Determining Truck Activities from Route Data

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Abstract. Monitoring trucks' routes and stoppages based on recorded discrete position and speed data is an important and, if not fully automated, a time-consuming transportation fleet-management task. The data are first visualised, then processed. It is argued in the paper that the data should be looked at processed at multiple semantic levels. At low level, in case of two-level processing, the trajectories are partitioned into short trajectory segments. Each of these corresponds to some primitive driving action, or in a physical sense to some (primitive) vehicle-movement, such as high-speed movement, low-speed movement, and stop. At high level, trajectory sections are formed; they are longer and more complex actions/movements than trajectory segments. The trajectory sections correspond to various truck manoeuvres (e.g., high-speed runs, various low-speed manoeuvres). The trucks' trajectories can be displayed as graphical overlays on satellite images; and thus their spatiotemporal characteristics are presented in spatial domain. In the paper, emphasis is given to the low- and zero-speed manoeuvres (e.g., loading/unloading) as these manoeuvres are more critical from a security point of view. The manoeuvres are formed from primitive driving actions using a linguistic approach. To this effect, a simple spatiotemporal pictorial description language is proposed to facilitate manual and semi-automatic evaluation of position and speed data, and that of truck manoeuvres. Descriptions of some low- and zero-speed manoeuvres are presented as examples.

Keywords: Transportation fleet management, Route monitoring, Spatio-temporal description languages.

1 Introduction

It is an understandable intention of transportation companies to *verify the proper use of trucks* of their fleets. Assuming a not fully computerised data processing, the first step of monitoring routes covered by trucks of a transportation fleet is the *visualisation* of the collected route data. Apart from possible other useful data, it should, at least, comprise discrete position- (trajectory) and speed measurements taken at regular intervals. Considering *truck fleets* comprising more than just an odd truck, and *haulage operations* with several trucks on long-haul national/international transport assignments, the *manual inspection of trajectory data* becomes highly time-consuming and unreliable. Therefore, *semi-automated tools*, and/or fully *automated route* *monitoring systems* are required by all but the smallest transportation companies. Such systems can work either in an online, or offline manner. In this paper, we argue that *segmenting the trajectories* into meaningful trajectory sections and classifying these sections based on their spatiotemporal characteristics into a small number of vehicle activity classes are useful pre-processing steps that facilitate both the manual and the automatic monitoring of truck routes. We also argue that the *trajectory and speed data* should be looked at and *processed at multiple semantic levels.*

The rest of the paper is structured as follows. In Section 2, the Google Earth program is used for the visualisation of the collected truck route data. The trajectories are described in Google's *Keyhole Markup Language (KML)*. In Section 3, a linguistic approach for segmenting truck trajectories based on their spatiotemporal features is proposed. Some trajectory sections are looked at in detail. Examples of low-speed manoeuvres and stoppages are presented as graphical overlays on satellite images. A simple pictorial language for describing truck trajectories is proposed. In Section 4, conclusions are drawn and further work pertaining to intelligent monitoring of truck trajectory data is suggested.

2 Visualisation of Trajectory Data

The first step in *monitoring truck routes* is *visualisation* of the collected route data. The collected route data should comprise, at least, the *position- (trajectory) and speed measurements* taken at some short regular intervals during haulages. In Fig. 1, the routes covered by a *small fleet* of trucks over a period of a few days are shown as concrete examples. The same routes are shown in Fig. 2 with the *braking locations* – i.e., the geographical locations where stronger braking were performed – marked. In Fig. 3, one of the truck routes from Figs. 1 and 2 is shown with markers indicating the magnitude of the intended braking force.

The trucks' *recorded braking locations* – together with other relevant braking measurement data, e.g., braking force exerted, deceleration intended, deceleration achieved – could be used also for *continual monitoring the road safety* of certain routes, particularly in case of bigger fleets with trucks *running mostly over some standard routes*. In an earlier paper, we evaluated trucks' routes from a road safety point of view [1]. A clustering approach was used for investigating trucks' brakings (e.g., in the feature space of vehicle velocity, demanded deceleration and type of the environment). In the present paper, however, we try to identify activities of trucks. This topic is related to *shipment and vehicle security*.

2.1 Off-the-road artifacts

The *temporal sampling frequency* of the position measurements must be chosen in a way that ensures a reasonable spatial sampling frequency, as well. For example, with an average truck speed of 100 km/h, and 30 seconds between geographical location measurements, the average sampling distance turns out to be about 0.8 km, while the average *spatial sampling frequency* about 1.2 samples/km. It should be noted that by such a low spatial sampling frequency *off-the-road artifacts* – i.e., truck seemingly leaving the road – appear in considerable numbers on highly bending road sections if interpolation is used for presenting truck routes.

Note that neither the roads themselves, nor the artifacts are discernible at the spatial resolutions used in Figs. 1-3. In Fig. 4, however, a higher resolution was chosen, and thus off-the-road artifacts can be identified for the truck moving along a highly curved road section.

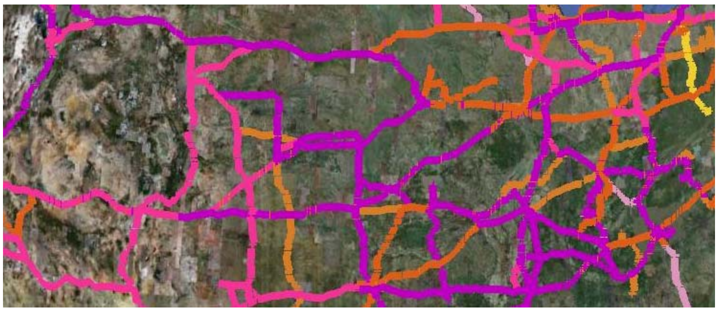


Fig. 1. Routes covered by a small fleet of trucks – as displayed by the Google Earth program – over a satellite image.

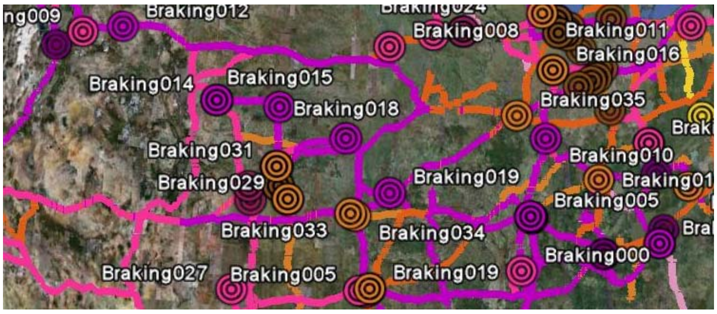


Fig. 2. The same routes as shown in Fig.1.– with the trucks' braking locations marked – as displayed by Google Earth.

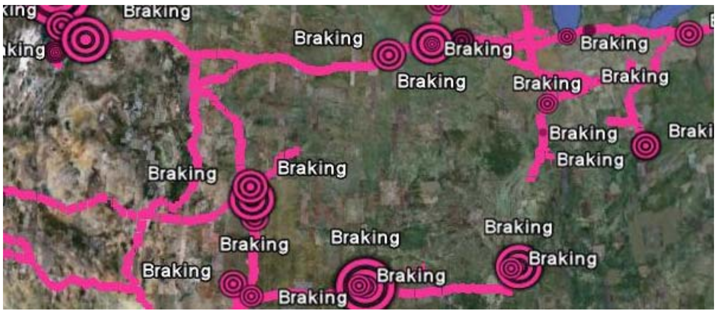


Fig. 3. Truck routes with braking locations as displayed by Google Earth. The marker size represents the strength of the intended braking.

2.2 Trajectory Data in KML

If we intend to use some *geographical visualisation program* to inspect route data – and perhaps other measurement data pertaining to the trucks' routes, e.g., braking data – then these data need to be converted into a graphical overlay description, e.g., into a KML description. KML is the abbreviation of Keyhole Markup Language. It is an XML-like *graphical overlay description language* developed by *Google*.

Fig. 4. Off-the-road artifacts appear in the visualization – due to the low spatial sampling frequency used for the route – at a curving road section of a motorway junction.

An excerpt from a *KML description* is shown below.

```
<kml ...><Document>
   <name>TruckRoute.kml</name>
   <Placemark><Style>
      <LineStyle>
         <color>ff2a7dd7</color>
         <width>8</width>
      </LineStyle></Style>
      <LineString>
         <coordinates> 12.3, 45.6, 0.0; ...
         </coordinates>
      </LineString>
   </Placemark>
</Document></kml>
```

One or more KML file can be opened and displayed by the *Google Earth* program at the same time. For example, Figs. 1 and 2 present two identical views of the same large continental area over which the trucks of the mentioned small fleet zigzagged during their transportation assignments. The two figures differ only in their respective *graphical overlays*. Each overlay was generated from several *KML descriptions* representing route data only, and route as well as braking data, respectively. Google Earth has *useful features* for checking truck routes. It can, for example, *zoom in* on the individual routes and braking locations, furthermore, it can *fly over* a given truck route and show it as if it were seen from an aeroplane. Its *StreetView* facility is very *convenient to look around* in a virtual manner at/from far away locations. For truck route *monitoring purposes*, these locations are normally various *road locations* (e.g., locations of strong brakings, slow vehicle movements, traffic jams) and *public areas* near businesses, e.g., near haulage destinations, such as plants, petrol stations.

3 Spatiotemporal Segmentation and Description of Truck Routes

It is an understandable, *acceptable* and valid *objective* of *transportation companies* to verify the *proper use of trucks* of their fleets. Such verification should certainly include *checking the routes* that are either being covered, or at some stage had been covered by their trucks. The first approach corresponds to the *online tracking* of the vehicles, while the second one is an *offline verification* of the route data. As the route covered during a *long-haul transportation assignment* can be of considerable length, even several hundreds of kilometres, furthermore, the spatial and temporal resolution of a non-trivial route-check – i.e., one that is useful from a security point of view for the transportation company – need to be at least 1 sample/km and 1 sample/minute, respectively.

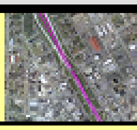
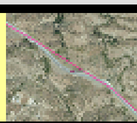
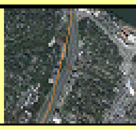
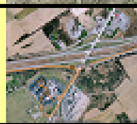
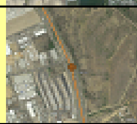
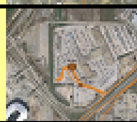
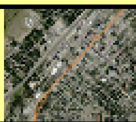
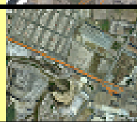
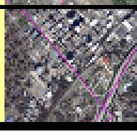
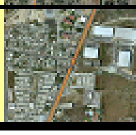
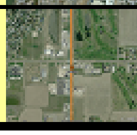
3.1 Characteristics of Trajectory Sections

It might be helpful to *segment the trajectories* into meaningful *trajectory sections*, and *classify* these sections based firstly on recorded truck position- and speed data, secondly, on *transportation specific data*, and thirdly, on *general road data* into a small number of vehicle activity classes. These classes could be, for example, high-speed runs (on main roads), low-speed manoeuvres (on narrow roads, on dust roads, or on closed areas) and stoppages. The transportation specific data should include geographic and descriptive data on various past and future truck destinations, on accommodations frequently used by the drivers of the company, and also on preferred refuelling stations. The general road data should provide a fairly general characterisation of the road segments, possibly in the manner shown Table 1. Such data should be gathered from relevant public or private *geographical information systems*.

In case of a *high-speed run*, its duration, the covered distance, the vehicle's average speed, and fuel consumption, as well as, the geographic coordinates of the route section's starting and end-points are some of the most important features a haulage company would be interested in. In case of a *low-speed manoeuvre*, its spatiotemporal character – or spatiotemporal morphology of the trajectory – could be also of interest for a transportation company as this character – together with the type of the location at/near/in which the manoeuvre took place – might give a clue concerning the intentions of the truck driver.

In case of a *stoppage*, the apparent purpose of the stoppages would be important to identify. For this, again, the type of the location should be known. Such segmentation of truck routes could, on one hand, help detect certain *infringements of traffic rules* and identify certain *suspect, or malevolent driver behaviours*. On the other hand, assuming *bona fide drivers* and *good-willing* companies, the collected stoppage data could be utilised in *structuring trips* and deploying shipments in a way that takes individual *driving and stopping habits* and *preferred stopping locations* of the truck drivers into consideration.

Table 1. Various road and neighbourhood classes. The knowledge whether a certain road location and its neighbourhood belong to one or more of these classes helps considerably in making sense of the route data.

	Urban	Residential	Industrial/ commercial	Rural
Motorway		✓		
Motorway entry, exit, or junction	✓			
Road entry, or exit	✓	✓		
Parking lot	✓	✓		✓
Near parking lot				
Near junction				

3.2 The Pictorial Truck Action Description Language

For the *description of truck manoeuvres and stoppage episodes*, such as a truck's parking at a roadside resting place, or its loading/unloading at a business location, we propose a simple intuitive pictorial language, namely the *pictorial truck action description language* (PTADL). It relies primarily on the spatial traits of the trajectory, though the vehicle's speed is also taken into account.

A somewhat similar spatiotemporal linguistic approach was taken by [2]. There, however, the proposed *moving object description language* is *very complex*, fairly general in terms of the *road vehicle-types* and supports a *wide range of database queries*. On the other hand, PTADL concentrates on truck activities, particularly, *low-*

and *zero-speed manoeuvres* (such as loading/unloading, parking, refuelling, and stoppages) as these manoeuvres are more *critical from a vehicle and shipment security* perspective.

In the next subsection, parallel to the analysis of a stoppage episode and some more complex manoeuvres (such as the loading/unloading of trucks at business locations) some of the more important *primitive driving actions* and their *pictorial signs* are introduced.

3.3 Low-speed Manoeuvres and Stoppages

Interestingly, the trucks' *low-speed manoeuvres* and *stoppages* pose *higher security risks* for the haulage companies than high-speed runs, as it is highly unlikely that the transported goods vanish into thin air from their trucks when they are in motion. For this reason, it is particularly worthwhile to look into low-speed and zero-speed truck activities. Complex low-speed manoeuvres and longer stoppages are mostly associated with *deliveries to/from some business location*. In order to reasonably segment the input truck data, one needs to *locate and identify such locations* and also the lengthier stops of trucks. The trucks' trajectories near and around such places are characterised by *several turnings* carried out *over a relatively small area* and stoppages of considerable elapsed time. These characteristics can be verified in case of loading and/or unloading of a truck at a dispatch centre with truck terminals shown in Fig. 6b.

A low-speed episode: parking at a roadside resting place

Having been driving for some hours, the driver stopped his truck at a roadside resting place. (See the *aerial view* of the resting place – together with the truck's trajectory – in Fig. 5a.) The driver might have poured himself a cup of coffee, perhaps listened to the news on the radio. He stayed there for a few minutes and then he drove on. We have no way of knowing the concrete reasons and exact details of his stay. However, the spatiotemporal details of this parking episode were recorded. In Figs. 5e-h, the parking episode's *spatiotemporal trajectory* is shown in four different views, more specifically, in three orthographic views and in a general axonometric view that was chosen for good visibility. In the figures, only the longitude, latitude and time values are shown; the altitude values were omitted to keep the visualisation task undemanding.

The lack of considerable position noise during stoppage, see Figs. 5e and 5h, indicates that only a relatively short time was spent in the parking place. (This is in agreement with the time-values shown in Figs. 5e and 5f.) The presented trajectory is simple and easy to interpret; there is no sign of any complicated parking manoeuvres. The trajectory can be easily partitioned into *trajectory segments* corresponding to *primitive driving actions* (pda's). These actions are shown in Figs. 5a and 5d in two different ways. The concrete pda's were selected from a small number of *action classes.* The selection was based on the spatiotemporal features of the trajectory segments. A *truck manoeuvre* – or driving/movement episode – can be seen as a *sequence* of primitive driving actions.

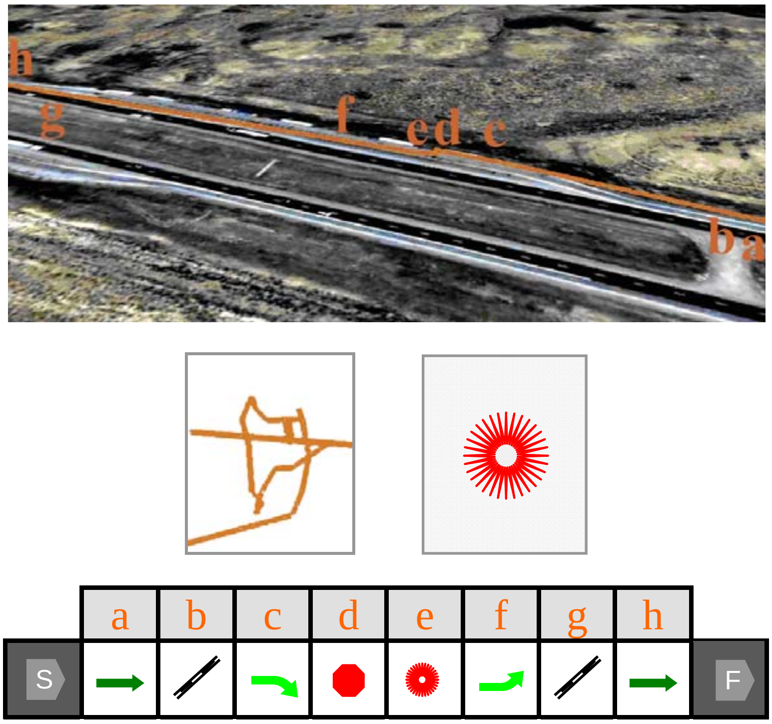


Fig. 5. A roadside parking place that had been used by the truck considered in the text. The parking place is displayed with the Google Earth program. The trucks parking in the parking place are most probably different from the one considered in the text. (a). The (noisy) trajectory of the truck during its stoppage (b). The pictorial sign used in PTADL for stoppage. The sign slightly resembles to the noise pattern experienced in such cases (c). Pictorial string representing the parking episode considered. The string is made up from the pictorial signs denoting primitive driving actions (d).

The *following sequence of pda's* corresponds to the low-speed episode mentioned above.

- Firstly, the truck *drew near to the location* of the resting place on the main road with a reasonably *high speed*. Such a speed is indicated in the signs of the PTADL by the use of colour . The truck kept right on the main road and its forward movement was fast and more or less straight. Such a movement is denoted by . In Fig. 5a, this trajectory section is marked with letter *a*.

- Then the truck *entered into the lane* that turns off the road and leads into the roadside resting place shown in Fig. 5a. That is, a *significant lane-change* was carried out by the truck. Such a lane-change is denoted by . This trajectory section is marked with letter *b* in the figure.

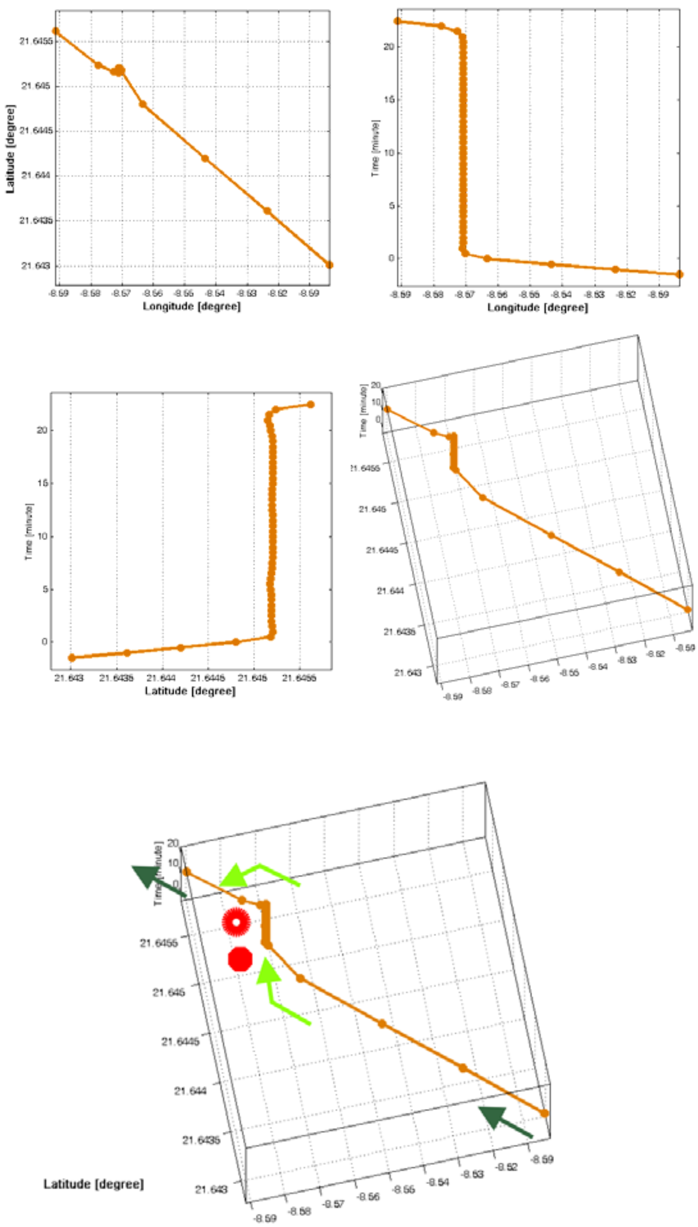


Fig. 5 (continued). Different views of a truck's spatiotemporal trajectory. The trajectory logs a brief parking episode at a roadside resting place (e-h). Some of the primitive driving actions associated with the spatiotemporal trajectory section of the parking episode mentioned in the text (i).

- In the meanwhile, the truck had *slowed down*. The *low-speed movements* are marked with colour ■ in PTADL. The truck moved along the exit-lane into a resting place, that is, it *turned slightly off from its earlier course* to the right. It is denoted by the sign in PTADL. This trajectory section is marked with letter *c* in the figure.

- Having arrived to the resting place, the truck *stopped* there. Stoppages are denoted by the sign in PTADL. This trajectory section is marked with letter *d* in Fig. 5a.

- The truck *stayed in the parking place* for about 20 minutes. The stoppage is marked with in PTADL. This section is marked with letter *e* in the figure.

- The truck *started again* and *moved slowly forward*. Then, it *turned slightly left*. This is denoted by . This trajectory section is marked with letter *f* in the figure.

- The truck then *returned to the main road* by carrying out a *significant lane-change* marked with letter *g* in the figure.

- Then the truck *moved forward* on the main road *with relatively high speed*. This trajectory section is marked with letter *h* in the figure.

In Fig. 5i, the *pictorial signs* were placed close to their corresponding trajectory segments. Pda's b and g were omitted from the figure, as information on lane structure and geometry would have been necessary to identify these pda's. Such information could be gathered via relevant *queries to some public road database*, or could be gathered via manual or computerized processing of the satellite images covering the area in question.

Another low-speed episode: loading/unloading at a business location

The *loading/unloading* of a truck at a *milk plant* of a supermarket chain appears in Fig. 6b. An *impression of the location and the surrounding area* can be gained from the photo shown in Fig. 6a. The time spent by the truck at this business location was considerably longer than the duration of the parking episode shown in Fig. 5.

Also, the *complexity of the manoeuvre* at hand was considerably higher than that of the parking episode. The truck's *spatial trajectory* is shown in Fig. 6b, while the truck's *spatiotemporal trajectory* appears in Fig. 6c. It is presented in a general axonometric view selected for good visibility of the details. The details of the loading/unloading manoeuvre can be traced in Figs.6e- h. These figures also provide context to the manoeuvre.

Some of the pda's that were carried out whilst the truck was driven along the trajectory are shown in Fig. 6b. The pictorial signs were placed close to the corresponding trajectory segments. The signs which have not been used earlier are more or less self-explanatory, except perhaps for sign . It represents a slow *haphazard movement* of the truck.

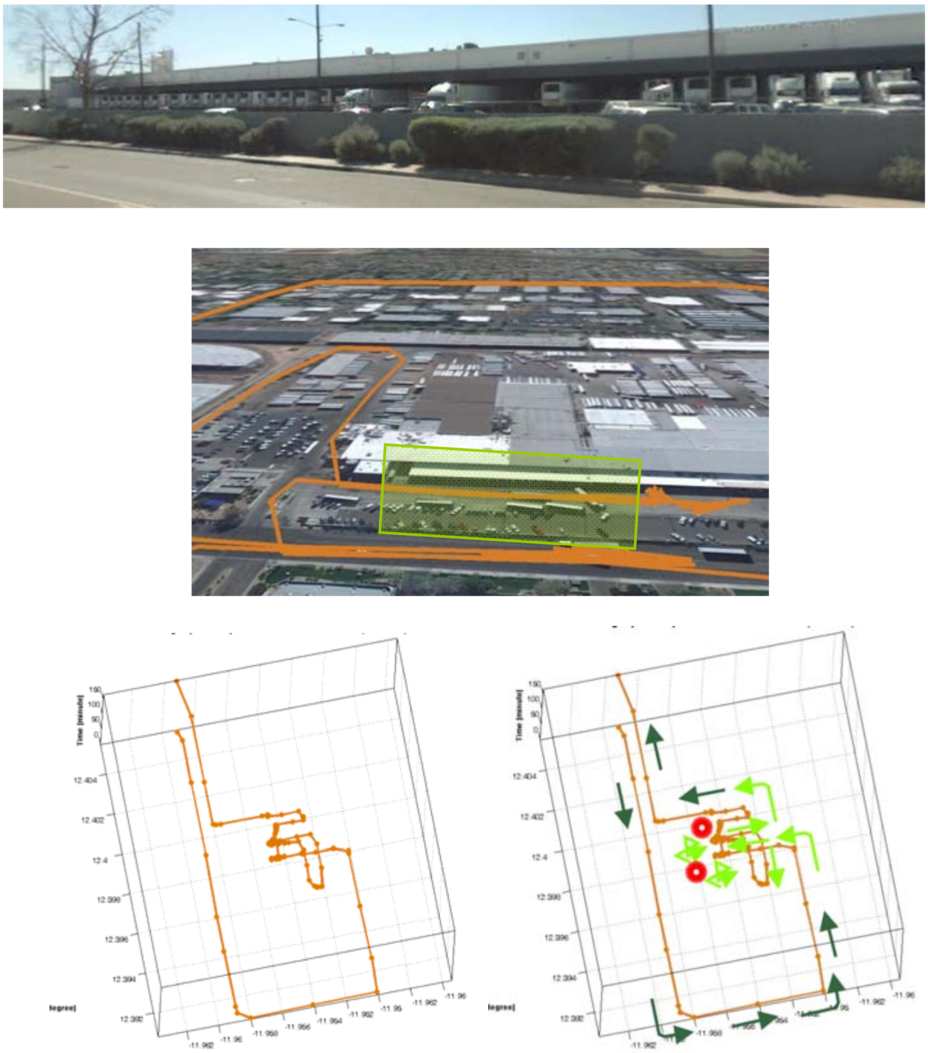


Fig. 6. A milk plant as displayed by Google StreetView (a). The route covered by a truck – as displayed by Google Earth – during a loading/unloading manoeuvre (b). The spatiotemporal trajectory of the truck (c). Some of the primitive driving actions associated with the spatio-temporal trajectory (d).

To differentiate between such movements and the random position noise *criteria concerning the amplitudes of the movements* are introduced. These criteria are touched upon in the next subsection.

Fig. 6 (continued). The milk plant shown in Figs. 6a-d is displayed here by Google Earth. The driver's efforts for precise parking before loading/unloading can be clearly perceived. The trajectory sections are repeated in the right images without the satellite images (e-l).

Yet another low-speed episode: loading/unloading at a business location – in a different way

The trajectory associated with another loading/unloading episode at a different business location (see Fig. 7a) is shown *several image resolutions* in Figs. 7b-i.

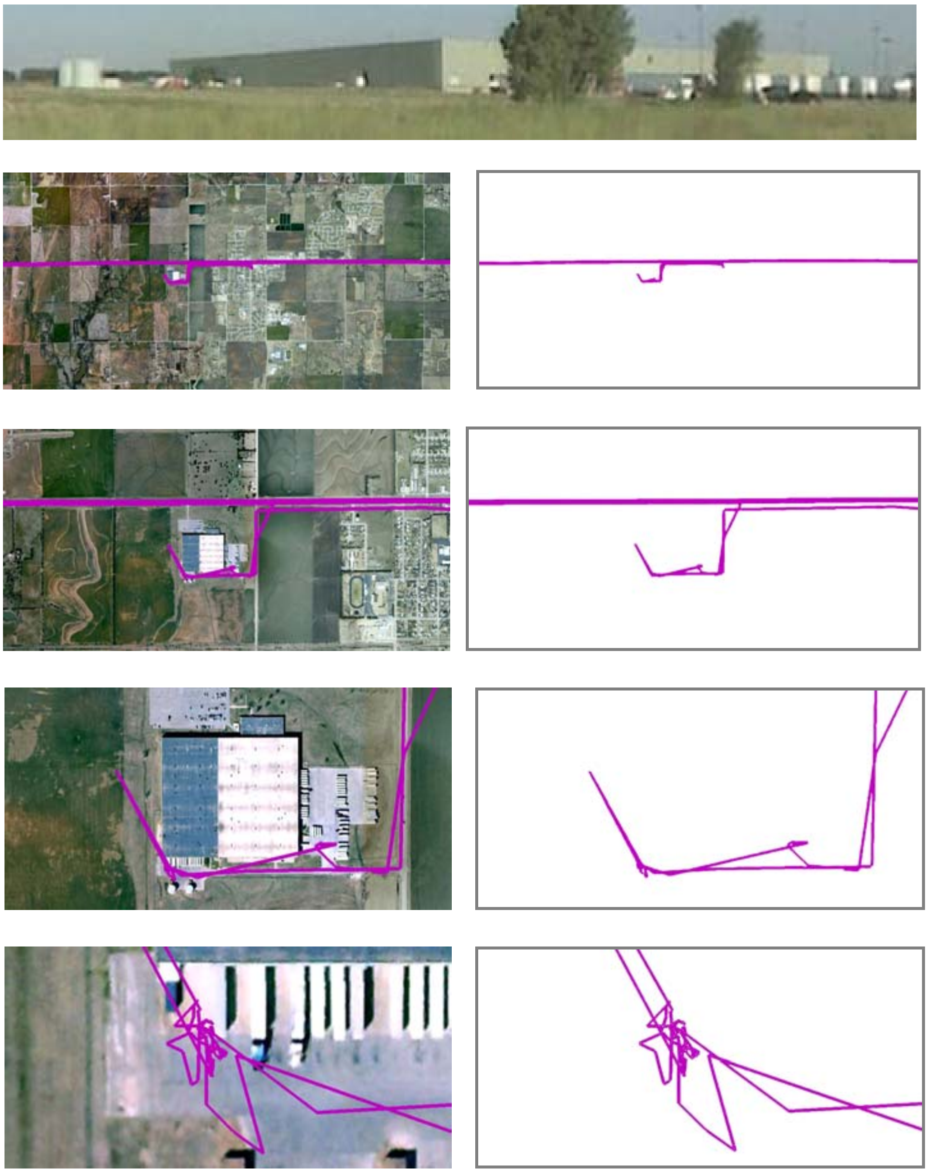


Fig. 7. A truck destination – a plant – mentioned in the text as displayed by StreetView (a). The truck's trajectory around the plant, with and without satellite images, in four different image resolutions are displayed by Google Earth (b-i).

The manoeuvre shown in Fig. 7b-i has a some what *different character* compared to the episode loading/unloading discussed earlier. In Fig. 7j, some of the pda's are shown near manoeuvre's trajectory section. Again, the signs are placed close to the corresponding trajectory segments.

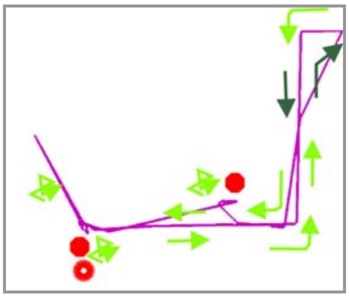


Fig. 7j. The primitive driving actions associated with the trajectory section shown in Figs. 7a-i.

A refuelling episode

A truck's detour to a *petrol station* is shown at different image resolutions – with and without satellite images of the area – in Figs. 8a-f. Clearly, the *morphological character* of the manoeuvre is quite similar to the loading/unloading episodes discussed above, particularly, to the one presented just above. In the episode considered here, however, the business location involved is a *petrol station*. The episode is refuelling which normally takes less time than loading/ unloading.

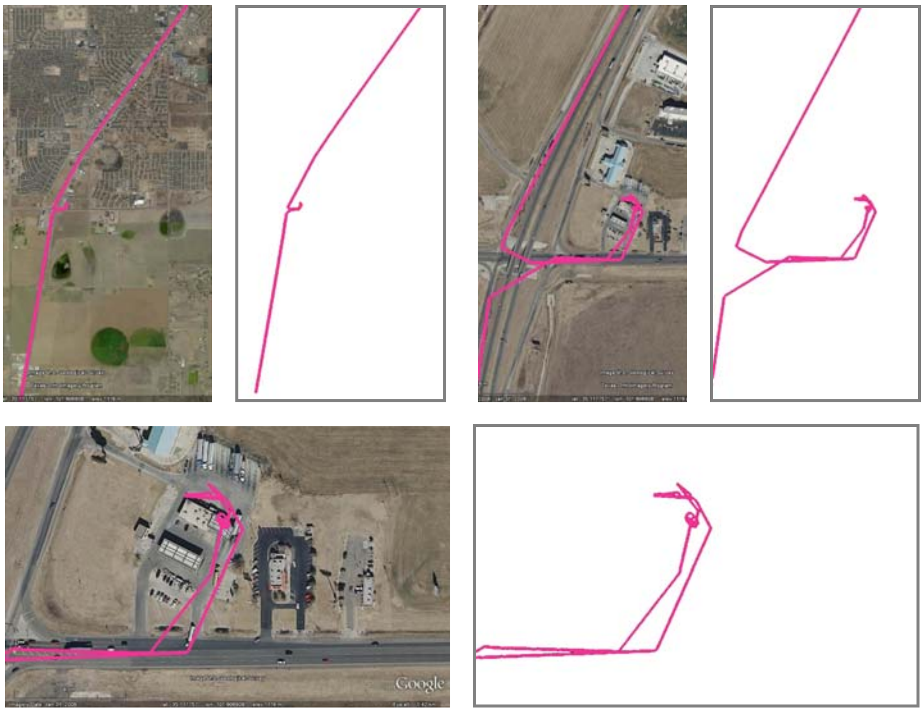


Fig. 8. A petrol station. The truck's route – with and without satellite images of the area – is displayed in three different resolutions by Google Earth (a-f).

3.4 Dimensional and other criteria for various manoeuvres

The pda’s are determined from *four consecutive sample points*. In case of the temporal sampling rate mentioned earlier, it seems a reasonable choice. For different temporal sampling rates, the *number of samples per pda* should be chosen to keep the pdas’ duration approximately the same as in this case. The pda’s are then aggregated using *simple grammatical rules*. For example, consecutive slow haphazard movements are combined.

For detecting slow and zero-speed manoeuvres, only the *relevant pda’s* (rpda’s) are considered. These include the directional changes (e.g., ,), significant lane-changes (). Around the spatial point associated with such driving actions, the *subordinate pda’s* (spda’s), namely , and are sought within some predefined distance.

In Fig. 8i, the pda’s for the trajectory appearing in Figs. 8a - f are shown. In Fig. 8h, *disks* – with the same predefined radii – *around four rpda’s* shown in blue, green, orange and yellow, respectively, are marked with matching colours. Within these disks, the *spda’s are sought*. If spda’s are present in the search area, as is the case for Fig. 8h, then a *manoeuvre of relevance* is detected. The small white circle, circumscribing both the rpda’s and the spda’s, marks the *approximate location of the manoeuvre*. As there is a petrol station at the location and as both the linguistic and dimensional *constrains* are satisfied, the manoeuvre is classified as a *refuelling*. Its location – together with the rpda’s and the spda’s detected there – is shown in Fig. 8i.

The *type of the location* (e.g., business location, parking lot, petrol station, known delivery destination) and the *number of various spda’s* detected in the manoeuvre area, the *time spent there* can be used to determine the actual manoeuvre type.

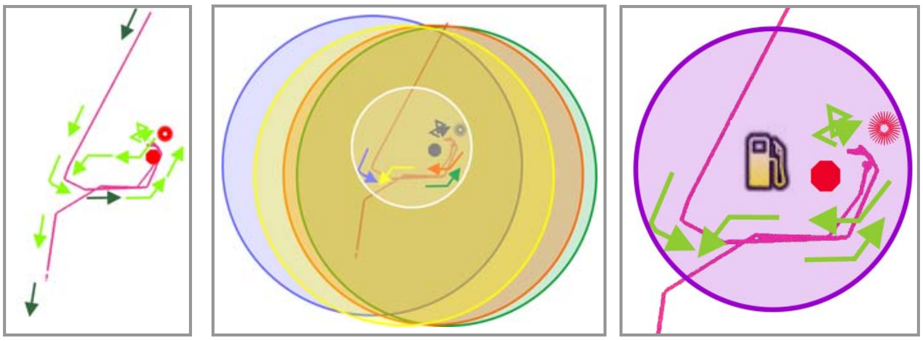


Fig. 8 (continued). The primitive driving actions associated with the trajectory section shown in Figs. 9a-f and their evaluation (g-i). See text for details.

4 Conclusions and further work

To facilitate *intelligent monitoring of routes and stoppages of trucks* from recorded route data, the data are looked at and processed at two different semantic levels. At the low level, the truck trajectories are segmented into short trajectory segments comprising only a few sample points. Each such trajectory segment corresponds to some primitive driving action.

At high semantic level, more complex, and more meaningful trajectory sections are formed. These trajectory sections correspond to various truck manoeuvres. The trajectory sections were displayed as graphical overlays on satellite images. More emphasis is given to the low- and zero-speed manoeuvres as these manoeuvres are more critical from a security point of view.

The manoeuvres are formed from primitive driving actions using a linguistic approach. To this effect, the simple spatiotemporal pictorial description language was proposed and used. Examples of low- and zero-speed manoeuvres were presented and analysed.

As the continuation of this work, a *pilot study* is on its way to construct *reliably performing PTADL* grammars and useable *dimensional constraints* for detecting various manoeuvres.

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