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BUS FLEET MANAGEMENT – A SYSTEMATIC LITERATURE REVIEW

ABSTRACT

The research on Bus Fleet Management (BFM) has undergone significant changes. It is unclear whether these changes are accepted as technological change or as a paradigm shift. Perhaps unintentionally, BFM is still perceived as routing and scheduling by some, and by others as maintenance and replacement strategy. Therefore, the authors conducted a Systematic Literature Review (SLR) to overview the existing concepts and school of thoughts about how stakeholders perceive the BFM. The SLR post-study exposed that BFM should be acknowledged as a multi-realm system rather than a uniform dimension of fulfilling timely service. Nonetheless, the work encapsulates BFM evolution which shows the need for the multi-realm research abstracted as "Bus Fleet Mobility Management" and "Bus Fleet Asset Management". The difficulties of transport agencies and their ability to switch from conventional to Zero-Emission Buses (ZEBs) illustrates why we propose such an agenda, by which the research is validated through needs both in academia and in practice.

KEY WORDS

bus fleet management; bus fleet mobility management; bus fleet asset management; systematic literature review;

1. INTRODUCTION

The transport industry is an integral part of the economy, and in the EU employs directly around 10 million people accounting for about 5% of GDP [1]. According to UITP [2], 243 billion transport journeys are made per year in 39 countries, while 63% is by public transport. Even though these numbers stress out the social and economic impact, transit agencies need to evolve beyond the environmental impact [3, 4] and move towards the concept of integrated sustainability [5]. Hence, the fleet managers should no longer be solely responsible for routing and scheduling problems; on the contrary, they must rely on performance associated with fuel economy [6], availability [7-9], operational efficiency [10, 11], life cycle management [12], and pollution [13, 14] – highlighting the complexity of decision-making in the BFM domain. The term Bus Fleet Management started appearing during the 1970s where Hauslen [15], and later Roth [16], discussed the benefits of AVM (Automated Vehicle Monitoring) to resolve the issues of "bunching" (simultaneous arrival of buses). Afterwards, Maze et al. [17] in a report "The Bus Fleet Management Techniques Guide" gave fully documented data of bus failures. The report contained systematically analysed failures of brake shoes, transmissions, and air compressors, providing easy-to-access data for maintaining the fleet. Hence, in early stages, BFM research was mostly concerned with the maintenance, eventually shifting the focus on routing and scheduling [18], with the tasks of detecting accidents [19], tracking location [20], and advising drivers [21]. Today's practice consists of mobility optimisation and asset-intensive issues in respect to energy management [22-25]; asset management [12, 26, 27], purchasing [28], replacements [29-31]; ensuring service life [32]; and maximising profit [33]. To unplait the complexity of BFM tasks, the authors will give a brief overview of the BFM and BFMS (Bus Fleet Management System), and the differences within.

1.1 Bus Fleet Management and Bus Fleet Management System

There are many propositional aspects and concepts of the BFM. For example, Hounsell [34] defines BFM as Fleet Management and Operations (FMO) application of the city bus location information available for fleet managers to take actions in case of disruptions [35, 36]. Adding architectures of RTI (real-time information) and AVL (Automatic Vehicle Location) system, BFM extends into a Dynamic Bus Fleet Management (DBFM) [37]. Moreover, Polyviou [36] further expands DBFM to develop SIBUFEM (Simulation Incidents Bus Fleet Management) as a model used to address traffic-related incidents. Additionally, Southworth et al. [38] state that BFM belongs to a wide range of operation and maintenance (O&M) activities [38, 39] aimed at reducing fuel consumption. In contrast, some [40] classify BFM into fleet maintenance and fleet replacement problems [41], where BFM uses a variety of strategies for early replacement [39, 42-44] concerning pollution reduction and energy optimisation [45-48]. Even though all concepts aim to improve bus availability, there is a difference between mobility and asset issues. In that sense, the authors propose, while some [49] agree, that "mobility management", instead of "fleet management", is the right term to be used when addressing the issues of routing and scheduling within the management system.

Bus Fleet Management System (BFMS), on the other hand, is perceived as a decision-making system aimed at supervising, controlling, and managing the fleet of buses. The activities within the decision-making system consist of, but are not limited to, O&M costs optimisation, pollution reduction, routing, and scheduling activities. There are different definitions of BFMS present in the literature. For instance, the Institute of Transport Studies [50] defines BFMS as "A system which facilitates the efficient management and scheduling of bus routes to ensure that buses run as per schedule". Zhou [51] states that BFMS operates using AVL devices that exchange information between bus and Bus Fleet Management Centre (BFMC). Taking into account the management centre, Bivona & Montemaggiore [7] state that the BFMS consists of four sectors: asset sector, maintenance sector, maintenance and human resource sector, and production sector, where every sector by itself consists of distinctive activities. Unlike these traditional systems aimed at reducing costs and providing timely service, the West Virginia University [52] developed an Integrated Bus System (IBIS) with additional data, including emission and fuel consumption. The IBIS system uses these data as a valuable source for fleet optimisation. Thus, understanding that BFMS is getting more sophisticated, Vaughan et al. [12, 27, 53] developed an interactive expert computer-based tool dedicated to fleet managers in aiding decision-making, taking into account four goals, namely: technological, economic [54], transportation [55], and environmental [56]. Besides, the development of ITS (Intelligent Transport System) architecture, digitalisation, and IoT (Internet-of-Things) facilitate the decision-making process considering these interrelated issues [46]. However, looking over the concepts it seems as if BFM is intertwined between mobility issues and asset issues, which is one of the drivers for the research. In addition, the aim of the paper does not include explaining all the myriad ITS support system architectures using real-time support system for analytical purposes, but to critically appraise the current state-of-the-art issues by decomposing the complexity of BFM and improving the management decision-making.

1.2 Research questions and hypothesis

The need for this study is provoked by inadequate elucidation of BFM, which led the authors to use a systematic approach to decompose the BFM based on mobility and management targets. Therefore, this study will answer the following questions:
RQ1: What does state-of-the-art bus fleet management represent, and what are the evolutions of the bus fleet management over time?

Following the first question, the authors point out that BFM is misinterpreted, and the hypothesis is that BFMM is an appropriate epitome when addressing routing and scheduling issues. Hence, the second question states:
RQ2: What is the difference between bus fleet management and bus fleet mobility management?

The rest of the paper is summarised as follows. Section 2 explains the methodology used to perform SLR research. Section 3 transparently shows the retrieval of studies and data insights. Section 4 consists of the discussion and hypothesis validation based on the aims of the research regarding the research questions proposal. The final section consists of concluding remarks and future research recommendation.

2. RESEARCH METHODOLOGY

The research methodology builds upon EBP (Evidence-Based Practice) and ORS (Objective Review Strategy), which is motivated by various guidelines [57-60]. The purpose of the EBP is that it assures transparency and replicability while ratifying the methodology in more rigorous and challenging manner. The objective of ORS is that all of the authors must reach a consensus on whether to include the article in the corpus. Unlike traditional narrative and critical review, the precedence of SLR is that aids peers towards evidence-based approach, assuring replication of results and data synthesis clearness.

2.1 Databases with Inclusion and Exclusion (I/E) criteria

Based on the research questions, the authors used the following keywords with Boolean operators for databases:

1) ("transit bus*" AND "fleet management") OR "bus fleet management";
2) ("city bus*" OR "transit bus*") AND "public bus transport";
3) "urban transport" AND "city bus*" AND ("transit fleet management" OR "fleet management");
4) "transit fleet management" AND "public transport" AND "bus*".

The proposed semantic search was used to search within SCOPUS and EBSCOhost. The SCOPUS is the largest database of peer-review articles, while EBSCOhost consists of Springer, John Wiley & Sons, PLOSone, Elsevier (ScienceDirect) and others. Besides, the authors included Google Scholar, for additional papers, respecting ORS and I/E criteria (*Table 1*).

2.2 Flow diagram for conducting the search

This SLR process was conducted in two phases (*Figure 1*). Phase one includes the first three steps defined in an SLR process, i.e. through screening of titles and abstracts up to the point of Exclusion (LR) criteria. By formulating the research question, search strings are modified to narrow the search in databases. After finishing the process of evaluation based on NR exclusion criteria, 93 papers remained

Table 1 – Description of I/E criteria for semantic search

I/E criteria	Criteria	Description of criteria
Inclusion criteria	Full-text (FTP)	Full-text papers – no posters, presentation or abstracts.
	Language (LAN)	Full text of the article must be written in English.
	Time frame (TF)	Published between 01.01.2009 - 31.12.2018.
	Studies selected (SS)	Journal articles, conferences, technical papers, book chapters, working papers, reports, and doctoral thesis.
Exclusion criteria	Non-related (NR)	NR1: Papers that still appear as search results but are not articles (e.g. editorial material, procedures, etc.)
		NR2: Papers that are not dealing with "city buses" but reference them (e.g. abstract, keywords, references).
		NR3: Reports of transit agency characteristics (e.g. procedures, and bus fleet statistics).
		NR4: Papers that are dealing with multimodal traffic.
	Loosely-related (LR)	LR1: Article is addressing bus fleet management influence on infrastructure problems.
		LR2: Article is not related to transit (city) buses (e.g. inter-city buses (coaches), vans, minibuses, etc.
		LR3: Article relates to transport management (e.g. metro, taxies, and other rail-based systems).
		LR4: Article is dealing with bus powertrain issues.

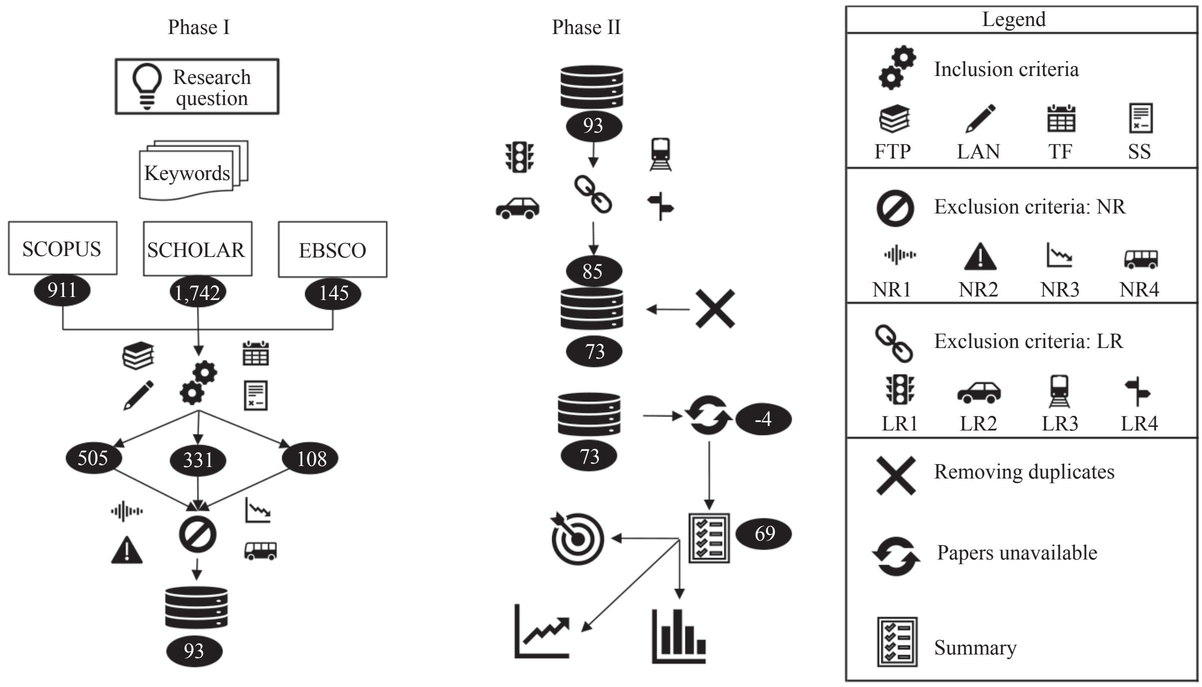

Figure 1 – Algorithm for conducting a systematic literature review

for in-depth analysis. Phase II followed an exhaustive review of studies concerning LR criteria. After the review process, the authors ended up with 73 papers, of which four papers were unavailable to the authors.

3. RESULTS

3.1 Summary of studies

The results show that most of the publications (*Figure 2*) are journal articles (44) and conference proceeding papers (14), followed by dissertations (4), chaptered books (3), reports (2), technical paper (1), and working paper (1). The results additionally show that studies rely on simulation and modelling with practical case studies (*Figure 3*) by which most studies include a comparison of DBs in with other technologies showing the need for evaluating the benefits and opportunities of new technologies. The authors would like to emphasise that no study showed research on a full battery or fuel cell fleet of buses.

3.2 Aims of the studies

The research on BFM topic usually included mobility management issues until, and during the 2000s with a little emphasis on minimisation on

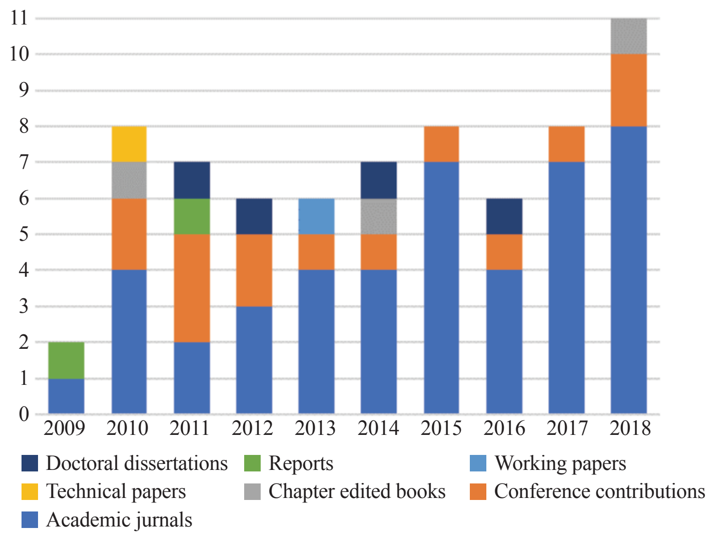

Figure 2 – Type of publications by year

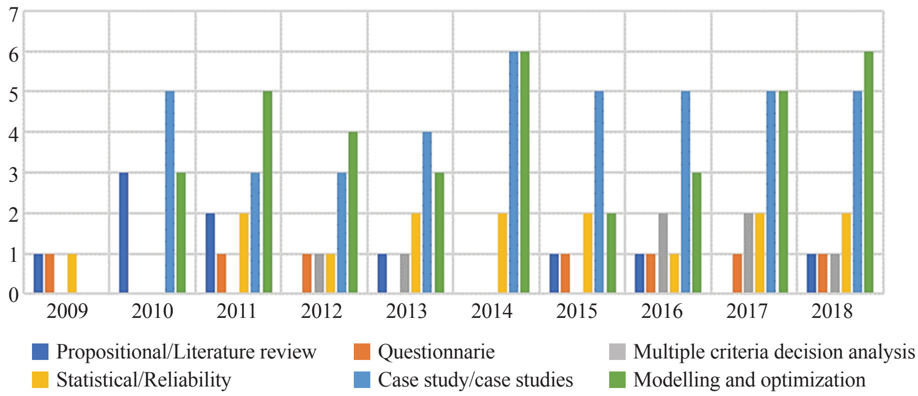

Figure 3 – Types of research method across studies

energy and pollution. However, with the advent of EURO norms, the issues started becoming complicated, shifting more attention to reducing environmental pollution and focusing on replacement and retrofitting strategies (*Figure 4*). Still, the research on mobility issues stayed active due to the expansion of sensor technology (e.g. RFID [61] and ZigBee [62]), internet architectures, and communication technologies (multi-agent systems, AI, IoT, etc.). In this period, BEBs and FCEBs were still considered as technology infants, i.e. in early Technology Readiness Level (*Figure 5*), and only the concepts hit the market. However, the research after 2013 shifts the focus from pollution and mobility issues (*Figure 4*) towards the bus replacement strategies and sustainable energy issues, due to battery

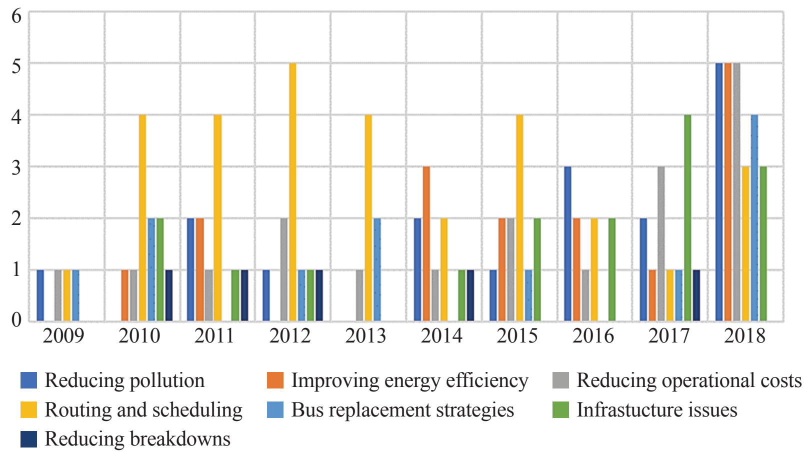

Figure 4 – The research aims within the studies

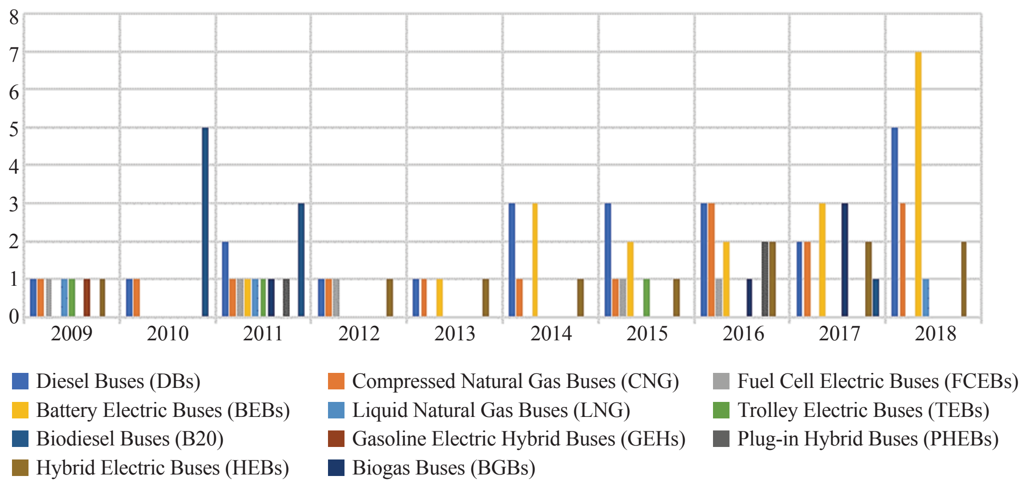

Figure 5 – Types of buses used in the research

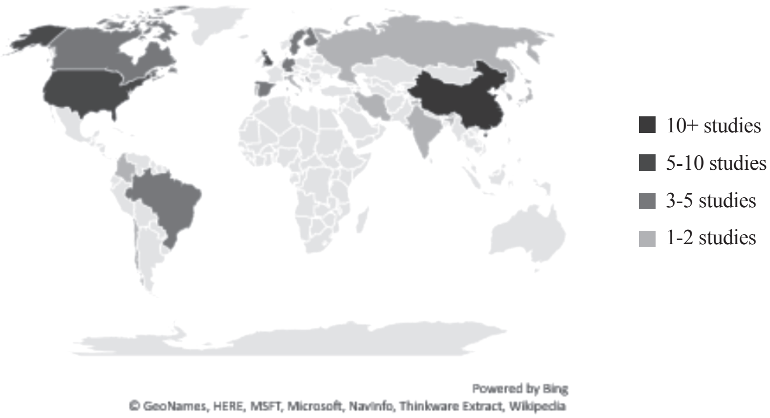

Figure 6 – Geographical research area of studies

and fuel cell technology [12, 26, 63-65] (*Figure 5*). Rhetorically, retrofitting and sustainability issues further opened a chapter of infrastructure-related issues due to the unavailability of a network for recharging and refuelling of electric and fuel cell buses. It seems as if that mutual understanding of this various energy-sustainable technology in terms of the environmental and social aspect, proved to be a win-win situation. However, the research shows progress only in the countries with available technology, where they can validate the results in the real-world setting.

The research case studies were mostly done in Asia, America, and Europe, namely: China (11 studies), the USA (9 studies), the United Kingdom (6 studies), Finland (3), Germany (3 studies), Spain (3 studies), Canada (3 studies), Brazil (3 studies), Sweden (3 studies), and the rest of the articles validated the research findings through two or fewer practical studies (*Figure 6*).

4. ANALYSIS OF DATA AND DISCUSSION

After careful considerations of state-of-the-art literature, the authors envelop the most important findings from the corpus of evidence. By responding to the first research question we used state-of-the-art research aims, which served as an apparatus to justify the research outcome. The evidence shows that the advent of innovation compelled the scholars to go beyond mobility management issues towards the asset management issues with more emphasis on revitalising the existing fleet with respect to environmental demands imposed by the government policies. As a consequence of accepting such radical changes, the landscape of BFM research domain started including the cost-benefit analysis due to the lack of financial incentives and investments in the new fleet. Besides, the development of new bus technologies has become a complicated ordeal lately with infrastructural demands. The need for retrofitting the existing fleets, lack of power supply, fuel efficiency issues, and similar, all produced limited solution space with budget constraints. To help ease the issues the authors propose that the BFM domain should be decomposed into two realms, namely: BFMM (Bus Fleet Mobility Management) and BFAM (Bus Fleet Asset Management). Therefore, addressing the specific point within the BFMS, such as routing and scheduling, will fall under the BFMM realm, and the issues of infrastructure and asset management associate with the BFAM realm. The actions of reducing costs, pollution, and fuel consumption, can implicate both realms, although it depends from which aspect these activities are addressed. Usually, in BFMM practice, these constraints are used with integer programming, and some encapsulate this topic as Mixed Bus Fleet Management (MBFM) [66]. Hence, many concepts of the mixed fleet, such as Green Mixed Bus Fleet Management (GMBFM) [43] and Green Bus Fleet Management (GBFM) [53, 67] have emerged over the years. While GBFM is primarily associated with the pollution reduction in relation to mobility issues, the MBFM focuses on fleet optimisation using, for instance, integer programming, to minimise the costs and energy.

4.1 Bus Fleet Mobility Management (BFMM) realm

The purpose of BFMM realm is routing and scheduling, while also including factors that can affect productivity and quality of service: deadhead trips [38, 68], idle times [23, 38], dwell times due to road design [69], way of ticketing [70, 71], platform issues [10, 51], headway regularity [72], emission [73], and special events [74]. All of the factors affect mobility managers' optimisation and scheduling whether they are Bus Rapid Transit (BRT) [75, 76] roadways, trolley fixed roadways [77], or conventional infrastructures. Even so, critics are often suspicious with trolley and BRT roadways, calling into question its heavy subsidy rate [63]. On the other side, a lot of different cost-saving methods exist within conventional infrastructures, for instance, eco-driving [78]. Eco-driving is a non-aggressive driving technique employed by drivers for efficient fuel consumption and environmental preservation [73]. With the constant development of ITS systems [35, 71, 72, 79, 80], whether they are based on GPS [34, 79-82] or GSM [11], eco-driving can benefit from various strategies to minimise fuel consumption, consequently reducing pollution. These strategies can include the use of different payment systems [82, 83], way of ticketing [61, 70, 71], platform regulation [10, 51], and headway regularity [72], and similar.

Even though the goals of BFMM today are to optimise the routes concerning minimal energy utilisation and pollution, before 2009 it was understood as a spare ratio issue, i.e. asset issue [29]. The state-of-the-art literature shows that most of the BFMM research today uses methods of integer-programming and scheduling algorithms for the optimisation of these issues [84, 85]. For instance, Zhen [86] uses GA (Genetic Algorithm) to compare bus technologies (DBs, B20, HEBs, FCEBs, BEBs) concerning operating costs and emission suggesting the most appropriate technology for different routes (HEBs and BEBs). Alam et al. [87] simulate operation and GHG emission of DBs and CNG buses to show that CNG buses can reduce emissions by an average of 10%. However, they emphasise that switching to CNG buses seems to be less appealing without traffic jams. Santos et al. [88] analysed the advantages and disadvantages of using BEBs showing a significant improvement in terms of fuel consumption and emission reduction, although with considerable operational costs. From an energy standpoint, Lajunen et al. [25, 89, 90] researched the requirements for HEBs and BEBs, giving a fully documented LCA analysis for different bus technologies (DBs, CNG, BEBs, HEBs, FCEBs) [91]. The implications show the predominance of BEB over other bus technologies but only in the cases of low average speed. Even though BEBs and FCEBs are favoured over other bus types, they are still in a technological research domain. Regarding management, the biggest problem at the moment is the slow implementation of these types of buses associated with huge infrastructural issues [92, 93]. Besides, these fleets notorious for high investment and operational costs, which the authors propose, are a BFAM issue.

4.2 Bus Fleet Asset Management (BFAM) realm

The authors address the Bus Fleet Asset Management (BFAM) as a realm of BFM concerned with the management of infrastructure, replacement strategies, and fleet maintenance. BFAM is becoming a topic of need due to clock-speed development of battery and fuel cell technology. Hence, crucial for the fleet management is to consider as many factors as possible when considering the renewal or replacement of the fleet, ensuring a reduced carbon footprint. Within BFM, the asset management is defined by some authors as a "systematic process of operating, maintaining, and upgrading physical assets cost-effectively" [32], thus covering a fraction of proposed mobility management practice, although focusing more on the physical asset availability. After the emergence of EU emission norms, upgrading a fleet was mostly done through retrofitting and re-building practice as a temporary solution, since it showed to be less effective. Remanufacturing the engine or transmission had a similar target of extending the life of a bus for at least 4-10 years [94]; however, with a significant portion of expenses, more maintenance-intensive activities later on. In this regard, considering new technologies, one must consider the location of the manufacturer [95], mostly because it is associated with easy-to-access and service maintenance. The reason above is mostly associated with the fleet replacement policy. Fleet replacement, namely, typically follows a uniform distribution where fleet age and mileage (approx. 8.33 years [95]) usually dictate the pace of fleet renewal. The underlying reason is the fact that it is more comfortable to conduct maintenance for vehicles that are of equally dispersed bus age. Moreover, considering the US practice, which states that bus must remain operational for at least twelve years to qualify for federal funds [32], shows just how much the operability depends on the maintaining quality. Therefore, under the pressure of budget constraints, the agencies are using alternative rebuilding programs, such as rehabilitation or remanufacturing [44, 94]. Besides maintenance, the factors affecting replacement of the fleet include gas prices, government subsidies, and programs promoting domestic manufacturing with tax reliefs (e.g. "Buy America mandate" [96]). The replacement and renewal strategies are clearly due to sustainability issues, thus apparently creating a gap for the electrification of the fleet. Following the statement, many studies [63-65, 97-99] dedicate to resolve the difficulties regarding the slow implementation of BEBs by transit agencies. However, due to high investment costs, the need for new facilities, personnel training, and low revenue, transit agencies are quite sceptical of acquiring new technology [63]. The risk of getting "stuck" with expensive technology, is somewhat seen through disruptive technologies. For instance, a revolutionary type of charging (e.g. wireless inductive, solar roofs), the lack of charging infrastructure, the impact on the utility grid, staff maintenance training, and technology shift in battery chemistry, lead to scepticism and sense of fear with transit agencies. Academics suggest that conventional buses should be replaced with HEBs and BEBs, highlighting the slow transition with minimal operational costs and emissions, before complete replacement of the fleet.

4.3 Final section remarks

The research of BFM in the traditional school of thought implied mostly routing and scheduling, while today it consists of a large number of activities aimed at assuring socio-economic sustainability. This means that to accept new technologies, such as a fleet of ZEBs, the transit agencies must first resolve all the barriers in the way of accepting such a radical change. These barriers present questions associated with pollution, fuel technology, operational efficiency, infrastructure and asset management issues. The obvious thing is that the present transport management research in underdeveloped countries is mostly dealing with the aspect of timely transport service, neglecting the challenges of emerging technologies. In that sense, the technology transfer practice and gentrification activities should be more in the centre of debate within the consortium of projects, to foster a smoother transition from conventional to the state-of-the-art fleet. Besides, the authors suggest that research and practice should address explicitly two different realms; namely, BFMM – mobility management optimisation concerning energy and pollution, and BFAM – ensuring operability and sustainability of the transit fleet.

5. CONCLUSION

Putting all together, the propositions and tenets of BFM brought little to the table in the sense of clearness behind the concepts since most researchers conceive BFM as various interrelated activities. Therefore, in the future, the academia needs to make more unambiguous results and delineate each study aim related to BFM, whether it is under the BFMM or BFAM realm. If studies are undertaken akin to our propositions, each of the realms is getting closer to the falsifiability of constructs. Besides, overviewing the problems of a slow transition from conventional to ZEBs, the most important issues are related to financial incentives, tax reduction, and the risk of being stuck with expensive technology. In order to support the EU policy of becoming the first free-carbon continent by 2050 [100], more research calls for attention regarding technology transfer and infrastructure issues. To address these issues, the first-ever conference held in the USA, followed up by the conference in Cologne, Germany [101], had as a goal to answer the simple question: Are ZEBs ready for mass-market deployment? Key messages provided insights regarding the current state-of-the-practice, stating that the global bus fleet is around 3 million in total, while BEBs make up 13% of which 99% of those are in China. Interestingly, as reported, there are less than 1,000 FCEBs, of which 400 buses are to be deployed in Europe by 2020, meaning that a growing number of projects and dissemination of the results are yet to be expected. Therefore, the state-of-the-art and the state-of-the-practice need to converge and solidify the groundwork to provide solutions in the procurement of ZEBs. As a consequence of the EU policy targets that imply biodiversity, clean energy, "farm to fork" and other strategies, the authors' future research agenda is dedicated towards mechanisms and drivers for a smooth transition between conventional fleet and the fleet of ZEBs by respecting EU initiatives and policy targets.

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MENADŽMENT VOZNOG PARKA AUTOBUSA – SISTEMATSKI PREGLED LITERATURE

ABSTRAKT

Istraživanje na temu menadžmenta voznog parka (MVP) autobusa trpi značajne promene. Nejasno je da li su ove promene prihvaćene kao tehnološke promene ili kao smena paradigme. Pretpostavlja se da je, nenamerno, MVP i dalje prihvaćen kao organizacija ruta i reda vožnje s jedne strane, dok sa druge to predstavlja strategiju održavanja i smenu flote. Prema tome, autori su sproveli sistematski pregled literature kako bi pregledali postojeće koncepte i škole misli na koji to način zainteresovane strane sagledavaju menadžment voznog parka. Studija je otkrila da MVP treba razumeti kao višedimenzioni sistem, a ne kao jedinstvenu dimenziju usluga poput reda vožnje. Pored toga, rad obuhvata evolucije MVP-a koje prikazuju potrebu za višedimnezionim sistemom apstraktovanih kao „Menadžment mobilnosti voznog parka" i „Menadžment imovinom voznog parka". Poteškoće agencija javnog prevoza i njihove sposobnosti da pređu sa konvencionalnih na autobuse nulte emisije ilustruju zašto predlažemo takvu agendu, pri čemu je istraživanje verifikovano kroz potrebe i nauke i prakse.

KLJUČNE REČI

menadžment voznog parka; menadžment mobilnosti voznog parka; menadžment imovinom voznog parka; sistematski pregled literature;

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