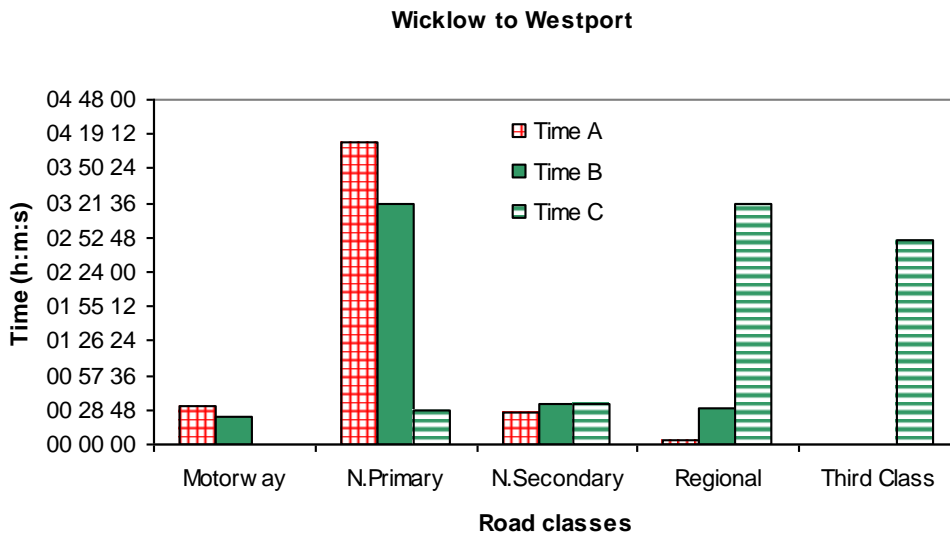
Wicklow to Ballinrobe



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523 Figure 2. Time Vs Road class for each of the 4 GPS routes recorded (Time A)

524 together with routes generated from the GIS (Time B and Time C).

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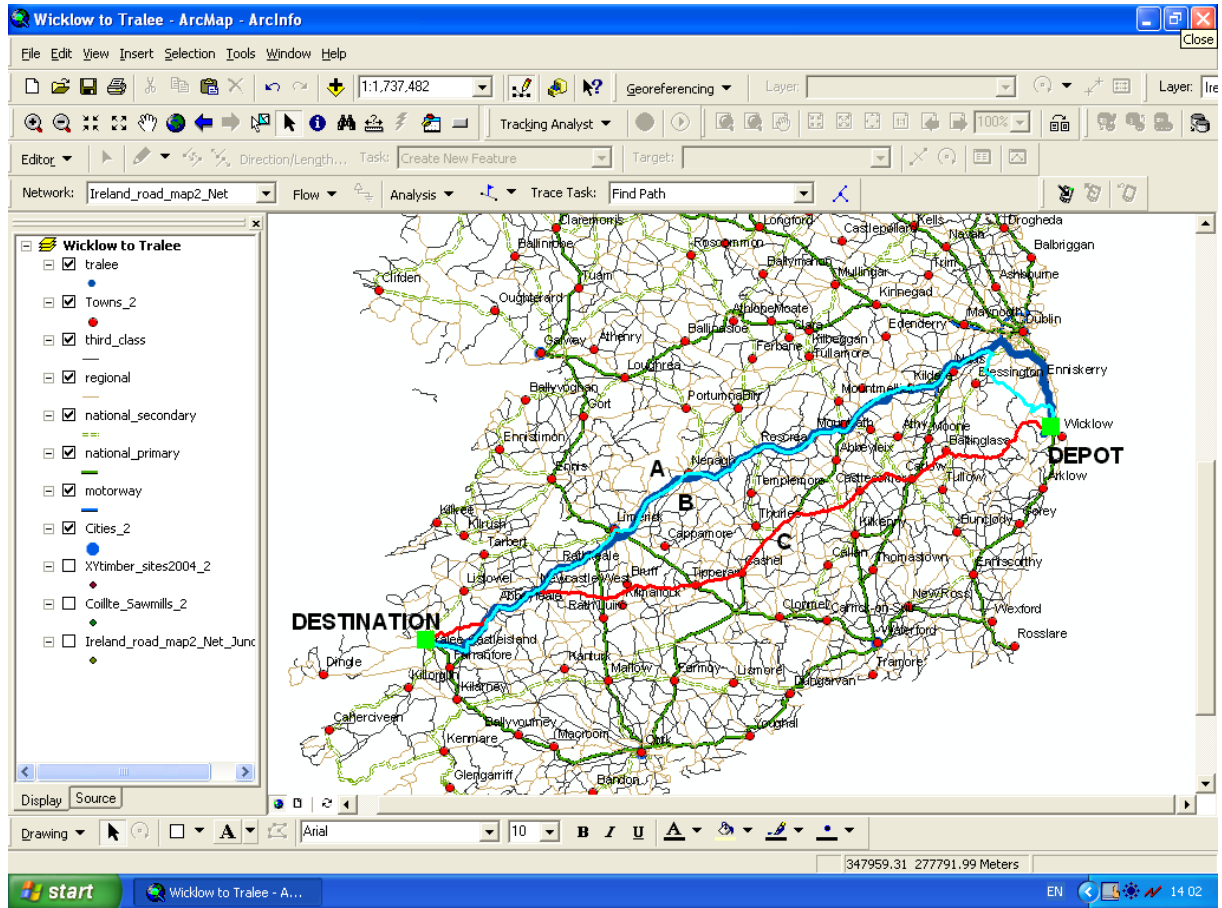
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533 Figure 3. GIS map showing routes A (GPS), B (road class) and C (shortest) from  
534 Wicklow to Tralee.  
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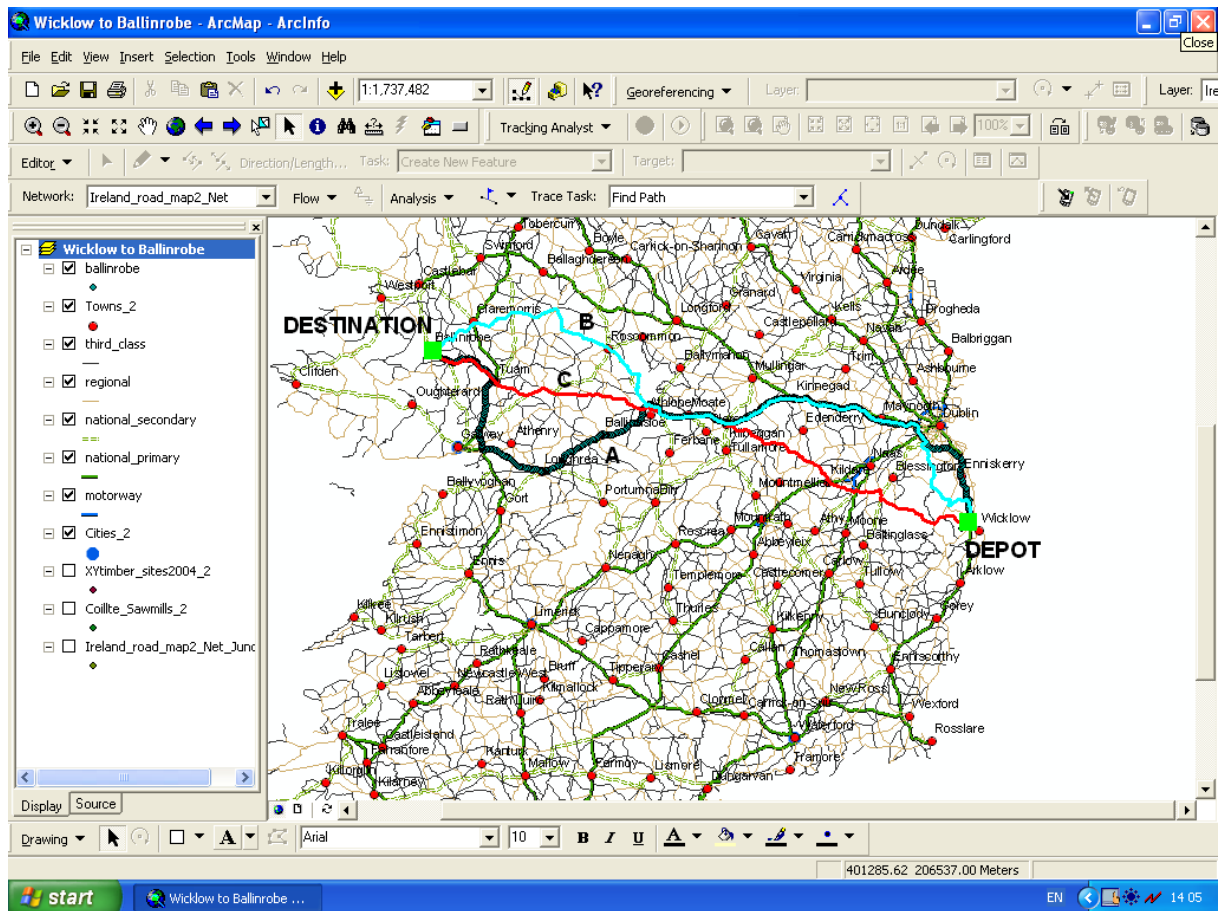
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548 Figure 4. GIS map showing routes A (GPS), B (road class) and C (shortest) from  
 549 Wicklow to Ballinrobe.

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