PASSENGER SAFETY, RELIABILITY IMPACTS ON COST EFFICIENCY OF VEHICLE MAINTENANCE

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Abstract: The financing challenge of the Public Transport should keep all cost elements under rigorous control. As one of main cost of the vehicle maintenance activity could have different approaches for each City, on each Region of the World, but a general guide could help the Authorities and also the Operator to select the right and efficient way to manage this issue. This article will provide an overview and some comparisons about different strategies, types of approaches, finally including few recommendations for Companies, examples of best practices.

Key Words: Efficiency, Maintenance, Passenger Safety, Key Performance Indicators

1. INTRODUCTION

1.1. About Public Transport "players": Authorities and Operators to serve the passengers

The Earth's population is growing causing an increase in the number of urbanizations, and consequently, people concentration in urban areas. According to the European Commission (EC, 2016), "(...) 50% of the world's population lives in cities, but they are responsible for three-quarters of the global energy consumption as well as approximately 80% of the global greenhouse gas emissions" [3]. The United Nations has suggested that the percentage of population could rise to 70% within four decades. This increase in population density within city affects the mobility as there is no sufficient infrastructure to support this massive growth, moreover there are actual physical limits within city areas when it comes to future expansion of road networks. Whilst people mobility remain vital to any society and critical enabler of economic growth, people usually tend to use private cars which in turn worsens the problem, by increasing urban congestion and emission of greenhouse gases from motor vehicles. The solution to this problem is not to enlarge the streets for cars asthis approach will only generate more traffic within cities.
The most widely spread mode of urban public transport is the bus, which plays a relevant role in urban mobility systems, without reducing the importance of other transports (train, tram, trolleybus, metro, ships...) with efforts towards a more efficient and environmentally friendly mobility in urban areas.
Public Transport can be directly managed by the Local Authorities or it can be in a form of public-private partnership where certain roles are kept by Local Authorities (DoT- Department of Transport). The Authority will enter into contracts with the selected operators signing a Public Contract (including the social responsibilities for entitled passengers – retired, students, low income persons), or will just provide Licenses through Commercial contracts transferring (partially or totally) the revenue risk to Operator's side. Through the classic formula the Authority (as the Public Transport system owner) keep the Fare Collection (ticket prices) and Network main decisions (routes, frequencies, timetables) on their side. Mix strategy could be a possibility, too: outsourcing part of responsibilities to selected Operator, but the monitoring and supervision will be retained under the control of the Local Authority.
Maintenance is one of the key elements in the cost structure of the service. That's why new approaches to this issue are important. This article intends to provide various maintenance strategies to the involved Key Personnel, decision makers and professionals in any sector with a better understanding of maintenance management, enabling the identification of problems and the delivery of effective solutions[1].

1.2. Key Operator responsibilities:

The Operator could be Municipality owned, state owned public entity, however as witnessed around the world this can be also be a privately owned establishment. Main responsibility is to provide the requested bus schedule in a given framework in a safe, reliable, punctual and efficient manner. In order to be able to achieve given KPI's and ensure quality is never compromised, operator must cover a wide spectrum of cross functional areas (from Human resources (driver recruitments and trainings, staff selection, optimized manpower management) till fleet management (including maintenance, cleaning and vehicle refueling).

1.2.1. Organizing operation (timetable, scheduling, and rostering)**:** Organizing the operation is the core activity of Operators. The fleet could be owned by operator, possibly under a leasing contract or by the Authority (or any subsidiary Agency) but entrusted to Operator to run them. In order to comply with the requested Timetable it is essential to ensure a sufficient fleet availability and manpower are always available.

Based on the received schedule the operator's dispatching officers, who are monitoring the whole operations in real time, will ensure operations are running smoothly and as planned. Furthermore, the Operator could be also entrusted with additional responsibilities by the Local Authorities, such as Timetable elaboration, fare collection (tickets sales and control) which are subject to supervision of the Authorities.

1.2.2. Monitoring and supervising operation (Control Centers, Intelligent Transportation Solutions-ITS and other equipment):As abovementioned, methods and efficiency of organizing Operator's services must be monitored and supervised by the Operator itself and this is mandatoryto sustain quality[1].This also includes free communication channels for passengers to provide their feedback to the Authorities. The real time monitoring can be implemented via Control Centers, in a centralized manner where all information is being collected by my means of pre-installed ITS systems to provide a real-time image of field activities conducted by the Operator. The AVM- Automated Vehicle Management system that was installed before commissioning the vehicles into operation, providesa real time vehicle location tracking and serves as a monitoring tool to validate compliance to prescribed timetable. Also, the AFC- Automated Fare Control system provides data about number of passengers, ticket revenues by means of validation RFID travel cards. All vehicles are also equipped with PIS; Passenger Information System which includes front and lateral displays, as well as TFT screens inside the bus itself. This system provides information to passengers on current routes and timings. System is even designed to integrate and display advertising messages which can serve as an additional revenue stream generator. The Fleet dispatchers are continually monitoringall aspects in real time and promptly intervene in cases of any non-conformities: such as accidents, route deviations, trip cancellations or bus replacements due to unforeseen breakdowns.

1.2.3. Maintenance responsibilities for vehicles and other accessories (ITS)**:** As stated earlier, all Public Transport assets (vehicle, ITS equipment & software, Offices and Maintenance Facilities-Workshops) usuallyfall under the responsibility of the selected Operator.A decision on how to choose the best method for a specific operation requires a multifaceted and comprehensive analysisbeforehand. The approaches vary and can be financially driven, whereas opting for the cheapest solution doesn't mean equal or most savings! Alternatively, an approach may be to focus on maximizing the fleet availability, and increasing the reliability of vehicles, which can be a more expensive option initially, however after considering the full effects and eventual impacts of having a lower fleet availability, this approach may prove to be practically more affordable to choose on the long run (avoiding penalties, etc…)! Impact on bus breakdowns or On-Board ITS equipment islimited to a specific vehicle, and that's somethingthat's easilyrectifiable, and is considered as minor issue. However, problems that might arise with back-office software systems could impact the whole system: if AVM or AFC have a system issue, the entire fleet will be affected, hence this is considered as a major incident, that needs to be rectified ASAP to sustain operational continuity and ensure required level of quality.

In case the Operator is responsible for the fleet and ITS availability, there are different maintenance approaches available: in-house by utilizing existing Operator's team; outsourced to a specialized subcontractor (one or more); or finally a mixed approach, whereasa certain scope is outsourced to a third party (subcontractor).

Additional Operator responsibilities involves bus cleaning, for example. This has been especially pronounced in recent times (during COVID-19 pandemic) the necessity of deep cleaning and sanitization was accentuated. These works must be executed and closely monitored to ensure required passengerHealth and safety conditions are meat and measures properly applied to all Public Transport related facilities (buses, bus stops)[2].This also includes applying specific protocols to ensure social distancing.

2. DEFINING THE MAINTENANCE SCOPE OF WORK

The maintenance function is defined as a set of eight component activities, which include: work assignment, maintenance scheduling, workforce development, labor allocation, inventory management, equipment management, information systems, and monitoring and evaluation [4].

2.1. Maintenance Goals and Objectives

A solid maintenance plan should include specific goals and objectives along with a means of achieving them. The overall goal should be to maximize the uptime of the vehicles by keeping them out of workshop and service (maximize availability). Generally, the goals and objectives of the maintenance program should include or address as a minimum:

- Flexibility for changes in route, schedule, environment, new technology and other impacts;
- Chassis, body, and component manufacturers' recommended maintenance practices;
- Systematic inspections, services, and repairs performed under local environmental, state and other regulations that apply;
- Defect reporting;
- A fleet life plan (LCM - Life Cycle Management);
- The proper level of fiscal control (Finance Management);
- The proper management of parts, equipment, facilities, fleet, and personnel; and
- A warranty recovery plan.

The common goal for all the topics above converges to an increase of bus fleet availability whilst keeping a very high reliability of the buses in question, and not only as secondary ensuring a financial efficiency of maintenance activity, keeping in rational cost margins the maintenance costs.

2.2. Maintenance organized by Operator

This is the most widely used and accepted maintenance approach (rare exceptions whereas the Authoritiesretain thisfunction inhouse). One of the main enablers to a successful Public Transport operations is to always ensure a sufficient availability of buses to cover the operational requirements mandated by timetable schedules. This can only be done by ensuring a sufficient manpower is also available, in parallel. Availability is in a direct link with an active fleet of buses, where to run a profitable business, a rigorous maintenance approach and strategy to maximize the availability by applying excellent planning of preventive measures to reduce the breakdowns and minimize corrective repairs is essential. Available choices are whether to organize the maintenance inhouse, outsource it to a third party, or possibly go with mixed approach (internal/external)are unique to each specific operation. The right choice as mentioned, can only be reached after carrying out study what works best in the given framework.

2.2.1. "Totally in-house" strategy: This approach is applicablein case the Operator is a Municipality or State-owned entity, and basically means that all functions and activities are totally centralized and kept under one umbrella. The company administration (ownership, leasing, rental) includes Workshop operations and technical staff to perform all maintenance activities for vehicles and ITS equipment. This hasn't been proven as the most efficient solution, due to many reasons. Main cons of this approach are risks of excessive spending in parts and service, parts stock obsolescence, lack of technical knowledge (no trainings updates provided by the Manufacturer, etc…), moreover this is not a core function of the establishments and often results with having either insufficient or excess staff. Many jobs are still being sublet "outside" to third parties for specific works due to lack of inhouse knowledge or capacities.This complicatesthings and creates unnecessary level of complexity that deviates from the core function – which is to operate the buses efficiently and safely.This approach still exists today and tendency of keeping it all "in-house" is a consequence of inherited government corporate immaturity that can be attributed to many Governmental establishments worldwide. Assumptions are generally being made on false pretexts or based on internal political strategies, that are given based on questionable foundations / feasibility studies. Governmentstend to overregulate and whilst they are defining the schedules, setting fares, anddefining scopes.It is fair to mention that generally, they are not as quite effective and professional in terms of running a fully-fledged vehicle maintenance operations like dedicated maintenance providers are. Risks of running a "totally-in-house" maintenance approach are high. Money drain is a real threat.Often this approach results with an unfortunate effect of fleet availability decrease and cost increase.

2.2.2. "Totally outsourced" strategy: Opposite to the above stated, this approach is where all maintenance jobs are completely outsourced.Different companies chose this approach for different reasons. Small companies are simply not able to handle it internally in efficient manner, othersmay be specialized for certain areas only and don't have sufficient in-house knowledge to perform the services (Bus or ITS maintenance). Yet, for big establishments this approach could be an efficient tool to effectively manage the costs and increase quality.By setting the right KPI's, contractually,the Operator can effectively influence and drive the maintenance towards most cost-effective level. Operator monitors and supervises compliance to given KPI's, to ensure high level of fleet availability and quality without having to deploy significant resources. This includes regular interaction between the Operator and its subcontractors regarding maintenance scheduling (bus deliveries, inspections…). This approach is not the most affordable one, on the contrary, but it comes with high availability, technical expertise, and predictable costs. Finding the right balance in terms of prices / level of quality all comes down to a successful negotiation between the Operator and its subcontractors and can basically define the efficacy of this approach.

2.2.3. "Mixed" strategy (partially in-house, partially outsourced): this is considered to be "a golden middle". It is globally proven as one of the best solutions, and it could be considered as a recommended option.Yet this approach depends on the many criteriathat will be derivedfrom the multifaceted in-depth analysis.Main objective is to ensure maximum fleet availability at optimal cost.Operator can perform an internal SWAT analysis and use its internal resources where they are strong (to drive the cost down) and opt. to outsource portions of business where internally they either lack resources or hiring and establishing would be too costly, as an example. This is where the synergy between companies comes into full swing and costs are usually balanced, without compromising fleet availability and quality.

3. MAINTENANCE STRATEGIES AND APPROACHES

Maintenance strategy consists of a mix of policies/techniques, which varies from facility to facility, from product to product. Studying a bus fleet found lot of similarities with general products. To really understand the scope of maintenance of a product (the bus), let see the details on the general graphics representation of a "performance index", which could be the reliability, availability of a product analyzed during his lifetime how will change, how can be redirect to expected, targeted values. On Fig.1 are explained the KPI moves between the three states of Performance KPI:

- Initial state: is the new buses' reliability, the maximum availability index (usually close to 100 %!);
- Service limit: is the accepted availability when the committed service could be done without fails, if any breakdowns or minor/major non-conformities till which not allow to continue the

service will have impact on the additional operational KPIs;

- Safety limit: is the major non-conformity which have direct impact on buses safety (passengers security and safety), which need immediate corrective maintenance (repairs or refurbishments), could be also by rehabilitation a lifetime extension method [6].

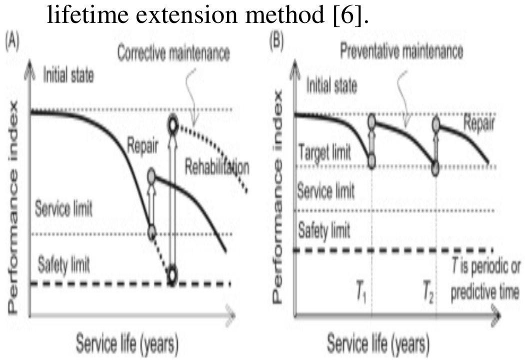

Fig.1 - Performance index analysis

3.1. Type of maintenance strategies:

Strategic Maintenance Planning deals with the concepts, principles and techniques of preventive maintenance, and shows how the complexity of maintenance strategic planning can be resolved by a systematic "Top-Down-Bottom-Up" approach. In fact it explains how to establish objectives for physical assets and maintenance resources, and how to formulate an appropriate life plan for buses. It then shows how to use the life plans, Life Cycle Management - LCM to formulate a preventive maintenance schedule for the total fleet as a whole, along with a maintenance organization and a budget to ensure that maintenance work can be resourced properly.
Three basic maintenance strategies we can define as [6]:

3.1.1. Failure-based maintenance (FBM): repair and maintenance actions taken when failure has been observed. Failure-based maintenance is usually considered acceptable for components with low risk of failure. Risk of failure consists of two components: failure consequences and failure probability.
Use-based maintenance (UBM): maintenance actions taken after a certain use period or loading regime. Use-based maintenance is acceptable for components whose failure mode and timing are predictable.

3.1.2. Condition-based maintenance (CBM): maintenance actions taken after a certain condition limit or criterion is exceeded. Condition-based maintenance is acceptable when the extent of deterioration is measurable. In addition to the above, the extent and type of maintenance and repair is a function of a several number of factors, including the buses lifetime as required by the owner (could be the Authority or the Operator), legal constraints, for commercial or functional reasons. The required level of serviceability of the fleet could be influenced by diversity of existing bus types, can also dictate the extent of different maintenance strategies, the CBM could be one the main recommended variants.

3.1.3. Preventive and Corrective (or Reactive) Maintenance: As per the defined types of approaches, a periodical review of vehicles and solving noticed non-conformities could be a preventive measure by checking and changing spare parts as per manufacturer procedures, to inspect all the important components and major elements of vehicle. Doing prevention could be reduced the main causes of any breakdowns or keep in service the buses, reducing the unavailability of vehicles. Even the preventive measures will reduce the risks of breakdowns and fails, statistically happens more or less failures which need to be corrected by immediate, short time reactions of maintenance providers, doing the needed repairs, spare parts changings and tests the vehicle to restart the operation.
Preventive Maintenance (PM): The declared goal of PM is to decrease the probability of any future failures and, consequently, corrective maintenance (repairs) needs. While this direct odometer-monitoring approach is theoretically sufficient to detect when vehicles are due for maintenance, in practice it produces several situations that can lead to inefficient results. The other option could be as per time definition the planning for PM or Safety Inspection by every week/month/year. As part of the PM could be considered the daily before shift start "Bus Walk Around- BWA" inspection done by driver and/or fleet safety responsible to check the immediate noticeable faults (lights, mechanical damages, vandalism, or as safety the steering or brake issues).
An efficient preventive-maintenance plan should have two main minimizing objectives. The first is to minimize the difference between the actual timing of specific upkeep activities and their ideal target. This can be achieved by penalizing delays and advances that fall outside a tolerance interval defined for each maintenance activity. The problem described gives rise to a very large number of variables for real-life problems, which makes them difficult to solve just with a mathematical programming approach. The scope of minimizing the unavailability of buses due PM activity is a goal which by optimization of procedures and implementing proper strategies can be a key element of efficient and successful evaluation of Operator.
The maintenance plan of an Operator has a major impact on the reliability of operations and the fleet size needed to deliver service. When ideal mileage targets are provided between consecutive maintenance activities, it is possible to generate an optimized plan that minimizes the deviations from these targets and smooths out the consumption of material and human resources over the planning horizon. This allows reducing the risk of failure and the number of vehicles that have to be kept in reserve
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The maintenance plan of an Operator has a major impact on the reliability of operations and the fleet size needed to deliver service. It is mandatory to optimize and adapt to real situation the manufacturer procedures and checklists recommended for periodical inspections, it is essential to define a rational limits the preventive maintenance measures to be not strict and costlier, but in same time to comply with all the safety requirements, ensuring excellent functional and esthetical conditions. When ideal mileage targets are provided between consecutive maintenance activities, it is possible to generate an optimized plan that minimizes the deviations from these targets and smooths out the consumption of material and human resources over the planning horizon. This allows reducing the risk of failure and the number of vehicles that have to be kept in reserve.

3.1.3.1. The Reactive/ Corrective Maintenance (RCM): The daily operations of buses are planned without any breakdowns, any failures, the buses are scheduled for continuous works. Unfortunately the reliability of buses could not achieve 100%, the availability will be affected by minor or major faults, which could be vehicle failures (engine, brakes, others…) or caused by accidents (driver or third parties faults). The maintenance works (in-house the Workshop or outsourced the Service provider) will be done soon as possible to not impact the bus daily availability. As per faults category the reaction times are different by type of failures. If minor non-conformities could be the scheduled repair in end of trip, end of peak hour or end of shift/day (usually yellow signals/messages on dashboard). If is more than minor fault (red signals/messages on dashboard) it is immediate stop at the event's location, or initiate the towing of bus to Depot. Same will happen in case of any accidents, surely as followed the Police Reports and orders. Very important for the Fleet Management efficiency is the Dispatchers how will react and in which time could replace from spare buses the unavailable bus to not loss any operational kilometer, to not disturb the passenger transportation.

3.2. Predictive Maintenance, as another level of Condition Based Maintenance:

3.2.1. As per definition: "*Predictive Maintenance is a technique that uses data analysis tools and techniques to detect anomalies in your operation and possible defects in equipment and processes so you can fix them before they result in failure*"[7]. Ideally, predictive maintenance allows the maintenance frequency to be as low as possible to prevent unplanned reactive maintenance, without incurring costs associated with doing too much preventive maintenance. Predictive maintenance uses historical and real-time data from various parts of your operation to anticipate problems before they happen.

3.2.2. Predictive maintenance techniques: The PM to ensure expected reliability as kind of mandatory applied maintenance method. To have a better cost efficiency in PM not all by initially previewed spare part (or consumable) changes must be done in prescribed period or distance, if the main parameters are acceptable for a reasonable next time of operation, earning extra mileage on same costs, reducing unit cost of maintenance per kilometer. At the periodical inspection all the parameters are verified, checked to be in range of acceptability warrant by producer/manufacturer [9]. Having the statistical records of usage, decreasing the parameter indicator, could be estimated in time or mileage the end of lifetime of spare parts (or consumables), when the parameter will be out of range and it's a must to be changed.

3.2.3. Inspections and prescriptions: As general approved modality of Predictive Maintenance application, as next level of Condition Based Maintenance strategy, the maintenance provider will do the periodical inspection (daily/weekly/monthly/yearly) or conditioned by operated mileages (on steps between 10.000 -50,000 km/inspection) and having different prescription of each type of service levels, will be checked on each the referred spare parts parameter. The recorded data will decide as per statistical expectation (through above mentioned prediction estimations) when will be next spare part (consumable) changing. As optimization possibility it need to synchronize the next inspection data with the next mileage prescription, based on operational expectation to be not twice or more redirect to Workshop the vehicle, to combine in one inspection/PM time all the necessary maintenance activities to ensure the maximum availability of buses, and taking care about the minimum possible RCM costs.

3.3. Type of Maintenance Contracts:

One the main issue of buses maintenance is the type of contracts which are in operator's hand the main tool to maximize the availability of fleet to ensure and cover all the operational needs. After new buses delivery in a period defined by a period (1-2-5 years) or executed mileages (100-500,000 km) for different bodies or for the whole bus will be under the warranty contract. All the PM and RCM (by material faults, excepted accidents) will be done on charge of bus supplier and executed by them or by their subsidiary Agency/local partners. The main debate under a warranty contract is what is included and what is out of terms, Operator need to clarify clearly what about consumables, tires, batteries or additional costs as the towing in case of major breakdowns. Also in warranty period is critical to notice if any systematic failures, any structure problems which need to be solved as general design issue for all the buses (in case of similar failures in short time in few buses!). The bus suppliers could offer and Operators usually prefer the “Extended Warranty” contracts, which give insurance of maximum availability of fleet in the best condition. Decision of this type of contract signing it is based on a strict financial analysis, but the analysis must be based on idea to “compare apple with apple”, costs for same results or same conditions, and otherwise could become a subjective interpretation.

3.3.1. Warranty contract: could be based on period or mileage, or could be also split and detailed as per vehicle components for different conditions, including or excluding all activities and consumables or accepting the “total inclusive” concepts. Operator having contract with a local dealer or bus supplier need to clarify the responsibilities between the bus manufacturer and supplier, preferable to be just on suppliers’ responsibility keeping his role of dealing with manufacturer. The warranty guarantee usually asked from vehicle supplier is not more than 5-10% of invoice, as last payable instalments for the bus supply just after expiring the warranty period.

3.3.2. Extended Warranty period: After the experience of warranty period partnership is a common used habit to extend the warranty contract in same Scope of Work and same conditions as was during the warranty, just will be negotiated the cost of extended warranty, which could be as per period or per mileage. Negotiation could be done during the Vehicle Supply Contract prepares or after expiring the warranty. Some of well-known vehicle brand suppliers/manufactures provide kind of total extended warranty combining warranty and after warranty period as on type of maintenance service as per manufacturer advise for PM and preparing to ensure a minimal RCM unavailability time for the vehicles. Surely the costing for maintenance provider/manufacturer will be the same, just divided in longer period, which allow a lower and dispersed unit price for Operator during total period, offering this opportunity as facility for financing for maintenance activity.

3.3.3. After Warranty period: The maintenance after warranty or extended warranty period till end of vehicle lifetime include many challenges for Operator, the increased costs of repairs, breakdowns of deserved old spare parts, obsolescence of few of spare parts, unavailability of original of after-market products… That period is characterized also by “cannibalization” method, when after fall down important major components of vehicle owner could decide to dismount for reusable spares, for refurbishment of vital components. The real lifetime of vehicles in fact is a financial decision, it is or not economically efficient to continue to use the vehicle or is time for a new investment... The Total Cost of Ownership- TCO theory is the method how could be compared different types of similar vehicles, having the sum of bus purchase, of expected lifetime period maintenance costs and expected fuel consumption for same distance calculated for each type… Surely are many additional conditions which could influence the multi-criterial analysis, as maximum and passenger capacity, environment friendly approach, recommended speed, acceleration of vehicle, level of comfortability, other quality parameters… Decision of owner will be made based on priority condition, not anytime the lowest TCO amount give the winner, could be additional information which could change the scores.

3.4. Technical preconditions for maintenance suppliers:

Even the Operator (in-house), even other specialized Company (outsourced) will do the maintenance for the referred fleet of Public Transport vehicles (different type and capacity buses), the technical requirements are mostly the same [3], [5], [7] which include lot of minimal preconditions, specifications:

- Workshop (capacity, quality) and additional facilities (special equipment and tools)
- Spare parts management (precondition of proper logistics and warehouse)
- Work and safety procedures, rules and regulations (ISO, documentation…)
- Software applications (main required Maintenance Management or TELEMATICS solutions)

4. MEASURING RELIABILITY OF BUSES AND EFFECTIVENESS OF MAINTENANCE

4.1. Availability, reliability:

The main parameter which give a “score” of maintenance, how it can be evaluated the efficiency of activity is the “Vehicle Availability”. The formula of availability for a vehicle or for fleet depends on the vehicle status definition, when is considered available ready to operate or out of service [11].

4.1.1. Status definition: The “*Available*” and “*Out of Service*” status is defined when a bus is prepared technically for operation, all safety and functional parameters are comply with the legal requirements or with specific rules of Transport Authority. For the vehicle (same as for fleet) the availability could be a momentary availability or averaged for a period (hour/day/week/month). During even a day will be some short moments, when the bus could be considered “*not available*” by different reason, just for maintenance referred issue let get the example of interior lighting, which to be repaired. The bus could continue without any safety or technical warn the trip, will need a few minutes arriving back to Depot/Garage for repair, which will not affect the readiness of bus, will not loss any operation duty. If is a major problem, as example door not close, will need at end station an intervention, with the high probability to loss one trip from daily operation. Usually the availability of buses are accepted if any minor failures will not impact readiness of buses, operation will continue. In case need to stop the bus and operation is impacted by loss mileages the bus is “*out of service*” for respective period.

4.1.2. Calculation formula for availability of buses (or of fleets): The availability is the reported time of readiness for buses (or fleet) to the studied period. The calculation formula is:

$$\boldsymbol{Busavailability} = \frac{\boldsymbol{Totaltimeas\ \text{"}readyforoperation\text{"}}}{\boldsymbol{Total\ analysedperiodtime}}\ \boldsymbol{x100}\ [\%]\ \textbf{(4.1)}$$

For the fleet availability evaluation another approach is accepted to calculate number of buses on "available" status during studied period reported to total active fleet, in fact number of buses which could be in operation if no any non-conformity, expressed by formula:

$$\boldsymbol{Fleet\ availability} = \frac{\boldsymbol{Number\ of}\ \text{"}available\text{'}\boldsymbol{buses}\ (\boldsymbol{per\ same\ period})}{\boldsymbol{Total\ active\ fleet\ bus\ number}\ (\boldsymbol{per\ same\ period})}\ \boldsymbol{x100}\ [\%](\textbf{4.2.})$$

As general accepted values for "*Availability*", could be for:

- a relatively young fleet (between 0 - 5 years) the 92-95 % is not unusual;
- An older fleet in normal lifetime of buses (between 6 - 12 years) 85 % is a realistic target less could impose several optimization measures…

4.1.3. Reliability expectations and quality of buses: Operator could estimate the expectations for a specified type of bus by existing statistical data, by his or other's experiences. Analyzed buses could be under the Operator or could be a new acquisition, it is important to be made the evaluations to estimate the maintenance needs to ensure the expected availability asked by Authority or economical constrains (by Timetable requirements compared to the existing active fleet).

4.1.4. Spare vehicles (ready to go immediately): To increase fleet availability to the expected levels (if the individual availability of buses are not cover estimations), is mandatory to have additional buses in active fleet than the maximum vehicle needs (Peak Vehicle Rate- PVR) to be able to replace any of unavailable bus for the short (or longer)period of breakdown, during his status "*Out of Service*".

$$\boldsymbol{Sparebuses} = \boldsymbol{Totalactivefleetbuses} - \boldsymbol{PVR}\ \ [\boldsymbol{busunit}]\ \textbf{(4.3.)}$$

Number of spares depends from expected availability and fleet size. As it is clear from above shared usual availability amounts, the rates for spare buses are varies between 5-15 % of necessary active fleet, depends from age and maintenance status of the buses.

4.2. Key Performance Indicators (KPI) monitoring the maintenance quality:

The tool of monitoring for maintenance efficiency is the Availability Index, which is one the main KPIs for evaluation. The quality of maintenance activity could be done by several other KPIs, which definition and applying condition are negotiated by Operator and Maintenance Supplier, but could be imposed also by Authority to be shared with them and use as constrains tool for increasing quality of passenger satisfaction.

4.2.1. The main Key Performance Indicators: used and generally accepted [9], [15] are referred to next:

- Mean Time between Failures
- Mean Time between Repairs
- Number of breakdowns (per mileage/per period)
- Average time (hours/days) spent on accidental breakdowns repairs
- Fuel consumption
- Emission Quality
- Preventive Maintenance (schedule adherence)
- Safety Inspections (schedule adherence)
- Complying with Vehicle Safety Requirements
- Missing Safety Equipment (on buses)
- Missing records of breakdowns (or "false" information)
- Information Accuracy
- Temperature in Bus
- Vehicle Speed Limiting Devices calibration and functionality
- Maintenance technicians training completed
- Heavy Bus Wheels and Tires (Operational Safety requirements)

5. BUS SAFETY FEATURES

The road safety as first condition need to ensure an ergonomic and safety workplace for driver, comfortable access to all controls and instruments, a perfect view of road and traffic conditions, as same control view possibility to bus interior. As one of main debates about buses safety was about the seatbelts. Many Passenger Transport Associations around the World has in study the application of seatbelts (International: UITP or local bodies: APTA, TSB…), the results are not concluded till yet, final decisions about rules and their application are kept with each individual situation, no any general law [14].

5.1. Bus Safety Technical requirements

By the new technologies the passenger vehicles safety was increased to highest levels in last decades. All technical developments from small cars were transferred to help bus drivers: from ABS (Anti-Locking Braking System), ASR (Acceleration Skid Control), TPM (Tire Pressure Monitoring), and ESP (Electronic Stability Program), till Sideguard Protect, Cornering Lights Control and Preventive Brake Assist became usual dotation on buses.

5.2. Safety equipment

The low floor concepts promoted by new technologies in bus industry, including installation of special ramps, are born to comply for Disability Person Access, for baby-trolley access, to facilitate the entrance and leaving of vehicle without any stairs.

5.2.1. Seatbelts: The On-Board equipment for safety of passenger could be also the seat belt. Which type of buses (Coach, Suburban/Regional, City/Urban, School buses or all types) are required or not to be equipped with them… Seat belts are important and no one would suggest otherwise, and Authority or Operator certainly will not suggest otherwise, but is not a miraculous feature to avoid any injuries if major accident happen, or advantage of implementation in cities will impact many operational questions [12], 15]. Depends on risk, mainly given by speed and traffic conditions exempted the downtown, urban conditions the seat belts are recommended. Decision makers have the opportunity to analyze the rules…

5.2.2. Fire extinguishers: The minimum equipment imposed in buses is the hand extinguishers dispersed on main positions in the interior of the bus. The eventually overheating and fire risk source is considered the engine. To avoid any fire possibility the buses are recommended to be equipped with "Fire Suppressor", fire extinguishing system for engine the compartment [13]. In case of danger the pressurized detection line brakes and sprays an extinguishing mixture made of water, engine coolant and a special additive via a series of nozzle around the engine compartment, which is thus cooled rapidly, the fire extinguished immediately and re-ignition of fire are prevented.

5.2.3. Safety electronics: By the newest developments the buses are whole computerized, from engine, gearbox and several other components are fully equipped with sensors, the vehicle parameters could be recorded and analyzed for a better Vehicle Health Management. The centralized software which collects and record, also as typically interpret the data is named "TELEMATICS system". As additional safety electronics dedicated for operational safety of passengers is the CCTV camera system, which by positioned cameras record in the interior of bus the passengers safety conditions, but in exterior in front and back help driver with positioning of bus or record the eventually events (as accidents).

6. OPTIMIZATIONS ON MAINTENANCE AND COST EFFICIENCY

Making a cost-effective maintenance decision is not an easy task, especially when the production system consists of several different components with different maintenance characteristics and the maintenance program must combine technical requirements with the firm's managerial and business strategies [8]. As was mentioned in this study, the "top brands" of bus manufacturer developed own software tools to help end-users to maintain one best and efficient way the buses. Also on Power Train supplies there is gearbox manufacturer's software, which delivers lot of records about the vehicle monitoring. Just for examples, without to be any complete list of European brands, next manufacturers are recognized as additional suppliers of software: DAIMLER, VOLVO, SCANIA, MAN, DAF, ZF, VOITH and few others.

6.1. Telematics Software example:

As one of the best practice from industry, provided by Daimler, as Software and Hardware together forms the Fleet Management System designed specifically for trucks and buses, named "*FLEETBOARD*" including:

- Evaluation of driving style and exploitation of savings potential;
- Automated recording and archiving of tachograph data;
- Analysis of operating data and optimized maintenance planning.

Using the bus-specific Telematics system for urban and inter-urban buses and touring coaches, Operators can optimize their economic efficiency as the right driving style can reduce both fuel consumption and wear by up to 10%[10]. Software interprets driver- and vehicle-related data by reference to marks awarded for driving, according due consideration to the given degree of difficulty. Vehicle speeds, engine speeds, heavy braking and other information provide an objective basis for conclusions on the driver's handling of the bus. Evaluations provide the bus driver with feedback about appropriate ways of improving his driving style and ultimately also making his journeys safer. The available data provides precise information on when and where the bus was stationary or in motion. In passenger safety issues, the company can reliably determine whether the doors were open or closed. In response to passengers' inquiries, it is possible to reconstruct precisely on the basis of this information whether a certain bus was actually ready for boarding at the bus stop at a given time, for example. Equally, bus operators can produce data on usage of the door ramp for people with restricted mobility. The driver is able to transmit standardized messages to his headquarters by means of defined message buttons. All key bus operating data, such as mileage or tank fill level, are displayed. Selected warnings are additionally transmitted from the vehicle. In this way, swift and well-aimed repairs are possible. The transmission of additional vehicle signals enables use of the retarder or the operating times of the auxiliary heating to be evaluated, for example.

On the basis of these data, conclusions can be drawn on the condition of the vehicle and, in turn, on economic or comfort aspects. The vehicle data are recorded via a standardized FMS interface in the bus. The conditions of operation where was applied is very important to be analyzed and compare on similar vehicles, similar cases. Our data sources were DAIMLER vehicles (unfortunately types and other specific data about them cannot be shared!), operated in MENA region and the weather and local environment conditions:

Table 1 - Analysis preconditions for comparisons of vehicle and driver performances

Comparison conditions	
Comparison duration	60 Months
Yearly Mileage	100,000 Km
Comparison mileage	500,000 Km
Hours of operation	400 h/month
Total hours of operation	24,000 O.H
Number of vehicles	50

6.1.1. Predictive Condition Based Maintenance example: The PM made for this vehicles (totally fifty units included in test) were based initially on manufacturer's prescription, general recommendations. As example let see one of the test vehicle data with next initial conditions for on due PM inspection:

- Odometer = 218.008 km;
- Total operation hours = 3.761 h.

Table 2 - Vehicle inspection and delayed maintenance dates based on parameter prediction

Service job	Due date/time	Estimated mileages till next changes	Estimated days till next inspection	Estimated date of next inspection
Rear axle 1	03.08.2021 18:21	10.408 km	50	28.09.2021
Transmission		37.621 km	205	02.03.2022
Engine		42.744 km	267	03.05.2022
Brakes on 3rd axle		86.526 km	419	02.10.2022
Brakes on 4th axle		125.203 km	522	13.01.2023
Brakes on 1st axle		154.254 km	645	16.05.2023
Air Filter		183.356 km	893	19.01.2024
Engine service		32.377 km	26	29.08.2021

During operational experience the Workshop analysis provided data which indicate the best solution is to apply CBM, and as optimization especially the Predictive Conditioned Based Maintenance will be an efficient tool to decrease the costs. During PM inspections several parts maintenance policy were analyzed using the functional parameters evolution and status of them in the moment of inspection. As per time/mileage based changings strategy was previewed more interventions, changings of several spare parts than was decided after verifying the parameters, comparing values with accepted range. If permitted values are in range the vehicle could continue without those elements change, but as per statistical data of evolution of normal wears and tear could be estimate next inspection date when will need the work to replace (or refurbish) the studied items.

6.1.2. Predictive Maintenance Policy: As summary of experiences the maintenance policies must be flexible and could be in continuous process of developments. During test period some of changing were approves as next:

Table 3 - Results for savings on maintenance cost due predictive maintenance strategy

Maintenance	Periodic Maintenance	Condition based (by *Fleetboard*)	Freq. PM	Freq. CBM	Var. %
Engine - oil and filter change	40,000 km/ 1200 h	80,000 km/ 3,000 h	12	6	-50%
Manual transmission - oil change (incl. transfer case & TRC)	120,000 Km	280,000 Km	4	1	-75%
PTO: oil and filter change	120,000 Km	280,000 Km	4	1	-75%
Rear axle/s : oil change (incl. through drive where applicable)	80,000 Km	100,000 Km	6	5	-17%
Coolant fluid replacement	300,000km/ 3 year	300,000km/ 3 year	1	1	0%
Replace fuel filter and clean fuel pre-filter (drain)	40,000 Km	60,000 Km	12	8	-33%
Replace fuel pre-filter & replace water separator	80,000 Km	100,000 Km	6	5	-17%
Replace air filter	100,000Km/ 1 Year	180,000 Km / 2 Year	5	2	-60%
Replace recirculation filter for A/C system	80,000 Km	80,000 Km	6	6	0%
Replace granulate cartridges for compressed air dryer (with oil separator)	80,000km / 1 Year	100,000 Km	6	5	-17%
Check and adjust valve clearance - V3	1st Service + (Each 120,000 Km)	1st Service + (Each 240,000 Km)	5	2	-60%
General Telligent lubrication	20,000 Km	80,000 Km	25	6	-76%
Replace filter in fuel tank ventilation line	80,000 km	100,000 Km	6	5	-17%
Ad-Blue® filter replacement	100,000km / 1 Year	200,000 Km / 2 Year	5	2	-60%
Safety related work	20,000 Km	80,000 Km	25	6	-

					76%
Wheel alignment	60,000 Km (Each Tire Replacement)	60,000 Km (Each Tire Replacement)	8	8	0%
Check Battery fluid	20,000 Km	60,000 Km	25	6	-76%
Check Battery Charging	20,000 Km	60,000 Km	25	6	-76%
Minor AC check	20,000 Km	80,000 Km	25	6	-76%
General maintenance perform (once at 1st service)	40,000 Km	80,000 Km	12	6	-50%
Retighten bolts and nuts (once at first service)	20,000 Km	80,000 Km	25	6	-76%
				Subtotal:	**-51%**

After recalculation of costs based on newly applied Predictive Condition Based Maintenance strategy the total costs of maintenance evolved to a hardly decrease, as per results the maximum reduction could be until ~50%. In reality the cost were reduced drastically, but not achieved this ideally level.

6.2. Fuel consumption data analysis

Having all the data of driver's driving style as "driver's behavior" analysis, the conclusion for Trainers must be detailed which behaviors need to be corrected, focusing on fuel saver style the results will conclude in quantities of fuel and cost savings. As general behavior analysis the engine status is monitored:

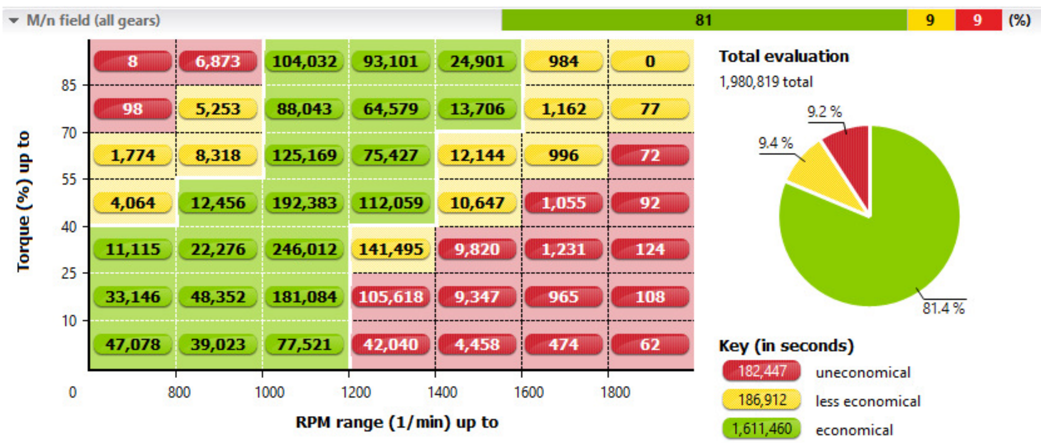

Fig.2 - Engine status monitoring (torque optimum!)

Based on the analysis the refresh trainings made with the drivers of tested vehicles, as reference result is compared second half of 2020 with first half of 2021 on fuel consumption records. Data are in next tables:

Table 4 - Rough data of fuel consumption for H2 2020 (second half of 2020)

Vehicle Group	# of units	Driving style (grade)	Degree difficulty (grade)	Total distance (km)	Average speed (km/h)	Total cons. (l)	Avg. cons. (l/100km)
#1	19	7.94	5.68	650,253.00	48.25	398,302.80	62.59
#2	5	8.35	5.50	133,372.10	46.00	79,995.30	59.91
#3	36	7.91	5.86	1,299,086.50	46.94	842,355.70	71.45
#4	11	7.98	4.34	505,953.00	48.21	246,273.50	49.05
#5	2	7.65	5.63	85,854.60	49.05	52,186.40	62.16
#6	1	7.64	5.73	34,669.20	47.90	24,037.20	61.43
#7	6	7.82	4.36	295,922.30	47.67	144,203.00	48.80
#8	1	7.99	4.08	30,411.20	43.40	15,792.70	51.93
#9	9	6.98	6.23	359,528.30	32.80	208,118.20	107.40
#10	9	5.79	6.35	192,253.20	31.54	149,751.20	79.38
#11	11	6.19	6.01	364,741.60	38.05	238,113.30	67.02
#12	6	6.30	5.95	171,415.80	34.82	113,536.10	68.95
#13	13	5.92	6.36	326,728.80	33.18	239,227.70	74.26
#14	1	5.61	6.20	23,991.00	33.50	17,637.00	73.51
#15	1	5.32	6.31	30,489.20	33.50	24,403.40	80.04

#16	2	6.07	6.14	73,276.00	40.15	47,033.70	64.14
#17	1	5.89	6.52	28,724.90	38.00	20,017.30	69.69
#18	23	5.92	6.02	872,903.70	39.40	519,981.50	62.02
#19	2	5.97	6.03	60,100.00	38.50	34,808.60	58.34
#20	1	7.87	7.37	56,045.30	51.60	34,735.90	61.98
#21	34	7.95	5.82	2,006,841.50	46.36	1,174,417.60	58.58
#22	48	7.81	5.82	2,925,835.50	46.57	1,696,056.00	59.15
#23	4	7.76	5.68	218,336.30	46.80	124,887.10	57.43
#24	5	7.82	5.60	300,276.40	49.10	171,680.30	57.34
#25	5	7.98	5.75	261,993.30	46.94	153,449.10	58.55
#26	1	7.28	5.99	54,810.10	43.70	33,113.00	60.41
	257			**11,363,812.80**		**6,804,113.60**	**59.88**

Table 5 - Rough data of fuel consumption for H1 2021 (first half of 2021)

Vehicle Group	# of units	Driving style (grade)	Degree difficulty (grade)	Total distance (km)	Average speed (km/h)	Total cons. (l)	Avg. cons. (l/100km)
#1	19	7.63	5.86	638,568.80	43.37	384,721.98	60.44
#2	5	7.59	5.78	170,561.00	44.80	98,203.40	58.37
#3	36	7.70	6.00	1,123,691.00	44.84	694,798.65	61.83
#4	11	8.30	4.59	407,306.00	48.20	179,371.40	45.05
#5	2	7.48	5.24	68,576.00	44.50	37,631.40	56.99
#6	1	8.15	3.66	32,630.00	46.00	14,332.65	43.92
#7	6	8.02	4.14	221,413.00	47.50	95,327.75	43.48
#8	1	8.03	3.89	21,004.00	48.00	9,417.35	44.84
#9	9	6.63	6.53	196,284.00	30.89	156,191.40	107.50
#10	9	6.77	6.68	199,153.00	30.56	144,614.70	74.94
#11	11	6.75	6.25	290,276.00	34.45	190,626.05	68.20
#12	6	6.31	6.70	117,130.00	31.50	90,649.95	77.25
#13	13	6.76	6.28	358,180.00	36.23	232,127.75	68.09
#14	1	6.69	7.08	14,502.00	28.00	13,358.90	92.12
#15	1	7.69	6.56	35,572.00	42.00	20,709.05	58.22
#16	2	6.62	6.54	42,419.00	39.00	27,083.55	62.07
#17	1	6.43	6.41	23,163.00	29.00	17,850.50	77.06
#18	23	6.91	5.97	789,307.00	43.26	444,656.05	57.38
#19	2	6.43	6.13	53,986.00	36.00	34,225.65	63.55
#20	1	8.01	7.60	5,764.00	44.00	4,521.05	78.44
#21	34	7.78	5.97	1,690,179.20	45.20	953,073.16	56.19
#22	48	7.77	5.98	2,293,325.30	44.39	1,294,566.52	56.74
#23	4	7.65	5.83	214,961.00	45.00	123,453.45	58.46
#24	5	7.38	6.06	244,264.00	41.60	146,750.30	60.15
#25	5	7.92	5.75	232,438.00	45.20	129,438.45	55.96
#26	1	7.17	5.89	68,908.00	47.00	38,386.65	55.71
	257			**9,553,561.30**		**5,576,087.70**	**58.37**

Summary of the collected data for the tested fleet are:

Table 6 - Results of data analysis for fuel consumption for related periods

Period	Total Distance (km)	Total consumption (l)	Period's average consumption (l/100km)
H2 - 2020	11,363,812.80	6,804,113.60	**59.88**
H1 - 2021	9,553,561.30	5,576,087.70	**58.37**
	Average fuel conservation [%]		**-2.52 %**

The result after training was a reduction of average consumption from 59.88 liter/100km to 58.37 liter/100km, which represents a decrease of 2.52% in fuel costs. Comparing the realized total fuel consumption 5.576.087 liter (on related period of H1 -2021) the fuel economy of 2.5% represent 139.402 liter/6 months! Monetary expression of the fuel is different from country to country, but for Europe accepting an average of 1.5 Euro/liter, the savings could exceed easily >200.000 Euro…

Detailed recorded data must be averaged for same mileages and same conditions, to compare "apple-to-apple". The difference of service level (different distances) for the two period will not affect the results of averages.

Table 7 - Fuel consumption results (comparisons H1/2021 with H2/2020)

Particulars	H2 2020	H1 2021	Δ
Total distance (km)	11,363,812.80	9,553,561.30	-16%
Avg. weight (tons)	49.98	49.42	-1%
Avg. speed (km/h)	43.67	42.18	3%
Total consumption (l/100km)	59.88	58.37	-2.5%
Driving style (consumption) (grade)	6.98	7.21	3%
Planning ahead score (grade) (consumption-related)	4.92	4.80	-2%
Green band (not highest gear) (grade)	8.68	8.69	0%
Accelerator pedal movements (grade)	6.64	6.81	3%
Uniform speed (grade)	8.57	8.89	4%
Maintain momentum (grade) (consumption-related)	6.72	6.67	-1%
Driving style braking (grade)	6.88	7.15	4%
Planning ahead score (grade) (brake-related)	4.93	4.97	1%
Braking force (grade)	8.83	8.90	1%
Average gradient (grade)	3.14	3.22	3%
Average weight (grade)	8.82	8.71	-1%
Stops (grade) (degree of difficulty)	4.85	5.44	12%
Service brake use over total distance (%)	4.82	5.35	11%
Driving style (grade)	7.35	7.46	2%

Comparing the periods on detail the analysis show lot of secondary conclusions which influence the fuel consumption and same time the driver's behaviors impacts the maintenance of vehicles. As one relevant observation the "Uniform speed" index increasing (8.57 to 8.89) it looks have benefice impact on fuel consumption. The results could be more better for fuel economy if route conditions were same, in H1-2021 the "Stops" were increased comparing to H2-2020 (4.85 to 5.44) which had impact on "Service brake use over total distance (%)", increased from 4.82 to 5.35. The final conclusion on "Driver style (grade)" was a positive change from 7.35 to 7.46!

7. CONCLUSIONS

Safe, well-maintained and optimally performing vehicles at all times are key instruments in maintaining and further improving the excellent road safety performance of bus and coach companies, increase service quality, improve customer satisfaction, and bring new customers on board buses and coaches worldwide.

Following general principles were developed few ideas, as bullet points of any guidelines:

- Authority's decision makers and Operator's Management: commitment for proper structured operational Public Transport Network organization and suitable Maintenance strategy (fleet, operation, maintenance synchronizations);
- Data collection and analysis: technological developments and appliance for maximum efficiency (determined by benchmarks, targets and measurement of fuel economy indicators);
- Human Resource: selection and training for drivers and staff of Operator and for technicians for maintenance, with very well trained instructors to improve continuously the manpower quality;
- Passenger centered Quality Public Transport: first priority the passenger safety and just after as secondary passenger satisfaction like increasing operational quality (punctuality, comfort)…

The maintenance remains one of the most important factor of Public Transport services, studies are focused for more and more improvement for safety and efficiency!

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