Transport Analytics in action: A Cloud-based Decision Support System for efficient City Bus Transportation

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ABSTRACT

Optimising city bus transport operations helps conserve fuel by providing the urban transport service as efficiently as possible. This study develops a Cloud-based Decision Support System (C-DSS) for transport analytics. The C-DSS is based on an intelligent model on location of depots for opening new depots and/or closing a few existing depots and allocation of city-buses to depots. The C-DSS is built on the Cloud Computing architecture with three layers and includes an efficient and simple greedy heuristic algorithm. Using modern information and communications technology tools, the proposed C-DSS minimizes the cost of city bus transport operations and in turn to reduce fuel consumption and CO_2 emissions in urban passenger transport. The proposed C-DSS is demonstrated for its workability and evaluated for its performance on 25 large scale pseudo data generated based on the observation from Bangalore Metropolitan Transport Corporation (BMTC) in India.

Subject Classification: decision: 7: 90B50 Management decision making / heuristics: 1: 68T20 Problem solving / decision: 6: 68U35 Information systems (

Keyword: City Bus Transport, Urban road transportation system, heuristic optimization, Decision Support Systems (DSS), Cloud-based DSS

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1. Introduction

Continuously every urban city is getting more and more crowded and the need of personal mobility is continuously increasing. In addition, as the urban city is continuously growing the decision-dimensions of the urban road transportation systems (URTS) and the interaction between these decision-dimensions and the socioeconomic system have increased by many folds. In India, these URTS are generally managed by Road Transport Corporations or Undertakings controlled by the Government. Each such organization is endowed with thousands of buses, thousands of crew and personnel, and passenger demand arising at different points of time in several directions. Associative with these are many decision problems such as rationalization of routes, scheduling of vehicles, crew scheduling, system oriented planning and designing of the transportation network, passenger oriented transportation system, traffic control and management, location of depots for opening new depots and/or closing a few existing depots, assignment of buses to depots for maintenance, fleet and crew sizing, vehicle assignment and scheduling, etc., and these need to be addressed at appropriate time and in a continuous interval for enhancing the flexibility of URTS. The most commonly cited objectives of URTS are efficiency in the use of resources, improved accessibility, environmental protection, and increased safety. To reach these objectives different descriptive, predictive and prescriptive analytics, such as forecasting, simulation, resource optimization models/techniques, etc., have been considered.

However, analysis of the literature, particularly in Indian scenarios, highlighted that modern transport planning professionals are no longer capable of solving ever increasing dynamic complex problems associated with URTS using traditional methods being followed in URTS and the required resources existing in the URTS. Analysis of the literature also indicated that considering the advantages of analytics such as heuristic optimization, and decision science along with modern Information and Communication Technologies (ICT) such as Geographical Information System (GIS), Intelligent Transport Systems (ITS), problem specific Decision Support System (DSS), Web and Internet, Cloud Computing and smart solutions would facilitate the transport planning professionals in better decision making. In addition to utilizing the power of today's analytics for analyzing collected data to solve the problem, some new approaches, which take decision maker behavior into consideration, have been added to transport planners' tools for getting a set of solutions with a comparative list of advantages instead of single solution. More generally, today, it is safe to say that the design and management of transportation systems of every URTS need to exploit every possible advanced and innovative Information and Technology (IT) based technique for continuous system performance. Importantly, analytics is a field which provides such techniques with today's power ICT such as cloud computing.

However, even today, the utilities of Information and Communication Technologies (ICT) and analytics in Indian URTS particularly for decision making issues are very limited. This could be due to the additional cost required for introducing ICT and the analytics tools as well as additional requirements of specific experts with ICT and Analytics background. With this backdrop, this study attempts to support the Indian URTS by developing a Cloud based Decision Support Systems (C-DSS), without newly introducing ICT, analytics tools and specific experts in URTS for minimizing the cost of the bus operations. Particularly, this study proposes a cloud-based Decision Support System for one of the important complex strategic / tactical decision problems, addressed by Mathirajan et al. [28], as this decision problem has impacts on social, economic, and development aspects of URTS. Particularly, the proposed C-DSS allows the decision maker for carrying out different what-if analyses and heuristically optimizing the decision problem on (a) allocation of buses to depots with an objective of minimizing the total dead-kilometer cost, and/or (b) an integrated decision problem on opening new depots and/or closing a few existing depots along with allocation of city-buses to depots to optimize the cost of operations by minimizing the sum of dead-kilometer cost, total capital cost due to introducing new depots, and total salvage cost by eliminating existing depots.

The novelties of the proposed prototype C-DSS is that the DSS cloud and Web service-based architecture is easy to manage as well as to update and able to provide flexibility in information exchange operations among the cooperative partners. In this context, the proposed C-DSS acts as an independent entity that collects all the relevant data and provides decisions to the decision maker, for improving the performances, and thus improving the specific objective of minimizing the cost of bus operations.

The organization of the paper is structured as follows: Section 2 describes briefly the real-life problem considered in this study on Location of Depots and Allocation of Buses to Depots (LD-ABD) observed in Indian URTS. Subsequently, closely related literature review is carried out in section 3. The development of the proposed prototype C-DSS for LD-ABD problem along with testing and verification are discussed in Section 4. The external validation of the proposed C-DSS, carried out, is presented in section 5. The section 5 presents the discussion of the present study. Finally, contribution of the study with implications, limitations and future research are outlined in Section 7.

2. Problem Statement and Objective

The use of data-based decision making for transport – also called transport analytics - requires sophisticated ICT and decision support (Harris et al., [12]). In line with this trend, this paper builds on the transport analytics model developed in a previously published research article (Mathirajan et al., [28]). The main objective of this study is to develop a Cloud based Decision Support System (C-DSS) for an important real life transport analytics problem on optimal/efficient Location of Depots (LD) and Allocation of Buses to Depots (ABD), defined in Mathirajan et al. [28], with an objective of optimizing the cost of operation, particularly to minimize the sum of the total (a) dead-kilometre cost,

(b) fixed cost associated with introducing new depots, and (c) salvage value due to closing the depots. The research problem considered for developing C-DSS is succinctly stated below but readers interested in knowing more about it should refer to Mathirajan et al. [28].

> We are given a set of $\mathbf{n_1}$ existing number of buses, $\mathbf{n_2}$ number of new buses/routes to be included in the existing URTS services due to increased population and city sizes, and $\mathbf{N\ (= n_1+n_2)}$ be the total number of buses available for optimally/efficiently allocating to the available depots. We are also given a set of $\mathbf{m_1}$ existing number of depots, number of maximum existing depots $\mathbf{m_2}$ (and $\mathbf{m_2< m_1}$) for possible to close, and exact number of existing depots $\mathbf{m_3}$ **(and** $\mathbf{m_3< m_2}$**)** to be closed. In addition, we are given a set of maximum number of new locations for new depots $\mathbf{m_4}$ for the possibility of opening, and exact number of new depots $\mathbf{m_5}$ **(and** $\mathbf{m_5< m_4}$**)** to be opened with available budget **b** for opening new depots. Considering the closing possibility of the existing depots and opening possibility of new locations, we are having a set of total number of available depots **M**for allocation of given number of buses (and $\mathbf{M = m_1+m_4}$) with depot capacity $\mathbf{CAP_j}$ **(j=1,2...M depots)**. Finally, the values of the additional required parameters: Fixed cost $\mathbf{FC_j}$ associated with opening of new depot 'j', Salvage cost $\mathbf{SC_j}$ associated with closing the existing depot 'j', and dead kilometre cost $\mathbf{C_{ij}}$ if bus 'i' (**i=1,2....N**) is allocated to depot 'j' **(j=1,2...M depots)** are also given. With these given data the objective is to propose a C-DSS to decide optimal/efficient choice of the depots for both opening and closing as well as allocation of buses to the depots for minimizing the sum of dead-kilometer cost, total capital cost due to introducing new depots, and total salvage cost by eliminating existing depots along with the assumptions defined in Mathirajan et al (2018).

3. Related Work

The closely related existing literatures are grouped into (a) the research problem considered for proposing the C-DSS and (b) the current status of DSS in general and C-DSS in particular for the research problem considered in this study and the same are discussed as follows:

There are various studies in the literature addressing operational level to strategic level decision problems associated with URTS. The recent review paper by Ibarra-Rojas et al. [15] nicely consolidated various decision problems related to URTS addressed in the literature. In addition, there are various studies (Guihaire and Hao [11]; Kepatsoglou and Karlaftis, [19]; Farahani, et al. [10]; Arbex and Cunha, [4]) addresses on transit (depot) network design problem associated with URTS. Surprisingly there is no explicit literature analysis in the review study carried out by Guihaire and Hao [11], and Ibarra-Rojas et al. [15] on the decisions problem related to (i) allocation of buses to depots (ABD), and (ii) location of depots and allocation of buses to depots (LD-ABD) with an objective of minimizing total dead kilometer cost and in turn minimizing fuel consumptions as well as CO_2. However, for a brief analysis of the literature on these decision problems, the interested reader can refer Mathirajan et al. [28]. Furthermore, from the analysis of the earlier research on ABD and LD-ABD problems, all the existing studies are focused to the development of mathematical and or heuristic optimization model with validation of the proposed model(s) either using real-life data or test data.

However, due to the increased complexity and the dynamic nature of the City Bus Transport Operations, it is very difficult for transport planner to make decisions by traditional methods of dealing with data without considering the utility of ICT. Further, due to the frequent changes in the original structuredness of the many decision problems in city-bus-transport planning, the decision-making process requires "what-if analyses" before taking any effective and efficient decision for any of the city-bus-transport decision problems. This decision making complexity made the decision maker to realize that the traditional computer based information systems could not address the decision-making contexts very well and this has resulted the next development of the IT, called " DSS – Decision Support System" (Turban and Aronson, [37]). DSS combine data and problem-solving methodologies to help decision makers in their work. DSS is originally running largely on mainframes and developed rapidly afterwards (Jun and Jun 2011 [17]). Akunal [1] defined DSS as "Decision Support Systems (DSS) are computer technology solutions that can be used to support complex decision making and problem solving".

Today, for developing an effective DSS it is very much essential to understand the specific objective(s) of the DSS and the sequence of the steps that lead them to make decisions and the extent of the decision maker's influence exerted on them by the subjective attitudes and the specific context within which decisions are taken. Akumal [1] presented the different classifications of DSS examples in transport planning area for better understanding the relationships and differences in various models and scales. Furthermore, DSS are proposed for assisting transport planners in many areas such as DSS for urban traffic control system with an objective of minimizing traffic congestion level (Bielli, [7]; Hasan, [13]; Utama *et al. [38]*; Jaworski et al. [16]), GIS based DSS for analysis and evaluation of different transportation policies (Arampatzis et al. [3]); DSS for urban road transportation network planning (Jun, and Yikui, [18]); Maintenance problems in road transport (Roy, et al. [32]); DSS for urban mass transit service planning (Tan et al. [36]); and DSS for effective management and to support complex traffic and transportation decision problems of Delhi Bus Transportation System (Kurian and Jian, [22]). Though DSS has been developed for various decision problems related to URTS, to the best of our knowledge, there is no DSS for an integrated decision problem on LD-ABD to optimize the cost of bus operations.

Today, many enterprises have moved away from centralized, applications based on mainframe to distributed computing models that are based predominantly on service-oriented and Internet-oriented architectures for supporting decision makers (Jun and Jun, [17]). That is, the availability of today's pervasive networking, inexpensive storage, and high-performance computing has created the foundation for a broad range of new approaches capable of delivering on the promise of cloud computing for decision making (Russell et al., [33]). In addition, Jun and Jun [17] highlighted that existing applications and IT resources that are designed according to the principles of service orientation provide a solid foundation for the adoption or integration of Cloud-based frameworks for decision making. Akunal [1] indicated that a good user-friendly interfaces, particularly in web applications and smart devises (example: cloud computing) in transport decisions not only help individuals but also pave the way for the formation of smart societies.

Cloud computing services is the best solution for increase operational efficiency and productivity, at the same time lowering the costs and maximizing the investments (Shuleski et al. [35]). Armbrust et al. [5] defined the "cloud" as the environment where computing resources are hosted in and used from the distributed Internet environment. Russell et al. [33] explained that Cloud computing extends the notion of desktop computing to the scalability and virtualization of distributed processing servers on the Internet. According to the National Institute of Standards and Technology, Cloud Computing is defined as "*Cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction (Mell and Geance, [30]). Furthermore,* Hsu et al. [14] defined Cloud computing as a distributed parallel computing technology based on the internet, in which computing resources are virtualized before they are provided to users so that they are able to access a variety of integrated hardware and software services via the internet. As cloud computing is capable of providing large amounts of high-capacity information storage and processing, it has led to a sharp increase in the amount of available information, as well as the need to provide timely value-added analysis services for large amounts of diverse data towards decision making. For understanding various key challenges, cloud computing evolution/milestones, cloud models and key cloud benefits, particularly with respect to Indian contact, readers can refer Agarwal and Dhingra [2].

Based on the continuous development on the IT paradigm and analytics, the transport planner has moved to utilize the cloud computing for many of their decision making. For example, there are studies related to Cloud computing based urban traffic control system (Jaworski, et al. [16]); Cloud based ITS (Ashokumar, et al. [6]); Intelligence transport management (Meneguette, [29]); Cloud-based intelligent transportation system (Hsu et al. [14]), etc. Though there are many key players in cloud computing arena (Martson et al. [25]) such as Amazon, Microsoft, Google, IBM, etc., there is no study utilizing the concept of cloud computing and DSS for the complex, dynamic and integrated decision problem on LD-ABD. This study attempts to fill this research gap.

4. Cloud computing and a Cloud based DSS (C-DSS) for URTS

Cloud computing represents a convergence of two major trends in information technology : (i) IT efficiency, whereby the power of modern computers is utilized more efficiently through highly scalable hardware and software resources and (ii) business agility, whereby IT can be used as a competitive tool through rapid deployment, parallel batch processing, use of compute-intensive business analytics and mobile interactive applications that respond in real time to user requirements (Marston et al., [25]). From the analysis of the literature, Cloud Computing is mainly described as an IT outsourcing model for on-demand, online delivery of scalable IT services on the basis of virtualization technology and pay-per-use pricing models (Leimeister et al. [23]). According to Weinhardt et al. [39] the Cloud Computing services are grouped into three categories: Software as a Service (SaaS), which refers to application services; Platform as a Service (PaaS), i.e. developer platforms; and Infrastructure as a Service (IaaS), which mainly denotes storage services and computing power services.

Due to availability of many Public IT cloud services, a cloud computing can provide the virtual infrastructure for utility computing integrating applications and it will enable businesses and users to access applications on demand anytime, anyplace and anywhere (Canellos, [9]). That is, cloud computing services are off-site from a customer's utilization point of view and the customer do not require any dedicated, application-specific or proprietary client-side hardware or software to support access. In addition, the advances in cloud computing and web of things (IoT) provides a promising chance to resolve the challenges caused by the increasing transportation problems (Ashokkumar et al. [6]). Particularly, using the cloud computing model, the organization that are involved in the passenger transport can significantly raise the quality of service they provide to the passengers with significant reduction of initial capital costs as this lets the organization's focus on the core activity itself, and minimize the resources necessary for work and control of IT infrastructure (Saric et al. ([34]).

Keeping the advantages of cloud computing and analytics, instead of proposing a specific DSS working on a stand-alone system in URTS, a cloud based DSS (C-DSS) is proposed for the decision problem considered in this study. Furthermore, according to the classification of cloud computing given by Weinhardt et al. [39], this study considers "Software as a Service (SaaS)" model for developing the proposed C-DSS. Accordingly, in this section, the complete description on the development of the Cloud based DSS (C-DSS), for Urban Road Transport System (called as C-DSS-URTS), for obtaining efficient strategic decisions on (a) Allocation of Buses to Depots (ABD), and (b) Location of Depots (LD) and ABD (LD-ABD) problems using analytics based on efficient greedy heuristic algorithm and what-if analyses is discussed along with testing, verification and validation of the proposed C-DSS-URTS.

4.1 Development of C-DSS-URTS

C-DSS-URTS is developed using latest web technologies with a user-friendly web interface, which can be used in any browser. The proposed C-DSS-URTS is developed as a SaaS (Software as a

Service) model in the cloud and it is currently deployed in Amazon Web Services, which enables the users to access it using from anywhere using any devices. The deployment architecture for this web-based C-DSS-URTS system is presented in *Annexure 1*. A schematic view of the proposed C-DSS-URTS for optimizing ABD/LD-ABD problem is given in Figure 1. The proposed C-DSS-URTS consists of 5 interconnected modules, namely (i) Web Interface Module, (ii) Database Management Module, (iii) Model Management Module, and (iv) Report Generation Module, (v) Control Module. The development details of these 5 interconnected modules of the proposed C-DSS-URTS for optimizing ABD/LD-ABD problem, and their role in it are presented in the following sections:

4.1.1. Web Interface Module (WIM)

The overview of the Web Interface Module (WIM), developed for C-DSS-URTS, is shown in Figure 2. As shown in the Figure 2, the WIM supports the user to choose any one of option: Depot Management Interface, Terminus Management Interface, Bus Management Interface, Constraint Interface, ABD Interface, LD-ABD Interface, and What-if Analysis Interface. Detail of these interfaces, provided under WIM, is as follows:

Depot Management Interface: The Depot-Management option introduced in the WIM provides the required user interface to display the existing depots and its details. This provides options to "Create New", "Edit" and "Delete" regarding depot related data. While adding the depot details, the user has to provide the values of "depot code", "depot name", "current capacity", "additional capacity", "operating cost", "fixed cost" and "salvage cost". The "salvage cost" is an optional field which should be provided in case of the depot-closure. The "salvage cost" for the specific depot can be provided using the "Edit" option. A sample screen snapshot of "Depot Management Interface" of WIM and "Create New Depot" option in Depot-Management is given in Figure 3 and Figure 4 respectively.

Terminus Management Interface: The Terminus-Management option gives a user interface to "Add", "Delete" and "Edit" the terminus details of URTS. A sample screen snapshot for the interface: Terminus-Management is presented in Figure 5. While adding the terminus, the user needs to provide "terminus-code" and "terminus-name" and values for these are mandatory. The other important input is the "distance between the terminus and the depot". The "distance between terminus and depot" provides connectivity with all the depot-codes and a field to enter the distance. A sample screen snapshot for the options on "Create New Terminus" and "Distance between Terminus and Depot", provided under Terminus-Management option are given in Figure 6 and Figure 7 respectively.

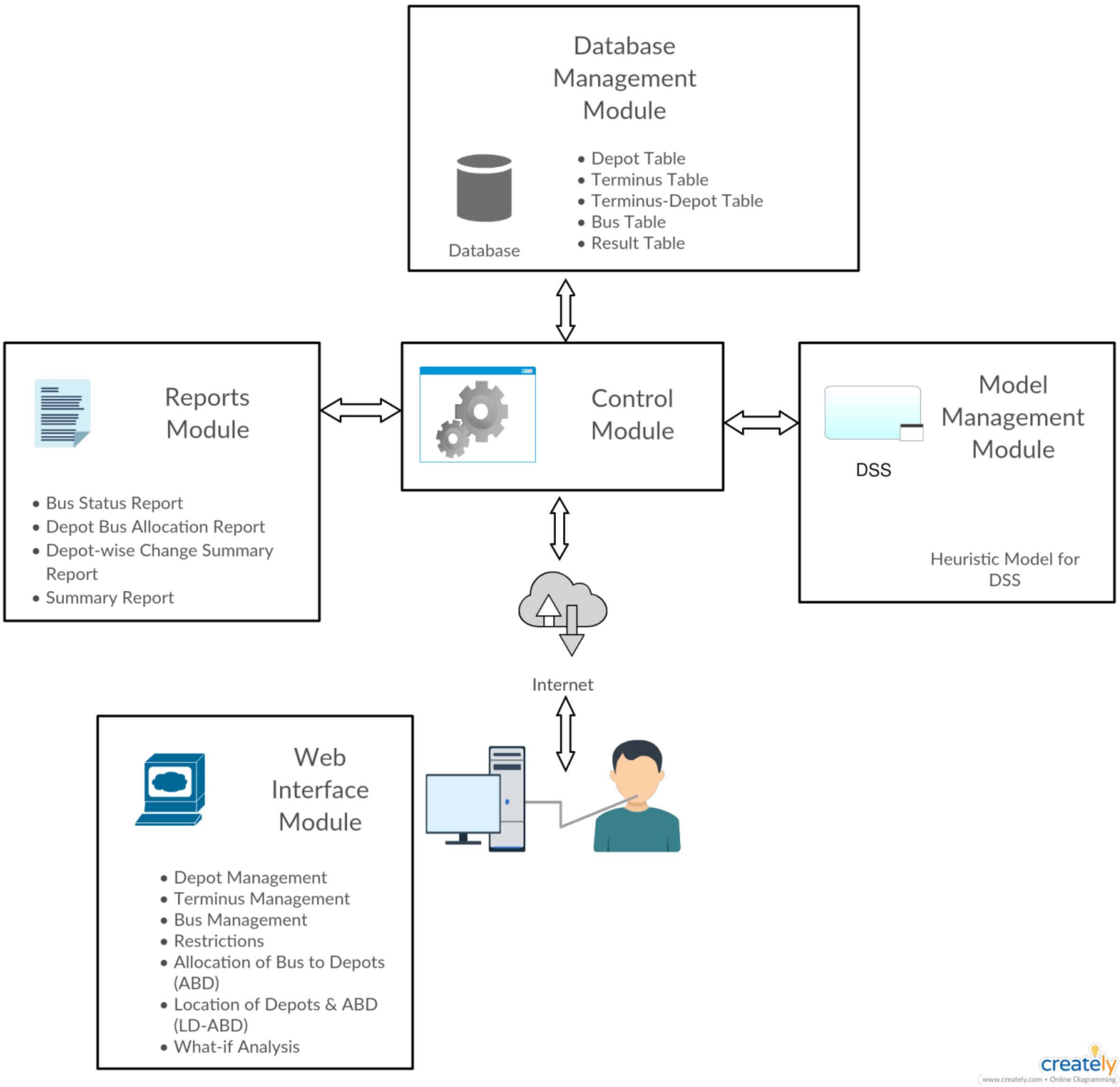


Figure 1: A Schematic View of the Proposed C-DSS-URTS

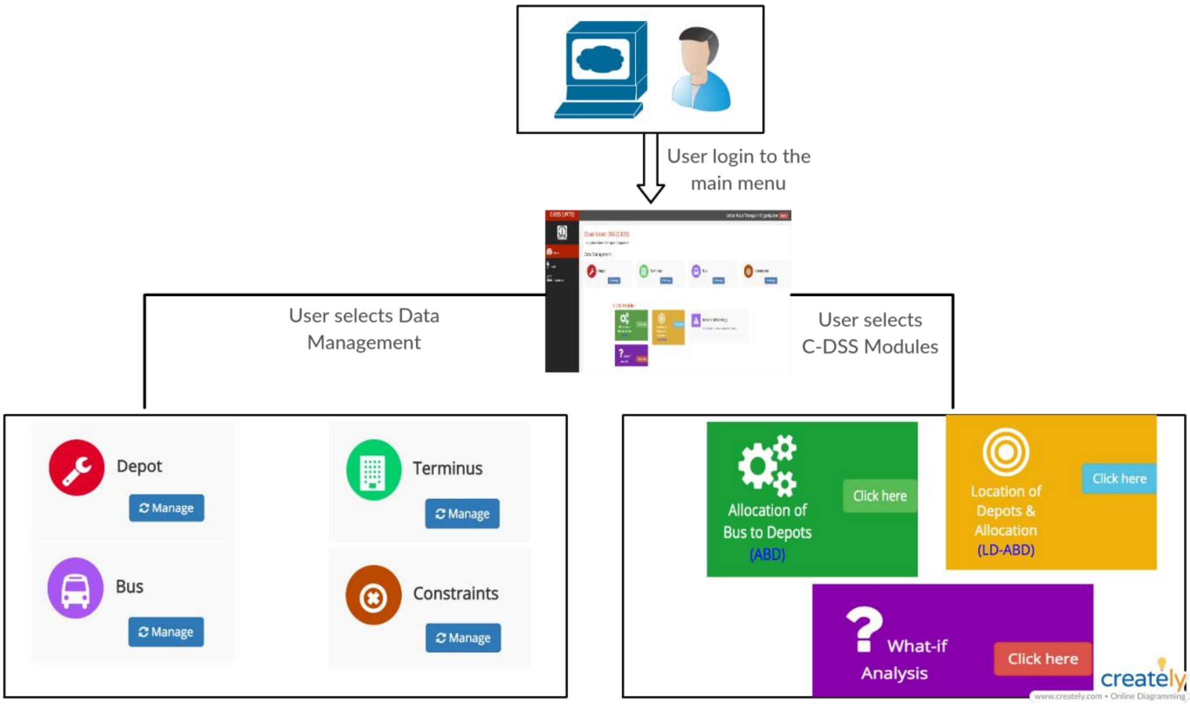
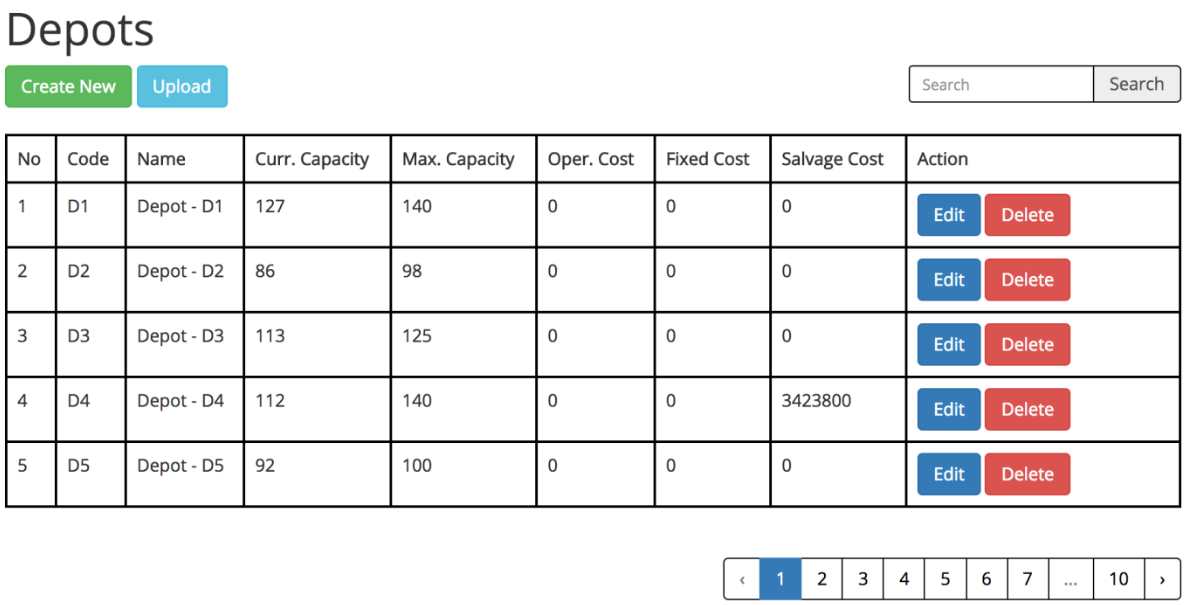


Figure 2: Web Interface Modules



Depots

Create New Upload

Search

No	Code	Name	Curr. Capacity	Max. Capacity	Oper. Cost	Fixed Cost	Salvage Cost	Action
1	D1	Depot - D1	127	140	0	0	0	Edit Delete
2	D2	Depot - D2	86	98	0	0	0	Edit Delete
3	D3	Depot - D3	113	125	0	0	0	Edit Delete
4	D4	Depot - D4	112	140	0	0	3423800	Edit Delete
5	D5	Depot - D5	92	100	0	0	0	Edit Delete

‹ 1 2 3 4 5 6 7 ... 10 ›

Figure 3: A sample snapshot of Depot Management Interface

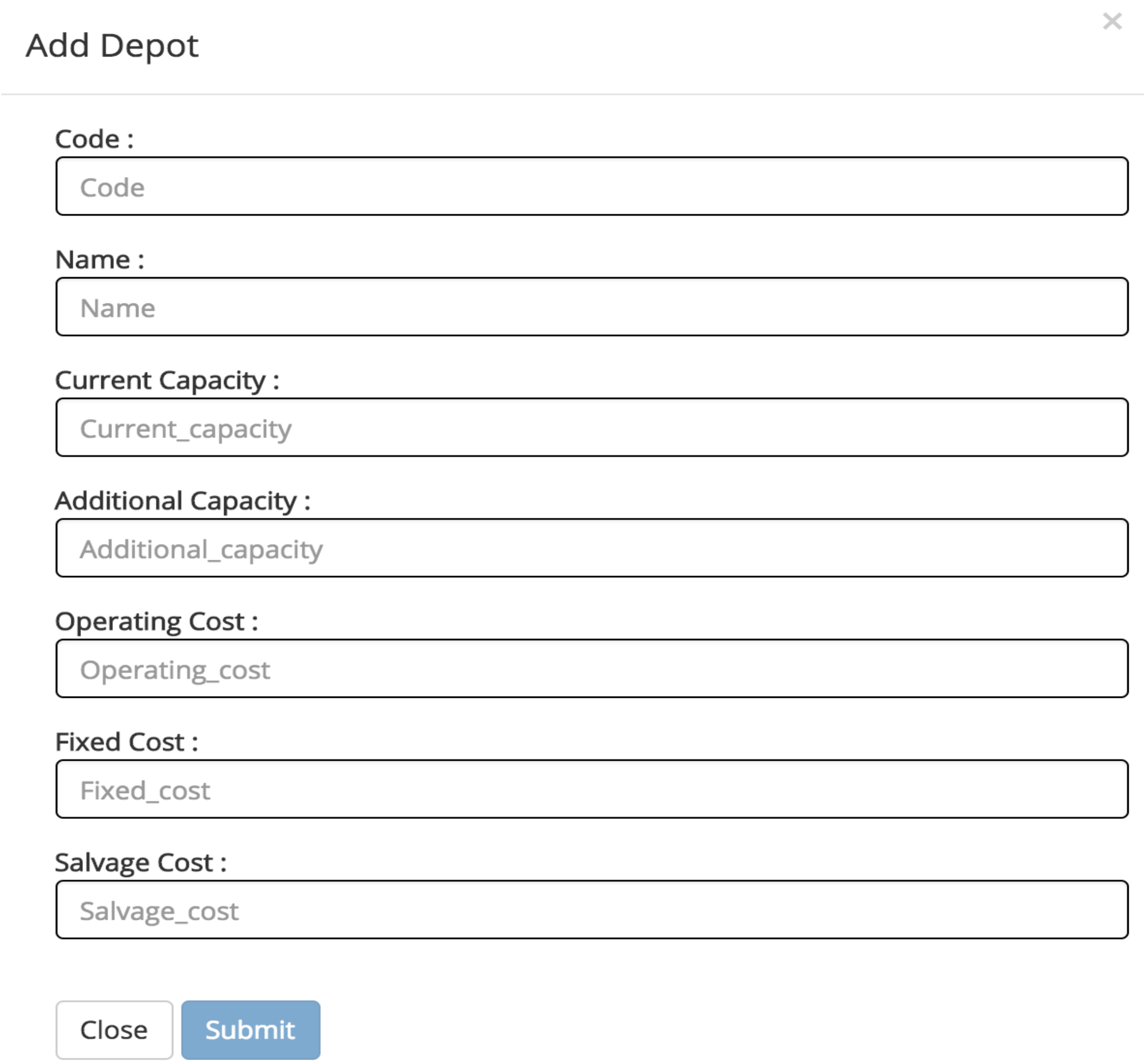


Figure 4 : A sample snapshot of “Create New Depot” option in Depot Management Interface

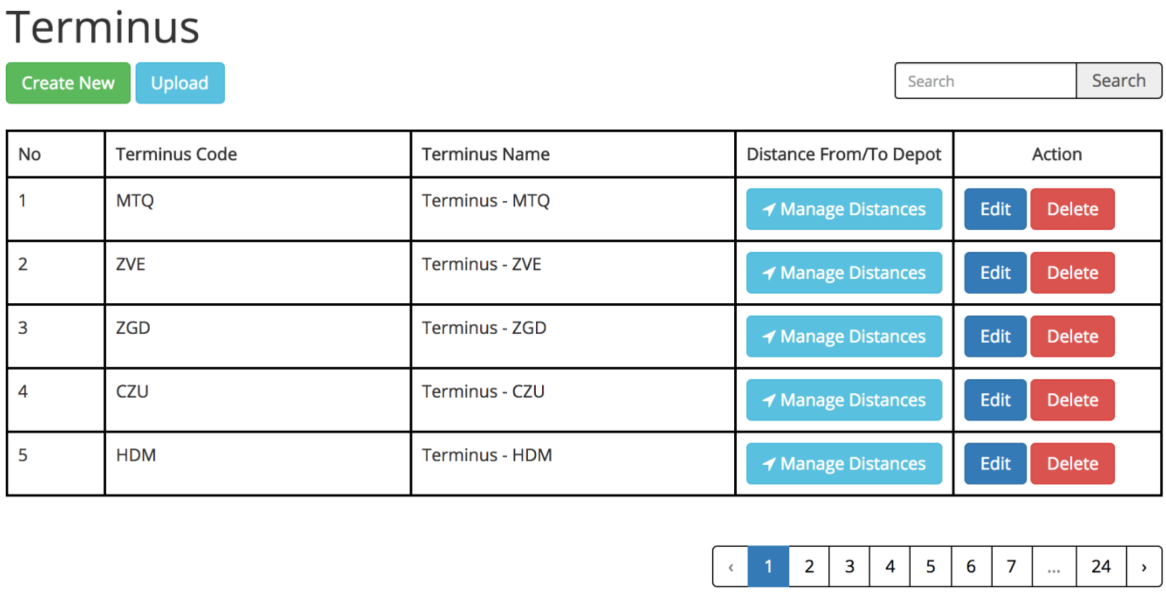


Figure 5: A sample snapshot of Terminus Management Interface

Figure 6: A sample snapshot of “Create New Terminus” option in Terminus Management Interface

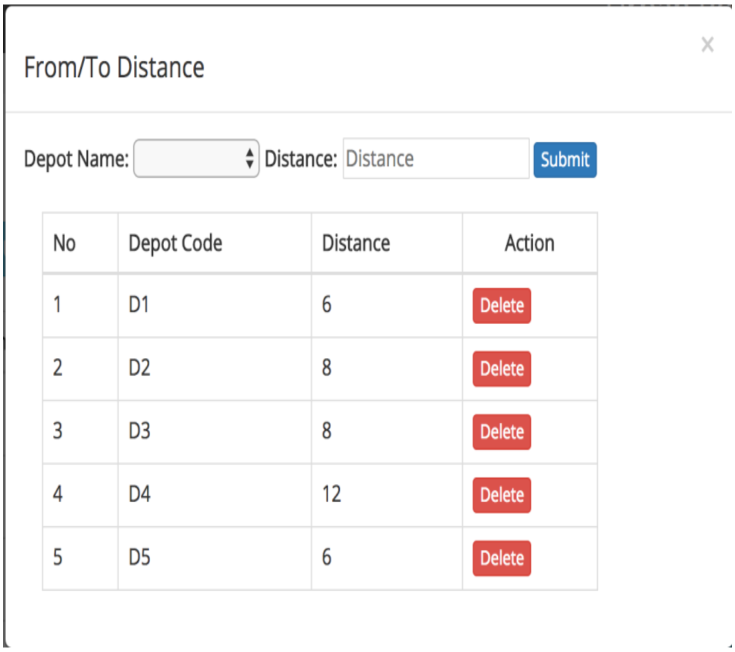


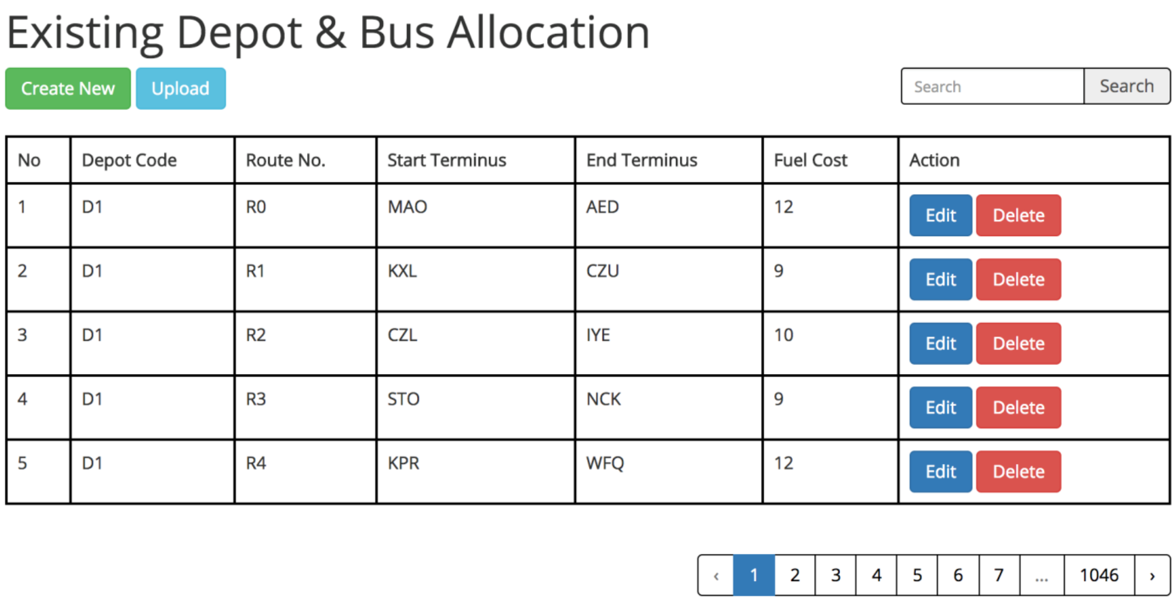
Figure 7: A sample snapshot of “Manage Distances” option in Terminus Management Interface

Bus Management Interface: The Bus-Management interface provides options to “Add”, “Edit”, and “Delete” data related to buses. When the user adds details of new buses into the system, the values for parameters: bus-number, start-terminus, end-terminus, depot-code and fuel-cost-per-km needs to be provided. The start-terminus and end-terminus values need to be chosen from the list of terminus and the depot-code shown for each of these two data. A sample screen snapshot for this interface is provided in Figure 8. Also, a sample screen snapshot for the option: “Adding New Buses” in Bus Management Interface is presented in Figure 9.

Constraints Management Interface: This interface provides user to specify any special constraints on the allocation of a bus to the available depots. For example, the management decides that a particular bus should not be allocated to a set of available depots due to bus-type (example: AC Bus, Non-AC Bus, etc.). If this constraint is added to the database, then the solution methodology, provided in the Model Management Module (MMM), will make sure that the bus is not allocated to those set of available depots. While adding a constraint, the user needs to select the bus-number and the depot-code where the bus should not be allocated to the depot by the proposed C-DSS-URTS. The user also can provide “remarks” for this constraint as an additional reference. A sample screen snapshot for providing the details on this specific constraint is given in Figure 10.

Allocation of Buses to Depots (ABD) Interface: The ABD interface provides the summary of data and an option to execute the solution methodology, provided in the Model Management Module (MMM) of C-DSS-URTS, for obtaining efficient solution/decision for ABD problem of URTS. A sample screen snapshot for the ABD interface is given in Figure 11. When the option “ABD” is invoked, there is an option “Optimize” appears. The option “Optimize” displays the basic data such as the number of depots, number of terminus, and number of buses. If we click “Optimize”, then the proposed C-DSS-URTS runs for efficiently allocating the given number of buses to given number of depots and stored the outputs for displaying using “Report Generation Module (RGM)” of the proposed C-DSS-URTS. If the efficient solution/decision is already obtained, the stored results can be displayed in multiple reports format using RGM of the proposed C-DSS-URTS. It also provides to re-run the algorithm if any data is modified.

Location of Depots and ABD (LD-ABD) Interface: The LD-ABD interface provides the user to finalize the data for “Possible depots to be closed”, “Exact number of depots to be closed”, “Probable number of depots to be opened”, “Exact number of depots to be opened”, “Terminus to be added”, and “Buses to be added” for obtaining optimal/efficient solution for LD-ABD problem of URTS. That is, the LD-ABD interface provides the existing data on ABD and LD-ABD data along with option to add other information as shown in Figure 12.



Existing Depot & Bus Allocation

Create New Upload Search Search

No	Depot Code	Route No.	Start Terminus	End Terminus	Fuel Cost	Action
1	D1	R0	MAO	AED	12	Edit Delete
2	D1	R1	KXL	CZU	9	Edit Delete
3	D1	R2	CZL	IYE	10	Edit Delete
4	D1	R3	STO	NCK	9	Edit Delete
5	D1	R4	KPR	WFQ	12	Edit Delete

‹ 1 2 3 4 5 6 7 ... 1046 ›

Figure 8: A sample snapshot of Bus Management Interface

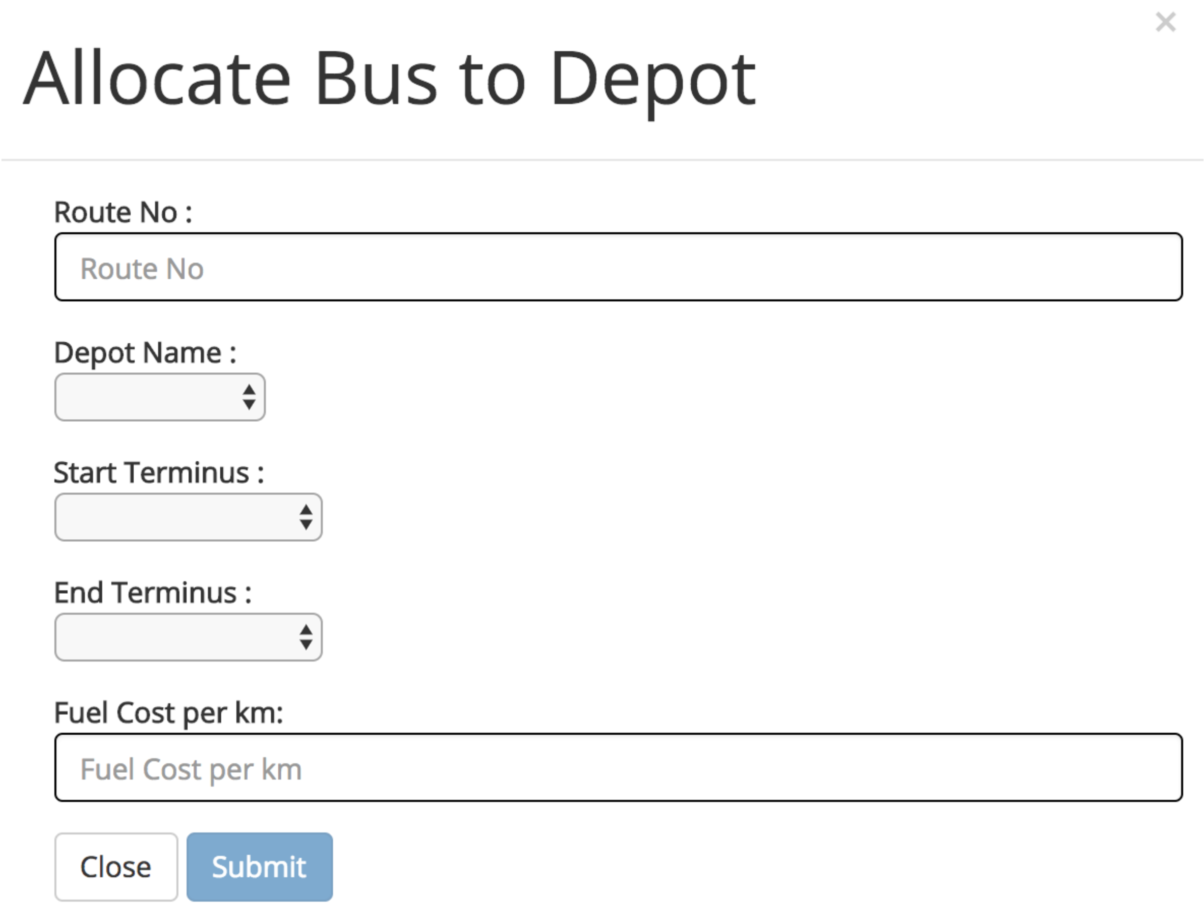


Figure 9: A sample snapshot of Create new bus in Bus Management Interface

Figure 10 : A sample snapshot of Constraints Management Interface

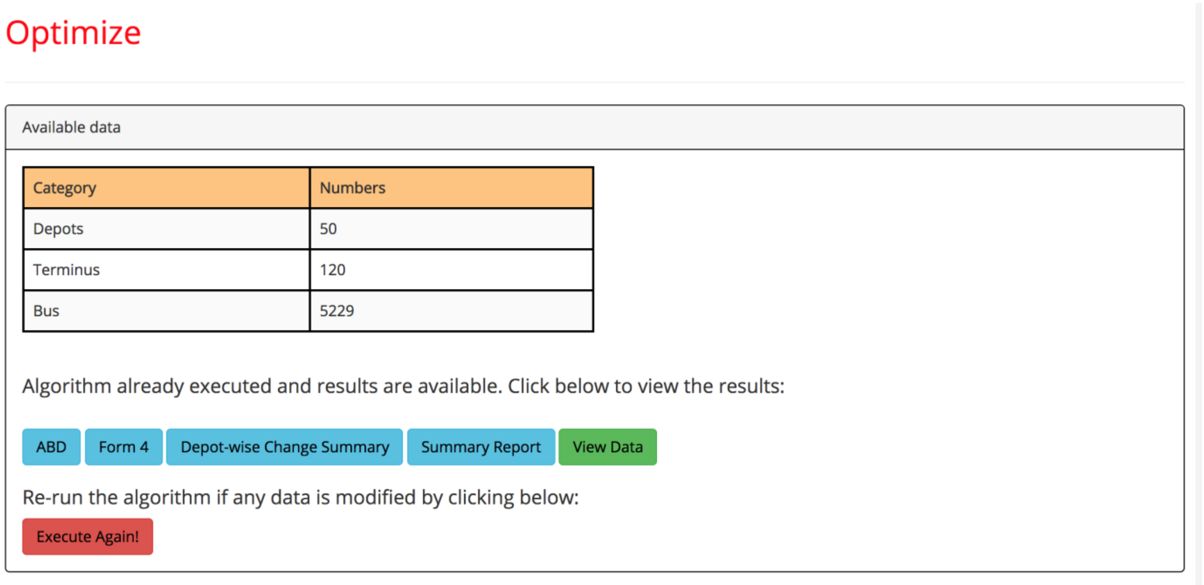


Figure 11: A sample snapshot of ABD Management interface

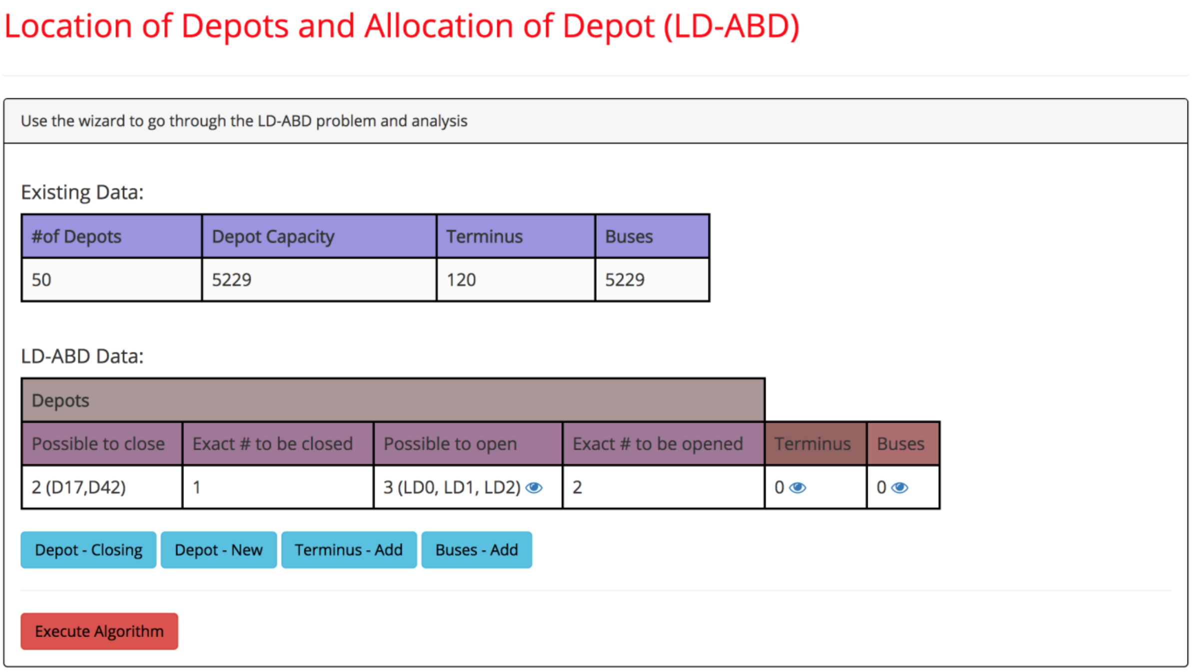


Figure12: A sample snapshot of LD-ABD Management Interface

After providing all the input information in LD-ABD interface, the option: ”LD-ABD” can be invoked. After invoking “LD-ABD” option, there is an option “Optimize” appears. When we click the option “Optimize”, then the C-DSS-URTS will run for each possible combinations of Closing exact number of depots from the feasible set of closing existing depots along with opening exact number of new depots from the feasible set of opening new depots, and displays the results for each combinations to choose the user’s choice on the combination of closing and opening depots with a criterion on total cost obtained due to dead kilometer cost, fixed cost and salvage value.

What-if Analysis Interface: The user can perform “What-if” Analysis for various scenarios by carrying out the operations: Modifying depot (specifying what-if capacity changes) capacity, Adding terminus, Adding buses, and Changing the existing terminus for a bus. For each of “what-if” analysis scenarios, the user can run the proposed C-DSS-URTS for obtaining optimal/efficient solution for ABD or LD-ABD problem for the change in scenario. A screen snapshot for the “What-if Analysis interface” is provided in Figure 13.

4.1.2. Database Management Module (DMM)

The Database Management Module (DMM) maintains all databases required for solving the decision problems: ABD or LD-ABD in optimizing the cost of operation of City Buses through C-DSS-URTS. The databases required for the C-DSS-URTS are (a) Depot_Table, (b) Terminus_Table, (c) Terminus_Depot_Table, (d) Bus_Table, and (e) Result_Table. The details on each of these databases are as follows:

Depot_Table: The Depot_Table captures, for each depot, 12 attributes’ values in 12 columns related to Serial number, Depot-Code, Depot-Name, Division, Current-Capacity, Maximum-Capacity, What-if Capacity, Operating-Cost, Salvage-Cost, Fixed-Cost, Organization-code, and Purpose respectively. The database structure of the “Depot_Table” defined in C-DSS-URTS is shown in Exhibit 1 of Annexure 2. The details on each of the 12 attributes of the Depot_Table are explained as follows:

Column 1: Serial-Number: This column contains serial number of the record, which is automatically generated by the database module of C-DSS-URTS. This will be the “primary key” for each record and this will have a unique value in all the depots. This value should not be modified, and it is used only by the database. This is not displayed in any reports.

Column 2: Depot-Code: For each depot, a code will be assigned. There is no specific naming convention followed in C-DSS-URTS. For all the testing-scenarios of the proposed C-DSS-URTS, the code was defined as “D” followed by serial number. For example, the first Depot-Code was assigned as “D1”, second depot as “D2” and so on. In some cases, the short form of the Depot-Name can be considered as Depot-Code. For example, if the Depot-Name is “Gandhi Nagar”, the Depot-Code can be “GND”, which indicates “Gandhi Nagar Depot”. The Depot-Code is used in the reports to indicate the location of the depot. The maximum number of characters (in the form of alphabets and numbers) for representing the Depot-code is 20.

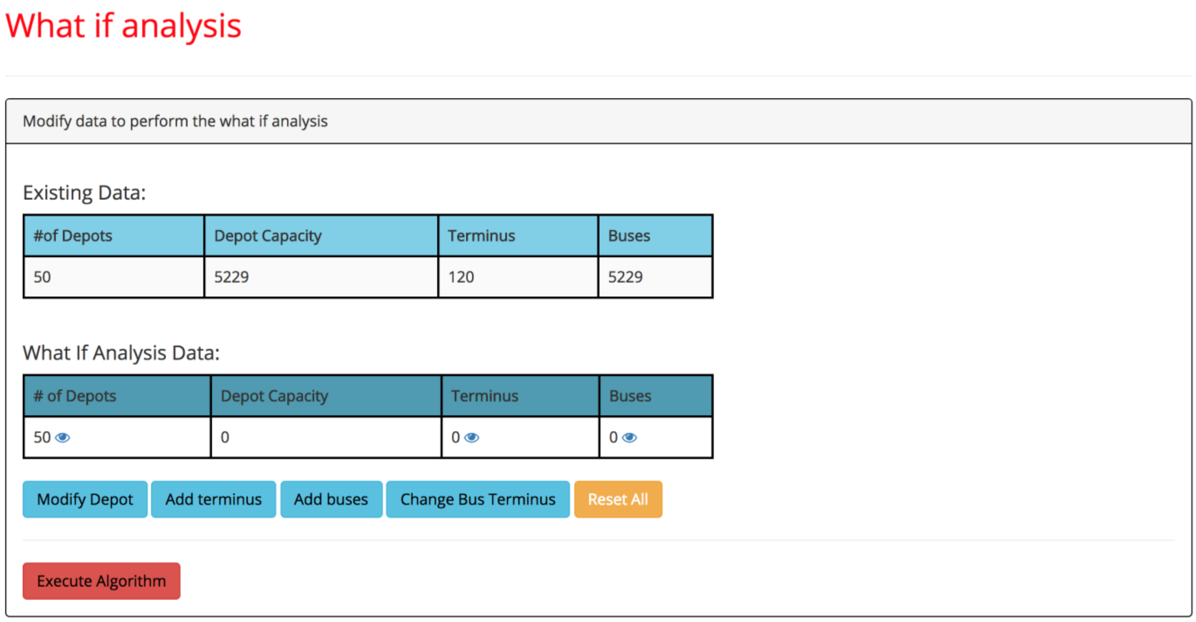


Figure 13 : A sample snapshot of what-if analysis management interface

Column 3: Depot-Name: The Depot-Name is stored in 3rd column of the Depot_Table. In general the Depot-Name will be the name of the location, where the depot is located. For example, if the depot is located in "Shanthi Nagar", then the Depot-Name can be "Shanthi Nagar". In some cases, if more than one depot is located in the same location, a roman numerical can be appended. (Eg."Shanthi Nagar I", "Shanthi Nagar II", etc.). The C-DSS-URTS allows a maximum of 40 characters (with special characters, numbers and alphabets) to represent Depot-Name. The Depot-Name will be displayed in all the relevant reports, to be generated by C-DSS-URTS.

Column 4: Division: The 4th column of the Depot_Table is used to store the value of the attribute: Division, if the depots are grouped into multiple divisions. For example, to represent a depot belongs to "south division" or "north division", etc., of the city, the attribute: Division will be defined in 4th column of Depot_Table. This is stored only for the information purpose.

Column 5: Current-Capacity: The number of buses currently allocated in each of the depot will be captured using the attribute: "Current-Capacity" of Depot_Table. The value of Current-Capacity should not be zero and it can store only integer numbers.

Column 6: Maximum-Capacity: The number of buses actually possible to allocate in each of the depots (called as Maximum-capacity), which is either equal or greater than the number of buses currently allocated (called as Current-capcity), will be stored in the attribute: "Maximum-Capacity" of the respective depot in Depot_Table. During the "What-if" analysis of C-DSS-URTS, the user can increase the number of buses from Current-Capacity to Maximum-Capacity of a specific depot in order to learn how the optimal decisions related to ABD or LD-ABD problems changes. However, increasing the number of buses to the specific depot should not exceed the valued stored in 6th Column of Depot_Table (that is, the value of "Maximum-Capacity").

Column 7: What-if-Capacity: The value of "increased capacity" (which is up to equal to Maximum-Capacity) from Current-Capacity, considered for What-if analysis, is stored in the attribute: What-if-Capacity of Depot_Table.

Column 8: Operating-Cost: The Operating-Cost of the depot is stored in this column. The accepted value is only integer. Currently this value is not used in C-DSS-URTS for obtaining optimal/efficient solution while solving the decision problems: ABD or LD-ABD.

Column 9: Salvage-Cost: The Salvage-Cost occurs to the transport organization when an existing depot is planned to close. This value is mandatory for "LD-ABD" problem when the existing depot is possible to close while running C-DSS-URTS. The accepted value is integer.

Column 10: Fixed-Cost: The value of the attribute: Fixed-cost is required for each of the new depots, which are planned to open while running C-DSS-URTS for LD-ABD problem. For the existing depots, this value should be zero. This cost indicates the overall cost in establishing and opening a new depot. This value is mandatory for "LD-ABD" problem and the accepted value is integer.

Column 11: Organization-Code[1]: The Organization-Code represents the specific URTS, who uses the C-DSS-URTS. As the proposed C-DSS-URTS can be used by multiple URTS, the value stored in "Organization-Code" will be used along with all the databases (that is, all input tables) and all the reports (that is, all output tables) to uniquely identifying the databases and the reports related to specific URTS. These values are stored automatically by the C-DSS-URTS based on the login. This will not be displayed in any reports.

[1] Input value for 'Organization Code' is captured in all the databases (that is, all input Tables), required for C-DSS-URTS. So this attribute is not detailed again in each of the other databases, mainly to avoid the redundancy.

Column 12: Purpose[2]: The value of this column indicates the purpose of depot data such as creating additional depots for "What-if" analysis or running "LD ABD" problem. Based on that, the value "Purpose" will have a unique code to identify the right records from the databases. This data is used only by the system and will not be displayed in any reports.

Out of 12 values of the 12 attributes in Depot_table, the critical attributes used by the optimal solution are Current-Capacity (This is mandatory for all the depots: both existing and new depots), Maximum-Capacity (value should be greater than the current capacity and indicates that this capacity can be expanded in the existing depot), and What-if-Capacity (used only to find the optimal solution in case of an increased capacity).

Terminus_Table: The Terminus_Table stores 5 values of the parameters: Terminus-Id, Terminus-Code, Terminus-Name, Organisation-Code, and Purpose in 5 columns. The database structure defined for the "Terminus_Table" is shown in Exhibit 2 of Annexure 2.

Terminus_Depot_Table: The Terminus_Depot_Table stores 6 values of the parameters related to Record-Id, Terminus-Code, Depot-Code, Distance, Organization-Code, and Purpose in 6 columns. The main objective of creating this table is to store the distance between each terminus to each of the depots. For example, if there is a terminus code "ABC" and 3 depots namely "D1", "D2" and "D3", then this table stores 3 records as distance between the terminus and each of the depot. The database structure defined for capturing the "Terminus_Depot_Table" is presented in Exhibit 3 of Annexure 2.

Bus_Table: The Bus_Table stores values of 8 parameters: Record-Id, Bus-Number (Route-Number), Depot-Code, Starting-Terminus, Ending-Terminus, Fuel-Cost-per-km, Organisation-Code, and Purpose and these are required for every bus. The database structure defined to capture "Bus_Table" is given in Exhibit 4 of Annexure 2.

Route_Depot_Constraints_Table: This table stores the information on special constraints (such as a bus should not be allocated to any one depot or specific set of depos), if any, between the depot and bus. If an entry made in this Route_Depot_Constraints_Table with a specific bus and depot code, then the C-DSS-URTS will make sure that this specific bus is not getting allocated to that specific depot as specified in the table. This Route_Depot_Constraints_Table stores 6 values of the parameters: Record-Id, Bus_Number, Depot-Code, Remarks, Organisation-Code, and Purpose. The database structure defined for Route_Depot_Constraints_Table is shown in Exhibit 5 of Annexure 2.

[2] Input value for 'Purpose' is captured in all the databases (that is, all input Tables), required for C-DSS-URTS. So, this attribute is not detailed again in each of the other databases, mainly to avoid the redundancy.

Result_Table: The Result_Table stores the values of 5 parameters: Record-id, Depot-Code, Bus-Number, Organization-Code, and Purpose related to the optimal/efficient solution for the problem ABD or LD-ABD. Once the C-DSS-URTS generates the results, it is stored in this table. Using the optimal/efficient solution stored in this table, various reports can be generated. The database structure defined for capturing the values of the 5 parameters related to Result_Table is presented in Exhibit 6.

LD-ABD_Table: This LD-ABD_Table stores the values of 8 parameters: Record-Id, Possible-Closing-Depot-Codes, Possible-Number-of-Depots-to-be-Closed, Exact-Number-of-Existing-Depots-to-be-Closed, Possible-Number-of-New-Depots-to-be-Opened, Exact-Number-of-New-Depots-to-be-Opened, Number-of-New-Buses-to-be-added, and Organisation-Code and these are required for executing the C-DSS-URTS for optimizing optimal/efficient solution for the LD -ABD problem. The database structure defined for the LD-ABD_Table is given in Exhibit 7 of Annexure 2.

4.1.3. Model Management Module (MMM)

The MMM is the most important module in C-DSS-URTS. Similar to DMM, the MMM module has model base and model dictionary. In general, the model base has a set of models for predicting, prescribing, and describing related to the problems considered in the specific DSS. From the analysis of the literature it is learnt that both ABD and LD-ABD problems, considered in this study for developing DSS, becomes computationally intractable when the actual real-life problem size and constraints are considered (Mathirajan, [26]) due to the violation Unimodular property (Winston [41]) of the mathematical model proposed for ABD and LD-ABD problems and/or due to the large number of binary variables involved in the formulation. With this many have proposed various heuristic algorithms for solving ABD problems (Mathirajan et al. [27], Kontu et al. [21]) and LD-ABD problems (Willoughby and Uyeno, [40], Mathirajan et al. [28]). With this backdrop, for the proposed C-DSS-URTS, the model base has a simple efficient heuristic algorithm to address ABD problem as well as LD-ABD problem and appropriate interface to carry out what-if analysis. The heuristic algorithm incorporated in the model base of the MMM is an extension to the heuristic algorithm proposed in Mathirajan et al. [28].

The heuristic algorithm proposed in Mathrajan et al. [28] to address the LD-ABD problem follows a two-phase approach. In the first phase of the algorithm a best combination of expected number of new depots to be opened and old depots to be closed is determined, by completely enumerating the possible combination of a set of expected number of new depots to be opened (from the given possible number of new depots for opening) along with a set of expected number of existing depots to be closed (from the possible number of existing depots for closing) and comparing the sum of fixed cost and salvage cost (associated with opening new depots and closing existing depots respectively) for each combination. After obtaining the best combination of a set of new depots by opening and a set of existing depots by closing, a new set of total optimal combinations of depots (= Total number of given existing depots – exact number of existing depots to be closed + exact number of new depots to be opened) will be arrived. Considering the total optimal combination of depots obtained from the first phase of the algorithm, the given number of existing buses plus the proposed number of new buses are optimally/efficiently will be allocated in the second phase of the algorithm using the popular VAM method to get the optimal/efficient solution for LD-ABD problem and to minimize the total dead-kilometer cost.

The two-phase approach followed in the heuristic algorithm proposed in Mathirajan et al. [28] for solving LD-ABD problem, all the three cost: total fixed cost associated with opening new depots, total salvage values associated with closing existing depots, and total dead-kilometer cost associated with ABD problem, are not considered simultaneously while optimizing the cost of operations. This might lead to inferior solution when we compare with a method which could consider simultaneously all the three cost. With this backdrop, the heuristic algorithm proposed in Mathirajan et al. [28] is extended to address all the three costs simultaneously and the step-by-step detail of this extended heuristic algorithm is presented in Annexure 3. In addition to the heuristic algorithm incorporated in the model base, an appropriate system routine is provided in the model-base for all the possible 'what-if analyses' proposed in the C-DSS-URTS.

As per the functioning part of the MMM, the MMM invoke the required input for ABD problem or LD-ABD problem suitably depending on the decision maker's choice on optimally solving ABD problem or LD-ABD problem respectively. Particularly the heuristic algorithm incorporated in the model base requires the following basic input data to obtain optimal/efficient solution for either ABD or LD-ABD problem of URTS:

- List of depots
- List of terminuses and the distance between each terminus to each depot
- List of buses and its existing allocation to the depots
- Dead kilometer cost for each bus

Particularly, these input data is invoked in C-DSS-URTS for obtaining optimal/efficient solution for the following scenarios:

- Allocation of Bus to Depots (ABD): In the case of ABD problem, based on the data provided, using simple greedy heuristic algorithm implemented in the MMM, the efficient allocation of buses to the depots to minimize the total dead kilometer cost will be obtained.

- Location of Depots and Allocation of Buses to Depots (LD-ABD): There are scenarios where the user wanted to close few depots by specifying the salvage cost and open new depots by providing fixed cost. In this context, the user also wanted to add new buses and terminuses. After adding the relevant data for these, the user wanted to make a decision on what is the right combination of closing (existing depots) and opening (new depots) the depots. To learn this, the C-DSS-URTS will run the ABD algorithm for each of the combinations made considering the constraints on number of depots to be closed and number of new depots to be opened. In the end, the C-DSS-URTS shows the optimal/efficient total cost for each combinations considered based on the given data for LD-ABD problem and allows the user to choose his/her combination in terms of the choice of the depots considered for closing and opening.

- What if Analysis : There are various scenarios (one at a time): modifying the existing depot capacity feasibly, and/or adding more buses to the depots feasibly, and/or adding more terminuses by providing all the required additional dead-kilometer between each of the new terminuses and each of the depots considered in the system are defined in What-if analysis routing of the C-DSS-UTRO. That is, the web interface module (WIM) provides user interface to modify the depot capacity, add more buses, add more terminus through ‘What if analysis option. All the scenarios defined under What-if analysis, the system uses the heuristic algorithm incorporated in the model-base of the MMM, appropriately. Furthermore, for each of the scenarios, defined in the C-DSS-URTS for What-if analysis, the C-DSS-URTS is executed to view the impact of the results due to the modified data on buses / depot capacity / terminuses. That is, these What-if analysis gives the user a learning features of what happens to the result for a specific scenario.

4.1.4 Report Generation Module (RGM)

The C-DSS-URTS generates the optimal/efficient solution and the same is stored into Result_Table. The report generation module (RGM) generates the reports based on the data stored in the DMM and the solution stored in Result_Table for the decision problem: ABD or LD-ABD. The generated reports can be presented in screen and can be stored in MS-Excel also. That is, the report generation module retrieves the data from the database tables as well as result table and produces the following reports:

- **Bus_Status_Report**: For each bus, the details about (a) the Starting-Terminus, Ending-Terminus, existing allocation in terms of the depot, the distance and the cost due to the existing system (and these are extracted from appropriate database tables); and (b) the optimal/efficient solution in terms of the choice of depot for allocation of bus, the distance and the cost due to the allocation of a bus to a depot due to C-DSS-URTS (and these are extracted from result table) are generated and reported as Bus_Status-Report. A sample report is presented in Exhibit 8 of Annexure 2.

- **Bus_Depot_Allocation_Report**: This report displays Bus-Number (or Route-Number), depot allocated by C-DSS-URTS, terminus details, fuel cost per km, dead kilometer cost, etc. A sample report is presented in Exhibit 9 of Annexure 2.

- **Depot_wise_Change_Summary_Report**: This report provides the change summary for each depot by providing details on 'list of buses moved from existing depot to the depot decided by C-DSS-URTS' and 'the list of buses allocated to depot by C-DSS-URTS from other depots'. A sample report is presented in Exhibit 10 of Annexure 2.

- **Summary_Report**: This report provides a summary at the depot level. For each depot, how many buses are allocated and its total dead kilometer as well as total dead kilometer cost. These details are presented corresponding to both existing allocation and the optimal/efficient allocation obtained from C-DSS-URTS. Finally, the cost savings also computed and presented. A sample report is presented in Exhibit 11 of Annexure 2.

4.1.5 Control Module (CM)

The control module (CM) receives the request from the web interface and redirects the control to the respective modules of C-DSS-URTS. The control interface in general follows the below steps for every request:

Step 1: Gets the request from the user interface.

Step 2: Checks the type of request.

Step 3: If the request is to add information related to depots, buses or terminus, it will invoke the respective operation in the Database Management Module (DMM).

Step 4: If the request is viewing the information, it requests the DMM to retrieve the data from the database. Then the control redirects to the user interface module with the required data/information and the user can view the data/information.

Step 5: If the request is to delete the information, it requests the DMM to delete the respective record in the database. An appropriate message is also displayed in the UI through web user interface module.

Step 6: If user requests to execute the algorithm, the control redirects to the Model Management Module (MMM) which executes the algorithm for solving the respective ABD or LD-ABD problem.

Step 7: If the report options are selected in the user interface, the Control Module (CM) generates the reports using the Reports Module (RM) and allows the user to download it in excel format.

4.2 Testing and Verification of the Implementation of C-DSS-URTS:

Testing: To assure the quality and reliability of any new software it is necessary to test it in different phases using various standard testing methods. The testing methods used for testing the proposed C-DSS-URTS are Module Testing, Functional Testing, User Interface Testing and Systems Testing. The details of these testing are as follows:

- ***Module Testing*** – Each module is tested independently to check whether the interfaces to the methods are working fine.
- ***Functional Testing*** – Each function written in the modules are tested independently and the functionality is tested using the simulated data.
- ***User Interface Testing*** – The web interface components are tested to make sure that the appropriate information is retrieved from the backend and also information is stored into the backend.
- ***System Testing*** – This testing makes sure that all the different modules along with the user interface works fine.

As part of the implementation, several test cases had been identified and testing is done against those test cases.

Verification: The appropriateness of the formulation of three decision making scenarios on ABD, LD-ABD, and What-if Analysis proposed in C-DSS-URTS, several small-scale data (sample small scale data is presented in *Annexure 3*) are considered. These small-scale problems are solved using the C-DSS-URTS and verified the solution obtained from the C-DSS-URTS with the solution obtained by solving these small-scale problems manually.

5 Validation of the Proposed C-DSS-URTS

For validating the proposed C-DSS-URTS, a real-life case study data is most preferred. Due to confidential problem of the real-life case study data of BMTC and the difficulty in obtaining multiple real-life data related to ABD and LD-ABD problems of various URTS, this study considered 25 large scale data, generated randomly based on the observation from BMTC, Bangalore. The macro characteristics of the ABD and LD-ABD problem of these 25 large scale data are presented in Table 2 (column 2 to 3) and Table 3 (column 2 to 9) respectively. Each of these 25 large scale data is solved considering ABD problem using the proposed C-DSS-URTS and obtained the total dead-kilometer as well as the total dead-kilometer cost. These results are presented in Table 2.

For performance evaluation of the proposed C-DSS-URTS for ABD problem, the solution obtained from the existing practice and the optimal solution obtained from the existing mathematical model (Raghavendra and Mathirajan, [31]) is compared. Accordingly, for each of the 25 problem instances, both total dead-kilometer as well as total dead-kilometer costs are obtained with respect to existing practice and the exact procedure. These details are presented in Table 2. From the performance analysis on the results presented in Table 2, it is observed that the proposed C-DSS-URTS is providing efficient solution with a loss of optimality between 1% and 4% for ABD problem.

Similarly, each of the 25 large scale data related to LD-ABD problem is solved using the proposed C-DSS-URTS and obtained the total cost (which is the sum of total fixed cost associated with opening a few new depots, total salvage value associated with closing a few existing depots, and total dead-kilometer cost associated with allocating the total number of buses to the available number of depots in the problem) and presented in Table 3. For evaluating the performance of the proposed C-DSS-URTS with respect to LD-ABD problem, the mathematical model presented in Mathirajan et al. [28] is considered as bench mark procedure. Accordingly, for each of the 25 problem instances are solved using the mathematical model presented in Mathirajan et al. [28] and the total optimal cost obtained is presented in Table 3. From the performance analysis on the results presented in Table 3, it is observed that the proposed C-DSS-URTS is providing efficient solution with a loss of optimality between 0% and 3% for LD-ABD problem.

6. Discussion

The most outstanding features of the proposed C-DSS-URTS for ABD or LD-ABD are its quasi-real-time decision making support, intuitive and wizard-style interfaces and excellent scalability. The appropriateness in implementing the proposed C-DSS-URTS is carried out by conducing suitable testing and verification. Finally, the external validation of the proposed C-DSS-URTS for ABD or LD-ABD problem is carried out on large scale 25 pseudo real-life data of URTS and showed that C-DSS-URTS for ABD or LD-ABD problem can meet the goals of achieving intuitive and concise interfaces and supporting real-time or quasi real-time decision making. In addition, the required modern information and communications technology tools and analytics as well as 'What-if analyses', which are based on simple greedy heuristic algorithm, are incorporated in the proposed C-DSS-URTS to decide the near optimal/efficient location of depots (from the options given for both opening new depots and closing a few existing depots) and allocation of buses to depots is extremely useful for optimizing the cost of bus operations in URTS.

Table 2: The Performance of the C-DSS-URTS for ABD problem in Comparison with Existing System and Proposed (0-1) ILP Model

Run	URTS with # Depots and Buses		Existing Systems' Performance w.r.t.		C-DSS-URTS's Performance w.r.t.		0-1 ILP's Performance w.r.t.		Relative performance of C-DSS-URTS, in terms of %age, w.r.t.			
	# of Depots	Total # of Buses	Total Dead Kilometer	Total Dead Kilometer Cost	Total Dead Kilometer	Total Dead Kilometer Cost	Total Dead Kilometer	Total Dead Kilometer Cost	Improvement over Existing System	Loss w.r.t. known solution	Improvement over Optimal Solution	Loss of Optimality
									in Total Dead Kilometer		in Total Dead Kilometer Cost	
1	10	1335	27486	303899	11871	130254	11729	129007	56.8	1.2	57.1	1.0
2	10	1058	13591	142599	6047	63467	5986	62866	55.5	1.0	55.5	1.0
3	10	1255	16646	175225	7069	74142	6981	73297	57.5	1.3	57.7	1.2
4	10	1463	18074	190343	8647	90835	8602	90353	52.2	0.5	52.3	0.5
5	10	1501	21335	224253	8891	93019	8707	91211	58.3	2.1	58.5	2.0
Average	**10**	**1322**	**19426**	**207264**	**8505**	**90343**	**8401**	**89347**	**56.1**	**1.2**	**56.2**	**1.1**
1	20	2384	49241	544908	17581	193690	17212	189858	64.3	2.1	64.5	2.0
2	20	2117	29454	309607	10751	112602	10415	109432	63.5	3.2	63.6	2.9
3	20	2505	35189	369556	11553	120718	11115	116614	67.2	3.9	67.3	3.5
4	20	2950	39880	418905	13049	136990	12824	134639	67.3	1.8	67.3	1.7
5	20	3105	40046	420390	13359	139962	13175	138129	66.6	1.4	66.7	1.3
Average	**20**	**2612**	**38762**	**412673**	**13259**	**140792**	**12948**	**137734**	**65.8**	**2.4**	**65.9**	**2.2**
1	30	4264	92829	1019536	24392	265799	23375	256611	73.7	4.4	73.9	3.6
2	30	3403	41954	440745	13370	139359	12773	133943	68.1	4.7	68.4	4.0
3	30	4311	58879	619002	17596	184124	17088	179349	70.1	3.0	70.3	2.7
4	30	4395	56509	591982	17503	182680	16927	177231	69.0	3.4	69.1	3.1
5	30	5211	70052	735146	20446	214029	20087	210715	70.8	1.8	70.9	1.6
Average	**30**	**4317**	**64045**	**681282**	**18661**	**197198**	**18050**	**191570**	**70.4**	**3.4**	**70.5**	**3.0**
1	40	4587	85803	939534	23965	260657	23201	253691	72.1	3.3	72.3	2.7
2	40	4102	56579	594815	14639	153083	14108	148151	74.1	3.8	74.3	3.3
3	40	4525	61550	646331	16472	171915	15906	166846	73.2	3.6	73.4	3.0
4	40	5017	60615	638108	18697	195657	18036	189622	69.2	3.7	69.3	3.2
5	40	6114	78652	827823	21955	229782	21107	221886	72.1	4.0	72.2	3.6
Average	**40**	**4869**	**68640**	**729322**	**19146**	**202219**	**18472**	**196039**	**72.1**	**3.7**	**72.3**	**3.2**
1	50	5229	71271	748970	16955	177479	16518	173391	76.2	2.6	76.3	2.4
2	50	5965	72344	757081	21052	218680	20279	211847	70.9	3.8	71.1	3.2
3	50	6000	83468	878691	21301	222528	20231	212648	74.5	5.3	74.7	4.6
4	50	7342	95221	999281	25004	260790	23868	250325	73.7	4.8	73.9	4.2
5	50	9443	197019	2166463	45235	494462	43922	482950	77.0	3.0	77.2	2.4
Average	**50**	**6796**	**103865**	**1110097**	**25909**	**274788**	**24964**	**266232**	**74.5**	**3.9**	**74.6**	**3.4**

Table 3: The Performance of the C-DSS-URTS for LD-ABD problem in Comparison with Proposed (0-1) ILP Model

Run	Depot Details		Bus Details			Terminus Details			Total Cost in Rs. by C-DSS-URTS	Optimal Cost in Rs. by ILP Model	Loss of Optimality in Percentage
	Existing # of Depots	Total # of Depots for the Run	# of Existing Buses	# of New Buses	Total # of Buses for the Run	# of Existing Terminus	# of New Terminus	Total # of Terminus for the Run			
1	10	11	1335	30	1365	130	7	137	8896054	8716485	2.1
2	10	11	1058	30	1088	60	5	65	8874518	8871357	0.0
3	10	11	1255	30	1285	72	6	78	9086995	9084817	0.0
4	10	11	1463	33	1496	75	6	81	9355308	9352283	0.0
5	10	11	1501	36	1537	81	30	111	9913680	9909729	0.0
Average									**9225311**	**9186934**	**0.4**
1	20	21	2384	24	2408	130	7	137	8935986	8934752	0.0
2	20	21	2117	111	2228	82	25	107	10360623	10149890	2.1
3	20	21	2505	69	2574	80	28	108	9790410	9782635	0.1
4	20	21	2950	84	3034	130	30	160	10048782	9773304	2.8
5	20	21	3105	111	3216	120	35	135	9657940	9648309	0.1
Average									**9758748**	**9657778**	**1.0**
1	30	31	4264	45	4309	140	15	155	10379542	9647311	7.6
2	30	31	3403	111	3514	110	27	137	10457121	10447480	0.1
3	30	31	4311	111	4422	140	35	175	10857723	10616520	2.3
4	30	31	4395	114	4509	135	38	173	10239930	9947385	2.9
5	30	31	5211	120	5331	140	40	180	9842127	9831332	0.1
Average									**10355289**	**10098006**	**2.5**
1	40	41	4587	54	4641	130	28	158	10253960	9977648	2.8
2	40	41	4102	75	4177	100	25	125	9707584	9695180	0.1
3	40	41	4525	120	4675	110	30	140	10178707	9722287	4.7
4	40	41	5017	105	5122	105	35	140	10730855	10719450	0.1
5	40	41	6114	120	6234	140	130	270	11121122	10877390	2.2
Average									**10398446**	**10198391**	**2.0**
1	50	51	5229	111	5340	120	110	230	10321261	10305710	0.2
2	50	51	5965	105	6070	85	30	115	10972387	10342290	6.1
3	50	51	6000	105	6105	95	28	123	10316719	10302580	0.1
4	50	51	7342	129	7471	120	55	172	10588091	10570880	0.2
5	50	51	9443	66	9509	150	30	180	10824945	10809600	0.1
Average									**10604681**	**10466212**	**1.3**

Note: For all the 25 Problem Instances, the data values for (a) Number of Possible Existing Depots to be closed from the existing ones : 02, (b) Number of Existing Depots exactly to be closed : 01, (c) Number of Feasible New Depots to be Opened : 03, and (d) Number of Feasible New Depots exactly to be Opened : 02. However, the choice of 'number of possible existing depots to be closed' among the existing ones is assumed to be randomly decided.

Apart from prescribing the near optimal/efficient locations for depots and allocation of buses to the depots by minimizing cost of operations, particularly minimizing the dead-kilometer cost, the UTRS could reasonable estimates the cost savings for the extent of pollutant emissions and energy consumption caused due to the dead-kilometers to be incurred based on the optimal/efficient decisions of the location of depots and allocations of buses to depots in comparison with existing practice.

The proposed C-DSS-URTS designed and implemented for obtaining optimal decision for ABD or LD-ABD problem has significant advantages. It reduces the deployment and processing time, provides learning feature for the decision makers by carrying out What-if analyses, facilitates the accessibility, and decrease the operational cost, including the capital expenditures. The proposed C-DSS-URTS for obtaining optimal decision for ABD or LD-ABD problem also has some other advantages. For example, it is accessible at any time and from anywhere by any URTS by using a browser via the Internet and thus these will prompt users to participate in the decision-making processes. It is easy to maintain and upgrade, as the system is deployed on the public cloud: Amazon's cloud services. However, in the prototype C-DSS-URTS, the today's real management practices in taking the decisions on (a) ABD, and (b) LD-ABD are not considered.

The novelties of the proposed C-DSS-URTS are that the DSS cloud and Web service-based architecture is easy to manage and update, able to provide flexibility in information exchange operations among the cooperative partners. In this context, the proposed prototype C-DSS-URTS acts as an independent entity that collects all the relevant data and provides decisions to the decision maker, in order to improve the performances, thus improving the specific objective of minimizing the cost of the bus operation.

7. Conclusion

This paper presents architecture of a Cloud-based DSS (C-DSS) that integrates the strategic problem on location of depots (for adding new locations and removing existing ones) and allocation of buses to depots (LD-ABD), as observed in an Indian Urban Road Transport System for optimizing the cost of bus operations. Furthermore, the proposed C-DSS-URTS is developed using latest web technologies with a user-friendly web interface which can be used in any browser. Precisely the proposed C-DSS-URTS is developed as a SaaS (Software as a Service) model in the cloud and it is currently deployed in Amazon Web Services (AWS Cloud), which enables the users to access it using from anywhere using any devices. The proposed C-DSS-URTS has some advantages such as (a) quasi-real-time decision is obtained by utilizing cloud computing technology, (b) an intuitive and user friendly GUI is provided to enhance the user experience, (c) it is very economic, as the C-

DSS-URTS is entirely built on efficient heuristic algorithms, and this feature lends to it great prospects of being applied to other URTS.

It is to be highlighted that this study is at an initial stage of the development cycle, and the proposed prototype C-DSS-URTS for obtaining optimal decision for LD-ABD problem is mainly for the purpose of demonstrating to and communicating with URTS for its easy utility and stimulating them to provide more specific and accurate system demands for further enhancements. That is, the proposed prototype C-DSS-URTS has some inadequacies related to the assumptions (e.g., any bus can be allocated to any available depot, depot operating cost is same across the depot for every bus, etc.,), considered in this study, for developing solution methodologies and thus, continuous improvement is necessary. In the next version of C-DSS-URTS, more management practices will be incorporated as immediate further research scope of the problem addressed here.

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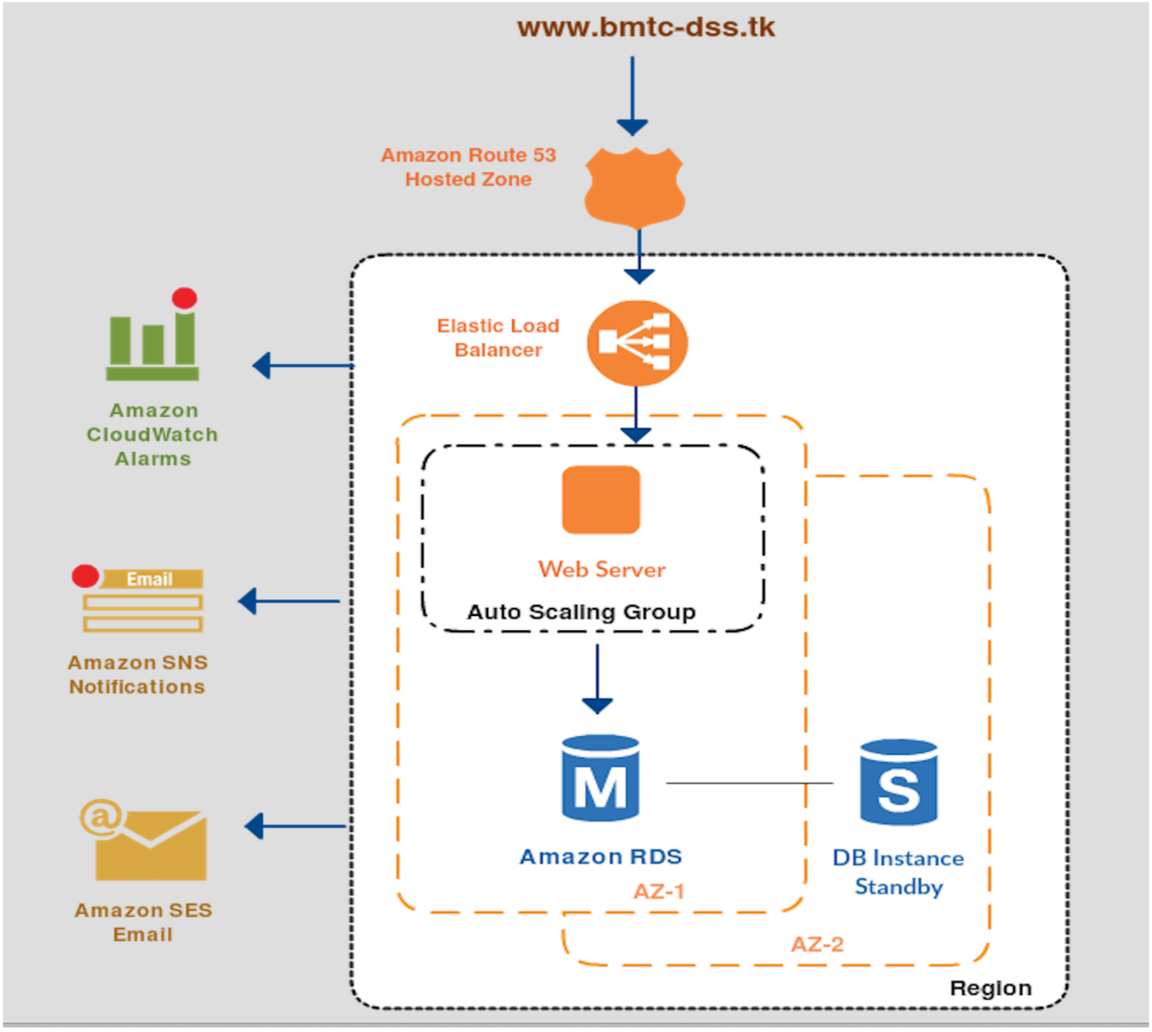
Annexure 1

A Proposed Cloud architecture for C-DSS-URTS

The proposed DSS is developed using latest web technologies like Angular.js, PHP, HTML and CSS with a backend MySQL database. This is deployed in the cloud infrastructure using Amazon Web Services (AWS). The following figure shows deployment architecture for this web based DSS system which is deployed over the internet for easy access.



The architecture considered is based on simple 2-tiers architecture with web layer and database layer. The web application is integrated with cloud watch, notification module and email module for external communication. The database is deployed in failover mode with two instances one as master and the other in standby mode.

Annexure 2

Input Tables and Output Tables Structure of C-DSS-URTS

#	Name	Type	Collation	Attributes	Null	Default
1	**serialno**	int(11)			No	*None*
2	**code**	varchar(20)	utf8_unicode_ci		No	*None*
3	**name**	varchar(40)	utf8_unicode_ci		No	*None*
4	**division**	varchar(5)	utf8_unicode_ci		No	*None*
5	**current_capacity**	int(11)			No	*None*
6	**maximum_capacity**	int(11)			No	*None*
7	**whatif_capacity**	int(4)			No	*None*
8	**operating_cost**	int(11)			No	*None*
9	**salvage_cost**	int(11)			No	*None*
10	**fixed_cost**	float			No	*None*
11	**org_code**	varchar(20)	utf8_unicode_ci		No	*None*
12	**purpose**	int(2)			No	*None*

Exhibit 1: The structure of "Depot-Table" in DMM

#	Name	Type	Collation	Attributes	Null	Default
1	**id**	int(11)			No	*None*
2	**terminus_code**	varchar(20)	utf8_unicode_ci		No	*None*
3	**terminus_name**	varchar(50)	utf8_unicode_ci		No	*None*
4	**org_code**	varchar(20)	utf8_unicode_ci		No	*None*
5	**purpose**	int(2)			No	*None*

Exhibit 2: The structure of "Terminus Table" in DMM

#	Name	Type	Collation	Attributes	Null	Default
1	**id**	int(11)			No	*None*
2	**terminus_code**	varchar(20)	utf8_unicode_ci		No	*None*
3	**depot_code**	varchar(20)	utf8_unicode_ci		No	*None*
4	**distance**	float			No	*None*
5	**org_code**	varchar(20)	utf8_unicode_ci		No	*None*
6	**purpose**	int(2)			No	*None*

Exhibit 3: The structure of "Terminus-Depot Table" in DMM

#	Name	Type	Collation	Attributes	Null	Default
1	**id**	int(5)			No	*None*
2	**route_no**	varchar(10)	utf8_unicode_ci		No	*None*
3	**depot_code**	varchar(10)	utf8_unicode_ci		No	*None*
4	**terminus_start**	varchar(50)	utf8_unicode_ci		No	*None*
5	**terminus_end**	varchar(50)	utf8_unicode_ci		No	*None*
6	**fuel_cost_km**	int(2)			No	*None*
7	**org_code**	varchar(20)	utf8_unicode_ci		No	*None*
8	**purpose**	int(2)			No	*None*

Exhibit 4 : The structure of “Bus Table” in DMM

#	Name	Type	Collation	Attributes	Null	Default
1	**id**	int(11)			No	*None*
2	**route_no**	varchar(10)	utf8_unicode_ci		No	*None*
3	**depot_code**	varchar(20)	utf8_unicode_ci		No	*None*
4	**remarks**	text	utf8_unicode_ci		No	*None*
5	**org_code**	varchar(20)	utf8_unicode_ci		No	*None*
6	**purpose**	int(2)			No	*None*

Exhibit 5: The structure of “Route-Depot Constraints Table” in DMM

#	Name	Type	Collation	Attributes	Null	Default
1	**id**	int(11)			No	*None*
2	**depot_code**	varchar(15)	utf8_unicode_ci		No	*None*
3	**route_no**	varchar(20)	utf8_unicode_ci		No	*None*
4	**org_code**	varchar(20)	utf8_unicode_ci		No	*None*
5	**purpose**	int(11)			No	*None*

Exhibit 6: The structure of “Result Table” in DMM

#	Name	Type	Collation	Attributes	Null	Default
1	**id**	int(11)			No	*None*
2	**depot_codes_closing**	varchar(100)	utf8_unicode_ci		No	*None*
3	**depot_close_possible**	int(2)			No	*None*
4	**depot_close_exact**	int(2)			No	*None*
5	**depot_open_possible**	int(2)			No	*None*
6	**depot_open_exact**	int(2)			No	*None*
7	**num_buses**	int(3)			No	*None*
8	**org_code**	varchar(5)	utf8_unicode_ci		No	*None*

Exhibit 7: The structure of “LD-ABD Table” in DMM

			Existing Allocation			Allocation by C-DSS		
Bus No	Start Terminus	End Terminus	Depot	Distance	Cost	Depot	Distance	Cost
R1	SBS	BBS	D1	18.5	203.5	D1	18.2	200.2
R2	CMT	CMT	D1	8	96	D3	8	96
R3	MBS	BBS	D1	17.3	190.3	D2	14.8	162.8
R4	GNR	SNR	D2	16.6	182.6	D2	9.4	103.4
R5	SNR	GNR	D2	16.6	199.2	D2	9.4	112.8
R6	GNR	GNR	D2	15.2	152	D2	8	80
R7	BBS	SBS	D2	18.5	222	D1	18.2	218.4
R8	CMT	BBS	D2	15	165	D1	15.2	167.2
R9	BBS	SBS	D2	18.5	222	D2	19	228
R10	CMT	BBS	D2	15	150	D3	15	150
R11	MBS	SBS	D3	13.8	151.8	D3	13.8	151.8
R12	MBS	MBS	D3	12.6	138.6	D2	11.6	127.6
R13	CMT	SBS	D3	11.5	138	D3	11.5	138
R14	SNR	BBS	D3	20	240	D2	14.4	172.8
R15	CMT	SBS	D3	11.5	115	D3	11.5	115
				228.6	2566		198	2224

Exhibit 8: A Sample Output Generated from C-DSS-URTS for “Bus Status Report”

								Depot by	
Sl. No	Bus No	Start Terminus	Distance	End Terminus	Distance	Fuel Cost	Dead Kilometer Cost	DSS	Existing
1	R8	CMT	5	BBS	10.2	11	167.2	D1	D2
2	R1	SBS	8	BBS	10.2	11	200.2	D1	D1
3	R7	BBS	10.2	SBS	8	12	218.4	D1	D2
4	R6	GNR	4	GNR	4	10	80	D2	D2
5	R5	SNR	5.4	GNR	4	12	112.8	D2	D2
6	R4	GNR	4	SNR	5.4	11	103.4	D2	D2
7	R12	MBS	5.8	MBS	5.8	11	127.6	D2	D3
8	R3	MBS	5.8	BBS	9	11	162.8	D2	D1
9	R14	SNR	5.4	BBS	9	12	172.8	D2	D3
10	R9	BBS	9	SBS	10	12	228	D2	D2
11	R2	CMT	4	CMT	4	12	96	D3	D1
12	R15	CMT	4	SBS	7.5	10	115	D3	D3
13	R11	MBS	6.3	SBS	7.5	11	151.8	D3	D3
14	R13	CMT	4	SBS	7.5	12	138	D3	D3
15	R10	CMT	4	BBS	11	10	150	D3	D2

Exhibit 9: A Sample Output Generated from C-DSS-URTS for “Bus Allocation Report”

Depot:D1 - Depot1

Route No	Start Terminus	End Terminus	To Depot	From Depot
R1	SBS	BBS	-	-
R2	CMT	CMT	D3	-
R3	MBS	BBS	D2	-
R8	CMT	BBS	-	D2
R7	BBS	SBS	-	D2

Exhibit 10 : A Sample Output Generated from C-DSS-URTS for "Depot wise Change Summary Report"

Summary Report

Depot-wise summary details

		Existing Allocation			Efficient Allocation		
Depot Code	Depot Name	# buses	Dead kms	Cost	# buses	Dead kms	Cost
D1	Depot1	3	43.80	489.80	3	51.60	585.80
D2	Depot2	7	115.40	1292.80	7	86.60	987.40
D3	Depot3	5	69.40	783.40	5	59.80	650.80
Total		15	228.60	2566.00	15	198.00	2224.00

Download Excel

Exhibit 11: A Sample Output Generated from C-DSS-URTS for "Summary Report"

Annexure 3

A Greedy Heuristic Algorithm for LD-ABD Problem of Indian URTSs

The step by step approach of the extended greedy heuristic algorithm, proposed in Mathirajan et al. (2018), is as follows:

Step 1: Let 'Combination' = 0

Step 2: Select a combination of existing facilities [after considering closing facility (or facilities) combination] and new facility (or facilities) [after considering opening facility (or facilities) combination]. And assign Combination = Combination + 1

Step 3: Compute Facilities Cost for the selected combination of existing facility and new facility

$$\textit{Facilities cost}=\begin{pmatrix} Fixedcostinvolved \\ inopeningofnewfacility \end{pmatrix} - \begin{pmatrix} Revenueobtainedfromclosing \\ theexistingfacility \end{pmatrix}$$

Step 4: Using the selected combination of existing and new facilities, allocation of buses to the given set of facilities (depots) is formulated as transportation problem. As Mathirajan et al (2010) empirically proved that the initial basic solution method by Vogel's Approximation Method (VAM) provides near optimal solution, VAM is used for allocation of buses to depots to optimize the total dead-kilometer cost.

Step 5: Compute the Overall Cost for location of depots and allocation of buses to depots for the selected combination of existing and new facility

$$\textit{Overall Cost (combination)} = (Facilities\ Cost) + (Total\ Dead\ Kilometer\ Cost)$$

Step 6: Repeat Step 2 to Step 5 for each possible combinations of existing facilities [after considering closing facility (or facilities) combination] and new facility (or facilities) [after considering opening facility (or facilities) combination].

Step 7: List combination wise the Overall Cost obtained and allow the user to choose the best combination based on the minimum overall cost and decision maker's subjective decision on the combination of existing facilities [after considering closing facility (or facilities) combination] and new facility (or facilities) [after considering opening facility (or facilities) combination].

Step 8: Based on the decision maker's choice on combination of existing and new depots the detailed reports on (a) list of closing depots, (b) list of opening new depots, (c) depot wise the overall summary on number of buses allocated along with the overall cost, (d) allocation of buses to depots are generated.

Annexure 4

A Numerical Example for Allocation of Buses to Depots (ABD) Problem

The objective of the numerical example problem given here is to minimize the total dead kilometer cost by optimally allocating the given N (= 15) number of buses to existing M (= 3) number of depots.

Existing Bus-Depot Allocation

Depot 1 : D1

Sl. No.	Route No.	Starting Terminus (ST)	Distance from ST to Depot	Ending Terminus (ET)	Distance from ET to Depot	Fuel Cost Per KM
1	R1	SBS	8.0	BBS	10.2	11
2	R2	CMT	5.0	CMT	5.0	12
3	R3	MBS	12.0	BBS	10.2	11

Depot 2 : D2

Sl. No.	Route No.	Starting Terminus (ST)	Distance from ST to Depot	Ending Terminus (ET)	Distance from ET to Depot	Fuel Cost Per KM
1	R4	GNR	4.0	SNR	5.4	11
2	R5	SNR	5.4	GNR	4.0	12
3	R6	GNR	4.0	GNR	4.0	10
4	R7	BBS	9.0	SBS	10.0	12
5	R8	CMT	7.0	BBS	9.0	11
6	R9	BBS	9.0	SBS	10.0	12
7	R10	CMT	7.0	BBS	9.0	10

Depot 3 : D3

Sl. No.	Route No.	Starting Terminus (ST)	Distance from ST to Depot	Ending Terminus (ET)	Distance from ET to Depot	Fuel Cost Per KM
1	R11	MBS	6.3	SBS	7.5	11
2	R12	MBS	6.3	MBS	6.3	11
3	R13	CMT	4.0	SBS	7.5	12
4	R14	SNR	9.0	BBS	11.0	12
5	R15	CMT	4.0	SBS	7.5	10

Distance between Starting/Ending Terminus and Depot#

Terminus Code	Terminus Name	Distance from 'Terminus' to the Depot		
		D1	D2	D3
BBS	Bangalore Bus Station	10.2	9.0	11.0
CMT	City Market	5.0	7.0	4.0
GNR	Gandhi Nagar	9.4	4.0	7.6
MBS	Malleswaram Bus Station	12.0	5.8	6.3
SBS	Shivajinagar Bus Station	8.0	10.0	7.5
SNR	Srinagar	5.0	5.4	9.0

This is a Crucial Input Data and generally this complete data is not be available in URTS in India [However, this is possible to generate this data if GIS is used in URTS]

Annexure 4 (Contd.)

A Numerical Example for Location of Depots and ABD (LD-ABD) problem

The numerical example for ABD problem presented in Annexure 3 is extended to capture the LD-ABD problem. For capturing the problem features of LD-ABD in the numerical problem, the following data are provided:

- Number of buses increased from 15 to 20 and the required data for these new additional buses is as follows:

Sl. No.	New Bus (Route) No.	Starting Terminus (ST)	Ending Terminus (ET)	Fuel Cost Per KM
1	R16	BTL	BBS	10
2	R17	SBS	JPN	12
3	R18	CMT	BTL	10
4	R19	JPN	BBS	12
5	R20	BTL	JPN	11

- Possible to close 2 exiting depots with immediate requirement of closing only one depot. To capture this requirement, the depot wise salvage cost, which is due to closing the possible depot, is given as follows:

Sl. No.	Existing Depot Code	Existing Depot Name	Existing Depot Capacity	Possible Depot to Close	Salvage Cost in Indian Rupees due to Closing Depot
1.	D1	Depot 1	3	Yes	180000
2.	D2	Depot 2	7	No	0
3.	D3	Depot 3	5	Yes	200000

- Possible to open four new depots with immediate requirements of opening 2 new depots only. For addressing this specific requirement, the new depot wise name of the depot along with depot code, fixed cost, and capacity is given as follows:

Sl. No.	New Depot Code	New Depot Name	New Depot Capacity	Fixed Cost in Indian Rupees due to Opening Depot
1.	D4	Depot 4	10	175000
2.	D5	Depot 5	8	100000
3.	D6	Depot 6	10	150000
4.	D7	Depot 7	9	120000

- Due to increase in the number of buses with new terminus (last two rows indicates new terminus) and a set possible new depots for LD-ABD problem, the date on *distance between (Existing and New) Starting/Ending Terminus and Depots (existing and New Depots) is required as follows:*

Terminus Code	Terminus Name	Distance from 'Terminus' to the Depot						
		D1	D2	D3	D4	D5	D6	D7
BBS	Bangalore Bus Station	10.2	9.0	11.0	8.5	7.0	9.0	11.0
CMT	City Market	5.0	7.0	4.0	6.0	5.0	5.4	4.0
GNR	Gandhi Nagar	9.4	4.0	7.6	8.0	6.5	8.5	7.0
MBS	Malleswaram Bus Station	12.0	5.8	6.3	8.5	6.5	7.5	8.0
SBS	Shivajinagar Bus Station	8.0	10.0	7.5	6.5	6.0	7.5	9.2
SNR	Srinagar	5.0	5.4	9.0	8.0	6.2	7.3	4.2
JPN	JP Nagar	9.0	10.0	6.0	7.5	8.5	8.0	5.7
BTL	BTM Layout	8.0	9.0	6.5	9.0	7.0	7.5	6.3