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PERFORMANCE INDICATORS FOR PROFESSIONAL DRIVERS' EVALUATION IN SUPPLY CHAIN

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Abstract: *Contemporary road vehicles are equipped with state-of-the-art devices and on-board computers that record parameters mainly from vehicle condition diagnostics and their operation. Along with the growing use of business information systems and with the implementation of telematics systems on vehicles, large amount of driver activity data becomes available to the fleet and transport manager, which enables and even facilitates the insight into drivers' activities and their evaluation. Naturally, besides the above mentioned electronic data, the company still maintains some paper- or computer-based registers and documents allowing further insight into driver behaviour. Such complete overview of driver activity from the aspect of driving behaviour, vehicle treatment and other business and transport related performances, as well as the possibility of these parameters' evaluation, ultimately leads to a better human resource management, lowering transport activity and vehicle maintenance costs, increasing traffic safety and lowering vehicle and driver negative environmental impact.*

Keywords: *drivers' performance, on-board devices, driving skills*

1. INTRODUCTION

Professional drivers of road motor vehicles represent one of the most important factors regarding vehicle operation costs, transportation and delivery service quality and in the long run the company image.

Automotive industry is involved in increasing vehicle fuel economy by introducing modern technology to lower harmful gas emissions and decrease fuel costs, as well as on-board devices allowing vehicle and driver operations monitoring and analysis. In general, the latest implemented technology in vehicles is not supported by adequate drivers training, on the one hand compulsory driving licensing and on the other continuous and periodic knowledge upgrade. This is especially true for commercial vehicles involved in the supply chain, where the related driver influence is more important having in mind their higher vehicle value, annual mileage and fuel consumption.

The objective of this paper is to present differences between professional drivers through an overview and systematization of overall driver performance indicators (PIs), based on literature, today's practices and specify those indicators that could be identified and measured by using modern vehicle and telematics technologies applied in the supply chain. This certainly represents the first and the most important step in models' building which would be later used

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for driver selection while employing, their ranking concerning rewarding / penalizing or even noticing individual weaknesses that could be corrected by a custom-made personalized training program.

The rest of the paper begins with a review of driver performances recognised as relevant in literature, as well as their measurement options, potential effects and limitations. Next section deals with PIs obtained from dataset collected as a result of drivers monitoring over certain period in Serbian logistics company using an on-board device. Finally concluding remarks are presented along with directions for future research.

2. LITERATURE REVIEW ON PROFESSIONAL DRIVERS PERFORMANCES EVALUATION

Supply chain are complex systems where drivers are required to possess different knowledge and skills except from driving. Those requirements depend on their interaction with other supply chain actors. Thereof originates the fact that driver's performance used to measure the quality of work is by nature multidisciplinary and roughly could be divided into technical (driving skills and other professional service skills) and nontechnical (social and other soft skills).

Technical driver performance, which will be considered in this paper, regarding:

- Driving skills, involve relations between: Driver and vehicle (vehicle technology comprehension, vehicle care and maintenance, ability to solve some unexpected problems, etc.), and Driver and vehicle in traffic (driving style, knowledge of traffic regulations, avoiding incidents and critical situations, etc.);
- Other professional service skills, involve interactions between: Driver and client (client request resolution, timely appearance, client feedback, etc.), Driver and vehicle on terminal / in warehouse (loading, unloading, goods handover, paperwork, administration, etc.), and Driver and company (task realization, obeying procedures, etc.).

Many papers are dedicated to other drivers' professional service skills, whose evaluation is mostly based on individual perception of their quality and importance. Meanwhile, this paper focuses on driving skills based purely on measured data with an attempt to obtain as exact and objective performances as possible.

Certain authors in their papers and studies highlight the importance of driving performance, presenting its measuring methodology and/or determine the acceptance thresholds, which could be as well perceived as drivers' PIs. Those indicators are mostly focused on quantifying road safety and fuel consumption and/or harmful or greenhouse gas emissions.

Kim and Choi (2013) stated the fact that the speed is a main factor to estimate macro amount of fuel consumption and emission of vehicles. However they have focused on acceleration and determination of critical values of aggressive acceleration influencing fuel consumption and emission significantly by testing vehicle speeds range from 10 km/h to 80 km/h considering different driving patterns in urban areas. Hari et al. (2012) developed and tested retro-fittable driver behaviour improvement device in real world conditions (15 vans on over 39,000 km). That device provided real-time audio and visual feedback to the drivers to improve their driving style. Analysis showed that fuel savings of an average 7.6% were obtained as a result of reduction in harsh accelerations and early gear shifting into higher gears. El-Shawarby et al. (2005) evaluated the impact of vehicle cruise speed and acceleration levels on vehicle fuel consumption and emission rates using field data gathered under real-world driving conditions. An on-board emission-measurement device was used to collect emissions of nitrogen oxides, hydrocarbons, carbon monoxide, and carbon dioxide using a light-duty test vehicle. The analysis demonstrated that fuel consumption and emission rates per-unit distance are optimum in the range of 60–90 km/h, with considerable increase outside this optimum range. The study demonstrated that over a sufficiently long fixed distance, fuel consumption and mobile-source emission rates per-unit distance increase as the level of acceleration increases. Rolim et al. (2014) assessed the impacts of eco driving training and on-board devices that provide real-time feedback on 600 bus drivers' behaviour regarding hard stops and starts, extreme accelerations and brakes, time spent idling and speeding. This analysis considered drivers characteristics (age and time working at company) and vehicle characteristics (bus age and type). Zarkadoula et al. (2007) showed the effects of eco-driving training for three drivers leading to a decrease of fuel consumption by up to 17.8% while the average decrease in fuel consumption for all bus drivers was 10.2%.

Barr et al. (2011) in their study assessed the impact of driver fatigue on driving performance using the naturalistic data of 42 local/short-haul truck drivers from two companies that participated in the field study that lasted for approximately two weeks per driver. The trucks were instrumented with cameras and data collection equipment consisting of sensors to monitor vehicle parameters: speed, lateral and longitudinal acceleration, steering position, and brake pedal activation. Predictive models were developed to determine the driver characteristics (e.g. age, years of commercial driving experience, sleep quality/quantity) and external or environmental factors (e.g. time of day, weather, traffic) that influence the likelihood of driver fatigue occurring on the job. Two measures of driver performance - lane-keeping and speed management - were evaluated in an effort to correlate driver fatigue and performance.

However, in tasks performed by drivers within supply chain, the sole fuel consumption indicator, that is often recurred to by fleet managers, is not sufficiently good indicator since it is influenced by other factors that could not be easily determined (such as landscape, traffic congestion, idling) and could even lead to inaccurate perception of different driver quality, even in similar activities and environments (since not all parameters match). Often the driver's impact on vehicle maintenance costs and lowering vehicle and its components lifecycle period and costs is disregarded or neglected. In (TIAX, LLC, 2009) are set fundamental driving segments that U.S. medium- and heavy-duty vehicle drivers should pay attention to, in order to lower fuel consumption: speed fluctuation, engine braking, shift optimization and gear selection, idling, tire condition and inflation, speed, cruise control, clutch control, trip planning, block shifting/skipping gears, aerodynamics, overfilling the fuel tank, and maintenance.

Morte et al. (2013) deals with multi-criteria ranking of drivers based on two quantitative and nine qualitative criteria obtained as decision-makers' impressions on the quality of each driver (out of the total of 31 drivers) using narrow or wide scales. They selected the following set of criteria: technical knowledge, labour legislation knowledge, accidents, fuel consumption, ability to solve unexpected problems, timely delivery, internal rules compliance, customer's standards compliance, information, conflict resolution, expectation fit, responsibility, and availability. This paper's main shortcoming is a great number of expert-based qualitative criteria values, without a clear determination approach, leading to subjectivity in driver evaluation and final ranking.

From the presented review it is obvious that there is a gap of a comprehensive model for driver performance evaluation and ranking. Since in previous evaluation models there is an issue of indicators' determination objectivity, the authors opted for data collected directly from vehicle sensors and processed in order to determine and evaluate driver PIs, which is significantly facilitated by todays' vehicles in conjunction with state-of-the-art on-board devices and telematics systems.

3. ON-BOARD DEVICES IN EVALUATING DRIVER PERFORMANCES

In order to use vehicle data for driver performance evaluation, authors have chosen a fleet of diesel-powered vans of one express courier delivery company from Serbia. Three identical vans (by make, model, and age) were equipped with an on-board diagnostic device, OBD MATRIX

(TEXA), which in this setting (compression-ignition engine) was limited to the following set of data: engine speed, vehicle speed, engine load and engine temperature. Data were recorded for a period of 5 days at every quarter of a second (at the largest possible frequency of 4Hz) while vehicle ignition was on, which resulted in large amount of data to be processed.

From measured data the authors have tried to determine a set of relevant and impartial PIs to evaluate drivers in view of basic fleet managers' objectives: fuel consumption, road safety and vehicle maintenance. For that purpose engine speed and vehicle speed, relevant by themselves, were used as raw data. Acceleration and deceleration were derived from instantaneous vehicle speed. Each of these values are rated based on a developed scale, shown in Table 1. For each PI, driver quality decreases with rating increase. Rating scales for acceleration and deceleration were set according to Beusen et al. (2009) and Kim and Choi (2013) researches, along with recommendations of fleet managers from the considered company and field experts. Engine speed range for the rating scale was set consistent with van manufacturer's specifications regarding maximum power and torque to engine speed diagram. The vehicle speed limit values are set in accordance with traffic speed limits in vehicle operating area. As considered company vans operate outside motorways, the authors have set the initial speed limit at 80 km/h (with 10 km/h increment).

Table 1 – Driver rating scale for different parameter values

Acceleration (a)		Deceleration (b)		Engine speed (n)		Vehicle speed (v)	
Range (m/s^2)	Rating	Range (m/s^2)	Rating	Range (rpm)	Rating	Range (km/h)	Rating
$0 < a \leq 1.7$	0	$-2.3 \leq b < 0$	0	$0 \leq n \leq 2600$	0	$0 \leq v \leq 80$	0
$1.7 < a \leq 2.3$	0.2	$-3.4 \leq b < -2.3$	0.5	$2600 < n \leq 2800$	0.2	$80 < v \leq 90$	0.2
$2.3 < a \leq 3.4$	0.5	$-4.5 \leq b < -3.4$	2	$2800 < n \leq 2850$	0.4	$90 < v \leq 100$	0.5
$3.4 < a \leq 4.5$	2	$-5.6 \leq b < -4.5$	4	$2850 < n \leq 3100$	0.6	$100 < v \leq 110$	2
$4.5 < a \leq 5.6$	4	$-6.7 \leq b < -5.6$	10	$3100 < n \leq 3350$	0.8	$110 < v \leq 120$	4
$a > 5.6$	10	$b < -6.7$	20	$n > 3600$	1	$v > 120$	10

Based on previous parameters and their rating scales, eight PIs were defined and calculated for each driver:

I. **Start-up acceleration** – Average acceleration rating per start-up (start-up consists of initial ten seconds of driving from standstill).
II. **Start-up engine speed** – Average engine speed rating per start-up.
III. **Halt deceleration** – Average deceleration rating per halt (halt consists of last ten second of driving until vehicle stop).
IV. **Acceleration in continuous driving conditions** – Average acceleration rating per acceleration time of all continuous driving periods (continuous driving consists of the period between initial and final 10 seconds of driving, i.e. after start-up period until halt period).
V. **Deceleration in continuous driving conditions** – Average deceleration rating per deceleration time of all continuous driving periods.
VI. **Engine speed in continuous driving conditions** – Average engine speed rating per duration of all continuous driving periods.
VII. **Idling** – ratio between idling time, determined as engine running time (engine speed ≠0) with simultaneous vehicle standstill (vehicle speed =0), and total engine running time.
VIII. **Speeding** – Average speed rating per driving time.

Authors have recognized three characteristic driving periods: start-up, continuous driving and halt. Start-up and halt events, as separate time sequences, allow for the drivers to be objectively compared on the basis of their skills to operate vehicle during start-up and halt. Besides, observing drivers' behaviour during continuous driving condition allows to identify those who accelerate or decelerate aggressively or operate the vehicle at high engine speeds beyond the start-stop regime where such inadequate driver actions occur most commonly. Average ratings were used for different characteristic driving periods in order to minimize the impact of route configuration and traffic conditions (mileage, travel time, unloading points, etc.) on driver performance rating.

Start-up acceleration and start-up engine speed are related to fuel consumption and vehicle maintenance by influencing engine, drivetrain and tire wear. Halt deceleration directly influences vehicle maintenance by brake wear and indirectly fuel consumption as indicator of insufficient driver anticipation leading to unnecessary stop-and-go situations. Extreme accelerations and decelerations in continuous driving conditions denote aggressive driver behaviour leading to road safety issues, increased fuel consumption and eventually higher maintenance costs. High engine speeds in continuous driving conditions influence fuel consumption, showing lack of adequate knowledge and skills regarding gear shifting techniques, which could be resolved by appropriate driver training. It could also imply that the driver is aggressive or negligent, tending to maintain vehicle acceleration capacity. Idling impacts only fuel consumption suggesting driver's negligent behaviour. It includes idling times longer than 120 seconds, in order to avoid accounting for congestion delays and waiting times at traffic lights. Speeding (driving over the speed limit) primarily influences road safety, as well as fuel consumption and reflects driver awareness and complying with rules and traffic regulations. The speeding indicator would be much more accurate if available speed data would be matched to speed limits on the network by using GPS data.

In order to examine vehicle data utility to obtain reliable PIs for driver comparison and evaluation, the authors decided to monitor, record and process vehicle operation data for three drivers. Based on fleet managers' opinion two moderate and one aggressive driver were selected to be further examined. Driver 1 was characterised as moderate and attentive driver. Driver 2 had a reputation of an aggressive driver, often exceeding speed limits. Driver 3 had a reputation of a moderate driver, confident in his own driving skills. After determination of driver PIs, for easier comparison, their normalization was made (Table 2).

Table 2 – Normalized priority of drivers' performance indicators

Drivers	Start-up acceleration	Acceleration in continuous driving conditions	Halt deceleration	Deceleration in continuous driving conditions	Idling	Start-up engine speed	Engine speed in continuous driving conditions	Speeding
1	0.3101	0.3519	0.3705	0.5208	0.1865	0.1365	0.4054	0.0058
2	0.2294	0.2375	0.1834	0.1258	0.1375	0.2308	0.0354	0.0004
3	0.4605	0.4106	0.4461	0.3534	0.6760	0.6327	0.5592	0.9938

From Table , it is obvious that there is a clear distinction of examined drivers in all PIs. Obtained results give detailed and measurable illustration of differences between their driving skills and behaviour. Very high difference in speeding indicator between the third driver and the others is result of differences between their operation areas. The third driver only operates in central urban area with speed limit at 50 km/h, opposed to others operating in suburban areas where the speed limit of 80 km/h is attainable, but still restricted.

4. CONCLUSION

Today, in supply chain fleets too much attention is given to driver evaluation upon easily available parameters, as fuel consumption, which in authors' opinion is not a parameter, but an objective. Fuel consumption does not represent a reliable comparison parameter, as besides driving skills, it also depends on other conditions resulting from transport task, loading/unloading technology, operating conditions, payload utilisation and a number of other, often unidentifiable indicators.

In this paper the driver evaluation is attempted by more objective indicators offered by modern vehicle technologies. Based on a simple on-board device and a small number of recorded parameters a larger set of PIs was derived that are not correlated among each other and therefore justify their application allowing high-quality and comprehensive perception of driving skills. For data processing and results analyses MS Excel was used, which caused important time delays with available dataset implicating the need for a more adapted database software for larger datasets. Aside from described PIs it is possible to generate other indicators obtained from used or more complex on-board devices. Likewise, for driver evaluation it is essential to involve other quantitative indicators accessible to fleet managers, such as: driver safety and accident costs records, different test results, vehicle maintenance costs as consequence of driver's behaviour, but also some qualitative PIs related to other professional service skills. It was earlier explained that PIs for driver evaluation are related to multiple logistics company objectives, hence next research step is creation of drivers' evaluation and ranking model including all mentioned PIs and objectives, their relations and importance.

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