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COMPUTER-BASED DECISION SUPPORT SYSTEM (DSS) APPLICATION IN TRANSPORTATION SECTOR: A REVIEW

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Abstract: *Poor planning in urban transport infrastructure causes severe congestion, pollution and stifles city productivity. Recently, computer-based decision support systems (DSS) that can solve several transportation decision problems have gained popularity. This paper concisely reviews the application and contribution of existing research of DSS for the transportation sector. A thorough systematic literature review (SLR) was employed to find relevant material using web search engines like Scopus, Google Scholar and Web Science. The currently available DSS are separated into two categories: (i) developed DSS primarily for research publication and (ii) established web-based DSS that are available online. Most of the latest DSS for research publication within 2017 and 2022 are more focused on public transportation management, road safety and hazardous materials transportation. It is found that existing web-based DSS apps available online, are not focused on efforts to avoid the variables that cause traffic accidents. Most systems only provide limited access to information about road safety issues and concerns. The survey found no research on DSS development, notably in addressing traffic accident causes such driver fatigue. As a result, a decision support system should be built that will monitor and detect the driver's fatigue level, provide a warning, make a judgement about the driver's current position, and recommend a solution whether the driver is safe to drive or not. This study will help academics, policymakers, and practitioners identify research gaps, future directions, and viable areas for multiple-criteria DSS in transportation.*

Keywords: decision support system (DSS), transportation, road safety, urban.

1. Introduction

Malaysia has become one of the most urbanized countries in East Asia. Malaysia's urban population has risen quickly, from 70% in 2010 to 77% by 2020 (O'Neill, 2022). This is predicted to increase to more than 80% by 2030 (Malaysia, 2019). The human population has become more reliant on transport as a result of urban sprawl. Malaysia's registered vehicle population has recently increased from 3,447,712 units in 1996 to 17,486,589 units in 2020 (CEIC, 2021).

However, the rapid growth of mobility in urban areas triggers massive economic losses in traffic safety and anthropogenic pollution (Moslem et al., 2020). In connection to traffic safety, the road accidents in Malaysia has increased from 414,421 cases in 2010 to 567,516 cases in 2019 (Malaysia, 2023). Despite the fact that traffic accident is one of the impacts of urbanization, there are still unanswered questions regarding how the number of crashes in urban areas relate to the population size at a given location (Cabrera-Arnau et al., 2020). On the other hand, cities are also the top causes of the pollution issue. The high concentration of people in cities lead to unfavourable anthropogenic pollution, mainly from transportation and factories (Martínez-Bravo & Martínez-del-Río, 2019). A study found that urban residents may suffer serious air contamination-related health burdens under the same air quality conditions (Hu et al., 2019). Also, poor road planning in urban areas would exacerbate the residential environmental exposures (Wang et al., 2019). Due to the above arguments, the governments and policy makers must take actions to overcome these critical issues.

Recently, there has been a surge in the use of computer-based decision support system (DSS) to control the impacts of transportation. DSS acts as an approach to expand the capabilities of decision makers in making decisions, without replace the decision maker's judgement (Soehodho, 2017). This computer-based tool is designed with an emphasis on aspects of high flexibility and adaptability (Mayer & Trevien, 2017). The DSS for transportation provides number of functionalities and solve numerous categories of transportation decision problems such as vehicle routing, road safety and transportation infrastructure (Zak, 2010).

In this article, a comprehensive overview of the existing transportation computer-based decision support system (DSS) was presented. The currently available DSS are separated into two categories: (i) designed DSS primarily for research publication and (ii) established web-based DSS that are publicly available online. Next, the application and contribution of the recent studies were discussed to determine a literature gap or promising areas for future research in development of DSS in transportation.

2. Review Method

A highly rigorous process known as a systematic literature review (SLR) was used to discover resilient and high-potential literature connected to the research subject. A SLR determines, selects and critically evaluates research to answer a specific question (Dewey, 2016). This method is significant since it focuses on discovering uniqueness and research gaps, as well as providing research direction by demonstrating previous work in the subject area and the research approaches and ideas that have been applied. First, relevant keywords such as "decision support system," "decision support system in transportation," "urban transportation," "urban mobility," "road safety," and "road management" were identified.

To get useful results, three simple Boolean operators: AND, OR and NOT were used to connect the keywords in a logical form that the database could understand. The AND command joins two or more search phrases by informing the database that all of these keywords must be in the resulting documents, such as searching on "decision support system" AND "urban transportation". If one key phrase appears in the item returned but the other does not, relatively few results will be returned because the item will not appear in the search results list. OR connects two or more synonym concepts, which means that any of the search terms, for example, urban OR city, can appear in the retrieved document. Meanwhile, the NOT command narrows a search by removing search results that include the search phrases that follow it, such as "decision support system in transportation" but NOT "decision support system in agriculture". The system will only consider papers that contain the key phrase "decision support system in transportation" and will disregard any results that contain the keyword NOT "decision support system in agriculture". However, while refining the search, extreme caution is advised because good records may be eliminated. It is advised to use double quotes (<<>>) around key phrases. Scopus, Google Scholar, and Web Science were three commonly used academic databases by researchers from various study fields. The PRISMA flow diagram in Figure 1 visually summarizes the screening process. The first electronic searches yielded 1214 documents. The documents were then subjected to a de-duplication process, which identified and discarded duplicates. The de-duplication process left 789 documents. The following step involved a two-step process: (i) screening titles and abstracts for those related to DSS in transportation, and (ii) selecting a full-text document for inclusion in the review. This batch's title and abstracts were examined, and 121 eligible documents were extracted. During the full-text screening step, all 668 documents were considered. Out of the potentially relevant batch of 546 documents, 122 were chosen as relevant to the research topic.

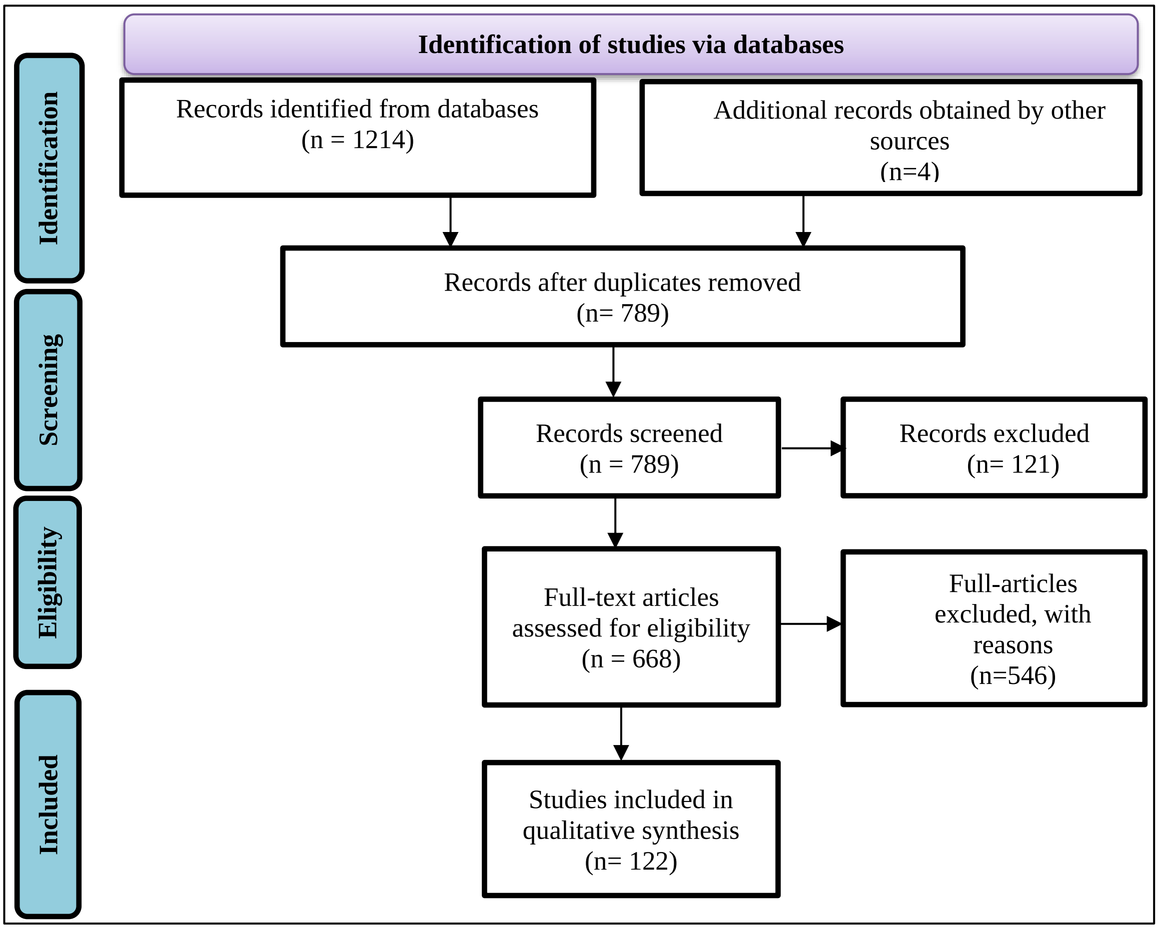

Figure 1: PRISMA Flow Diagram Illustrating Selection of Articles

3. Decision Support System (DSS)

Decision Support System (DSS) is a computerized program with an organized collection of analytical tools, graphical user interfaces and databases to support decisions making and timely-problem solving (Geetha et al., 2021). This information system allows decision makers to integrate directly with computers to collect useful information from raw data, personal knowledge and documents to determine and solve problems for structured and unstructured problems and execute decision making as well (Syafrizal, 2010). To tackle issues in the transportation filed, a number of DSS have been proposed and developed. The currently available DSS are separated into two categories: (i) designed DSS primarily for research publication and (ii) established web-based DSS that are publicly available online.

3.1 Designed DSS Primarily for Research Publication

DSS is constantly evolving. Advancements in new technologies, new measures and ever-changing management and business needs are the reason for the continuous evolution. Therefore, to identify a direction for further improvement in existing research, the articles related to the DSS development for transportation realms are limited from 2017 to 2022 as presented in Table 1. The findings yielded that most of the current studies from 2017 to 2022 were focused more on public transport management, road safety and hazardous material transportation.

Table 1: Summary of Transportation – Oriented DSS Research Articles Published from 2017 to 2022 Focusing on (i) Public Transport Management, (ii) Road Safety and (iii) Hazardous Material Transportation

Author	DSS Aim(s)
Public Transport Management	
(Puchongkawarin & Ransikarbum, 2021)	DSS Aim 1) To evaluate the factors that influencing the quality of current public transportation in an integrated way. 2) To determine the optimal routes for buses to connect with all tourist destinations. Outcome 1) DSS addresses few factors influencing the quality of public transportation: (i) seat propriety and (ii) seat availability. 2) DSS indicates that all desired locations can be connected with a minimum distance of 389 kilometers.
(Santos et al., 2020)	DSS Aim 1) To establish timetables to be fulfilled. 2) To check if operational travel times are correct based on plan. Outcome: DSS evaluates the schedule reliability through two perspectives: i) if operational travel times specified in each connection are being fulfilled. ii) if all vehicles in the network are leaving the hubs based on planned timetable.
(Sulistiyo Soegoto & Ramadhani, 2020)	DSS Aim: 1) To assist the inspection officer in making decision to determine the proper transportation to operate. Outcome: DSS processes the data of physical examination of the transport vehicle filled in by the drivers, before suggested whether the vehicle is viable to operate or not.
(Utama et al., 2020)	DSS Aim: To make a decision in determining the best service among the two types of public transport. Outcome: DSS scientifically evaluates the quality services by considering few parameters like travel time punctuality, availability, driving quality, safety and driver's concern towards passengers
(Meethom & Koohathongsumrit, 2018)	DSS Aim: To suggest best road freight transportation route in term of cost and time. Outcome: DSS discovers route 2 as the optimal route with the minimum total deviation (transportation cost and time) compared to route 1,3 and 4.
(Makarova et al., 2017)	DSS Aim: 1) To determine the most loaded region of the road network. 2) To suggest optimal alternative for traffic flows management. 3) To suggest best routes with low traffic flows and accidents history. Outcome: DSS reduces the traffic load on the considered risky urban road region from 1469 vehicles to 1212 vehicles.
(Wulandari, 2017)	DSS Aim: To assist the distribution number of buses in each route. Outcome: DSS suggests: i) 74 buses are required to operate for all routes. ii) capacity of each bus is 41 passengers. ii) each route must have three buses up with 15 minutes' interval and 20km/h average bus speed. The total cost for the entire route operations is 5189 rupiah/km.
Road Safety	

(Ivajnšič et al., 2021)	DSS Aim: To avoid road accidents occurrence in hot spots area in different weather conditions. Outcome: DSS provides advanced warning when the drivers enter and leave hot spots accident area under various weather conditions.
(Domínguez et al., 2020)	DSS Aim: To correctly distinguish vehicles and pedestrians to avoid crashes. Outcome: DSS provides advanced warning and alert the drivers by generating the visual signals if there are pedestrians who are crossing a crosswalk.
(Fancello et al., 2019)	DSS Aim: To determine the most dangerous road sections in urban networks. Outcome: DSS identifies and ranks the most critical road regions in urban networks according to a set of evaluation criteria.
(Vera-Baquero & Colomo-Palacios, 2018)	DSS Aim: To give insights into the road network's efficiency on an acceptable response time basis through the application of big-data based and process-centric method integrates with operational traffic information systems. Outcome: DSS is able to monitor and analyze of very vast amount of data in nearly real time.
(Ait-Mlouk et al., 2017)	DSS Aim: To determine the top causes contributing to the severity of road accidents. Outcome: DSS assists drivers to make selection based on personal preferences and needs, for example by providing information to avoid dangerous routes.
(Utama et al., 2017)	DSS Aim: To propose most optimal strategy decision in road traffic engineering. Outcome: DSS suggests the best decision to avoid road with heavy congestion by considering few aspects like U-turn, motorcycle and public transport elimination, traffic light modification and public transport stop point.
(Kazak et al., 2017)	DSS Aim: To determine the hot spots in city area. To prevent the cognitive issues of the decision making process for a non-expert. Outcome: DSS is able to determine the hot spots and assist in making decision to avoid accidents in these hot areas.
Hazardous Materials Transportation	
(Ouertani et al., 2022)	DSS Aim: To determine the optimal routes that reduce the transportation cost and travel risks. Outcome: DSS suggests routes that can minimize transportation cost and accident risks for the users to select.
(Li et al., 2019)	DSS Aim: 1)To determine the uncertainty during the risk management 2) To analyze the significance rating of risk factors. 3) To maximize the total risk control effectiveness. Outcome: DSS exhibits superiority in systematic risk identification, risk assessment, and risk control of hazardous materials road transportation.
(Gromov et al., 2019)	DSS Aim: To minimize the total delivery costs. Outcome: DSS reduces delivery cost per liter to 15% in comparison with the previous years prior to the DSS implementation.
(Hirsch et al., 2018)	DSS Aim: To improve selection of design and operating parameters of a long distance Heat Transportation System (HTS).

	Outcome: DSS assists users to plan best strategies for pipe-laying installation in terms of safety and cost.
(Yazdani et al., 2017)	DSS Aim: To evaluate and rank logistic providers based on the quality function deployment. Outcome: DSS evaluates and clarifies the interaction relationship and impact levels between the customer attitudes and logistic provider's basis.

3.1.1 Public Transport Management

The overall objective of the reviewed papers related to public transport- oriented DSS is to improve the service quality by overcoming transportation issues like routing and scheduling. Vehicle scheduling is a process to determine the optimal vehicle allocation in a given transportation schedule by referring to the execution of all trips (Ibarra-Rojas et al., 2015). Meanwhile, vehicle routing is the design and assignment to determine optimal routes for multiple vehicles visiting a set of destinations (Mutingi, 2014). A study conducted a global review regarding the importance strategic and tactical steps of transit planning in design and network scheduling (Guihaire & Hao, 2008). The review traced a five-step planning process, namely timetable development, bus scheduling, driver scheduling, network design and frequencies setting (Ceder, 2016). An excellent vehicle routing and scheduling can effectively minimize transfer waiting time and improve service connectivity (Shang et al., 2019). Reducing waiting time can effectively improve customer satisfaction, which, in turn, resulting in the growth of ridership and revenues. Another study developed a DSS to optimize vehicle routing system for a feed compounder company, which, in turn, successfully decreasing the delivery time by increasing the reduction of distance travelled from 7% to 12% and the operational cost savings from 9% to 11% (Ruiz et al., 2004) . A different study minimized tourist travelling time by determining the optimal routes for buses to connect with all tourist destinations through DSS application (Puchongkawarin & Ransikarbum, 2021). The system found that 6.27 hours is sufficient to visit all the eleven destinations. In fact, longer time was required for travelers to visit all the locations in one trip by using usual routes prior to the DSS implementation.

3.1.2 Road Safety

A study had classified human, vehicle and environment as the risk factors influencing road accidents (Vogel & Bester, 2005). Human factors include inconsiderate driving behavior like excessive speeding, tailgating, negligence, age and driving experience (Zhang, 2010). Vehicle factors are mostly about brake malfunction and tire failure (Mphekgwana, 2022). In general, most of the road safety-oriented DSS studies from 2017 to 2022 focused on efforts to mitigate the effect of environmental factors. Environmental factors like various weather conditions and road characteristics are reported in the literature review as having a critical impact on the road safety (Ivajnšič et al., 2021). A study investigated the effects of rainfall on the severity of single-vehicle accidents, found that, rainfall intensity, wind speed and road geometries (horizontal or vertical curves) increase the probability of road accident occurrence in rainy weather (Jung et al., 2010). This is in agreement with (Andreescu & Frost, 1998) as the number of road accidents in Montreal, Canada were reported higher during snowy and rainy seasons (Andreescu & Frost, 1998). A study found that crash hotspots have significant impacts on road accident severity (Wang & Zhang, 2017). Hot spot is a dangerous section of the road system, created from the natural and environmental determinants (steep, sharp turn and slopes) and weather (snow, wind, rain black ice and fog) (Xie & Yan, 2008). However, it is certain that traffic collision hot spots are imperative spatial information with considerable applicative value, where the current, modern open-source navigation systems do not offer for road users (Durduran, 2010). Therefore, most of the recent studies developed a DSS to assist drivers in making decision to avoid accident hotspots during various weather conditions by providing warning and suggesting safer routes in order to reach their destinations.

3.1.3 Hazardous Material Transportation

Overall, the recent DSS development studies related to hazardous material transportation are more focused on the identification of the transportation routing plans between a pair of origin and distribution routes that reduce transportation risk and cost. A study that developed a methodological framework for a DSS system covering transportation hazard analysis, argued that a DSS for HazMat transportation risk management should address risk assessment and cost minimization (Lepofsky et al., 1993). The risk minimization criterion is expressed through the identification of paths with the lowest total transportation risks. The cost reduction is achieved through the optimum utilization of the transportation vehicles and the identification of economical routes (Zografos & Androutsopoulos, 2005). A study that developed a decision support system (DSS), through a case study, compared the existing practice of a petroleum transportation company in transporting gasoline from the refinery to customers' buildings in terms of transportation cost and risk. The proposed system reduces the monthly transportation cost from 5218€ to 1020€ and corresponding risk from 1520 to 1600 units (Zografos & Androutsopoulos, 2008). (Gromov et al., 2019) analyzed the delivery operational system of petroleum from a bulk terminal to petrol stations by using petrol tank trucks, successfully decreasing the delivery cost per liter to 15% in comparison with the previous years prior to the DSS implementation (Gromov et al., 2019).

3.2 Established Web-Based DDS that are Publicly Available Online

Table 2: Independent Product for Old and Cheaper Vehicle

Web Name	Details
Safety Cube	SafetyCube (Safety CaUsation, Benefits, and Efficiency) is a research initiative in the domain of road safety supported by the European Commission under Horizons 2020, the EU Framework Program for Research and Innovation (Safety, 2016). The main goal of the SafetyCube project is to create an inventive road safety Decision Support System (DSS) that will allow policymakers and stakeholders to choose and implement the most appropriate strategies, measures and cost-effective methods to decrease fatalities of all road user types and severity levels in Europe and around the world. Web Link: https://www.roadsafety-dss.eu/#/ Limitations: A good safety system is usually made to make sure that no one gets killed or hurt badly. However, the Safety Cube merely evaluates the influence of risks and measures only on fatalities as a specialized topic. From a system standpoint, this is not optimal. It is hoped that future studies will look at significant injuries as well as fatalities.

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Figure 2: SafetyCube (Safety, 2016)
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<tr><td>Crash Modification Factors (CMF) Clearinghouse</td><td>
The CMF Clearing House is financed by the Federal Highway Administration of the United States Department of Transportation and operated by the University of North Carolina Highway Safety Research Center (Transportation, 2022). A Crash Modification Factor (CMF) is a multiplicative factor that specifies the percentage of road accidents that would be predicted when a countermeasure is implemented. Examples of countermeasures include adding a traffic signal, extending the width of edge lines and constructing a median barrier. CMFs smaller than 1.0 suggest fewer accidents are predicted. CMFs greater than 1.0 imply an expected rise in road accidents. For example, a certain stop-controlled junction is predicted to experience 5.2 total collisions per year. The city is considering building a traffic signal and has determined a CMF for building a traffic signal of 0.56 for total (or "all") crashes (Harkey, 2008).. The estimated total road accidents after implementing the signal would be 5.2 x 0.56 = 2.9 total accidents each year.

Web Link: https://www.cmfclearinghouse.org/

Limitations:
The system solely includes metrics for infrastructure and does not include any statistics for human behavior, vehicle technologies or post-accident care. Additionally, it does not examine the dangers to road safety. The system is designed for professionals and is limited to obtaining CMFs and relevant research with an abstract. Furthermore, there are only single studies for each intervention and no introductions or summary (synopsis) documents. Despite the cost-benefit analysis tools offered, the Clearinghouse does not provide an online tool for analyzing economic efficiency.

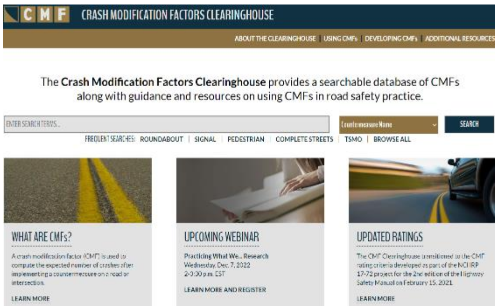

Figure 3: Crash Modification Factors (CMF) Clearinghouse (Transportation, 2022)
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<tr><td>Road Safety Toolkit</td><td>
The Road Safety Toolkit was developed in collaboration with the International Road Assessment Programme (iRAP), the Global Transport Knowledge Partnership (gTKP) and the World Bank Global Road Safety Facility (Programme, 2022). The ARRB Group (Australian Road Research Board) provided expert advice during the Toolkit's development. The Road Safety Toolkit provides free information on the causes and prevention of car accidents that result in death or injury. Based on decades of road safety research, the Toolkit provides engineers, planners and politicians with critical information on countermeasure development, effectiveness, cost, and implementation issues. The Toolkit included information on 58 different types of interventions, 42 of which related with infrastructure, 5 with vehicle safety, and 11 with behavior. Interventions can be accessed through a variety of entry points, including "Crash Types" (choose from eight common accident situations), "Road Users" (six key road user
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	groups), "Road types (five key road types), "Management" and "Treatments" (grouped into infrastructure, vehicles, and behavior). Web link: https://toolkit.irap.org/ Limitations: The Road Safety Toolkit emphasizes common-language treatment recommendations across several fields of road safety activity, removing the need for post-accident care. Furthermore, several links to source documents are broken. Rather than scientific studies, the available source documents are largely guidebooks, project reports or links to other websites. The system is also not intended to support cost-benefit analysis directly and does not provide any risk assessment for road safety.  **Figure 4: Road Safety Toolkit (Programme, 2022)**
Road Safety Observatory	The Road Safety Observatory, established by a number of road safety organizations including RoSPA, the Department of Transport, Road Safety GB, PACTS, and RoadSafe, aims to provide free and easy access to independent road safety research and information for anyone involved in road accidents as well as members of the general public (Observatory, 2023). It includes research summaries and reviews on a variety of road safety themes, as well as links to original research publications. By bringing together many of the significant road safety NGOs and organizations, the system wants to present a unified perspective of road safety evidence and the potential impact of alternative measures. The Road Safety Observatory was previously an independent website that was established in response to a desire for improved access to research and information in a format that was comprehensible to both the general public and experts. Web Link: https://www.rospa.com/road-safety/projects/road-safety-observatory Limitations: The UK Road Safety Observatory makes it simple to find information about road safety issues and concerns. The method, however, is not intended to directly supplement cost-benefit analysis and does not give a structural examination of road safety problems.  **Figure 5: Road Safety Observatory (Observatory, 2023)**
PRACT Repository	PRACT stands for "Predicting Road Accidents - a Transferable Methodology Across Europe," and it was developed by the University of Florence, the National Technical University of Athens, the Technical University of Berlin and Imperial College London as part of a competitive project funded by the Conference of European Directors of

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Roads (CEDR) (Florence, 2017). The PRACT Repository offers the most recent Accident Prediction Models (APMs) and Crash Modification Factors (CMFs), demonstrating the effectiveness of global road safety interventions for use by global road safety decision makers and practitioners. Various filters, such as road features and types, geographic regions of studies, types of intersections and traffic control, and crash severity and types, can be used to narrow down the search for specific CMFs or APMs.

Web Link: https://www.pract-repository.eu/

Limitations: The system concentrates on CMFs and APMs in the context of road infrastructure characteristics and solutions. However, it is aimed at road infrastructure specialists who are already familiar with CMFs or APM theory and practice. There is no explanation or synthesis material provided for the inexperienced user. Also, the system is not intended to support cost-benefit analysis directly and does not provide any risk assessment for road safety.

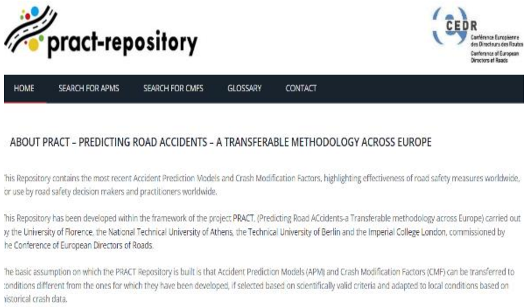

Figure 6: PRACT Repository (Florence, 2017)
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4. Conclusion and Recommendation

This paper presents a literature survey regarding the application and contribution of existing research of computer-based decision support system (DSS) for transportation published in year 2017 to 2022. A thorough systematic literature review (SLR) was employed to find relevant material using web search engines like Scopus, Google Scholar and Web Science. The goal is to identify research gaps, exciting directions and promising areas for future research off DSS development in transportation sector. The DSS for transportation provides number of functionalities and solve numerous categories of transportation decision problems. The reviews found that, most of the recent DSS development developed within this period are more focus on public transport management, road safety and hazardous material transportation. However, to the best of the author's knowledge, there are no works that consider the development of DSS aiming at the causes of road accidents especially driving fatigue. Driving fatigue is the condition where the drivers experiencing extreme physical and mental tiredness, which could result in traffic accidents. To bridge the above mentioned gaps, it is recommended to develop a robust DSS system that specifically focus on detection and monitoring of driving fatigue. The DSS acts as a system to assess and systematic analyze the driver's fatigue level before start the driving and draw a conclusion whether the driver is safe or unsafe to drive. The outcomes from this study will guide researchers, policy makers and practitioners in this field to develop a system that can significant reduce the road accidents, hence improve the road safety.

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