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RESEARCH ARTICLE

Survey on Vehicle/Fleet Tracking Methods Applied in the Transportation and Construction Industry

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Abstract
The need for monitoring vehicles and equipment during their activity is growing as the globalization spreads. The companies require distinct information about their machines which can operate in various locations in large numbers for different purposes. Beside that information demand also appeared at the client side which has to be satisfied by the firms. This paper summarize the present possibilities and recent researches for gathering and distributing the necessary data first at the transportation then in the construction industry.

Keywords
vehicle tracking, fleet management, survey

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1 Introduction

The aims of using so called vehicle tracking systems (VTS) vary in wide range. The most common ones can be categorized as surveillance, control, navigation, data prediction and customer service. Naturally, because of the high level of development of mobile machine tracking other applications are showing up continuously. Fuel, vehicle security monitoring, transit and asset tracking the main elements of surveillance category but one can also find here such things as temperature monitoring of food delivery vans. By measuring and changing some parameter from distance the remote controlling of the covering motion of unmanned vehicle just as feasible as some machine parts'. These systems can help in field service management and sales by locating the closest expert to a customer or the customers nearby to the salesman location so the scheduling much easier and quicker. The prediction of arrival times is known by everybody from the navigation systems built in cars but tracking systems nowadays can do a lot more, they can provide real-time data for simulations and for example in case of heavy equipment calculating future productivity and by that helping decision making is possible. The customer service application have many side too. In the public transportation there are well-established networks to provide information about vehicles to the passengers. The possibility of tracking of the ordered or posted products during its way is also frequent at transport companies. But today it is far more than that, in Singapore limousines of a hotel are installed by vehicle tracking systems to make sure the welcome of their VIP guest by the moment of reaching the hotel. (Roadpoint Website, 2014) The goal of this paper to introduce the applied tracking systems especially by technological viewpoint in the case of two industries where it is frequently used, namely in transportation and construction.

2 About VTS and AVL in general

A VTS consists a software which gather and uses the data of more than one automatic vehicle location (AVL) systems installed in different vehicles, so it allows the possibility of monitoring multiple vehicles at the same time.

An automatic vehicle location system has four parts:

- Hardware ensuring the locating possibility
- Communication package which connects the individual units to the central server
- Computer display system
- Advanced components

The first three parts are indispensable, the fourth one is conditional depending of the use of the AVL (e.g.: engine monitoring elements).

Categorizing the AVLs by its locating hardware we can distinguish four basic type (Table 1):

1. GPS-based: The Global Positioning System is a satellite navigation system which uses 24 satellites at about 20.000 km orbiting altitude. It was developed for military purposes but the civil utilization of it has been working for decades. (There is an alternative satellite system which is the GLONASS.)
2. Sign-post technology: The common idea of these technologies is the application of some kind of short range communication channels between the vehicle and the so called sign-post. This method tracks the vehicle when it is passing a given point.
3. Ground based radio: Ground based radio (GBR) technology utilizes one or more fixed land-based antennas to locate vehicles by radio triangulation. One example for its application is the Loran-C radio navigation system which uses low frequency radio signals.
4. Dead-reckoning: The essential of the dead reckoning is the principal if the starting position is known, the velocity (speed and orientation) of the vehicle is continuously being recorded, its position can be calculated. For this purposes different speedometers and compasses are installed in the machines. (Zygowicz et al., 1998)

An example for an approach which utilize other tracking technologies than the above four basis ones is published by (Fujimoto et al., 2014). This method was developed for the specific purpose of law enforcement in urban environments and uses fixed cameras and unmanned aerial vehicles (UAV) to locate a vehicle and predict its motion.

Inspecting the AVL-s from the side of communication component we can classify them by technology and by data transferring time point of view.

Communication technologies:

- radio (analog/digital)
- cellular (analog/digital)
- satellite

Data transfer:

- online (real-time)
- off-line
- quasi online

Table 1 Basic AVL types

	Accuracy [m]	Advantages	Disadvantages
GPS-based	<30	Flexible Very accurate (with addition)	Signal interference Satellites are government properties
Sign-post	1-20	Accurate Small interference	Fixed Maintenance need
GBR	30-2000	Flexible	Varying accuracy
Dead-reckoning	<75	On vehicle Accurate on short distances	Measuring on each vehicle Inaccurate on large distances

The online systems provide continuous data flow into the direction of server machine, while in the case of off-line systems, the recorded information is stored in a memory card and the read of it happens when the vehicles arrives to the center. The drawback of the online systems is the fix communication cost which can be eliminated by using an off-line system; however, it have much more human resource need. Beside that there are applications which require real-time or near real-time data. An off-line so called quasi online system is implemented in (Aradi and Bécsi, 2007) with automatized card reading at the garage (or even in stations). The quasi online feature means that the system can utilize the free wifi-spots for data transmission as well.

Once the vehicle is located visualizing the information on a map is the task of a computer display system. Digital maps can perform street geocoding, providing best route and guidance too. Nowadays Geographical Information Systems (GIS) can be used as computer display systems which results even more useful information, (Huang et al., 2011) based on this vehicle routing problems can be solved too. (Shankar et al., 2014)

In order to store the position data one can choose from the following options:

- Direct position data storage: relational database (x,y coordinate, speed, moving direction, time, etc.), consumes very large space
- Motion functions description method: constructs a motion function which can help prediction (in urban areas it is complicated)
- Spatial-temporal database: Store data in a space-time cube, in the field of spatial-temporal GIS, it is widely spread (Weng et al., 2005)

The most of the AVLs uses cellular communication technology with one of the most frequent applied location mechanisms which can be stand-alone GPS (Salim and Idrees, 2013) or some hybrid of the basic location technologies. The mathematical basis of the GPS technology is the so called triangulation but in reality it is rather a complicated calculation process which considers the errors caused by the atmosphere, clocks, etc. (Wang, 2006) To improve the accuracy of GPS to a specific level different techniques are available for different applications:

- DGPS (Differential GPS): network of reference stations helps the positioning up to 10 cm (requires DGPS station closer than 1000 km to the receiver)
- AGPS (Assisted GPS): uses auxiliary software in order to know the exact positions of the satellites, requires active data connection
- RTK (Real Time Kinematic): it provides cm-level precision by measuring the phase of the carrier wave of the signal
- e-Dif (extended Differential): useful at regions where differential corrections are not available ensuring 1 m accuracy
- other augmentation systems (Acosta and Toloza, 2012)

There are algorithms also for successful data analysis, combining GPS signal with external aids including Wiener filter, Kalman filter, neural networks, etc. Kalman filter which is an improvement of the Wiener one has the advantage of requiring only the current measurement and state compared to Wiener filter. However, the Wiener filter proved to be the most precise one according to (Garcia & Zhou, 2010) comparison and using the fact that it is linear the authors were capable of further improving its precision by using parallel architecture. Beside the accuracy another significant topic of nowadays researches is reducing the cost of GPS systems. (Jain & Goel, 2012) suggested the following for low cost Intelligent Vehicle Tracking Systems (IVTS) in urban environment:

- minimizing the calculations in vehicle,
- minimizing data transfer between in vehicle unit and the basis,
- under poor satellite visibility adopting alternative approaches.

3 Vehicle tracking in transportation

The transportation industry shows high-level diversity in the field of vehicle tracking just as in general. The freight sector is their most significant user. It applies VLS systems for monitoring the driver, checking the validity of vehicle documents, generating automatic reports, etc. One example for that is TC eMap which is a logistic vehicle tracking system provided by TimoCom, one of the biggest European freight exchange. (Tc eMap, 2014) Online fairs such TimoCom can offer high number of freight for the providers in order to the select the optimal one and because of the dynamic processes the real-time data management is essential. The passenger transport is also continuously evolving in its every subdivision and provides tracking possibility to us. In the aviation (where air traffic control is still mainly radar-based, GPS provides information only for the pilot) we can track flights on webpages like http://www.flightradar24.com. There are present many webpages and applications for all kind of public transportation vehicle. The rail transportation has the so called vonatinfo google-map based application in Hungary which extracts the number of the hauled train and the GPS location from the locomotive on-board equipment and combines it with schedule data in order to inform the passengers. Very similar webpage is working all around the world (for example in Slovakia: http://poloha.vlaku.info). The locomotive on-board equipment has the tasks of:

- connecting to the network of vehicle and driver surveillance system
- electronic travel card management
- complete energy monitoring including fuel consumption
- providing other useful information about the operation

Fig. 1 Locomotive on-board equipment (Prolan Web site, 2014)

About satellite-based railway positioning systems a detailed survey has been made by (Kiss, 2000).

Analogous tracking applications are available at some bus companies too in Hungary and there is a new development in the capitol, Budapest so called FUTÁR. The FUTÁR is a traffic control and passenger information system which broadcast real-time information on displays at the stations beside the internet application. The publication of (Rančić et al., 2008) introduce the developing process of a similar system in Niš. They propose to record travel time data in different daytimes and use it in arrival prediction to raise its performance. Their system is based on two earlier ones which are the Nextbus, (it is a commercial passenger information system applied in several cities in the USA) and the Mybus. The so called Mybus is a scientific project of University of Washington. This arrival time prediction system applies Kalman filter and divides the complete route into such small segments on which the travel speed can be considered constant. The Department of Transport Technology and Economics of the Budapest University of Technology and Economics is also working on a project called BusEye, This passenger information system aims to improve the public transportation. (BusEye, 2014)

In public transportation in some cases of rail transport odometer and inertial sensors are sufficient to locate a train.

But if we talk about public transport in urban environment it cannot be considered as 1D despite the fact of known path (but it can help the positioning). In these cases GPS-based technology is applied generally but it has a remarkable drawback namely it is its price. (Mishra et al., 2012) compared GPS technology to two sign-post technology, the first one is the so called vehicle card technique and the second one is Radio Frequency Identification (RFID), and RFID proved to be the best. The vehicle card technique is a method where a card containing vehicle data is required to carry to tracking points to transfer data, its disadvantage is the high scope of human intervention. The realization of the proposed method would contain RFID transmitters on the buses, receivers at the bus stops and Global System for Mobile Communication (GSM) connection to the server.

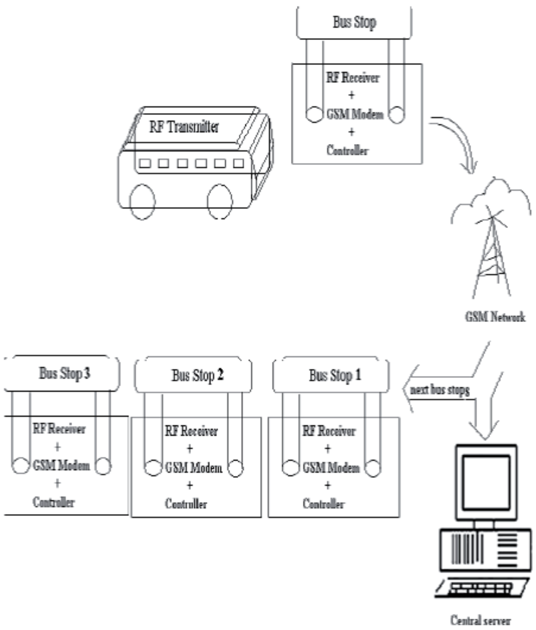

Fig. 2 The proposed system (Mishra et al., 2012)

4 Vehicle tracking in construction

The application of VTSs during construction processes is relatively new, however the elements of these systems have been present long time ago at construction sites. RTK GPS is applied in civil engineering as a high precision 3D measurement system offering good alternative instead of laser level systems. (Roberts et al., 1999), however, (Peyret et al., 2000) had not found the precision of the technology mature enough yet for asphalt paving because of multipath effects (the reflection of signals from surrounding causes measurement errors). Another example of the first uses of GPS in construction automation is the piling rig positioning in (Seward et al., 1997).

The recently applied technologies of Real Time Locating Systems (RTLS) at construction sites:

- GPS
- RFID: this technology is also used to allocate tools at the construction job site in order to get information about their availability (Goodrum et al., 2006) and for auditing the wearing of personal protective equipment (PPE) (Kelm et al., 2013)
- Ultra Wideband technology (UWB): the technology enables the transmission of large amount data using large spectrum of frequency and in resource location tracking in construction sites it has been already replacing the earlier used angle of arrival (AoA), time of arrival (ToA), traditional time-distance-of-arrival (TDoA) or non-senor networked technologies like Robotic Total Station (RTS). (Cheng et al., 2011)
- Bluetooth: This license-free wireless short range beacon technology is integrated in the VTS of (Lu et al., 2007). This system combines GPS, DR and fixed position Bluetooth beacon positioning in order to track mixer truck in urban environment and construction site.
- Laser and vision based detection: laser based technologies are long time inevitable elements of construction processes for example in elevation control but cameras and image processing algorithms are also present in recent researches of detecting equipment. In (Memarzadeh et al., 2013) an algorithm was developed for recognizing machinery and workers.

The prerequisite of the monitoring of constructions is the precise process description, modelling this is supported by different methods (simple flow chart, Gantt diagram) and process description languages (e.g. IDEF0, BPMN, EPC). (Karhu, 2003)

The researchers aim to find the optimum solutions for all the different purpose applications of vehicle tracking in construction sites.

Simulation: The goal of the simulations is always the helping of decision making and the vehicle tracking has a great importance in that since if we support the simulation with real or near real-time data we get much more accurate results. That is why Dynamic Data-Driven Application Simulation (DDDAS) (in which measurement, simulation and application are present at the same time) is one of the most improving fields nowadays. (Song and Eldin, 2012) In (Akhavian and Behzadan, 2012) this paradigm is supplemented by visualization too. (Vahdatikhaki and Hammad, 2014) propose a framework for near real-time simulation (NRTS) in which the parts of the machineries are equipped with UWB RTLS e.g. for positioning the bucket of an excavator in a local coordinate system and after averaging its movement and uses the GPS location data of the machinery an algorithm determines the activity of the machine. So the cycle time of the action can be recorded and with these data the simulation can be tuned in near real-time.

Control: With the help of RTK GPS receiver in (Rausch et al., 2010) instrumentation, software (for the calculation of the excavated volume, productivity) and control approach is introduced for excavation.

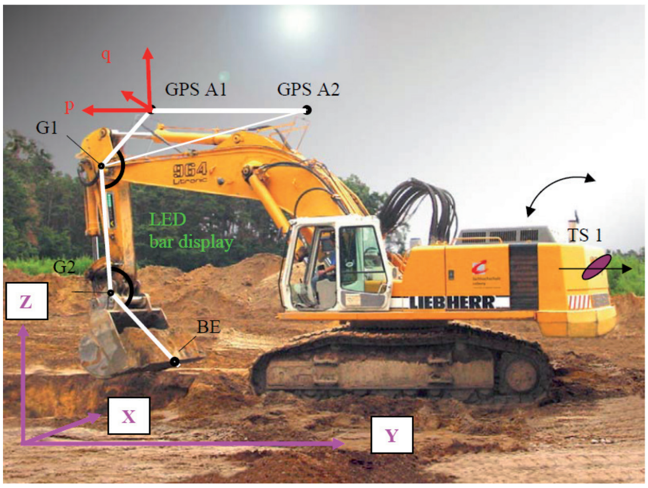

Fig. 3 Installed GPS-antennas (GPS A1/2) and encoders (G 1/2) (Rausch et al., 2010)

Safety considerations: In (Oloufa et al., 2003) one can found a detailed comparison about collision detection systems used earlier. Ultrasonic technologies with fast response time and low cost but their working radius of few meters restricts their use. Vision technologies are in developing phase and they are very expensive yet. Infrared technology has the advantage of small size and low cost but because its high response time it is not applied recently. Radar technologies would prove to be the most effective one but they also have high cost. So the academic study mentioned before propose a collision detection system with GPS technology and wireless communication. The main goal of the application presented in (Pradhananga and Teizer, 2013) is the analysis of the GPS gathered data (mainly of cyclic activities) for improving productivity but it demonstrates the possibility of automatic (hauling, loading, unloading) zone detection based on criteria like vehicle speed through an algorithm and this way the safety of machines working close to each other can be ameliorated.

Surveillance: Inter alia the registration of the duty time or measuring the loaded weight are available tracking services but the most common used one is the fuel management. There are three fuel level detection spread:

- Float level meter: these devices are inbuilt gauges. The drawback of these that upper 10 % of the tank cannot be measured because of the float encounters the wall of it. Its signal can be read on CAN bus.
- Flow meter: It is the most precise and expensive one, the in- and outflow can be measured but the time of the fuel loss cannot be determined and it also requires maintenance because of its filter.
- Capacitive probe: It can register the fuel amount all the time in a capacitive way, and records the sudden level drops. (Itrack Web site, 2014)

In (Deák et al., 2010) a continuous register test system shows that the installed sensor cannot measure smaller change than 1% and abnormal change can be stated above 4 %. Between these limits the uncertainty of the system works as slope or temperature variation. This system provides data (e.g. fuel level, mileage, date) only if the motor has been started.

5 Recommendations and conclusion

Considering the specialties of the two completely different industries the article dealing with, the authors have done so called KIPA analysis in order to propose optimal AVL for each of them. There are several other multicriteria decision support methods (Tánczos, 1998) for possibly further researches, investigations on the topic, like decision tree (Bozsik, 2011) or Analytical Hierarchy Process (Hruška et al., 2013). These can vary in wide range, can rely on logistics controlling (Bokor, 2008) or can be very case specific (Szőnyi, 2010).

The main components of automated vehicle location systems are listed earlier (in chapter 2). The locating hardware and the communication package (in the viewpoint of optimal type of data transfer) are the components we are interested in (the computer display system is supposed to be given, and the use of any advanced components are task dependent). In case of transportation we handled separately the urban and the long-distance transportation because they show high level of diversity in so generally speaking manner too.

Locating hardware:

The factors we took in to consideration are the following **accuracy** (which is ensured by the device), **cost and difficulty of installing** and the number of **registered coordinates.** The determination of weight numbers () of each factors was done by pairwise comparing during preference tables, so finally we got values on an interval scale ranges 1 to 5. In point of a fact the two industries resulted distinct weights (actually they are in reverse order). However, one can conclude this easily. Thinking about a construction, it is require much more accurate positioning than any process in transportation in general because of the smaller distances. In the other hand much lower frequency of position data registering is allowed because of the same reason.

An illustrative example can be followed for the decision process started by the base table of the KIPA method for the urban transport case (Table 2).

Table 2 Base table for urban transport (own work)

	Accuracy		Installing		Coordinates	
Weight number	=1		=3		=5	
GPS	G	30	G	30	VG	40
Sign-post	VG	40	S	10	S	10
GBR	US	0	G	30	VG	40
DR	S	10	M	20	VG	40

One verbal qualification and a quantitative metric belongs to every alternative-factor pair. The meanings of abbreviations and corresponding values:

- US: unsatisfactory (0),
- S: satisfactory (10),
- M: medium (20),
- G: good (30),
- VG: very good (40).

These numeric values () are consistent to 10 % weight. The true quantitative metric can be calculated by:

Based on Table 2 one can construct the KIPA-matrix (Table 3), which is a pairwise comparison of alternatives in terms of preference (c_{ij}) and disqualificance (d_{ij}) indices. (Kindler and Papp, 1975)

The conditions of evaluations:

- c_{ij}50 (one method is preferred to another, if it is valid in terms of 50 % – considering their weights – of evaluation criteria),
- d_{ij}100 (the maximum disadvantage is not allowed).

Table 3 KIPA-matrix for urban transport (own work)

		GPS	Sign-post	GBR	DR
GPS	c_{ij} [%]	-	89	100	100
	d_{ij} [%]	-	5	0	0
Sign-post	c_{ij} [%]	11	-	11	11
	d_{ij} [%]	75	-	75	75
GBR	c_{ij} [%]	89	89	-	89
	d_{ij} [%]	15	20	-	0
DR	c_{ij} [%]	56	89	67	-
	d_{ij} [%]	15	15	15	-

Reading the results from the matrix we got the preference order in case of urban transport:

1. GPS
2. GBR
3. DR
4. Sign-post

There are two reasons for which it is worth to investigate separately vehicle tracking in urban, long-distance transport and construction industry. The first one is the earlier mentioned different weight of evaluation factors, and the second one is the dynamic behavior of these factors. Their evaluations are strongly dependent on the application. Some example are given in the followings for illustrative purposes:

- GPS is less accurate in urban environments.
- Relatively small number of “sign-posts” are enough to cover a construction site.
- If a construction site is completely covered continuous data registration is secured.

The remaining two base tables can be seen in Table 4 and Table 5.

Table 4 Base table for long-distance transport (own work)

	Accuracy		Installing		Coordinates	
Weight number	=1		=3		=5	
GPS	VG	40	G	30	VG	40
Sign-post	VG	40	US	0	S	10
GBR	US	0	G	30	VG	40
DR	US	0	M	20	VG	40

Table 5 Base table for construction industry (own work)

	Accuracy		Installing		Coordinates	
Weight number	=5		=3		=1	
GPS	G	30	G	30	VG	40
Sign-post	VG	40	M	20	M	20
GBR	US	0	G	30	VG	40
DR	M	20	M	20	VG	40

Our analysis found that the GPS is the most appropriate locating hardware for long-distance transportation and Sign-post technologies are for the construction industry (Table 6).

Table 6 Preference order of locating hardware technologies. (own work)

	Urban transportation	Long-distance transportation	Construction
1.	GPS	GPS	Sign-post
2.	GBR	GBR	GPS
3.	DR	DR	DR
4.	Sign-post	Sign-post	GBR

Besides, the reader should note that we only have considered basic types in the selection process in a much generalized manner.

Data transfer type:

For the case of transportation in urban environment obviously quasi-online would be an optimal choice because it combines the advantages of online and off-line ones, but in the other two sectors it is hardly feasible. In most of the applications long-distance transport requires online communication because of the capability of reacting relatively sudden changes (e.g. freight exchange), while in the construction industry traditionally off-line data gathering is satisfactory (for instance considering of monitoring of low speed vehicles). However, many of the previously presented researches require real-time data for simulation, control etc. purposes. The right choice of the data transfer type requires further evaluations.

Although the work is comprehensive insight to the field of vehicle tracking in general and detailed in the transportation and construction industry with informative purposes, besides it contains some suggestions about technology selection. Its aim to help the first stage of the decision making and to provide further literature for the selection of the right apparatus. We can conclude that the methods, instruments, algorithms show wide variety and because of that to find the proper choice we need to deal with all the cases as unique ones.

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