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Aims and Scope

South Asia, and Sri Lanka in particular, are currently facing many transitional challenges; transport and logistics being among those most critical and important ones. Rapid economic growth and increasing income levels have radically changed the aspirations of people and thus, their demands, while expanding global markets and international competition have made meeting such demands highly complex and knowledge intensive. Ever expanding motorization increasingly generates negative externalities, pushing the transport industry to the limits of being unsustainable in the medium term. These factors make it imperative for transport and logistics professionals, including industrialists and academics, to focus on research and dissemination of results in view of addressing the challenges the mankind is facing in meeting mobility needs. The Journal of South Asian Logistics and Transport (JSALT) seeks to fulfil this mandate.

The JSALT is a refereed bi-annual English language journal published by the Sri Lanka Society of Transport and Logistics (SLSTL). It creates a space where findings of original research can be disseminated, and thereby contributes to the knowledge base and thought process in the discipline of Transport and Logistics. Critical evaluation of policies, investment, expansion, service delivery, pricing, equity and social welfare, technological progress and challenges posed to such fundamentals, in regard to transportation and logistics, are the major areas of interest of the journal. Sub-sectoral issues, such as Public Transportation, Railways and Roads, Ports and Shipping, Aviation and Airports, Freight and Passenger Haulage, Logistics and Supply Chain related issues also are addressed through dissemination of industry-related research, particularly focusing on the South Asian context.

Apart from the research articles the journal carries a special section titled ‘Strategic Perspectives’ which articulates alternative strategic thoughts and policy approaches.

All research articles in this journal are subject to a rigorous double-blind peer-review process and are then reviewed by the Board of Editors prior to final acceptance for publication.

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A NOVEL FRAMEWORK FOR ROAD DATA SURVEYING BASED ON DEEP-LEARNING AND GIS

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ABSTRACT

This paper proposes a novel framework for road data surveying and 3D urban visualisation based on deep-learning technologies, open data, and GIS techniques. Existing road inventory preparation methods are time-consuming, labour-intensive, inefficient, and lack an acceptable method for 3D urban visualisation in Sri Lanka. Thus, modern approaches are not applicable due to a lack of resources, technology, and financial capacity; the proposed framework will enable us to overcome these weaknesses.

The study comprised of three main stages: a literature review, development of the framework, and its validation in Ranna area. The framework was applied to two consecutive model validation events: the first related to the road data surveying model and the second to the 3D urban visualisation model. Its proposed returned KAPPA Accuracy Scores were 92% and 90% respectively.

The findings of this study further the use of cutting-edge deep learning and mapping techniques in transport and urban planning, making the preparation of road inventory surveys and 3D urban visualisations more cost-effective and efficient. Transport engineers, urban and regional planners, geographers, and GIS experts can employ the proposed framework for road data collection and 3D urban visualisation.

Keywords: *Road and Land Use Data, Deep Learning, Open Data, Transport Planning, GIS*

1. INTRODUCTION

The transportation system is considered one of the essential components of modern urban development [1]. It helps to increase mass passenger and resource distribution and to enhance the accessibility. In such a context, road inventory surveys provide essential information for decision-makers and engineers to evaluate diverse characteristics of the transportation system (i.e., road safety, level of service, passenger and vehicular demand, quality of the transportation network, etc.) [2], [3]. Therefore, maintaining road inventory information in a fresh and up-to-date manner contributes to efficient and sustainable transportation management [4], [5]. There are many techniques to collect road inventory information. A number of research have been conducted using diverse techniques [6], [7], [8]. However, many of these techniques are costly, labour-intensive, and unable to capture rapid changes in transportation networks [3].

Therefore, in this study we introduce a novel framework to collect road inventory information including road material, road type, and surrounding land use character of a road network. This framework is useful for sustainable transportation management and development because it provides many types of information on current road networks [9].

Road material information is very important to identify the road segments that require maintenance during road construction projects. At the same time, road type information provides essential information to estimate passenger car units (PCU), level of service (LOS), and traffic flow patterns of the transportation network [10], [11], [12]. Information of the land-uses alongside the road network is important to understand urban development patterns in a given area and the quality of the transportation systems that serves the area [13], [14], and [15]. The framework extracts each of these types of information using cutting-edge, deep learning and mapping techniques.

At present, diverse technologies are used to extract road inventory information, such as field inventory, photo/video logs, integrated GPS/GIS mapping systems, aerial photography, satellite imagery, virtual photo tourism, terrestrial laser scanners, and mobile mapping systems (i.e., vehicle-based LiDAR and airborne LiDAR) [2], [8], [16], [17], [18]. The field inventory data collection method delivers rich road inventory data as it follows the in-situ data collection method [7]. This method has several limitations such as the crew being exposed to traffic, lengthy field data collection time, and lower accuracy due to human biases of the surveyors and the technical faults of equipment, etc. Therefore, many studies tend to use ex-situ, (i.e., remote) road inventory information extraction methods by using the image classification techniques with terrestrial laser scanners, aerial photography, satellite imagery, and LiDAR data. However, this approach also has significant limitations and failures due to the nature of data used. For example, although LiDAR, a relatively new type of mobile mapping system, can collect large amounts of detailed 3D road data, it requires expensive equipment and significant data reduction to extract the desired inventory data [6]. Hence, the use of these techniques is not feasible in developing countries. On the other hand, satellite imagery and aerial photography have limitations due to low spatial accuracy of sensors and the non-availability of diversified imaging indexes that capture feature objects [11]. Therefore, it is difficult to design a general-purpose algorithm to effectively extract road material, type, and land use feature information based on imagining indexes and classification techniques [10].

This paper proposes an innovative framework to collect road inventory information related to road material, road type, and land use features using state-of-the-art computer visioning technologies and Google Street View Imagery (GSVI). Unlike satellite imagery, GSVI is free and widely available in many countries, and it is free of cloud distortions [13], [19], and [20]. The most important benefit of the GSVI is that, since the images are taken from the road with a 360° view, they detect surrounding land use features and roads without disturbance [20]. Therefore, it is relatively more convenient to extract road information from the GSVI and to classify corresponding road network materials, types, and land use features. Therefore, the proposed method is well-suited for developing countries to prepare their road inventory systems in a cost-effective, efficient, and accurate manner.

This study tries to overcome four major limitations noted in previous research in this area.

- existing road data collection methods are expensive, labor-intensive, and unable to capture rapid changes in transportation systems.
- multi-spectral imaging indices are incapable of capturing ground objects due to the similar spectra and textures of feature objects in imageries.
- satellite images have several limitations due to their aerial nature and spatial accuracy.
- most state-of-the-art road data collection systems use expensive and labour-intensive methods of primary and secondary data collection. Hence, those approaches are not feasible for developing countries.

Considering the above limitations, the primary objective of this study was to propose a sophisticated modelling framework to collect road inventory information in countries like Sri Lanka. It used the Southern Province of Sri Lanka as its demonstration area. Figure 1 depicts the process adopted in the study.

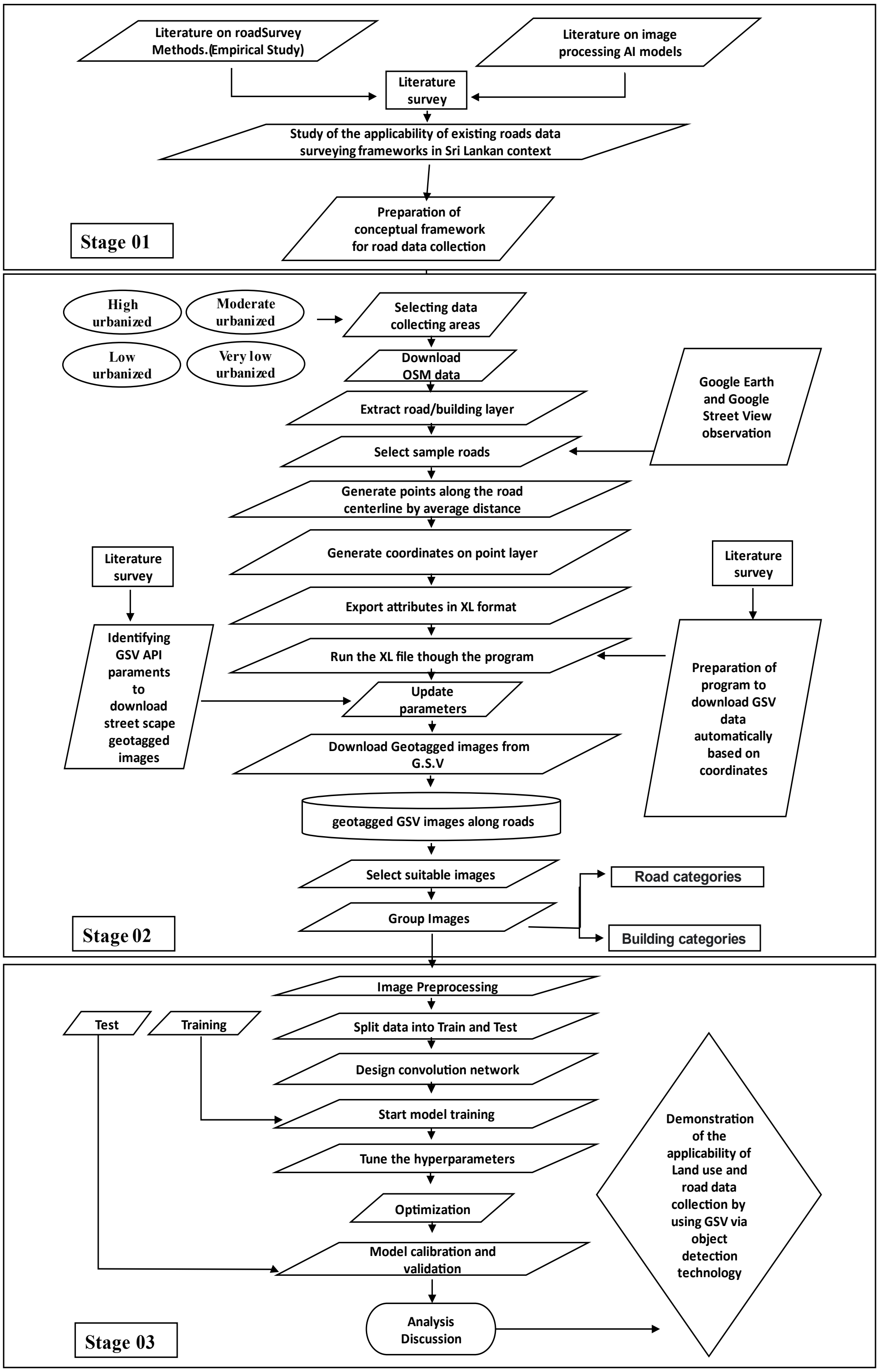

Figure 1: Research Design

The findings of this study may contribute to a more accurate approach to capturing the road information that may be essential for future transportation management and development, land use visualisation, and land value capture models.

The rest of this paper is organised as follows: the model formulation section discusses the proposed analytical framework; it is followed by the accuracy assessment; analysis and results; and the conclusion of the study.

2. MODEL FORMULATION

Literature review, model development, application, and validation were the main steps of model formulation. This literature review has two main components. The first component examines existing road and building classification systems. Different road categorisation and building use mapping methodologies were studied at this point. In the second component, the efficacy of several models in identifying urban features, the limitations of existing classification methods, and the limitations of using global approaches in Sri Lanka were reviewed.

Following this, a semi-automated framework was formulated to circumvent the aforementioned limits. Therefore, the Road Category Model (RCM) and the 3D Urban Visualisation Model (3D UVM) were developed as core elements of this study. The main technical approach employed to develop this framework is deep learning (DL). Finally, a demonstration was carried out to test the validity of the suggested framework, and an expert interview survey was conducted to determine its efficacy in Sri Lanka. This section delves into the framework's development in depth.

2.1. Proposed Framework

The Road Classification Model (RCM) and 3D Urban Visualisation Model (3D UVM) are included in the proposed framework. Both models employ GSV pictures and OSM data as their primary inputs. Apart from these, Digital Elevation Model (DEM) was the secondary input for 3D UVM. OSM data was extracted using QGIS software, while GSV photographs were retrieved using custom Python software.

The primary processing phases for each model are explained in the sections that follow.

2.1.1. Road Classification Model (RCM)

As part of the RCM model's initial process, polyline properties needed to be retrieved from the extracted OSM data. This data consisted of five categories. Significant road layers were then necessary to choose amongst the transportation routes. Following the selection of road layers, sample points and road segments were identified.

Using QGIS geometry tools, the GPS information for the attribute table of the point layers were updated. The GSV image processing model was employed in the second stage of data processing, which was the most important phase. Using updated GPS coordinates and proper parameters, the Python script collected GSV pictures of the roadways. The georeferenced GSV images for the defined locations were then directly downloaded. The image processing model was then assigned to work with these GSV images. Each image categorised as two-lane demarcated asphalt, two-lane not demarcated asphalt, one-lane asphalt, one-lane concreates, two-lane concrete, and four-lane asphalt roads.

2.1.2. 3D Urban Visualisation Model (3D UVM)

Building footprints were extracted from the OSM polygon layers. The same method as in RCM was employed to produce a GPS point layer for specified road layers. As a result, based on context, the distance between points needed to be maintained. The 3D UVM then functioned similarly to the RCM. This model can predict GSV images in four different categories since it has been trained to distinguish commercial and residential buildings into two height categories (one storey and two or more floors). In the building footprint layer, the height and building use information were modified. Finally, the new building footprint was merged with the DEM layer using the Agis threeJS plugin.

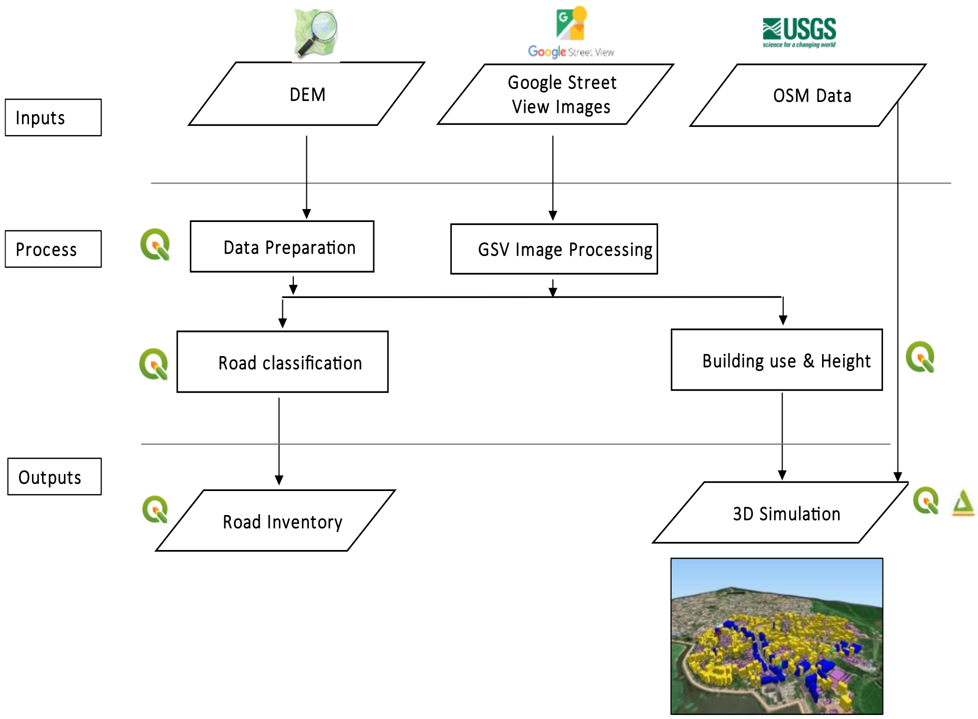

Figure 2: Structure of the Proposed Framework

Figure 2 depicts the combined processes of both models. The major outputs of the framework are 3D urban visualisation and information on road categorisation by location. Once both models are operational, users can construct a 3D urban environment by merging DEM with road layers, which specify road material and the number of lanes.

2.2. Testing of the Proposed Framework

Ranna, a locality in Sri Lanka's Hambantota district, was the study area selected for the testing/demonstration of the novel method. It was chosen as the most appropriate study area within walking distance of the research team because of COVID-19 and transportation restrictions that prevailed during the research period. Several types of roads exist within Ranna's borders. The location of the case study area is depicted in Figure 3.

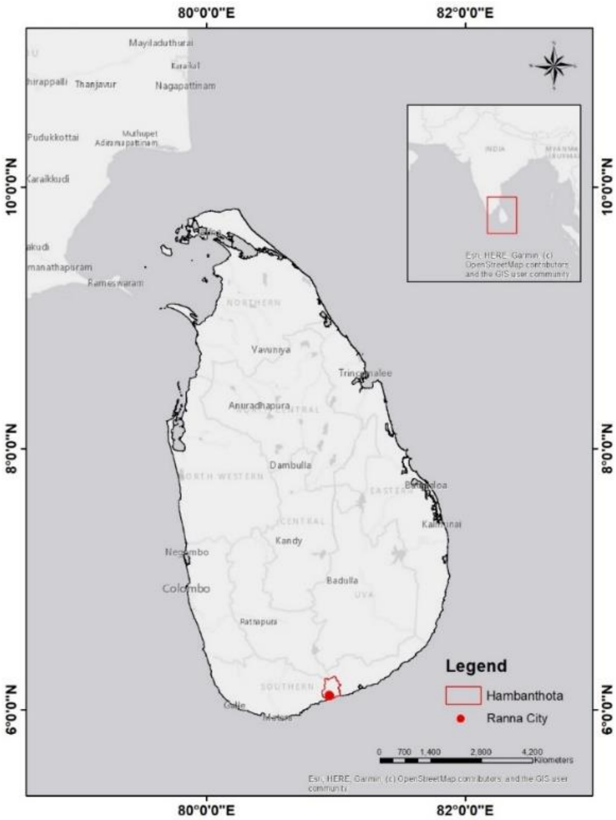

Figure 3: Location of Ranna in Sri Lanka

In a large urban centre, only commercial land uses may be seen along the roads. In small towns like Ranna, however, a single road might include a mix of land uses such as residential, commercial, and other uses. Table 1 summarises the basic profile of the location.

Table 1: General Information on Ranna

	Area (sq.m)	Population Density	Urbanisation Level
Ranna	4,276,409*	1656*	Relatively lower

Source: * Department of Census and Statistics, Sri Lanka (2012) Compiled by the authors

2.3. Data

The RCM was formulated using two key public data sources, as indicated in Table 2.

Table 2: Main Data Sources Used for RCM

Data	Source
OSM data	Open Street Map
Google Street View Images (GSV)	Google street view static API

Source: Compiled by the authors

The 3D UVM was created using data from four different sources (Table 3).

Table 3: Main Data Sources Used for 3D UVM.

Data	Source
OSM data	Open Street Map
Google Street View Images (GSV)	Google street view static API
Google Earth Image	Google Earth Pro
DEM	USGS Earth Explorer

Source: Compiled by the authors

OSM data is part of the VGA (Voluntary Geographic Information) collection, which is a widely available free and open-source resource. Table 4 shows the data extracted from the OSM for this study.

Table 4: Data Extracted from OSM

OSM Source	Extracted Data
Polyline	Road
Multi Polygon	Building footprint
Points	Industry, Education, Institute

Source: Compiled by the authors

GSV images were the other major data source in this study. GSV is the world's most widely employed streetscape data source. GSV images provide you with a 360-degree perspective of an area. GSV images were used to create road section views and streetscape view images in this research.

2.4. Data Preparation

OSM data acquired via QGIS open layers plugin under the data preparation. QGIS and Open Layers Plugins are freely available resources that can be used without financial outlay. The process of data acquisition is shown in Figure 4. According to this, transportation layers, POI data, and building footprint data were gathered from OSM.

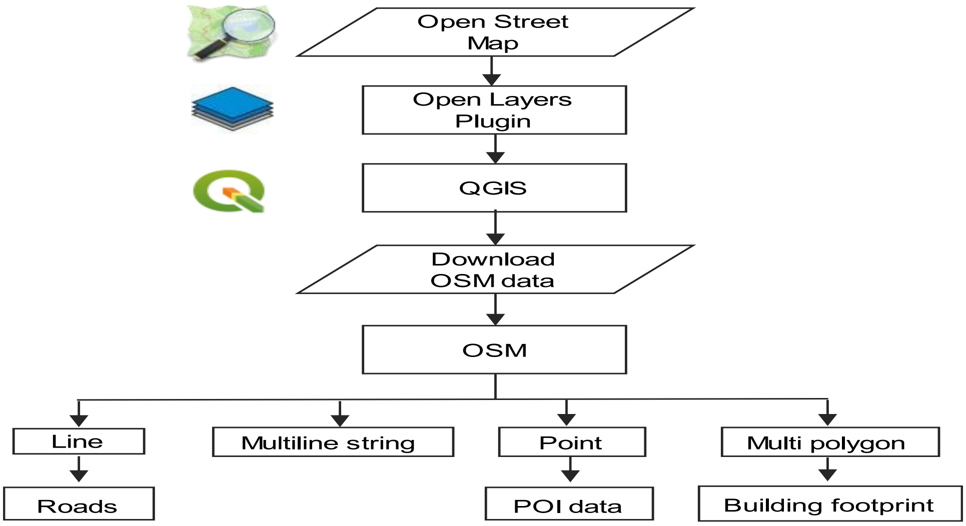

Figure 4: OSM Data Acquiring Process

GSV Statistic API was applied to acquire GSV images via an HTTP URL request. A python-based automated program was developed, as depicted in Figure 5, to capture GSV images based on the coordinates and the API parameters.

```
location = '6.02999718865,80.7931057252'
apiargs = {
'size': '600x300', # max 640x640 pixels
'location': location,
'heading': '210',
'pitch': '0',
'fov':'100',
'key': 'key'}
```

Figure 5: GSV API Image Extraction Parameters

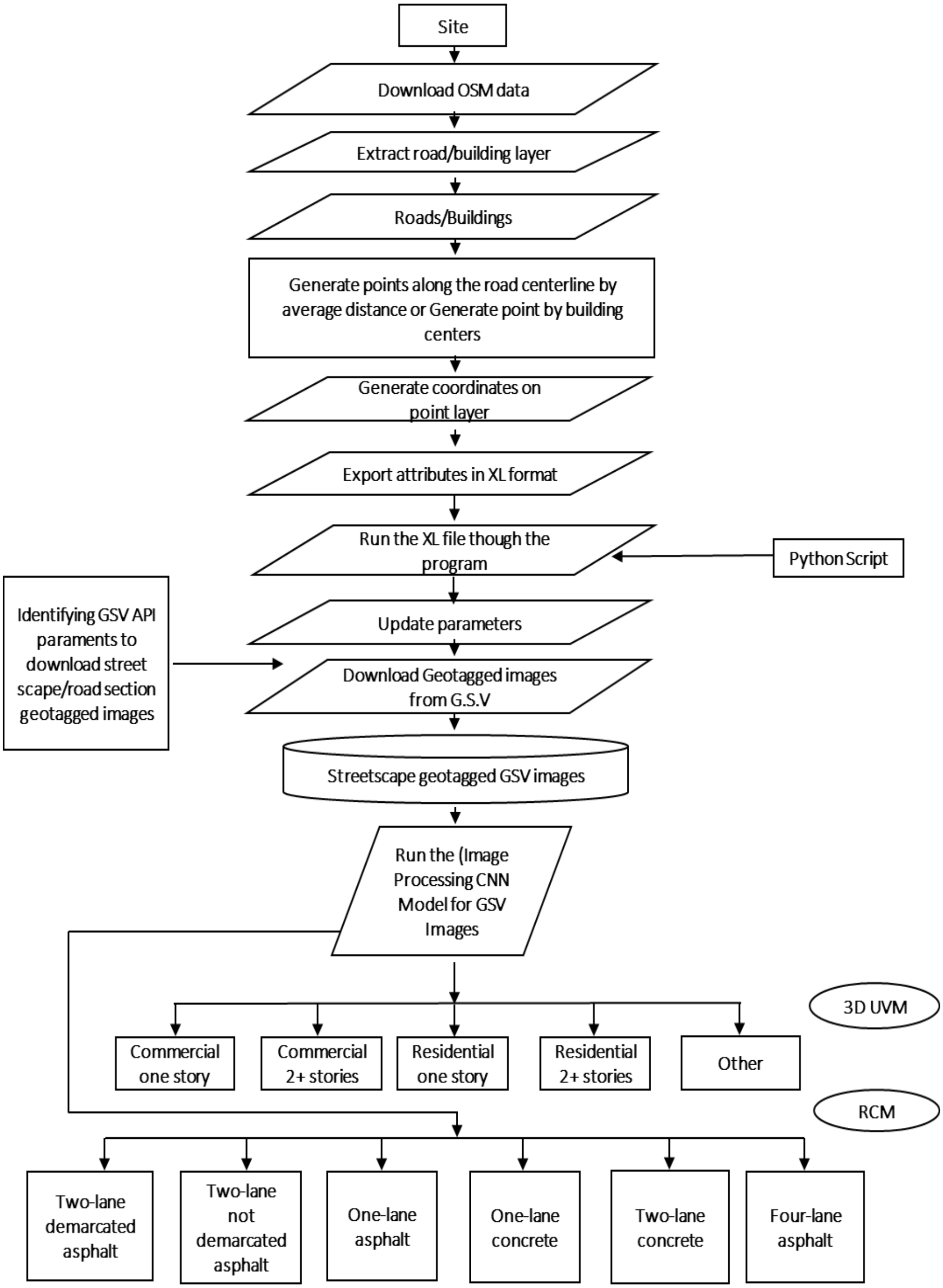

Figure 6: GSV Image Preparation

Figure 6 presents the GSV image preparation process. GSV images were also captured to their respective coordinates. The GPS positions of the selected roadways were prepared as part of that procedure. Highly urbanised, moderately urbanised, and low urbanised were the three urban classifications applied to pick routes for sample data collecting. As a result, 45 cities were chosen. Figure 7 exhibits some sample images from seven different cities.

Figure 7: A Collection of Sample Images from Different Cities in Sri Lanka

Subsequently, a point layer was created for each route that spanned a large distance. Later, a built python script was employed to retrieve GSV images from the road point locations with GPS information. For RCM training, images were categorised into two-lane demarcated asphalt, two-lane not demarcated asphalt, one-lane asphalt, one-lane concrete, two-lane concrete, and four-lane asphalt categories; for 3D UVM training, images were categorised into commercial single-storey, commercial two or more floors, residential single-storey, residential two or more floors, and other categories.

Figures 8 and 9 exhibit examples of the above-mentioned categories. In the RCM, 2500 images were gathered for each category, and 5000 for the 3D UVM. To extract road features, the dataset was optimised with multiple locations. Roads in developed areas, rural areas, and areas with vegetation cover are examples of location types. However, 3,046 images from the GSV collection have been altered by vehicles, humans, and vegetation. These images were deleted from the total of 50,000.

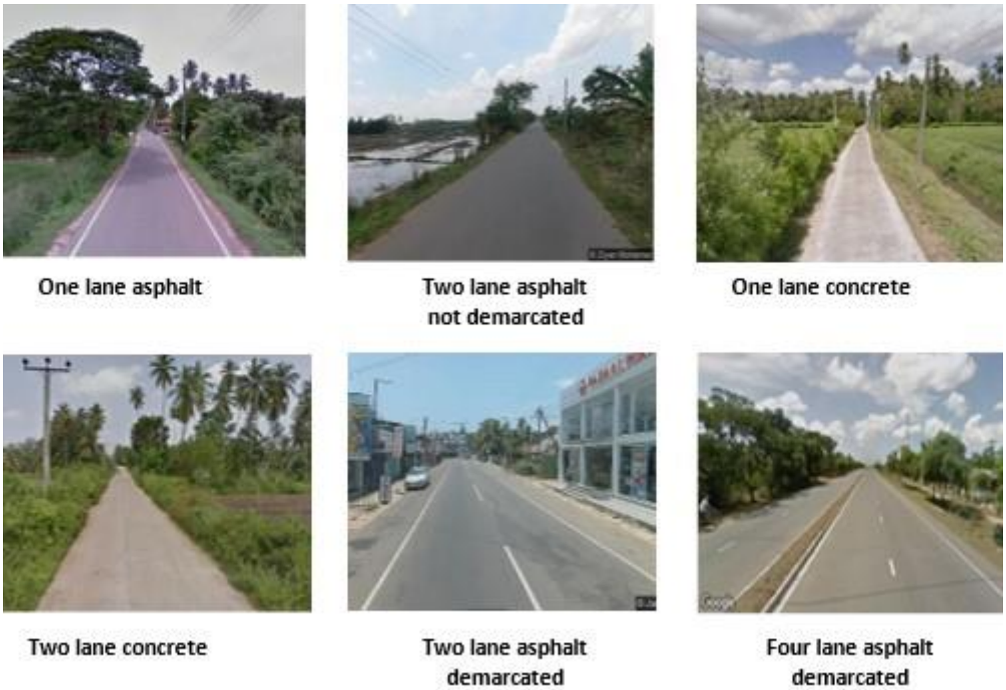

Figure 8: RCM Training Categories

Figure 9: 3D UVM Training Categories

2.5. Model Calibration

The image processing (IP) model is the centrepiece of this proposed framework. It was built with the "Keras" and "TensorFlow" libraries and Python was exploited as the programming language. The model was developed using the "transfer learning" technique in this study. As a result, it does not need a large number of training samples. Using classified GSV images, IP models were trained. 80% of the images were exploited to train the models, and 20% of the total images were utilised to test each model in the process. For binary classification, the sigmoid activation function was utilised. Therefore, the last layer was activated using SoftMax, whereas the middle levels were activated with "Relu" and model's optimiser was "adam." In addition, both models were built using the same CNN architecture. The mini batch selecting method was chosen at random in that process, and it was repeated to obtain a significant value while increasing accuracy.

SoftMax,

$$\sigma(z)_i = \frac{e^{z_i}}{\sum_{j=1}^{k} e^{z_j}} \quad \text{......} \quad (1)$$

σ = SoftMax

$\vec{z}$ = input vector

e^{zi} = standard exponential function for input vector

k = number of classes in the multi-class classifier

e^{zj} = standard exponential function for output vector

Sigmoid,

$$S(x) = \frac{1}{1+e^{-x}} \quad \text{......} \quad (2)$$

$S(x)$ = Sigmoid function

e = Euler's number

2.6. Model Validation

The validation and use of the framework in the study are discussed in this part. Six roads and structures along the designated roads were chosen considering the following factors.

(i) The GSV image quality of the roads.

(ii) Hierarchy of the roads.

(iii) 5 KM buffer from the town canter.

The study executed accuracy assessment in the RCM model, 3DUVM model separately. In addition, the effectiveness of the proposed framework was investigated based on an expert survey.

Under RCM validation, accuracy was first discussed with the testing dataset, followed by a comparison of model predictions and manual road category classification. Finally, the RCM model accuracy was determined using the kappa accuracy and confusion matrix.

$$k = (p_o - p_e)/(1 - p_e) \quad \text{......} \quad (3)$$

p_o = Probability of observed agreement.

p_e = Probability of agreement by chance.

Similar to RCM model validation, 3DUVM accuracy was discussed with the testing dataset first. After that, the 3DUVM model forecast was compared with the manual categorisation of the buildings. Kappa accuracy was employed to demonstrate the model correctness in the 3DUVM model as well.

To measure the effectiveness of the proposed framework and to identify limitations of the proposed framework in the real on-the-ground application, eight criteria were selected based on literature reviews. The rationale of conducting an expert survey was to evaluate the above-mentioned criteria. Thus, participants needed to know the existing LU mapping techniques, road inventory methods in Sri Lanka, and the proposed framework techniques.

A snowball sample method was employed to conduct the expert survey. Therefore, ten professionals were selected from different professions based on the expert recommendations. The professions and the institutional affiliations of survey participants are listed in Table 5.

Table 5: Participants in the Experts' Survey

Profession	**Institution**
Academic	University of Ruhuna
Town Planner	Urban Development Authority
Postgraduate Researcher	University of Huddersfield, UK
Surveyor	Survey Department Sri Lanka
Town Planner	Urban Development Authority
Surveyor	Survey Department Sri Lanka
Planner/ Scientist	National Building Research Organisation
Postgraduate Researcher	Osaka University Japan
Planner	General Sir John Kotelawala Defence University
Surveyor	Survey Department Sri Lanka

Source: Compiled by the authors

3. RESULTS AND DISCUSSION

This section delves into the evaluation of the proposed framework. First, trained models were tested using a testing image set. Both models were fine-tuned using test data. Therefore, both models were found more than 90% accurate with the training dataset (Figures 10).

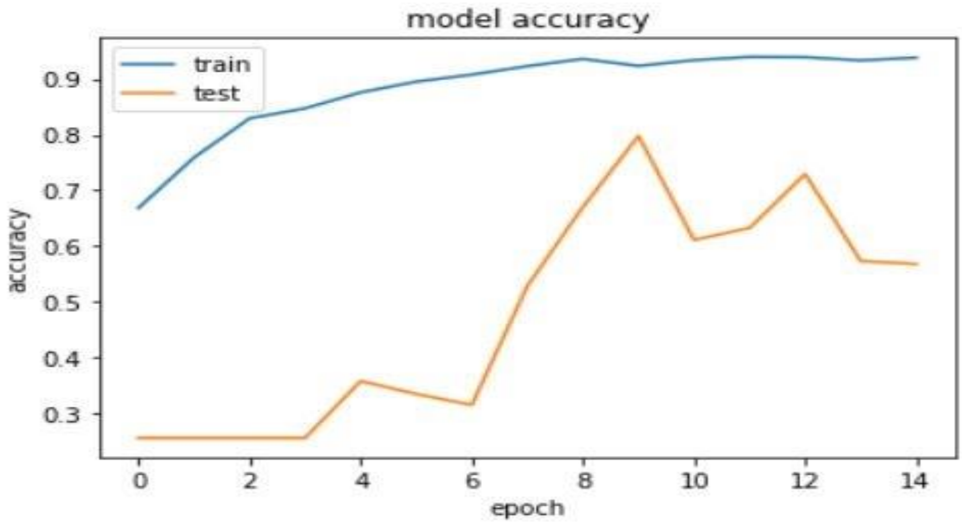

Figure 10: Testing of the Accuracy of the Model with Sample Data

3.1. RCM Results

As explained in the method, five different types of roads were chosen based on the road selection criteria. Figure 11 indicates the accuracy level for each road type. One-lane asphalt, for example, exhibited 100 % accuracy, which is significant in the RCM model. One lane concrete category had the lowest accuracy of 80%. Because Ranna is a small town, samples for the four-lane asphalt road category were not available. Most importantly, all road classifications had an accuracy rate of greater than 80%. The RCM accuracy of Kappa is 92%. Therefore, the RCM model was found to be useful in classifying road types in Sri Lanka.

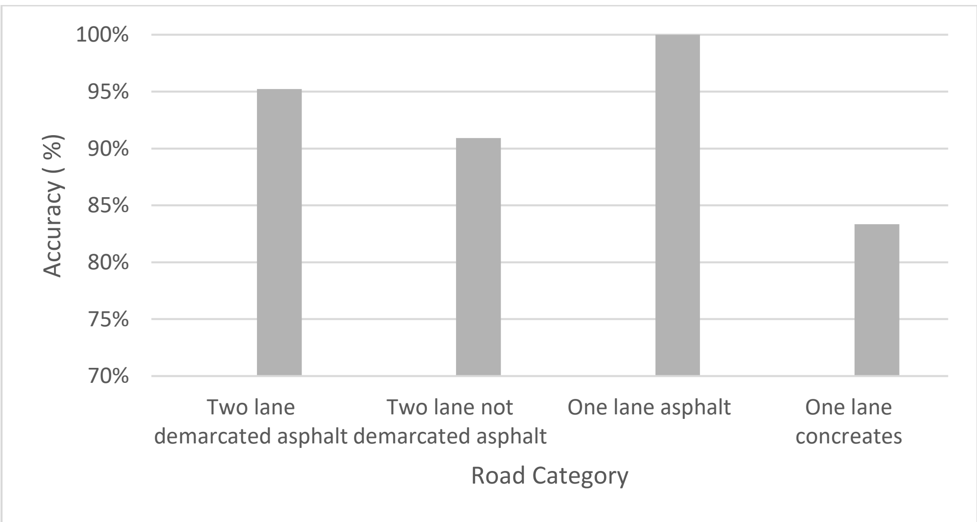

Figure 11: Level of Accuracy of the RCM by Road Types

Table 6: Level of Accuracy of the RCM Tested with Confusion Matrix

	Two lanes demarcated asphalt	Two-lane not demarcated asphalt	One lane asphalt	One lane concreates	Grand Total
Two lanes demarcated asphalt	95%	5%	0%	0%	100%
Two lanes not demarcated asphalt	9%	91%	0%	0%	100%
One lane asphalt	0%	0%	94%	6%	100%
One lane concreates	0%	0%	0%	100%	100%

Source: Compiled by the authors

According to the confusion matrix presented in Table 6, 5% of the images in the two-lane demarcated asphalt category were mislabelled as two-lane not demarcated asphalt. The road material in both groups is similar in this scenario. It demonstrates that the model correctly identified asphalt as road material. Furthermore, 6% of one-lane asphalt road images have been classified as one-lane concrete: this meant that although the model has identified the lane type, it had not identified the material. Therefore, the study was carried further to reveal the model's flaws. The failed images were then evaluated to determine the causes. The images that were incorrectly classified revealed other irrelevant features but not road components, according to the results. The reason for misclassification is the use of GSV images in this study. This can be avoided simply by visiting the location and capturing geotagged photographs instead of GSV images.

3.2. 3D UVM Results

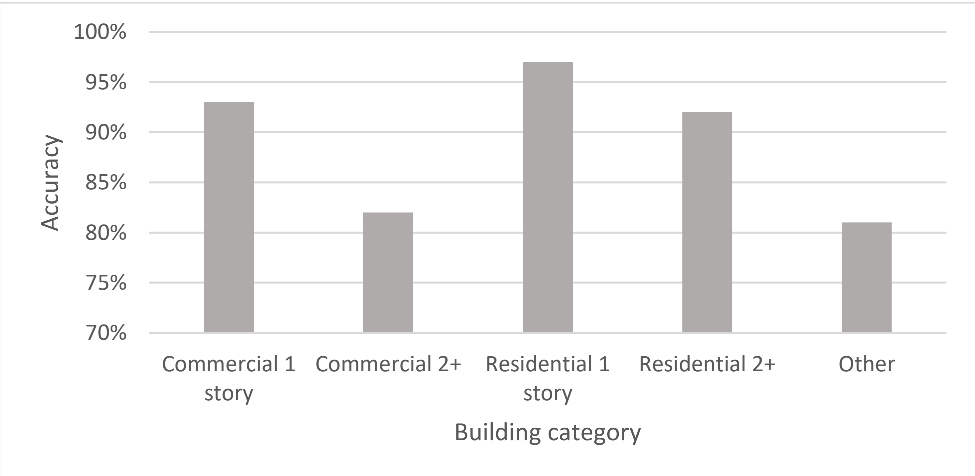

Figure 12: Level of Accuracy of the UVM by Building Category

According to the accuracy level of the 3D UVM model which presents by Figure 12, the highest accuracy shows in the residential one-story category that is 97%. The commercial one-story category shows the second-highest accuracy that is 93%. Also, the residential two or stories category shows a 92% level of accuracy, and the commercial two or more stories category shows 82%. Significantly, all the categories of the 3D UVM show an accuracy of more than 80%. At the same time, 3D UVM models' kappa accuracy is 90%. Therefore, the 3D UVM is significant on building category and height identification in the SL context (Figure 13)

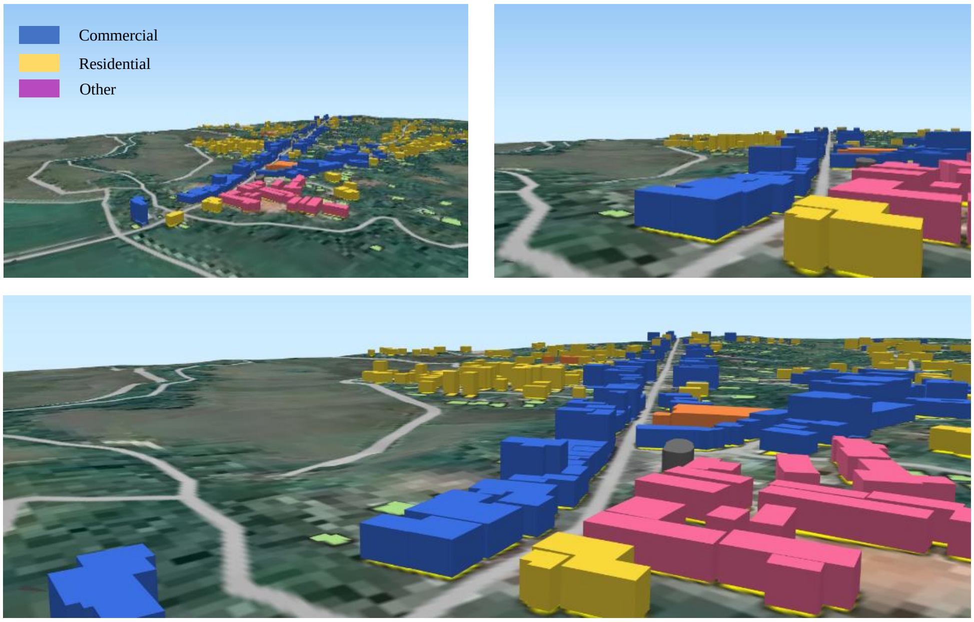

Figure 13: 3D Urban Visualisation - Ranna

3.3. Effectiveness of the proposed framework

According to the expert survey results in Figure 14, the proposed framework scored highest in terms of cost-effectiveness, time effectiveness, efficiency, labour effectiveness, and the level of importance in planning: these demonstrated the higher effectiveness of the proposed framework. And usability, learnability, and applicability in the Sri Lankan context indicate moderate effectiveness. However, the expert survey proved that the efficiency of the proposed framework is significant under the selected criteria. In concluding the effectiveness analysis, none of the parameters scored less than 3 and most of the parameters have scored more than 3 value range. Therefore, it proves that, in terms of all parameters, the proposed framework is effective in the Sri Lankan context. Therefore, the study has successfully achieved its objectives by developing an effective framework to classify roads and built-up land use.

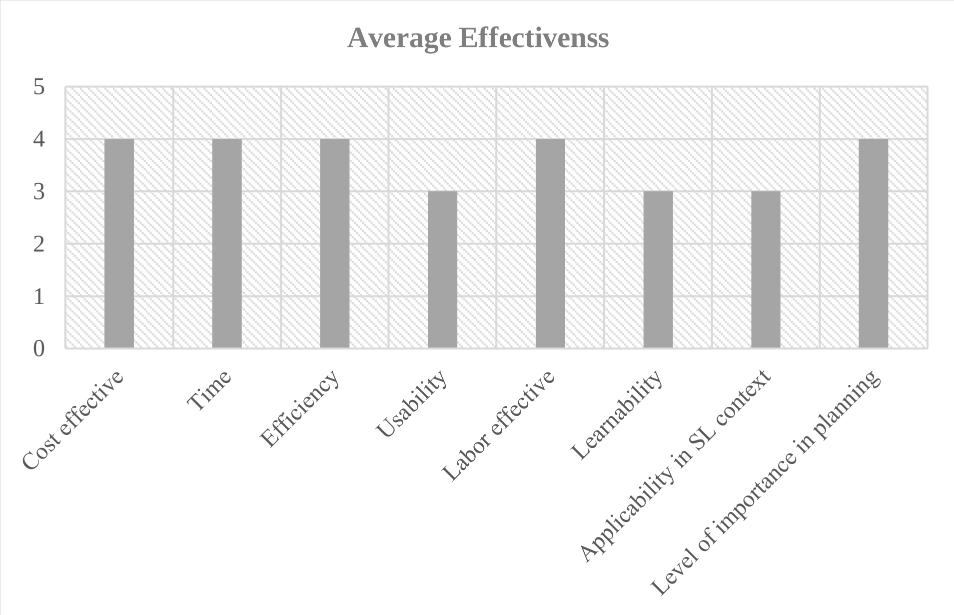

Figure 14: Effectiveness of the Proposed Framework

4. CONCLUSION

The key contribution of this work is the development of a methodology to collect road inventory information and map buildings with their uses and heights in urban areas. The study uses state-of-the-art of deep learning technologies and GIS mapping techniques. Field surveys are currently conducted to acquire road inventory data. This method is inefficient, time-consuming, and, most critically, cannot be updated on a regular basis. At the same time, due to a lack of data sources and mapping methodologies, little emphasis has been paid to mapping 3D land uses. Therefore, the proposed framework has effectively fulfilled the study's goal of providing an efficient framework for collecting road inventory information with 3D land use. Furthermore, the use of deep learning and GIS, both of which have superior performance and methodologies, brought further value to the proposed framework.

The proposed framework yielded KAPPA accuracy of 92% for the road inventory information surveying model and 90% for the 3D urban visualisation model, according to the research. As a result of the model's accuracy, the proposed framework is ideal for collecting road inventory and 3D land use data. Furthermore, expert discussions through detailed interviews suggest that the framework can be applied to the Sri Lankan setting. Therefore, key findings demonstrate that the study has built an efficient, financially feasible, labour-effective, and accurate framework for collecting road inventory and urban visualisation. Despite the fact that the study achieved its aims, it is not free from limitations. These can be found in a critical review and that may be addressed in future research. The first such limitation is the framework's applicability, which is dependent on GSV image coverage. Because the GSV databases in developing nations do not cover the entire road network. Second, since GSV images are not updated on a regular basis, output information will not be updated. However, these limitations can be addressed by employing a variety of data sources. Therefore, more research utilising a variety of AI techniques and data sources is required. Also, the testing of the framework and the model was limited to one particular study area. However, it is essential to test it in more areas to generalize the validity of the proposed framework. Although the framework has several limitations, the paper presented an effective application for collecting road inventory and 3D land use data, that was tested in Sri Lankan urban area. Since this framework can use streetscape images to map building uses and collect road data, it can be given inputs with manually collected images for higher accuracy. Therefore, those involved in transportation planning and management, urban development, and the similar engagements can employ the proposed framework to collect road information and 3D land use data for the purpose of developing effective transportation management and urban planning strategies that will lead to sustainable development.

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FACTORS INFLUENCING ELECTRIFICATION OF URBAN FREIGHT VEHICLES: A CASE STUDY OF THREE INDIAN CITIES - AHMEDABAD, DELHI, AND SURAT

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ABSTRACT

India's high levels of transport-related air pollution endanger public health. The transition to electric mobility will address this challenge while also reducing the country's dependence on oil imports. The Government of India has offered incentives to electric vehicle manufacturers and purchasers that promote faster adoption of electric vehicles. The states have framed electric vehicle policies offering additional fiscal and non-fiscal incentives supporting this objective, but the adoption rate of electric vehicles in India is far below expectations.

This paper aims to understand the factors that influence the electrification of urban freight vehicles. It does so with reference to urban freight movements linked to textile markets in Ahmedabad and Surat, and the fruit and vegetable market in Delhi.

By studying these, it attempts to assess the impact of key policy and market conditions on the adoption of electric vehicles. Based on stakeholder perceptions, it further tries to identify the enablers and barriers to the electrification of urban freight vehicles.

Keywords: *Electric Freight Vehicle; Urban Freight Vehicle; Case Cities; Total Cost of Ownership; Potential Shift*

1. INTRODUCTION

India has signed the Paris Agreement, committing to reduce the greenhouse gas (GHG) emission intensity of its GDP by 33–35% of its 2005 levels, by 2030 [1]. In 2017, Niti Aayog, a public policy think-tank of the Government of India (GoI), released a roadmap for adopting electric vehicles (EVs) in India.

Key objectives of the policy were to reduce India's oil consumption for transportation needs, reduce its impact on pollution, enable better transportation mode choices, facilitate customer adoption of electric and clean energy vehicles, and encourage technology enhancements for faster adoption, adaptation, research, and development of EVs [2].

The Government of India offers financial incentives under the FAME (Faster Adoption and Manufacturing of Hybrid and Electric Vehicles) scheme, of which the primary focus has been the electrification of public transport (buses), taxis, two-wheelers, four-wheelers, passenger three-wheelers, and freight three-wheelers.

Freight vehicles in urban environments produce more emissions than passenger vehicles [3]. Difficulties in loading and unloading and navigating traffic to serve last-mile deliveries often contribute to local air pollution, affect urban air quality, and ultimately impact people's health.

In India, light commercial vehicles (LCVs) accounted for 26.9% of the total registered vehicles in 2017; 16.2% of them were four-wheelers and the remaining 10.7% were three-wheelers [4]. Most urban freight vehicles at the city level run on diesel and are a critical source of GHG emissions [5]. Therefore, it is imperative that these are considered under the electrification strategy.

There are several benefits to switching urban freight vehicles (UFVs) from internal combustion engines (ICEs) to electric power. The benefits, when compared with ICE vehicles, are that electric vehicles result in reduced air emissions, lower noise levels, provide greater driving and riding comfort for drivers and passengers, and incur lower energy and maintenance costs; leading to an overall reduction in operating costs [5].

However, despite these apparent benefits, the adoption of EVs in general and urban freight transport in particular, remains below expectations. Total EV sales in 2021-22 were 276.3 thousand, of which only 971 (0.35%) were freight vehicles and three-wheelers, including passenger vehicles, were 126. 7 thousand (45.87%) [6].

The electrification of freight vehicles will be challenging due to the complex nature of the sector, which is characterised by informal operations, small vehicles, and multiple stakeholders. The public sector has a limited role in the urban freight EV transition decision process, which also constrains the adoption rate.

2. LITERATURE REVIEW

In addition to the environmental benefits of EVs when compared with conventional fuelled vehicles, several other considerations influence the decision of UFV operators to switch to EVs. They may be grouped into technical, economic, market, and policy and regulatory considerations. Additionally, the potential buyer's characteristics also influence the decision. The technical factors include battery size and range, charging time and station access, capacity and energy quality, and reliability; the economic factors include the comparative costs of ownership and operations, and access to finance. The market factors include the availability of electric vehicle models, the availability of spares, and the presence of servicing infrastructure [7] [8]. Analyses of the EV potentials in commercial transport have shown that, in terms of trip patterns and daily mileage, EVs are suitable for urban freight transport and city logistics [9]. However, due to high battery costs, the upfront costs of EVs are 1.5 to 2 times the costs of diesel or CNG vehicles [10].

Due to the high cost of batteries and their weight, manufacturers tend to optimise the size of the battery pack. This has a direct impact on the potential range per charge, vehicle capacity, and energy efficiency. The range is a limiting issue and depends entirely on the city's logistics operations [11]. To overcome the limitation on the range potential, the options explored are opportunity charging or swap. Long charging times limit the operational flexibility of commercial vehicles. The ecosystem to provide for battery swap is yet to evolve. According to a survey, many fleet operators are also resistant to electric freight vehicles (EFVs) unless they can be assured that quick repairs can be made to their vehicles to avoid extended periods of downtime [12]. Failing batteries support, equipment availability issues, long charging times, and the need to adapt charging infrastructure for fleet demands were all identified as technical issues [13].

The average payload of e-commerce delivery may not be a range killer (they usually "space out" before "weighting out"), but several other factors, also applicable to ICE vehicles, will affect range. Factors that affect battery life include payload (including goods/tonnage), road slope, driving style, speed, weather, driving surface, battery state of charge, ambient temperature, and battery degradation over time—which reduces maximum charge capacity [14]. The cost-parity of EVs with diesel, petrol, and CNG vehicles is a necessary condition for wider acceptance. It is widely accepted that EVs have a high purchase price compared to petrol or diesel-fuelled counterparts, primarily driven by R&D costs [15] and the need for additional components such as battery packs. These costs are passed on to consumers [9]. While initial capital costs are higher, the operating costs of electric vehicles are much lower. A comparison of the available models in terms of cost economics is necessary to assess the potential for EV adoption. A Total Cost of Ownership (TCO) model, which includes capital and operating costs of the vehicle over the life of the vehicle, could be used to analyse the cost-parity of electric vis-a-vis conventional vehicles [10]. To bring cost-parity, national and state governments have provided fiscal and non-fiscal incentives. The fiscal incentives include subsidies for the purchase of vehicles and the establishment of public charging infrastructure. Some states have also waived the registration charges for EVs [16].

The market factors in terms of product choices, the existence of critical mass, and the availability of infrastructure should also be assessed while analysing EV adoption scenarios [11]. The limited availability of standard vehicles and vehicle types (particularly for larger vans and trucks) has been noted as a significant barrier to the introduction of EFVs [13]. It is noted that several initiatives, aimed at fostering the use of EVs by public bodies and politicians have proven less successful than expected. Lack of knowledge and information among companies is the most inhibiting factor [9]. The potential buyer characteristics in terms of socio-economic characteristics, their awareness about the market, ownership characteristics, and UFV operating characteristics would also influence the decision to electrify.

3. OBJECTIVES, APPROACH, AND METHODOLOGY

In the light of the above, the primary objective of this paper is to understand the factors that influence the electrification of urban freight vehicles. More specifically, the paper addresses the following questions:

- What are the characteristic features of freight mobility in the three case cities for select commodities? What are the operational requirements of UFVs?
- What is the status of the electric vehicle offering for urban freight transport in India? What types of EFV models are available? How suitable are they for urban freight transport?
- What are the potential shifts to UEFVs under various policy and market conditions?

The paper assesses the urban freight movements in the case cities of Ahmedabad, Delhi, and Surat. It attempts to identify key factors influencing the adoption of EFVs and to assess the impact of key policy and market conditions on such adoption. Of the case cities, Ahmedabad and Surat are located in the state of Gujarat, and Delhi is a city-state. Gujarat and Delhi are front runners in the promotion of EVs in India. The freight movements in cities are anchored on commodity-specific markets or industrial nodes. This paper focuses on textiles in Ahmedabad and Surat, and fruits and vegetable distribution in Delhi as these contribute to significant externalities in respective cities [17] [18] [19]. The markets for primary surveys were identified after studying various commodities, total intra-city trips made to transport the commodity, total tonnes carried, and potential for faster electrification.

The paper is organised into seven sections. In the first, we set the context for the study. A brief literature review on factors influencing UFV transition to electric vehicles is presented in Section 2. The objectives, approach, and methodology of the study are presented in Section 3. Section 4 presents a review of the status and trends in electric vehicle use for urban freight transport in India based on market analysis. Freight mobility characteristics in case cities are assessed based on a primary survey of UFV operators: these are presented in section 5. The suitability of EFV for urban freight transport is assessed based on the available vehicle models vis-a-vis the requirements derived from primary surveys; these are presented in section 6. As a part of this, a comparative assessment of the electric vehicles to conventional fuel freight vehicles is done adopting the TCO approach. Various policy and market scenarios are constructed, and utilising Stated Preference Analysis, the market potential of EFVs is assessed and presented in section 6. Section 7 concludes the paper.

4. URBAN ELECTRIC FREIGHT ECOSYSTEM IN INDIA

An electric mobility ecosystem includes the physical components like EV models, an energy source within the vehicle (i.e. battery), a charging mechanism for the battery, a source of energy to the battery (i.e. electricity from the distribution network with defined mechanisms); and stakeholders. The urban electric freight ecosystem in India has been detailed in this section.

4.1. Urban Electric Freight Vehicle Models

In India, EFVs may be two-wheelers, three-wheelers, or light commercial vehicles (LCVs). Two-wheelers are used for less than 30 kg delivery of lightweight Business to Consumer (B2C) parcels (groceries, food parcels, e-commerce shipments), whereas three-wheelers and LCVs are used for heavyweight B2C parcels (furniture, electric appliances) and B2B supply from manufacturers to retail shops (Fast Moving Consumer Good (FMCG) supply). These vehicles are being targeted because of their price competitiveness with ICE vehicles, ease of setting up charging stations given their use in a hub-and-spoke model, and high utilisation rates as Business to Business (B2B) and B2C supply accounting for 40% of all logistic movements in the country [20].

The paper explores E-three-wheelers and E-LCVs, as they are used on a large scale for deliveries in wholesale markets involving a large number of unorganised transporters. This segment of vehicles has been unexplored for electrification. Currently, available models are in the E-three-wheeler category. Only one model is available in the E-LCV section with a 0.75-tonne capacity catering to the last mile urban freight movement. However, the market is evolving and new models of EFVs are anticipated across all payload categories.

4.2. Batteries

A battery impacts the driving range and charging time of the electric vehicle. Lithium-ion is currently the most widely used battery type. The battery capacity of goods vehicles is marginally (1.5 kWh) higher than that of corresponding passenger vehicles. The battery capacity of an E-three-wheeler is between 4.8–7 kWh, and for an E-LCV with a payload of 0.75–1 tonne, it is about 20 kWh. The battery can be fixed or detachable, with an on-board or off-board charger; these influence the charging mechanism. The battery can also vary based on input voltage; impacting charging time. Table 1 shows a few Indian battery manufacturers and their battery specifications. Different vehicle manufacturers have paired with battery manufacturers to introduce EFVs.

Table 1: Battery manufacturers with battery specifications

Manufacturers | Providers	Chargers	Battery Type	Battery voltage
Gayam Motor Works	Onboard	Detachable	48 V
DOT	Onboard	Detachable	60 V
Lithium Power	Off-board	Detachable	48 V
Technigence	Off-board	Fixed	48 V
Omega Seiki	Offboard	Detachable	48 V

Source: [21]

4.3. Charging Infrastructure

Charging infrastructure varies according to the combination of vehicle and battery specifications used. For in-home charging of EFVs, a 15A socket suffices; public charging stations are subject to standards set by the Ministry of Power, Government of India. Bharat DC 001 can be used to charge E-three-wheelers and Bharat AC-001 can be used for E-LCVs. Swapping stations are currently limited to E-three-wheeler, and no standards have been set, as swapping varies according to battery design and hence the manufacturer.

4.4. Others

The EFV ecosystem components also include owners (transporters or drivers), battery and charging infrastructure manufacturers and providers - Original Equipment Manufacturers (OEMs), and Distribution Companies (DISCOMs), and lastly, the regulatory bodies which are planning and development organisations.

5. FREIGHT MOBILITY IN CASE CITIES

A primary survey was carried out at three identified markets of the case cities—Ahmedabad, Surat, and Delhi—to understand urban freight mobility. The primary survey included a sample size of 100–120 freight three-wheeler and LCV fleet owners per city. The current vehicles and operational characteristics provide inputs to the definition of UEFV requirements. In this section, we describe vehicles, supply chain, operator and operating characteristics.

5.1. Case Cities

Ahmedabad, with over seven million people, is the seventh-largest metropolis in India and the largest in the state of Gujarat. Historically, Ahmedabad has been one of the most important centres of trade and commerce in the western part of India. The city is the second-largest producer of cotton in India and has an economy primarily dependent on textile, pharmaceuticals, and natural gas [17]. The city was also known as the 'Manchester of India' on account of its textile industry. The total number of registered vehicles, in the year 2021, in Ahmedabad was 0.12 million, of which 2,204 (1.83%) were freight three-wheeler vehicles and 2,549 (2.12%) were LCVs. Much of the textile commodity movement is linked to the new cloth market located in the old city of Ahmedabad near the main railway station. Over 300 wholesale agents operate from the market. An estimated 2,727 freight vehicles (1,841 3-wheelers and 886 LCVs) operate through the market.

Surat is India's eighth most populous city and the second most populated city in Gujarat. The city houses a population of 4.5 million and spans an area of 1351 sq. km [22]. Surat is known as the textile hub of India. There are 10 textile industrial zones, 125 thousand textile units, 165 textile markets, 65,000 wholesale agents, and 75,000 textile shops in the city, mainly being concentrated on the inner ring road [18]. The total number of registered vehicles in Surat was 0.13 million in 2021, of which 1,617 (1.24%) were three-wheeler freight vehicles and 1,457 (1.12%) were LCVs. An estimated 4,442 goods vehicles (2,074 3-wheelers and 2,368 LCVs) operate through the market.

Delhi, the National Capital Territory of Delhi (NCT), is spread over an area of 1,484 sq. km and houses a population of 16.78 million [22]. 3.4% of the LCVs and HDVs contribute to 63% of GHG emission levels in the city. Urban freight trips identified within the city are 3.95 lakhs and constitute three percent of the total urban trips. The total number of registered vehicles, in the year 2021, in Delhi was 0.46 million, of which 2,555 (0.56%) were three-wheeler freight vehicles and 13,865 (3.02%) were LCVs. An estimated 16,119 goods vehicles (9,372 3-wheelers and 6,747 LCVs) operate through the market.

5.2. Freight Vehicle Operations in Case cities

The movement of commodities in Ahmedabad is linked to the manufacturing and distribution of textile goods. The textile supply chain is described in five stages. In the first stage, raw material (yarn) from outside the city reaches Ahmedabad's power looms to produce grey (greige) cloth. This cloth is transported to the textile market for further processing in heavy and medium commercial vehicles (HCVs and MCVs). Subsequently, in stages two and three, the cloth from the textile market is dispatched for processing (dying and printing) and the processed fabric is sent back for physical quality checks in LCVs. In stage four, the processed fabric from the textile market is sent to various small-scale retailers for trading or value addition in freight three-wheelers and two-wheelers. In the final stage, after the quality checks in the textile market, the processed and value-added fabric is sent to the warehouse or distribution centre for export in LCVs and freight three-wheelers. At various stages of the supply chain, the fabric is sent back to the textile market for quality checks, which results in significant empty vehicle trips. The supply chain is explained in Figure 1 below.

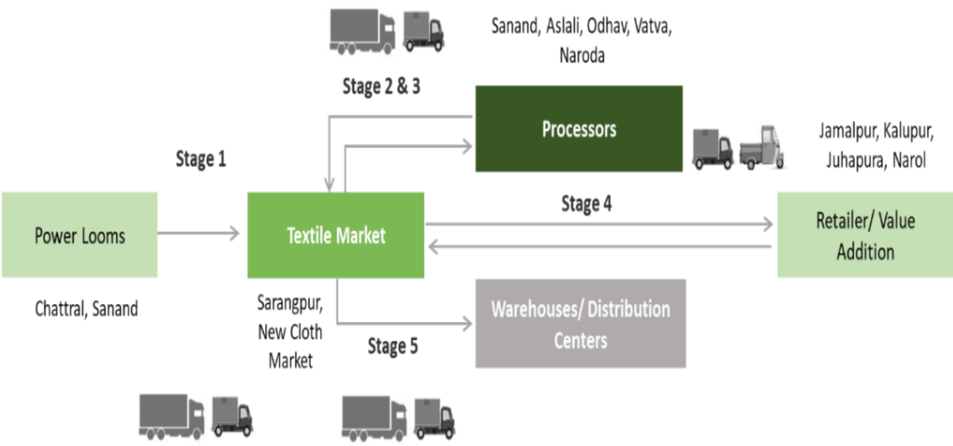

Figure 1: Diagrammatic representation of the stages of textile supply chain in Ahmedabad

The supply chain movement in Surat is similar to Ahmedabad except that the use of freight 3-wheelers and LCVs are predominant in stage one. This may be attributed to the large number of individual operators in Surat.

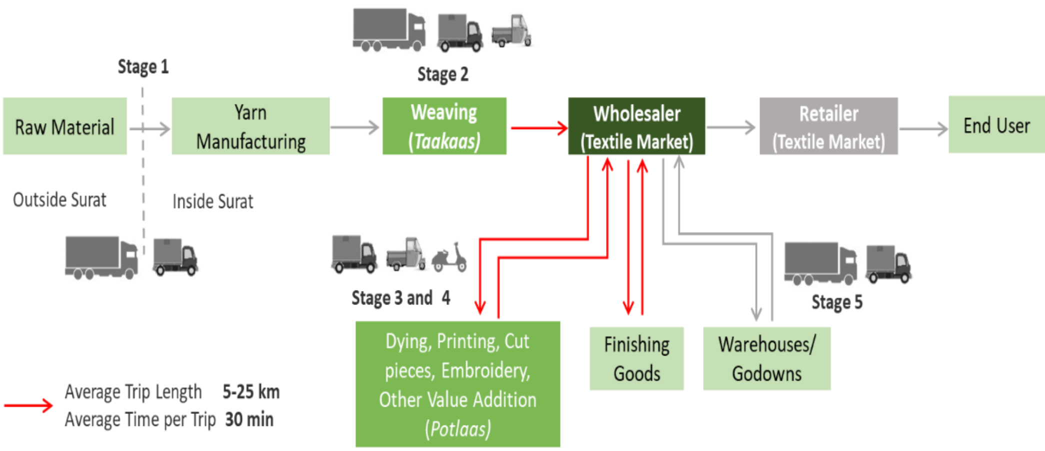

Figure 2: Diagrammatic representation of the stages of textile supply chain in Surat [18]

In the territory of Delhi, there are three Agriculture Produce Market Committee (APMC) *(mandis - consolidation centre)*, namely, APMC Azadpur, Keshopur, and Shahdara. These mandis receive the supply of fruits and vegetables from farmers. This produce is brought in large trucks. In stage 2, the commodity is distributed to several other local mandis located district-wise in LCVs, MCVs, and HCVs, depending on demand. From the local mandis, the produce is picked up by local fruit and vegetable vendors. Depending on the vendor operating capacity, the product is picked up by two to three vendors jointly riding with an LCV or by the vendors' themselves using LCV or freight three-wheeler. Cycle rickshaws and animal carts are also used for distribution purposes. Some vendors even directly purchase from the APMC.

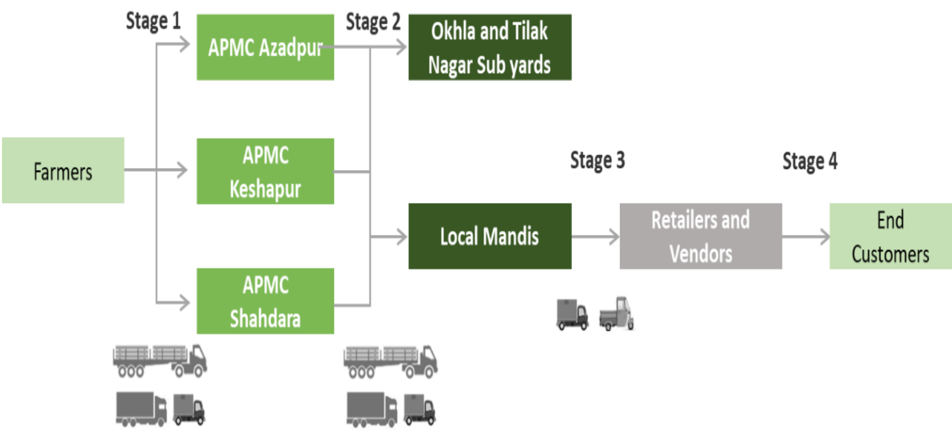

Figure 3: Diagrammatic representation of the stages of the F&V supply chain in Delhi [23]

6. SUITABILITY OF URBAN ELECTRIC FREIGHT VEHICLES

The suitability of the adoption of electric vehicles for urban freight transport is analysed in two parts. The first is in terms of the availability and specifications of the electric vehicles vis-a-vis the requirements, and the second, analysing the comparative economics of operations.

6.1. Requirements of UEFVs

The comparative UFV characteristics are presented in Table 2.

Table 2: EFV and Conventional Freight Vehicle Characteristics

Vehicle Model	Fuel Type	Vehicle purchase cost (in Thousands)	Payload (Kg)	Fuel tank capacity (L/Kg/kWh)	Fuel efficiency (Km per L/Kg/kWh)	Range (Km/Fill)
Freight 3-Wheeler						
Atul Shakti Premium	Diesel	225	575	10	35	350
Atul Shakti Delivery Van	Diesel	200	575	10	36	360
Bajaj RE Maxima	CNG	215	619	5.6	33	185
Piaggio Ape	CNG	224	494	5.1	24	122
Mahindra Champion	CNG	250	665	24	22	528
EV Option	Electric	120-273	310-550	4.3-7.4 CT* (3 to 8 hours)	18	70-130
Light Commercial Vehicle (LCV)						
Mahindra Supro	Diesel	650	1050	33	21.2	700
Tata Ace	CNG	500	640	12	20.1	241
Ashok Leyland Chota Dost	CNG	750	1208	21.6	15	320
EV Option	Electric	775-1081	600-750	14.4-20 CT* (4.5 to 8 hours)	8	112-120

CT* - Charging Time

Source**:** [24] [25]

From the table above, it is evident that the available non-EFV models have significantly higher payload and range. However, the requirements in urban applications require a lower payload and range. The surveys reveal that the urban freight operators own and operate the vehicles themselves. About 60% of vehicles are freight three-wheelers and 40% are LCVs. The case cities of Surat and Delhi have mostly single fleet owners whereas Ahmedabad has an equal mix of single and multiple fleet owners. The average age of the vehicles in the case cities is five to seven years. The operators have on an average expense of 25% of income on fuel, operation and maintenance (O&M), and parking fees, with a daily profit ranging between INR 700-1400. Their daily operations vary significantly by season and the day of the week. They, on average, perform seven to eight trips a day with an average vehicle utilisation of 60-80 km. In some cases, the maximum goes up to 110-130km; matching the range potential of currently available UEFV models.

All the case cities have drivers with multiple deliveries in a day and have 50-80% of the vehicles overloaded. The actual load carried often exceeds the capacity by 40 to 50%. This may still act adversely in deciding to shift to EFVs. There are also apprehensions expressed about the capability of EVs in negotiating flyovers with a full load. Charging infrastructure is an essential part of EV deployment. The available options include charging overnight when the vehicle is parked. The vehicles come with a charger and operators prefer home charging as it is an easier option. It is also to be noted that home charging is subject to domestic electricity rates, which are cheaper than commercial rates.

The operators are from poor economic backgrounds and have limited housing facilities. As they predominantly operate on an own-operate basis, they park on-street near home during the night time and in the markets during daytime. Provision of charging points at the markets is necessary to promote faster adoption of EFVs. In between trips, operators find adequate time for opportunity charging. As trip patterns are pretty well-defined, dependence on opportunity charging may not be an adverse factor for adopting EVs in urban freight transport.

6.2. Total Cost of Ownership

Based on the preliminary survey, it was also found that the higher purchase cost of EFVs may act as a barrier, but the lower O&M costs act as a significant enabler in increasing the willingness of shifting to EFVs. Considering the available vehicle choices in the market and the evolving EV ecosystem, the influencing factors streamlined are the capital and O&M costs, to be analysed adopting the TCO approach.

TCO of any mode of transport is a function of its capital and operational cost over its period of service [26]. TCO analysis also considers cost variation due to factors such as inflation, fluctuating battery cost, residual value or salvage value of the vehicle, and infrastructure after the period of service [27]. Sensitivity analysis for TCO calculations provides insights into the impact of factors such as vehicle usage, subsidies, and lower operational cost on vehicle ownership cost [28].

TCO is compared between ICE and electric vehicles for freight three-wheeler and goods LCV under the same payload capacity. ICE vehicles are considered to have CNG as the fuel type as per the government notification for freight vehicles to be CNG in tier-1 Indian cities; concurrently creating a constructive TCO comparison between the choice probable's.

The following assumptions apply:

- vehicles operate for 310 days for an average of 80 km per day with a design life of 15 years;
- the fuel rate of CNG is ₹ 53/kg and the electricity price is ₹ 4/kWh;
- fuel inflation rates are 3% and 1% per year for CNG and electricity respectively; as per WPI (Wholesale Price Index);
- cost of the workforce is assumed to increase by 3% per year, and the cost of the battery is assumed to be decreasing at 5% per year considering the trends from 2010 to 2020 [29];
- battery replacement is considered after every five years;
- cost of setting up charging infrastructure is reflected as 15% of the energy rate; and
- battery range of only 70% is achieved during operations.

Table 3: TCO Comparison Parameters

Parameters	**Freight 3-wheeler**		**Goods LCV**	
	Bajaj RE Maxima	Kinetic Safar	Tata Ace BS-VI	E-trio LCV
Model				
Fuel type	CNG	Electric	CNG	Electric
Payload (in kg)	470	550	750	750
Subsidy (FAME II)*	NA	42	NA	NA
Subsidy (Delhi State)*	NA	30	NA	NA
On-road price * (W/O Subsidy)	207	225	481	790
*All prices are in ₹ Thousand				

Source: [24] [25]

Under freight three-wheelers, Bajaj RE Maxima (CNG) is compared with Kinetic Safar (Electric); both having similar payload capacity. TCO per km of an ICE vehicle is ₹ 11.9 and for EFV is ₹ 9.8, i.e. profit per km for an EFV is ₹ 2.1. TCO of electric freight 3-wheeler is 17% lesser than CNG freight 3-wheeler and with the FAME II capital subsidy addition of ₹ 42,000, the difference increases to 18%.

Under goods LCVs, TATA Ace (CNG) is compared with E-trio (Electric) having similar payload capacity. TCO per km of an ICE vehicle is ₹ 19.7 and for EFV is ₹ 18.6, i.e. profit per km for an EFV is ₹ 1.2. TCO of E-Goods LCV is 6% lesser than CNG Goods LCV. Currently, there is no subsidy available on E-LCVs.

The above values have been calculated based on a daily operational distance of 80 km and price of CNG of ₹ 53/kg, whereas in the case of Delhi, the average operational distance under the fruits and vegetable (F&V) market is 50 km, and the price of CNG is ₹ 47/kg. Hence savings per km for electric freight three-wheeler changes to ₹ 1.9/km and that for E-LCV to ₹ 0.8/km. Thus, it can be deduced that the savings per km on electric freight vehicles increase with a longer operational distance. A summary of TCO across the three cities is given below in Table 4.

Table 4: TCO comparison across cities

Market Attributes	**Surat and Ahmedabad**				**Delhi**			
	Textile Market				**Fruits and Vegetables**			
Average trip length (km)	80				50			
Price of CNG (₹/kg)	53				47			
Vehicle	Freight 3-Wheeler		LCV		Freight 3-Wheeler		LCV	
Fuel type	CNG	Electric	CNG	Electric	CNG	Electric	CNG	Electric
TCO (₹/km)	11.9	9.8	19.8	18.6	17.3	15.5	19.4	18.6
O&M Cost (₹/km)	2.9	0.7	4.5	2.3	2.8	0.9	4.1	2.3

Currently, for urban freight trips, freight three-wheelers and goods LCVs have a strong presence in the market. The cost factors have a critical impact in choosing vehicles, and the comparative analysis of TCOs found that even when the TCO of EFVs is much lower than that of the ICEs, their initial capital cost is much higher. Upon operations, the ICE vehicles degrade, increasing the maintenance costs, which is not the case with EFVs with lesser moving elements. The total capital cost of E-Trio over its lifetime (15 years) is 40% (₹ 0.32 million) higher than Tata Ace (CNG), attributing to the higher initial capital cost, absence of subsidy, and battery replacement costs. However, the O&M cost of Tata Ace (CNG) is 57% (₹ 1.04 million) higher than E-Trio, attributed to the higher fuel and regular maintenance costs.

7. ESTIMATING POTENTIAL SHIFTS TO ELECTRIC FREIGHT VEHICLES

Stated preference (SP) methods are widely used in travel behaviour research to identify behavioural responses to choice situations that are not revealed in the market and where the attribute levels offered by existing choices are modified to such an extent that the reliability of revealed preference models acts as predictors of response [30]. The preferences would be input to the discrete choice model, formulated based on the utility theory and maximisation. The model estimates the exclusive choices to maximise the utility while considering the socio-economic conditions of the consumer [31]. The utility equation is expressed as a linear relationship of the independent variables.

The target year considered for demand estimation is the year 2030, in alignment with national targets. The vehicular freight growth has been estimated based on the growth rates from the vehicle registration data. The projected goods vehicles on the road by the year 2030 have been provided in Table 5 below.

Table 5: Growth of goods vehicles in the market

Attribute	Ahmedabad		Delhi		Surat	
	Freight 3-Wheelers	LCV	Freight 3-Wheelers	LCV	Freight 3-Wheelers	LCV
Registered vehicles (2016)	53,130	1,49,463	66,741	1,99,822	40,424	54,045
Growth rate	4%	2%	3%	5%	5%	4%
% Goods vehicle share in the market	5%	1%	20%	5%	5%	4%
On-road goods vehicles (2030)	2,561	1,023	12,811	9,576	3,123	3,448

Source: [19] [32]

7.1. Discrete Choice Model

In transport demand estimation, discrete choice modelling has been used for modelling mutually exclusive choices to achieve utility maximisation. The choice of the shift towards electric freight vehicles will depend on the vehicle operators and their weighted benefits against the use of existing ICE vehicles.

A stated preference survey is conducted with the freight operators of the respective case city markets based on existing (ICE) and proposed scenarios (electric) across combinations of show-cards. The scenarios are then converted into levels based on how the capital and O&M cost of the vehicle might increase, decrease or remain the same under different scenarios. The differences of electric freight vehicles based on capital and O&M costs are presented in Table 6 and this forms the base for setting the levels for existing and proposed scenarios.

Table 6: Setting attributes and levels based on operator survey

Type	LCV		Freight 3-Wheelers	
	Tata Ace	E-Trio	Bajaj RE Maxima	Kinetic
	ICE	Electric	ICE	Electric
O&M (₹/km)	3.63	1.58	2.85	0.78
Percentage difference	-	-60%	-	-70%
Capital purchase (₹ lakh)	4.81	7.92	2.07	2.25
Percentage difference	-	+64%	-	+9%

Through orthogonal design in SPSS, four-choice sets (showcards) are generated.

i. **Showcard 1** consisted of existing scenario 1 (E1) for purchase cost and O&M cost as same as of now and proposed scenario 1 (P1) has a purchase cost 20% more than ICE vehicle and O&M cost 85% less than ICE vehicle,

ii. **Showcard 2** consisted of existing scenario 2 (E2) as same as of now for purchase cost and O&M of ICE vehicles 20% more than the current scenario. Proposed scenario 2 (P2) has a purchase cost 20% more than ICE vehicle and O&M cost 65% less than ICE vehicle,

iii. **Showcard 3** consisted of existing scenario 3 (E3) 15% more than the existing purchase cost of ICE vehicles and O&M of ICE vehicles 20% more than the current scenario. Proposed scenario 3 (P3) has a purchase cost 15% less than ICE vehicle and O&M cost 65% less than ICE vehicle,

iv. **Showcard 4** consisted of existing scenario 4 (E4) 15% more than the existing purchase cost of ICE vehicles and O&M as now. Proposed scenario 4 (P4) has a purchase cost 15% less than ICE vehicle and O&M cost 85% less than ICE vehicle.

The show card chosen by the operator represents the combination of capital and O&M cost that maximises the utility. After entering the recorded choices, a binary logit model was run in SPSS to formulate the utility equations for proposed (P1, P2, P3, P4) and existing (E1, E2, E3, E4) scenarios. The output consists of beta (β) and significance value (Sig.), as shown in Table 7 below.

Table 7: Output sample for freight 3-wheeler under the textile market of Surat

		β	S.E.	Wald	Df	Sig.	Exp(β)	95% C.I. for Exp(β)	
								Lower	Upper
Step 1[a]	Purchase	-3.371	.390	74.67	1	.00	.034	.016	.074
	O&M	-9.140	4.753	3.698	1	.05	.000	.000	1.192
	Constant	9.317	.971	73.400	1	.00	4094.723		

a. Variable(s) entered on step 1:Purchase, O&M

Significance value determines whether the relation between the two attributes is significant or has come out by chance. A significance value less than or equal to 0.05 is statistically significant and a value greater than 0.05 is statistically insignificant. The utility equation is formulated by the summated product of beta (β) coefficients to the respective independent variables i.e. purchase and O&M cost. The utility equations obtained for different case cities are provided in Table 8 and are found to be statistically significant.

Table 8: Utility equations of different cities

City	Mode	Equation
Ahmedabad	Freight 3-Wheeler	(-0.178)*(Purchase Cost) + (-1.128)*(O&M Cost)
	LCV	(-0.223)*(Purchase Cost) + (-1.448)* (O&M Cost)
Surat	Freight 3-Wheeler	(-3.371)*(Purchase Cost) + (-9.140)* (O&M Cost)
	LCV	(-0.440)*(Purchase Cost) + (-2.326)* (O&M Cost)
Delhi	Freight 3-Wheeler	(-1.924)*(Purchase Cost) + (-7.801)*(O&M Cost)
	LCV	(-0.538)*(Purchase Cost) + (-3.701)*(O&M Cost)

The utility equations define the relationship between independent variables, and the values are derived for the proposed and existing scenarios. The exponential of the utility equation values for both the scenarios ($U_{proposed}$ and $U_{existing}$) is calculated (*Equation 1 and 2*) to identify the choice as provided in *Equation 3*.

$U_{proposed} = \ln[p/(1-p)] = (\beta1*(\text{Purchase cost}_{proposed}) + \beta2*(\text{O\&M cost}_{proposed})$ …*(1)*

$U_{existing} = \ln[p/(1-p)] = (\beta1*(\text{Purchase cost}_{exisitng}) + \beta2*(\text{O\&M cost}_{existing})$ ……*(2)*

$\text{Choice} = (U_{proposed})/((U_{proposed}) + (U_{existing}))$ ………………………………………*(3)*

Where,

"ln" is the natural logarithm,

"p/(1-p)" is the odds

"$U_{proposed}$ and $U_{existing}$" are utility values under the proposed and existing scenarios.

7.2. Scenario Classification – UEFV Demand

A sensitivity analysis on the utility equations (Table 8) for the year 2030 was carried out to understand the impact of capital and O&M costs on the choice shift from ICE to EFVs. The business as usual (BAU) scenario is derived without altering the purchase cost and considering the current fuel hike rate per annum. The existing fuel hike per annum is three percent for cities Ahmedabad and Surat and 1.2% for Delhi.

The scenarios have been developed based on the subsidy and fuel hike parameters directly related to the purchase and O&M costs. The provision of subsidies will reduce the purchase cost of the vehicle and shall attract more EFV operators. Currently, a subsidy of ₹ 40,000 (20% of vehicle cost) is offered on selected modes of freight 3-wheeler under FAME II and ₹ 32,000 (15% of vehicle cost) under Delhi EV Policy [33]. No subsidy is offered at the state level on E-freight 3-wheeler in Gujarat and at any level for E-LCVs. Based on this market understanding, for the sensitivity analysis, subsidies in a combination of 20% (only central subsidies) and 35% (state and central subsidies) are considered for both freight 3-wheelers and LCVs. Simultaneously, the O&M cost of ICE was increased with fuel hikes to attract more ICE users to EFV. Fuel hike per annum of double the existing values (six percent for Ahmedabad and Surat and 2.4% for Delhi) and 10% scenarios are considered for sensitivity analysis.

Thus, four scenarios are considered against the BAU scenario.

Scenario 1: 35% subsidy on purchase of new EFVs

Scenario 2: 20% subsidy on purchase of new EFVs

Scenario 3: 20% subsidy on purchase of new EFVs and double fuel hike

Scenario 4: 20% subsidy on purchase of new EFVs and 10% fuel hike

It shall be noted that the provision of subsidies and fuel hikes together will have socio-economic implications on the economy at a macro level, an understanding of which is beyond the scope of this research. The shift obtained in each scenario is applied to the growth of vehicles in respective markets identified in the case cities to find the on-ground electric freight vehicles by 2030; the summary is given in Table 9. The electric freight vehicles are also given as the percentage of the total on-ground freight vehicles.

Table 9: Scenario summary across cities

Scenario	Growth	Ahmedabad		Surat		Delhi	
		3-Wheeler	LCV	3-Wheeler	LCV	3-Wheeler	LCV
Business as Usual (BAU) scenario	% shift in 2030	51%	35%	43%	20%	67%	32%
	EFVs on road by 2030	497	40	335	184	2680	1826
	EFVs as % of total vehicles on the road	**19%**	**4%**	**11%**	**5%**	**21%**	**19%**
Scenario 1: 35% subsidy	% shift in 2030	54%	48%	93%	50%	78%	44%
	EFVs on road by 2030	514	49	688	354	2951	2261
	EFVs as % of total vehicles on the road	**20%**	**5%**	**22%**	**10%**	**23%**	**24%**
Scenario 2: 20% subsidy	% shift in 2030	53%	43%	80%	36%	66%	32%
	EFVs on road by 2030	508	45	651	317	2655	1826
	EFVs as % of total vehicles on the road	**20%**	**4%**	**21%**	**9%**	**21%**	**19%**
Scenario 3: 20% subsidy + double fuel hike	% shift in 2030	53%	44%	82%	37%	67%	32%
	EFVs on road by 2030	508	46	653	319	2680	1826
	EFVs as % of total vehicles on the road	**20%**	**4%**	**21%**	**9%**	**21%**	**19%**
Scenario 4: 20% subsidy + 10% fuel hike	% shift in 2030	54%	46%	86%	41%	73%	35%
	EFVs on road by 2030	514	47	673	346	2,829	1,937
	EFVs as % of total vehicles on the road	**20%**	**5%**	**22%**	**10%**	**22%**	**20%**

From Table 9, it can be deduced that in the BAU scenario, Delhi will have nearly 20% EFVs, whereas Ahmedabad and Surat will have only 5-10% EVFs. The impact on subsidies is found to have a positive shift to EFVs in all three case cities, whereas fuel hike scenarios did not have any effect. The fuel hike is found to be inelastic towards the shift to EFVs as the increase in fuel hike would compensate for the decrease in battery prices, thereby still of the need for subsidy allocation. NITI Aayog targets to achieve 30% EVs across all modes by 2030 [2], and for that, the government will have to provide subsidies at least to reduce the capital cost of electric vehicles or attract demand from ICE vehicles to EVs by raising CNG prices. It shall be observed from Table 9 that these efforts will not be enough as on-ground EVFs will still not reach the target across all scenarios for the case cities of Ahmedabad, Surat, and Delhi.

7.3. Economic and Environmental Benefits

Apart from the savings in the treatment of the vehicular emissions by shifting from ICE to EV, as TCO analysis shows, savings are also made from vehicle O&M cost as well. Together, these are considered as benefits to society due to the electrification of UFVs. The costs and benefits of the selected scenarios are analysed for the lifetime of the vehicle. The project's cost is the subsidies being proposed to be provided for the adoption of EFVs in the scenarios. The benefits are being analysed for the vehicle maintenance, fuel, and emission savings For all the cities across scenarios, the minimum benefits to cost ratio is 1.15 and goes as high as 5.56, i.e. the economic benefits of electrification are two to five times the expenditure on subsidies.

8. CONCLUSION

The transition to EFVs will improve air quality and reduce GHG emissions depending on the renewable components of the power grid. The paper identifies six factors that act as enablers and barriers to the faster adoption of EFVs, as summarised below.

- **(i) Technological suitability -** The choice of EFV models with the required operational range and payload is limited in the existing market. The payload, battery size, and content of the vehicle were understood to be well within the current operational requirements even with the constrained model choices. The primary survey in the three case cities deduces that, on average, 20–30% of the owners are aware of EFVs, but the novelty perception over its operation is still a barrier. The battery prices are evolving and are currently given a warranty period of three years; the uncertainty over costs of replacement is found to be a barrier for the potential buyers of EFVs.
- **(ii) Charging infrastructure and locations -** Overnight home charging is constrained because of the non-availability of secured parking places. Charging facilities at the markets are yet to be created and necessary institutional measures are to be put in place.
- **(iii) Operational economics -** The operating economics is met under the existing vehicle models and no subsidy considerations. Observed trends suggest that

diesel and CNG prices are increasing rapidly and prices of the batteries are decreasing. This trend continues, the costs of conventional fuel vehicles will become costlier than that of EVs. However, this is not adequate to bring absolute cost parity for quite some time. Hence, given the anticipated environmental and climate benefits, fiscal incentives for the purchase and operations of electric vehicles is necessary.

(iv) Fiscal incentives - Subsidies granted by the national and state governments bring capital cost parity between CNG/Diesel and UEFVs. The TCO analysis shows that shifting to UEFV is economically viable as there is a vast cost advantage for UEFV due to cost savings in energy and maintenance.

(v) Financing possibility - Commercial banks do not extend loans for the purchase of EVs. The loans advanced by the financial arms of the EV manufacturers charge exorbitant rates of interest making an adverse impact on the EV economies. Institutional financing of the EFV procurement is still primitive as the resale asset value is not known, and the resale market has not come into operation. Policy measures to encourage commercial banks to advance loans to EV buyers need to be initiated.

(vi) Awareness of UEFV - Lack of awareness among the UFV operators leads to unfounded apprehensions such as the ability of EVs to manoeuvre steep gradients, low speed, fire risk, etc. Therefore, knowledge dissemination and live demonstrations need to be organised.

The potential shifts to EFVs are identified based on the utility maximisation theory, whereby user perceptions are recorded based on the influencing factors impacting the choice of EFVs. The scenarios are classified by subsidy and fuel hike combinations. The potential shift in all the case cities is found to increase with greater subsidy allocations having a direct and positive impact on the capital cost. The fuel hike is found to be inelastic to the potential shift to EFVs. The economic benefits of electrification are found to be two to five times the expenditure on subsidies.

The perceived shift to EFVs is expected to increase with the better cost advantage over ICE vehicles and the provision of an enabling ecosystem by the government through additional incentives and market prices. Electrification of freight vehicles should therefore be considered as an opportunity to improve the efficiency of the existing supply chains and as imperative to achieving India’s commitment to combatting climate change.

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INTEGRATING USER PSYCHOLOGY IN ROAD TRANSPORT SAFETY: A MODEL FOR LOW AND MIDDLE-INCOME COUNTRIES, BASED ON SRI LANKA

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ABSTRACT

Low and Middle Income Countries (LMICs) account for 90% of road collisions that occur globally. These collisions account for 17.63 million serious injuries and deaths while costing LMIC economies 1.7 trillion USD amounting to 6.5% of aggregate annual GDP. Though there are a plethora of models on road transport safety, few address the impact of user psychology and the contextual environment in LMICs on road safety.

This paper proposes such a model formulated and developed using existing literature and focus group discussions. The model is composed of three key constituents - behaviour, skills and knowledge, and infrastructure. It further interprets behaviour as an integration of three sub-elements—mindset, circumstances and legal system—pertaining to the incident. The interaction between these constructs constitutes user behaviour in a given circumstance. The research also proposes an implementation guideline to authorities that is instrumental in changing society's perception of transport safety.

Keywords: *Road safety model, road users, collision prevention, skills and knowledge, LMIC, behaviour*

1. INTRODUCTION

As the mobility needs of individual grow exponentially, road transportation becomes an essential provision [1],[2]. Resource and space constraints emerging in recent decades have led to the introduction of many new road transportation concepts. In contemporary solutions, both the industry and researchers have shifted towards Transport Management with existing or slightly higher supply provision [3]. Disrupting technologies have been employed to integrate capabilities, leading to optimum and technology-driven solutions [1],[4]. Safety has become paramount, closely followed in importance by the need to achieve spatial and temporal efficiencies. However, the situation is markedly different in the majority of Lower- and Middle-Income Countries (LMICs) who are still struggling in their journey towards efficient, effective, innovative and futuristic transport solutions amid multifaceted constraints [5],[6].

LMICs together account for around 140 countries and about 82% of the world's population. They often face challenges such as managing their natural resources, reducing pollution, and facing climate change, while being extremely vulnerable to natural disasters. Most LMICs are excessively dependent on export commodities, and are therefore vulnerable to global economic changes. A recent study identified communicable and non-communicable diseases and road traffic collisions as key challenges faced by the healthcare industry in LMICs [7]. Some studies pinpoint road traffic crashes as a major healthcare problem affecting developing countries, given their lack of resources. Different road safety measures have been developed and implemented, but crash rates appear to be increasing [6],[8],[9]. Road collisions have resulted in more than 17.63 million deaths and serious injuries while costing these economies 1.7 trillion USD, which is 6.5% of the GDP of LMICs in 2016[6].

One of the key underlying issues is the lack of emphasis given to the design and planning aspects of infrastructure and networks in LMICs [8]. On top of accidents caused by inappropriate infrastructure, this has resulted in plenty of idle hours spent on the road daily by the workforce: these could have been used either as productive hours or for recreational activity and social interaction. This has a reversible effect on the attitudes of people via creating a competitive mindset where they compete for spatial and temporal efficiencies in fulfilling their transport needs [5],[10]. Another reason for increasing accident rates is that LMICs lack effective policies and strategies that are backed by empirical research: the available data is less reliable, possibly as a result of poor data collection methods and underreporting [9],[11].

This paper aims at providing a conceptual model to address transport safety concerns in LMICs through mechanisms mainly focused on behavioural changes among users and planners in the road transport sector. The model was developed for the Sri Lankan context based on the inputs captured through interviews and focused group discussions conducted in both industry and academia. It contributes to the practice by introducing a conceptual model for road safety in LMICs while providing fertile ground for future research aimed at enhanced road transport services in LMICs.

The remainder of this paper is organised as follows: the literature review evaluates existing literature prior to proposing the methodology followed in the model development. The paper then discusses the implementation of the model, highlighting the key interventions that need to be made by the respective authorities. It concludes by synthesising the main constructs identified through this study and by indicating future research directions.

2. LITERATURE REVIEW

Road collisions are estimated to cause more than 1.35 million deaths and 50 million injuries each year. Around 90% of these occur in LMICs. Further, these numbers are continuously increasing, retarding the economic growth of those countries while causing suffering, loss and grief [6]. Para-transit services have been identified as a leading factor increasing collisions in LMICs, given the lack of discipline and also owing to profit-seeking, competitive behaviour under which they operate [12],[13].

Three-wheelers, accounting for 15% of the entire vehicle fleet in Sri Lanka and catering to around 6% of the passenger kilometres transported, is one example substantiating the above fact [14]. The awareness of the road users about the contextual environment (weather conditions, speed, traffic conditions, demography etc.) also plays a significant role, where 25% of collisions were found to be caused by issues pertaining to this reason, whereas vehicle defects accounted for 8%. Law enforcement is also weak, due to poor performance of relevant officials, owing mainly due to lack of training [12],[15]. Upon investigating collision data of 40 countries, it has been found that human error was a reason for 95% of collisions, and the sole reason 65% of the time. Errors of perception, psychiatric disorders, deficiency issues, errors in manoeuvring the vehicle and impairment or exhaustion were also recognised as key reasons [16],[17],[18]. Most of these reasons have a considerable influence on the psychological state of the user in a given situation. Hence it is vital to understand the key constructs that affect the road user psychology when developing proactive measures to reduce roadside incidents.

2.1. Road User Behaviour

Road users mainly include drivers and pedestrians. This can be extended to include micro-mobility users such as cyclists, scooters and skateboarders depending on context [19],[20],[21]. Drivers are considered the main stakeholders or decision-makers in the road because of their comparative speed and mass Šucha [21]. Driver behaviour has been identified as a key aspect that leads to collisions. Van der Wall, et al. [22] has found that fatigue and sleep deprivation as key factors affecting driving behaviour; these could sometimes be worse than the effects of drunk driving. The mood of the driver is a factor that impacts focus and therefore driving safety. It has been noted that when the driver is sad, the response time to hazards is slower, increasing the risk of incidents, when compared to driving with positive and neutral emotions. Evidence shows that emotional arousal or unrest acts similar to negative emotions, which demands mental effort to control the emotions [23],[24],[25]. Thus, irrespective of whether it is positive or negative, a heightened state of emotions tends to distract drivers. Hence, findings indicate a positive mood with mild or no arousal as the best state of mind for driving [23].

Zimasa, et al. [26] conducted a study seeking ways of disengaging the drivers from mind wandering[1] while car-following[2]. The research found that mood valence and arousal have different impacts on driving safety. Negative moods have appeared to cause more dangerous driving whilst mild cognitive loads have resulted in disengaging the drivers from a mood induced mind-wandering state. The cognitive loads were given in the form of questions where the driving-related loads (DRL) resulted in improving the driver's attention while non-driving related loads (NDRL) created no such effect. Further research has been suggested to quantify the amount of load necessary for the disengagement pertaining to different moods.

Tornros and Bolling [27] using the experimental method on both handheld and hands-free mobile devices when driving, found that there was a significant reduction in the performance of drivers due to phone usage. This is due to the increased mental workload resulting from the phone conversation. However, there was a significant drop in speed due to phone usage, and an increasing number of collisions given the low performance on a peripheral detection task (PDT) - a measure of mental workloads – such as driving.

Drivers' failure to follow rules and regulations was also considered a trivial factor that hampers road safety. Lack of knowledge on the impact of behaviour on safety was also identified as a factor leading to collisions [15]. Although road users are aware of the negative impacts of unsafe driving behaviours, such behaviour is still

[1] Mind wandering refers to "a condition in which thoughts do not remain focused on the task at hand but range widely and spontaneously across other topics" and car-following refers to "the incident of how vehicles follow one another on a roadway"

[2] When the driver follows a lead car.

evident. A study in Nigeria analysed the road user type, location, and time of the day of 946 incidents that occurred due to unsafe driving behaviours. Researchers reported that road users had engaged in either one or more unsafe behaviours before the collision. Tailgating and incorrect use of indicators were found to be the most prevalent misconducts while road user type, location and time-of-the-day were statistically associated with such behaviours. Better road infrastructure, effective regulatory enforcement and proper road safety education have been recommended as measures to improve road safety in Nigeria [8].

A study conducted in Iran by Mohaymany, et al. [15] identifying driver characteristics that lead to crashes pointed out that drivers aged 18-28 years were more likely to face crashes due to risk taking, aggressive, and ambitious behaviour. Thus, it suggested enforcement and educational activities targeting the above age group. It further mentioned that drivers with less than two years of experience and with Type-2 licences (a category which permits heavy and large vehicle access) were more responsible than the other drivers who possessed Type-1 licences with relatively high experience.

Another study [28] revealed that 50-60% of the collisions have taken place on two-way, two-lane road segments where drivers tend to overtake others using the opposite lanes. Further, the study found that driver characteristics and geometric design of both the vehicle and infrastructure also played a critical role in the passing decisions of drivers.

Batool and Carsten [29] conducted a study in Pakistan based on the premise that driving behaviour would be mediated by the attitudinal and motivational factors. It suggested a market segmentation approach for drivers based on their attitudes measured through their responses to attitudinal factors. This approach was instrumental in discovering the interactions between attitudes, behaviour, and social demographic factors. Further, it also suggested that a similar mechanism would be effective in implementing safety interventions based on the diverse characteristics of different driver segments.

Timmermans, et al. [30] conducted an exploratory study in the State of Qatar to examine the impact of *Attention Deficit Hyperactivity Disorder* (ADHD) using self-reported inattention and hyperactivity-impulsivity traits on the aberrant driving behaviour. They arrive at a similar recommendation. Young male drivers with hyperactivity-impulsivity traits were found to report more aberrant driving behaviour while inattention traits had an insignificant effect on them. However, inattention traits among young female drivers were identified as the most vital factor behind safety violations. The study has suggested gender-sensitive driving education and training about ADHD traits would reduce the risk of road safety violations.

In Sri Lanka, there were several newspaper articles written by industry experts regarding road traffic collisions although academic literature is scant. They have highlighted poor licence issuing procedures, lack of law enforcement (bribing), the attitude of the drivers to catch-up delays and lost time (last-minute push and rush), the attitude of the people (pedestrians crossing roads at random locations), poor road conditions, type and suitability of the vehicles as the key factors attributable towards transportation safety [31],[32].

Drinking and driving is another factor that has led to the increase of road traffic accidents in developing countries, including Sri Lanka. This is underpinned by a lack of legislative procedures and lack of awareness among the drivers about the allowed percentage of alcohol in the blood[33]. A study conducted by Damsere-Derry, et al. [34], has noted that there was a decrease in drunk driving in developed countries due to increased legislation and random breath testing.

A study conducted by Uzondu, et al. [11] in Nigeria on road crashes stated that traffic directionality, time of the day, road user's age, gender and driving speed as the key determinants behind the severity of a crash. Another study [13] conducted in Northern Ghana [14] on motorcycle driver behaviour and its implications on road traffic violations has posited that background characteristics such as age, occupation and ownership of motorcycles were significantly associated with the wearing of helmets. Change in registration protocols of motorcycles with stringent driving tests, increased frequency of public education programs on road traffic rules and regulations and enforcement of laws through the respective authorities have been recommended for the city Wa in order to reduce the rate of increasing motorcycle crashes and fatalities.

The studies conducted by Zinebi et al. [25],[35] claim to be the first attempts at collating all the variables that control driving behaviour into a single model. Based on a systematic literature review, the first study identified speed, acceleration/declaration and braking as the main variables to define driver behaviour in quantitative studies while position, time range, mileage, and road type being the other factors. After analysing behavioural questionnaires used in the literature via Pareto and ABC analyses, the second study came up with 23 factors; namely, anxiousness, carefulness, anger, bad perception, inattention, overtaking, speed, absent-minded, aggressive braking, aggressive expression, not respecting signs, patience, route planning, sensation seeking, turning, use of vehicle, alcohol consumption, distraction, forgetfulness, lane changing, revenge, slips, and tailgating. Some of the less officially accepted facts mentioned above, such as assertiveness, sensation seeking and competitiveness were found to affect the overtaking behaviour as some drivers would feel victorious when overtaking others and would feel defeated if overtaken by others [36].

Pedestrians can be considered as the most vulnerable type of road users who tend to face roadside collisions. Half of the fatalities in road traffic crashes involve "vulnerable road users" (VRUs) such as pedestrians [6],[37]. A study conducted in Lahore, Pakistan, has noted that 25% of fatalities involved pedestrians. Results have shown that pedestrian behaviour would be safer at pedestrian sites in highly developed commercial areas. Older pedestrians (over 60 years of age) seemed more cautious in their road usage while children were the most exposed group given their weak mental and physical abilities in addition to their limited peripheral vision. It has been suggested to use regression analysis in modelling pedestrians at road crossings and sidewalks to understand accurate behaviour which could be useful in designing safe infrastructure [38]. Increased focus towards elderly pedestrians, use of temporal epidemiology and injury profiles have been considered as critical factors needing to be considered when developing road traffic interventions [37].

The relationship between roadside incident rates and the roadway crash rates has also been highlighted by a study on Washington State highways, in the process of modelling roadway and roadside accident rates. The study was conducted by the Washington State Department of Transportation (WSDOT) to improve the efficiency of safety projects [39]. Combination of Histogram of Gradients (HOG) method and Haar partial detection has been identified as an effective method that can be used to warn drivers about possible collisions with pedestrians [40]. Another study on the importance of considering the "Pedestrian Falls (tripping, slipping and colliding with other objects)" has highlighted that this aspect has not been given adequate attention when investigating the pedestrian collisions. The paper suggested including *pedestrian falls* into the definition of crashes so that the analysis of collision risks would consider pedestrian falling instances. This would pave the way for planners, designers and policymakers paying more attention to pedestrian infrastructure planning[41]. Constant and Lagarde [42] has suggested separating motorised and non-motorised road users, improving the visibility focusing on street lightning and on the promotion of injury prevention mechanisms (wearing a helmet, pedestrian right of way, etc.) as key policy interventions to reduce the fatalities among VRUs.

2.2. Road safety Models

The development of proper models to address road safety concerns needs a thorough understanding of multiple interfaces upon which a particular system is built. A model can be defined as a careful and thoughtful representation of concepts, which would assist their understanding. A model should assist in creating a mental picture which also facilitates questioning, evaluating, and understanding the concepts presented. Models can be visual, mathematical or physical, based on the purpose they are intended to serve [43]. Most of the models which are developed to explain the human error in technological systems have been designed to evaluate the situation from a retrospective angle without giving adequate attention to prospective mechanisms. Such models add less value unless those provide inputs to road designers in view of collision prevention [44],[45].

Hughes, et al. [45] state that concise descriptions of holistic entities could be called models, frameworks, concepts or other terms. They conducted a study of all safety models and categorised them into seven key types: namely, component models, sequence models, intervention models, mathematical models, process models, safety management models and system models. They also identified each model in terms of its strengths and weaknesses. The model which is presented in this research falls within the category of "system models"; thus, more focus is given to such models when perusing literature.

System models can be used to analyse systems, including effects of countermeasures, influencers, and consequences. Strengths of these models are their holistic nature, consideration of interdependencies among different elements of the models and being supported by a theoretical basis. Often, their weaknesses tend to be complexity, not being able to predict all outcomes, and lack of quantitative basis [45]. If a model is to be calibrated in a purposeful manner, structural, human, political and symbolic aspects must be recognized and addressed systematically [17]. Economic and social factors have been highlighted as essential aspects of a road safety model which have often been omitted or rather briefly considered.

Johnson (1980) has pioneered the system aspect models where he initially presented the dynamics of home injuries introducing *Background factors* (person, home, incident susceptibility and incident potential), *Initiating factors* (change in patterns and agent of the incident), *Intermediate factors* (mainly psychological and physiological) and *Immediate factors* (which are leading to an incident). The system approach to the investigation was also presented by Stang [46] as a response to the Chernobyl incident by proposing a human-machine interaction system. He suggested that the functioning of the whole system would depend on the proper quality and interaction among all the sub-components. That study also recognized the possibility of areas that could not be explained or understood without a "system approach" towards an incident. Human integration brings plenty of complex interactions to a system that could not be explained as a sequence. Human failure is one of the key factors which leads to the ultimate failure of a system as per this model [46].

As cited by Williams [47], the Haddon Matrix is a renowned and recognised model for collision analysis, considering the perspective of the host, agent/vehicle, physical environment, and social environment. This approach provides three dimensional perspectives of an incident namely: pre-, during, and post. Further, this can also be used as a preventive mechanism. Yet, the causation (i.e., conceptualisation of contextual factors with the causal effects) is not captured through the model, making it a more brainstorming tool than a conceptual model or a framework [48].

Actor System Dynamics (ASD) model developed by Burns and Machado [49] depicted an integration in social structures, sociotechnical systems, physical and ecosystem structures, processes, and influencers. It further explains the interrelationships and interconnection among the above-mentioned factors in their combinations leading towards road collisions or incidents. Whitefield [50]suggested a system that could improve the level of safety management within a given context. Drivers who could be considered as “inputs to the system” and, as the “initial element”, would lead the way towards avoiding hazards. “Safety management” would be the second element focusing on how safety should be implemented in each context. The third element is “measurement”, which considers the output of the above activities. This model focuses more on changing the attitudes and behaviour of persons which would lead towards forming a safety culture.

May, et al. [51]developed a social-ecological model for road safety with four main dimensions, namely road safety, road crashes, road safety enhancement and road safety inhibitors. This also addressed how the environmental factors would affect road safety, studied under those four dimensions. Katsakiori, et al. [52] analysed the types of models which would provide collision investigation mechanisms. Most models were related to causation principles which would analyse reasons for causation, while some other models such as Tree-Analysis would break down each and every activity into a single unit [45].

A systematic literature review has been conducted by Staton, et al. [53] on road traffic injury prevention initiatives. It summarised the 18 most relevant out of a totality of 8,560 articles. Half (9) of these articles focused on legislation. Other focuses have been on public awareness and education (4), enforcement (2), road improvement (1), speed and control measures (1) and multi-faceted intervention (1). Legislation has been identified as the most common intervention which resulted in the best outcomes when combined with strong enforcement initiatives.

The literature further proposes to perform road traffic injury prevention with patient-centred outcomes as a guide to prevent injuries in complex settings. Recently, there has been an increased emphasis placed on improving the integral road network system of a country as a means of preventing road collisions. It encapsulates the fact that the road system should be able to address the limitations of human capabilities and behaviour. “Sustainable safety” in Netherlands and “Vision Zero” in Sweden are two examples that are built upon this view where the road transport system has replaced the driver as the key reason behind road collisions [54].

2.3. Road safety models for LMICs

The models discussed above indicate how the context and the external environment would play a critical role in shaping the driver behaviour leading to collisions. Yet, integrated models, combining both psychological factors, causation relationships and applicability concerns pertaining to developing countries, are limited.

Some studies have been conducted focusing on LMICs pertaining to road safety incidents. A procedural model has been posited [55] which focused on establishing a surveillance system aiming at Road Traffic Injuries (RTI) and supported defining the level of burden, identifying high-risk groups, planning necessary interventions and monitoring the impact. That study was conducted in the emergency departments of five major hospitals in Karachi, Pakistan. It revealed that such models could be established and effectively managed in a developing country context, despite limited resources. Another study was conducted [56] to evaluate the effectiveness of road safety programmes in LMICs which yielded 13 lessons; namely (a) defining the evaluation scope, (b) selecting study sites, (c) maintaining objectivity, (d) developing an impact model, (e) utilising multiple data sources, (f) using multiple analytical techniques, (g) maximising external validity, (h) ensuring an appropriate time frame, (i) importance of flexibility and a stepwise approach, (j) continuous monitoring, (k) providing feedback to implementers and policy-makers, (l) promoting the uptake of evaluation results, and (m) understanding evaluation costs. A study conducted in Nigeria proposed Traffic Conflict Technique (TCT) as an alternative to crash statistics given the quality concerns of existing data. It proposed that TCT could be practically applied in developing countries as a complement to crash data; a method of observation in which near-crash situations would be recorded and used to predict the collision risk and to understand the factors leading to crash situations [11].

However, given the increasing rate of road collisions in LMICs, it is vital to have a more focused approach addressing both environmental and sociological aspects prevailing in such countries. Though several procedural approaches have been developed, as discussed above, a proper model aggregating the behavioural and environmental contexts appears to be a necessity. Such a model would help the authorities to develop preventive mechanisms way before the incidents occur while saving the overwhelming economic and social costs.

3. METHODOLOGY

This study was conducted as qualitative research, using extant literature and focused group discussions; the latter being employed as the primary sources of data. Newspaper articles and published data on road collisions in LMICs were used as secondary sources of data.

3.1. Case of Sri Lanka

After understanding the scope of existing models and the factors that could have led to increasing road accidents in LMICs through the literature survey, several candidate cases were evaluated for the purpose of primary data collection. Sri Lanka was selected as the case study for this research for three main reasons; namely, (i) the country being an LMIC facing an increase of roadside incidents over the last few years, (ii) the convenience of recruiting participants and grasping in-depth knowledge which otherwise would be costly and time-consuming, and (iii) the familiarity of the researchers pertaining to the Sri Lankan context.

Sri Lanka is an Asian country situated in the Indian Ocean in close proximity to the most renowned east-west maritime route, just south of India. It encompasses 65,610 square kilometres with a population of 21.7 million. Sri Lanka is considered as a lower-middle-income-country with a per capita Gross Domestic Product (GDP) of USD 3852 as of 2019 [57],[58] .Yet, over 4.1% of the population in the country lives below poverty line, and the proportion of the employed population with incomes below $1.90 purchasing power parity a day was 0.8% in 2019 [59].

Sri Lanka has a road length covering 12,438 km of A, B and E grade roads. A and B roads stand for national highways; A being those with higher capacities. E stands for Expressways which are tolled. In 2019, Sri Lanka had 7 million vehicles on its roads [60]. Table 1 depicts the distribution of the entire road length in their respective categories.

Table 1: National Highways in Sri Lanka (Class "A", "B" & "E" Roads)

Road Class	Length (km)
Class "E" Roads	217.82
Class "A" Roads	4,217.42
Class "AA" Roads	3,720.31
Class "AB" Roads	466.92
Class "AC" Roads	30.19
Class "B" Roads	**8003.17**
Total of "A" & "B" Class Roads in Sri Lanka	12,220.59
Grand Total of National Highways in Sri Lanka ("A", "B' and "E" Class Roads)	**12438.42**

Source: Road Development Authority (2019)

Though the most populous Western Province (with nearly 27% of the population of the country) has higher GDP, and highest road infrastructure per square kilometre [61], the transportation system has not been able to cater to the mobility needs of the people of Western Province to a satisfactory level. A significant share of people's time is spent on roads due to inefficient mechanisms that are put in place vis-à-vis transport management. Lack of emphasis given to public transportation has resulted in increased congestion levels in peak hours which increases day by day [62].

According to the most recent statistics of the Ministry of Transport (MOT) in 2019, there were more than 33,000 traffic collisions in Sri Lanka, accounting for 2,829 deaths and 7,693 critical incidents [63]. Though these are somewhat lower than the numbers reported in 2017 (36,599 accidents, 33,452 recorded injuries, and 3,147 deaths), and in 2011 (40,258 accidents and 2,677 deaths), these statistics indicate that Sri Lanka is facing an intolerable burden of roadside incidents. On average, nine deaths were recorded per day due to road collisions in 2019. Most victims were pedestrians (776) and motorcyclists (1,162); given their vulnerability in the face of a collision.

These statistics are grim and underscore the need to take action to save lives. It is also widely believed by the public that the behaviour of citizens is a crucial part of this puzzle.

3.2. Study design

The study was designed in two stages. The Stage-I used focused group discussions and the Stage-II involved an expert panel consisting of academia and industry. The focus group discussion had 34 participants who were selected based on convenience sampling, but with a mix of genders, age and education levels. It revolved around key themes, namely, the opinions of the road safety of Sri Lanka and the factors that lead towards collisions, factors that affect the road user behaviour (drivers and pedestrians), and the potential issues in implementing road safety mechanisms in Sri Lanka. The researchers noted down the key points highlighted throughout the discussion.

The expert panel consisted of representatives of academia and industry who were interested in improving road safety. Three academic experts, four industry experts, and two institutional representatives, were thus included. The themes that emerged from the literature review and focus group discussions were evaluated within the panel to understand their interrelationships and their comprehensiveness in explaining the situation in the Sri Lankan context. A particular focus was given to those aspects pertaining to roadside incidents in LMICs that had not been adequately addressed by the existing models.

4. DATA ANALYSIS

The data gathered in Stage-I were analysed using thematic analysis. The notes were examined looking for excerpts which fall under the focus of the study, i.e., the factors that lead to roadside incidents. Table 2 provides a summary of the initial themes developed using the agglomeration of the excerpts.

Table 2: Excerpts and themes developed through the analytical process

Excerpt	Verification from literature	Thematic category	Discussion stage
Lack of road signage, poor design of the transport infrastructure, condition of the road	[31], [32], [42]	Physical context	Focus Group Discussion I
Lack of concern towards safe driving, poor attitudes, lack of focus, unnecessary rush, short-sighted actions	[26], [29], [31], [64], [65]	User context	Focus Group Discussion I
Lack of acknowledgement on safety culture, not adhering to rules, lack of enforcement, bribery and corruption	[6], [31], [32]	Social context	Focus Group Discussion I
Inadequate investigations and monitoring, lack transparency in the licensing process	[9], [11], [32]	Procedural context	Focus Group Discussion II
Attitudes and values, deep-rooted practices through culture, social interactions, opinions and feelings about driving and road safety	[23], [27], [65], [18], [29], [66], [42], [67]	Mindset	Focus Group Discussion I
Without adequate sleep, with medication or under the influence of drugs, Physical and mental unfit conditions, during night-time, At high speed to reach the destination on time, With an overloaded passenger/load capacity, In adverse weather conditions, In unfit vehicles & road infrastructures	[22], [68], [69], [70], [18], [33], [34], [64], [22], [16], [71], [15]	Circumstances	Focus Group Discussion I
Taking timely actions, developing stringent rules and regulations, enforcing the law	[6], [8], [72]	Legal System	Focus Group Discussion II
Manoeuvring a vehicle, detecting a dangerous situation and managing the situation, detecting a technical fault, concentrating on driving, managing the stress on the road, being patient, being calm and not being panic, road space analysis and decision making, crisis management	[16], [69], [26], [30], [24], [64], [15], [18]	Skills and Knowledge	Focus Group Discussion I
Proper road and vehicle infrastructure, adherence to design guidelines, having the right technology	[8], [16], [73]	Infrastructure	Focus Group Discussion II

The excerpts that had close meaning and interpretation were investigated to find the common theme that is emerging through the excerpts. These were validated with the constructs identified in the literature while examining the overlaps and deviations. The deviations were considered as the key points of discussion for Stage-II.

All the constructs identified in Stage-I were documented and presented to the discussion at the focus group, which included the expert panel. Additional themes emerged in Stage-II as stated in Table 2. In Stage-II, "Behaviour" was suggested as the umbrella theme for the mindset, circumstances, and legal system. Expert opinions on the relationship between themes were evaluated during the discussion. This formed the basis for the conceptualisation of the double triangulation model for road safety which integrates user psychology in a detailed manner. Few iterations of the models were developed until the model encapsulates the factors that emerged through the focused group discussion adequately.

5. DISCUSSION ON THE FINDINGS

5.1. Findings

The key factors which resulted in the causation of collisions in Sri Lanka could be summarised as below. These factors are similar to those in a majority of LMICs. The common causes are resource constraints and lack of emphasis placed by regulatory authorities [5],[6],[8]

(i) **Physical context -** This refers to the level of existing physical infrastructure which leads to collisions, such as poor road conditions, lack of additional signage and non-ergonomic designs. This is due to the lack of emphasis placed on the development, implementation and maintenance of such vital infrastructure due to inefficient planning and allocation of available resources [31],[32],[42].

(ii) **User context** – This refers to the mood and attitudes of road users, which lead to different short-sighted actions to satisfy their needs, despite the negative consequences of such acts. Urgency, dominance, unnecessary rush, lack of focus and poor attitudes could be identified as some such acts which appeared frequently in the extant literature and focus group discussions [26],[29],[31],[64],[65].

(iii) **Social context** – Social context refers to the societal conditions which shape the behaviour of persons as a society. Lack of adherence to rules, lack of prominence given to safety, bribery and corruption have become norms in society. Lack of enforcement of rules and regulations owing to inadequate monitoring systems is the key reason behind these developments [6],[31],[32].

(iv) **Procedural context** – Processes and procedures related to road safety are not defined and sequenced in an orderly manner. Lack of mechanisms to report and evaluate the safety incidents have led to poor visibility of the existing statistics in most LMICs [9],[11]. Bribes could play a role, particularly in the areas of renewing and issuing licences and vehicle emission certificates, due to undefined processes. These need to be addressed through the enforcement of law and order [32].

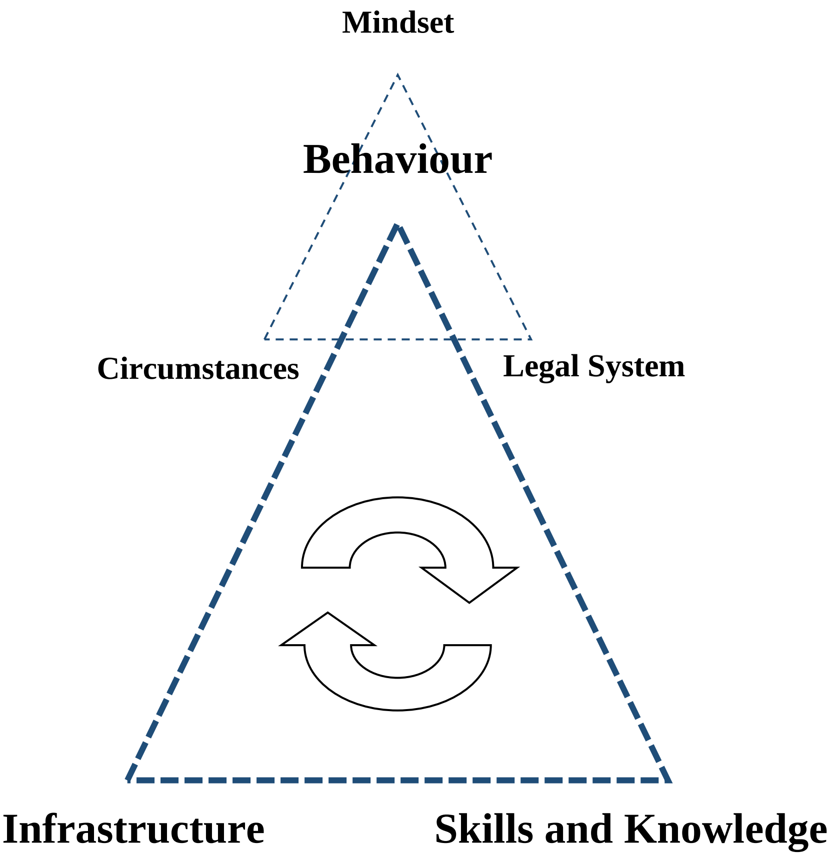

Figure 1: A conceptual model for LMICs integrating user psychology

Figure 1 depicts the model developed to elaborate the interaction of the key themes that emerged to address the above contextual factors. The model consists of two triangulations; thus, called a *double triangulation model*. The first triangle consists of three main dimensions which are Infrastructure, Skills and Knowledge, and Behaviour. The second triangle comprises how the behaviour is impacted. The three key dimensions are the mindset, the circumstances, and the legal system of a particular country. Table 3 compares the proposed model with other models which were identified as key safety models developed based on the systems approach.

Table 3: Comparison of the major system models proposed for transport safety in literature

Model	Factors considered	Areas of applicability	Characteristics and limitations (if any)
Haddon Matrix (1975)	Host, agent/vehicle, physical environment, and social environment	Collision prevention	Provides both pre-during-post dimensional viewpoints of the incidents, causation or conceptualisation with the causal effect is not captured through the model
Actor System Dynamics (ASD)	Integration in social structures, sociotechnical systems, physical and ecosystem structures, processes, and influencers	Collision prevention	States interrelationships and interconnection of the above factors in combination lead towards road collisions or any incidents
Whitefield (2009)	Inputs, safety management and outputs	Road Safety	Inculcating a safety culture
May et al. (2010)	Road safety, road crashes, road safety enhancement and road safety inhibitors	Road safety	Inclusion of preventive actions based on identified reasons
Double Triangulation model (The model proposed in this paper)	Behaviour (mindset, circumstances, legal system), skills and knowledge, infrastructure	Road safety	Improved emphasis placed on behavioural aspect and contextual factors Applicable in the context of LMICs

5.1.1. Behaviour

This explains driver behaviour (whist driving and parking) and behaviour of road stakeholders such as pedestrians and the general public. Behaviour is highly influenced by the mindset of the drivers and other road stakeholders, circumstances as well as degree of strictness of the enforcement of the law. Plenty of studies emphasise "behaviour" as a key aspect in ensuring road safety [8],[24],[26],[29],[64],[65],[74]. These are explained in detail as follows.

(i) **Mindset –** This can be explained as to how the mind of a driver/pedestrian works in a particular context. This is influenced by a combination of attitudes, values, upbringing, and other deep-rooted subconscious thought patterns as well as the strictness of the legal system [23],[27],[65]. Values are moral principles, ethics, or standards of behaviour on the road. Values are directly influenced by family, friends, culture, religion, and social interactions. Attitudes are a settled way of thinking and feeling which also play a critical role in road user behaviour. These are opinions or feelings about certain subject matters such as road safety, speed driving, drunk driving, driving without physical fitness etc. [18],[29],[66]. Attitudes are influenced by values. Mindset can be enhanced to a desirable level using tools such as training programs, workshops, on the job training as well as rewards and punishments [42],[67].

(ii) **Circumstances –** This can be explained as facts or conditions connected to a situation, event or action that are unavoidable, or avoidable only with reasonable efforts [18],[75]. Such factors are listed below; among which, the first three factors are related to the condition of the driver and other factors are related to the environment, context, vehicles and road infrastructure.

- Without adequate sleep [22],[68],[69],[70]
- With medication or under the influence of drugs [18],[33],[34]
- Physical and mental unfit conditions [64]
- During night-time [22]
- At high speed to reach the destination on time [15],[68]
- With an overloaded passenger/load capacity [14],[70]
- In adverse weather conditions [70],[71]
- In unfit vehicles & road infrastructures[16],[71]

It is advisable to avoid the circumstances, where possible, by proactive planning and organising. However, in an unavoidable circumstance, the situation should be managed diligently.

(iii) **Legal System –** This should be timely, practical and adequately enforceable. Strict measures should be promptly taken [29]. Where possible technology should be used to detect and fine road traffic violations in order to overcome the loopholes in physical controls [6],[8],[72].

5.1.2. Infrastructure

Infrastructure is two-fold. Road infrastructure and the infrastructure related to vehicles. Road infrastructure should be designed, constructed, and maintained considering user safety as an aspect of paramount importance. Design codes and guidelines should be addressed accurately. Construction needs high-quality construction materials, the right technology, and processes as well as close supervision. Maintenance of roads should be given high priority and prompt action [8]. This includes pavements, curves, traffic signals, illumination and all the other road infrastructures [16],[73]. Vehicles are suggested to be designed and manufactured with adequate safety measures, which need frequent maintenance to ensure the roadworthiness of vehicles.

5.1.3. Skills and Knowledge

Driver skills are suggested to be tested using proper mechanisms to ensure that they are ready for safe and competent driving [8],[13],[64]. This includes, but is not limited to, the skills of,

- Manoeuvring a vehicle [16]
- Detecting a dangerous situation and managing the situation [69]
- Detecting a technical fault
- Concentrating on driving [26],[30]
- Managing the stress on the road [24],[64]
- Being patient [15],[18]
- Being calm and not being panic
- Road space analysis and decision making [41]
- Crisis management

5.2. Method of implementation

Method of implementation was one of the key areas that emerged in the Stage-II, although this was not related to the constructs included within the model. It was evident in Stage-II that the approach towards implementation of the model is vital for its success, and also for a smooth propagation of the safety culture in LMICs, regardless of the level of superiority of a given model. Hence, it is recommended that respective authorities in LMICs should pursue the six steps suggested below in the process of implementing the proposed model.

(a) Make road accident prevention a main health and safety goal of LMICs:

Road collision prevention has not been given prominence in a majority of LMICs. Yet, the number of fatalities demands immediate attention by the responsible parties towards necessary actions [6]. Each year, 1.35 million people lose their lives on roads, which is almost similar to the deaths recorded due to the COVID-19 pandemic throughout the world in the year 2020. A major reason behind the low fatality rates of road collisions in developed countries is the increased emphasis placed on the road safety culture. Sweden's vision zero is an example of robust systems introduced based on the acceptance of the fragile nature of human behaviour to reduce collisions. This is supported by the stringent rules and regulations which demand 100% compliance by people. This has reduced Sweden's road fatality rates from seven people to less than three people per 100,000 [54],[73]. In order to observe the expected behaviour from people, the top-level authorities should recognise the importance of road safety in the first place. This should be included as key health and safety goal each year which can be tracked and reported continuously.

(b) Provide necessary resource allocations:

In order to enforce the aspects in the model, governments need to make some investments without which the implementation would not be successful. Transport infrastructure such as proper roads and signposts should be developed and maintained as per the safety standards. Additionally, investments need to be allocated for technologies such as violation detection through CCTV cameras [73],[76]. Furthermore, effectively trained human resources are required for the smooth and efficient operation of enforcement services.

(c) Have adequate controls and comprehensive tests to examine mindset, skills and knowledge:

In the present context, the skills and knowledge of many citizens in LMICs in the domain of road safety is minimal. This is due to the poor quality of training and awareness programmes provided to road users, such as drivers, pedestrians, etc. Strict control should be implemented in the training institutions to ensure that the training they provide is up to the expected standards. Specifically, the process of issuing and renewing driving licences should be made more stringent to avoid the risk of producing, through the process, a weak and harmful driver. This can be done through improved testing and monitoring embedded in the process, together with responsible officials. Separate training should also be provided to those officials involved in such critical tasks to ensure the quality of outputs. These standards could be benchmarked with the existing schemes adopted by developed countries which show low roadside fatalities and collision/incident rates. The mindset of the people should be framed in such a manner that they understand the impact of violations on the community. Gender and age group responses should also be taken into consideration when formulating controls that are proven, through past research, to have variations [65],[75],[77].

(d) Continuously develop and update the mechanisms focused on improving mindset, skills and knowledge:

The process of disseminating and updating knowledge should be continuous. The importance of each user's activity should be encapsulated in the minds of the users such that they take their initiatives to improve their conduct concerning road safety [66]. Research studies have found out that focused programs aimed at the improvement of attitudes and behaviour of drivers could be conducted in addition to any policy level interventions [29],[30]. This will not be achieved unless all prior steps are taken in an appropriate manner. Authorities issuing licenses should ensure that the renewal process includes considerations such as proper mindset, skills and knowledge.

(e) Develop new policies, procedures and legal systems in line with the proposed model:

Government and the respective authorities should work towards implementing new policies aimed at developing infrastructure as well as skills and knowledge related aspects. Policies that improve existing infrastructure and controls would directly impact the behaviour of the people [72]. While introducing and implementing policies towards road safety, it is also important to have stringent legal systems and enforcement systems to complement stringent policies [34]. Many LMICs lack strong legal systems and have loopholes in law enforcement [6]. In addition, processes should be designed to capture and report incidents in an accurate manner, which leads to improved visibility and may assist in monitoring safety performance. Apart from user negligence, institutional issues [9] also constitute a significant key factor behind underreporting, which could be reduced through proper enforcement of policies and procedures. Immediate attention to alleviating this problem is critical to saving lives.

(f) Implement a legal system with adequate and prompt fines:

Heavy fines can be identified as one of the key reasons behind the improved rates of compliance recorded in developed countries. The government of Sri Lanka increased the fines for road offences in February 2019 with the intention of reducing the growing number of road collisions. This initiative failed during its implementation due to lack of enforcement and policing, combined with the increased rate of bribery that came as a by-product of this move [78],[79]. With the five-fold increase of fines, some offenders and police officers opted to bribery to evade those high fines. This is partly due to the highly bureaucratic system in operation pertaining to settling fines which require an offender to visit the police station and the nearest post office multiple times. Fines would be more effective if technologies such as video surveillance could be integrated; this fact is much evident when investigating the mechanisms in developed countries [73]. Moreover, simplification of the fine settlement processes and the legal procedures (as an example refers to Figure 2 for the current process in Sri Lanka), is warranted and must be established without fail to ensure road safety is effectively enforced.

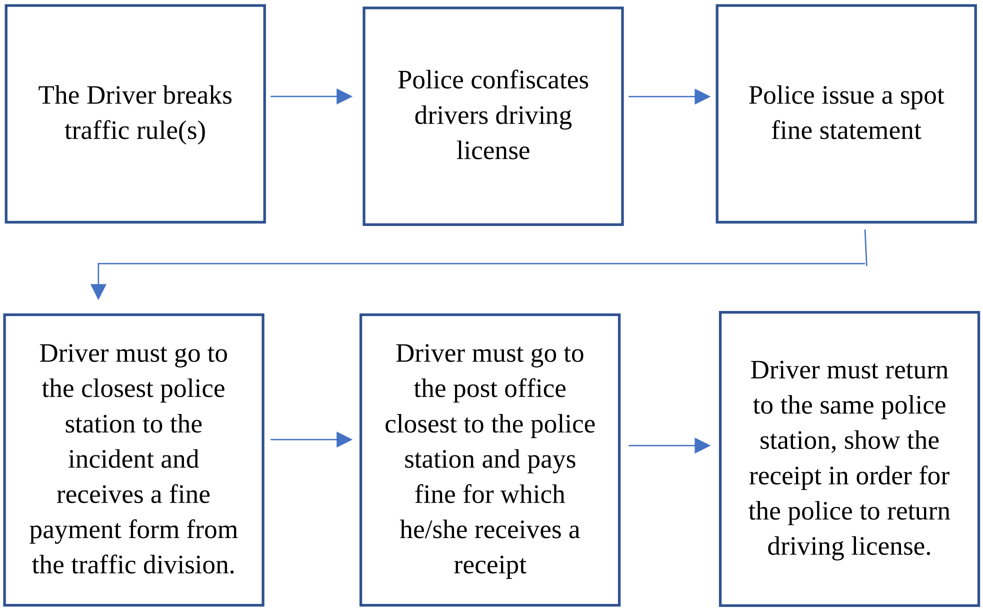

Figure 2. Existing fine settlement process

6. CONCLUSION

Road safety in LMICs is at a critical stage as 90% of the collisions which happen in the world occur in LMICs. A plethora of models are available in the literature which were developed to address the causes of road collisions. Yet, it is necessary to develop a model considering both behavioural and contextual parameters of LMICs that would address their concerns more specifically. The model proposed in this paper is characterised as a system model according to Hughes's classification [46]. It aims to understand different interrelationships between causal and contextual factors that leads to an incident and to facilitate systematic improvements towards road safety.

Contextual environment and sociological aspects prevailing in the LMICs should be considered when formulating a conceptual framework aimed at achieving safer roads [8],[45],[66],[80]. The authors of this paper have studied the specifics prevalent in Sri Lanka both through focus group discussions and literature upon which the base for the proposed model was developed. The researchers' personal experience in the Sri Lankan context was instrumental in conceptualising the phenomenon. This paper has proposed a *double triangulation model* which aims to address the above gap; the first triangle consists of *behaviour, infrastructure, skills and knowledge*, whereas the second triangle consists of parameters that influence the behaviour that include *mindset, circumstances* and the *legal system*. We see a cyclical iteration between the dimension of the first triangle which is impacted heavily by the behaviour which is again triangulated through the mindset, circumstances and legal system Hence, this model has integrated the key constructs that affect the psychological state of the users which are seldom found on road safety models while necessitating the emphasis that needs to be placed on the contextual environment in LMICs. The reduction of traffic collisions can be achieved by addressing the behaviour while improving the infrastructure and skill related aspects. Further, an approach to implementing this model in LMICs are provided in brief, elucidating the key focus areas and necessary actions. Authorities are requested to refer to the proposed model in their approach towards addressing the road safety strategies in both present and the future.

Further research could be conducted on ways and methodologies which can validate the constructs of this model. Additionally, a detailed implementation mechanism could be proposed defining the stakeholder responsibilities and the amount of resources required to proceed with the implementation.

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BENEFITS OF SUPPLY CHAIN PROCESS IMPROVEMENT INITIATIVES: A STRUCTURED LITERATURE REVIEW

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ABSTRACT

There is growing interest across industries to apply Business Process Improvement (BPI) initiatives in supply chains. Academic literature and standard industry practices indicate that these initiatives are undertaken subject to technological advancements. This paper aims to set the context for BPI initiatives by presenting the first structured literature review explaining how different organisations perceive the benefits, confront challenges, and realise critical success factors in the context of supply chain management. A tool-supported four-phase literature review approach was adopted as the methodology for this research and 81 papers were considered for analysis based on their relevance to the scope of this research. The analysis comprises benefits of different process improvement initiatives, classified under procurement process improvements, manufacturing process improvements, warehousing and distribution process improvements, and miscellaneous improvements. Furthermore, this study elaborates the general success factors and challenges that could be considered for any process improvement initiative. The paper concludes by summarising findings and suggesting future research directions to expand the role of BPI initiatives in decision-making.

Keywords: *Process Improvement Initiatives, Critical Success Factors, Supply Chains, Benefits, Challenges*

1. INTRODUCTION

In the current dynamic business environment, organisations must eliminate drawbacks embedded inside a system and bring performance close to perfection. To do this, businesses set the context with problem-solving initiatives. According to Smith [1], every instance of quality problem-solving entails five kinds of quality problems related to: (1) conformance, (2) unstructured performance, (3) efficiency, (4) product design and (5) process design. This predominantly includes either devising new processes or substantially revising existing processes. Accordingly, the importance of managing awareness of organisational processes, establishing process design, and constant improvement are ongoing requirements for organisational success [2].

These represent a new orientation to problem-solving, making it an integral part of the management function, practiced throughout the firm. Overall, an effective process for problem-solving ensures that the context aligns with improving the quality of products, reducing costs, eliminating wastages, reducing defects, improving skill levels, motivating workers, and enhancing morale [3].

It was observed that there is an ongoing scepticism on defining process orientation. Consequently, different authors define “process” based on the following dimensions. Hammer and Champy [4] describe a process as “set of activities which, when taken together, produce a result of value to a customer.” According to Davenport [5], a process is denoted as “a set of structured and measured activities designed to produce a specific output.” Palmberg [6] considers the process to be “a horizontal sequence of activities that transforms an input (need) to an output (result) to meet the needs of customers or stakeholders.” The global standard that discusses quality management systems defines process as “a set of interrelated or interacting activities that transforms inputs into outputs”. Business Process Management (BPM) paradigm is a novel way of looking at organisations based on the processes they perform rather than on the functional units, departments, or divisions. The incentive for change in process-based management is recognised as a prominent success factor in the literature. Trkman et al. [7] describes the importance of accepting process-based management principles to cope with the business challenges.

Business Process Improvement (BPI), as a term, is widely used in literature. According to Realyvásquez-Vargas et al. [8], when process improvement starts with careful planning, corrective and preventive actions are supported by appropriate quality assurance tools that lead to real process improvement. More importantly, BPI is an umbrella term for well-known techniques such as Lean, Six Sigma, Total Quality Management (TQM), process redesigning, and process reengineering.

Ujvagi [9] reports the interdependency prevailing between BPI and BPM. The latter term combines BPI, performance management, and organisational change management with technology. This representation has assured the success and sustainability of process improvements initiatives while enabling a process excellence culture.

The supply chain is a combination of business processes. It starts with procuring of raw materials and ends with delivering value-added finished products or services to end-users [7], [10]. Therefore, to become competitive in today's world while reaching the strategic objectives, an organisation must take necessary actions to eliminate the inefficiencies embedded to supply chain processes. BPI initiatives make this possible by removing wastage, utilising resources, and optimising processes [11]. However, it is necessary to identify the suitable BPI initiatives that can be adapted to supply chain processes with reference to the benefits that can be gained. Moreover, identifying the success factors and challenges that have to face when taking such BPI initiatives are critical.

Understanding how BPI initiatives yield benefits across the supply chain is important given that modern supply chains are increasingly tiered, with stakeholders interacting in complex ways. Several authors have discussed the benefits of supply chain process improvement initiatives using theoretical and exploratory studies [12], [13], [14], [15]. However, there is a lack of literature which combine the findings of all these studies and provide opportunities to identify comparative benefits. Thus, this paper targets to emphasise the importance of adopting BPI initiatives for supply chain processes by presenting the first structured literature review and bibliometric analysis on benefits of supply chain process improvements. It focuses on exploring how different organisations perceive the benefits, confront challenges, and realise critical success factors through process improvement initiatives in the context of supply chain management.

The remainder of the paper provides with key definitions, research background, and theoretical foundations in Section Two, the method adopted to compile the literature database in Section Three, and a bibliometric analysis of the collected papers in Section Four. Section Four provides an end-to-end perspective on BPI initiatives; it is followed by Section Five, which identifies potential gaps and suggests evidence-based implications for practitioners and future researchers regarding the state-of-art in supply chain process improvement initiatives.

2. BACKGROUND AND THEORETICAL FOUNDATION

This section highlights the key research domains in the field and a basic overview of the theoretical foundations related to the reviewed literature.

2.1. Business Process Management

There is a rich literature on Business Process Management (BPM). The first study of BPM was conducted in the 1990s, where Elzinga et al. [16] defined it as "a systematic, structured approach to analyse, improve, control, and manage processes to improve the quality of products and services". Two years later, Zairi [9] characterizes BPM as "a structured approach to analyse and continually improve fundamental activities such as manufacturing, marketing, communications and other major elements of a company's operation". In the early 2010s, researchers considered BPM as a discipline with no academic foundation or an academic conceptual framework [17], [18]. Later, its interpretation was aligned with a list of organisational requirements that set a context for emerging discussions viz: product and service quality improvements; effective fulfilment of globalisation and highly competitive environments; and response to client needs [19]. Basically, BPM can be interpreted as a combination of Business Process Improvement (BPI), performance management, organisational change management and technology that strives organisations towards success and sustainability through process enhancements [9], [20].

2.2. Business Process Improvement

Business Process Improvement (BPI) is a one aspect of BPM [9], [20]. It is beneficial to possess BPI initiatives integrated with BPM disciplines and responsibilities, to achieve better results in the organisational BPM [19].

Evidence suggests that BPI paradigms include both continuous process improvement initiatives (Kaizen) and radical process improvement initiatives (Kaikaku) [17]. The continuous count on small improvements is advocated in the Kaizen concept, providing ambiance through gradualism. The basic tools prevailing under this discipline are mostly Lean and Six Sigma. According to Davenport [21], Kaizen represents everyone in the workforce, from managers to clerks, and is applied every day and in every position. In contrast, Kaikaku is a progressive method when large changes are needed to remain competitive or solve larger problems. Kaikaku allows organisations to transform their culture, processes, or even business models by addressing large structural reforms. The basic tools under this discipline are mostly Enterprise Resource Planning (ERP) implementation, process reengineering, and process redesign [22].

2.3. Business Process Improvements and Supply Chains

The supply chain is a combination of business processes that starts with procuring of raw materials and ends with delivering value-added finished products or services to end-users [7], [10]. BPI initiatives should be incorporated into supply chains by obtaining an activity-wise characterisation of what occurs in the end-to-end supply chain. Procurement contributes to the process of meeting particular need(s) through an identified and evaluated source [23]. In the context of the supply chain, procurement is defined as, "overall sequence of events that sum up the purchasing activity from identification of a need to payment of invoices in respect of the goods or service purchased to satisfy a given need" [23], [24]. Most BPI initiatives in the procurement function are dedicated to improving planning, decision-making, and information sharing disciplines [25], [26]. Manufacturing is an input-output system that transforms manufacturing resources (materials and energy) products or semi-products [27]. Much of the literature tries to incorporate process innovation, total productive maintenance, and real-time information sharing as means of advocating BPI initiatives in the manufacturing discipline of supply chains [28], [29], [30]. In the context of BPI, outbound logistics functions, including warehousing, distribution activities, are more concerned with integrative business implementations [31]. One area of research in this domain that has received burgeoning attention is Lean Six Sigma (LSS) integration [32], [33]. Despite this, adopting various BPI initiatives in the outbound logistics context, including warehousing, distribution activities, has further room for contributions. Hence, it is evident that BPI initiatives vastly improve end-to-end supply chain processes [34], [35], [36].

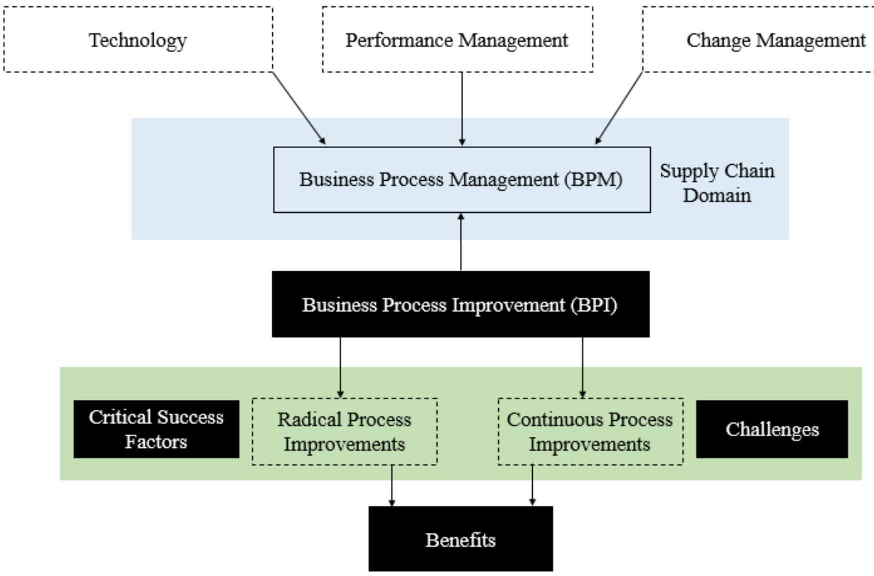

Figure 1: Structure of the theoretical background considered for the research

Moreover, the Covid-19 pandemic has caused supply chain disruptions due to lockdowns and health concerns [37], [38]. It is important to put efforts to improve supply chain resilience to cope with these challenges. As the literature demonstrates, both continuous and radical process improvement initiatives help to maintain supply chain resilience while ensuring safety, transparency, responsiveness and collaboration [38], [39], [40].

Even amid growing academic interest in determining the relationship between BPI initiatives and the overall supply chain, there is a lack of literature that considers the state-of-the-art in BPI initiatives. Such literature should reflect benefits, challenges, and critical success factors targeting BPI initiative success. This literature review project has bridged this gap and created novel knowledge by focusing on the research question, how benefits, challenges, and critical success factors of BPI initiatives and the end-to-end process of supply chain management have been integrated into existing literature? It will be useful for future researchers to discern the already existing work and save time and resources during future research.

2.4. Research Objective

It is important to define the role of BPI initiatives, thereby increasing the organisation's overall performance and making the system resilient to dynamic environments. Thus, the main objective of the present study is to explore how different organisations in the literature perceive benefits, confront challenges, and realise critical success factors in the context of supply chain management. Hence, three Research Questions (RQs) are denoted as: (RQ1) What is the role of BPI initiatives suggested by recent research in advocating end-to-end supply chain? (RQ2) How can recent research on BPI initiatives be classified in terms of the perceived benefits, challenges, and critical success factors? (RQ3) What are the implications to practice and future research directions?

3. METHODOLOGY

A structured literature review was conducted to find answers to the above-mentioned research questions. Structured literature review is a review method which has a pre-defined plan along with criteria to search, review and analyse literature [41], [42].

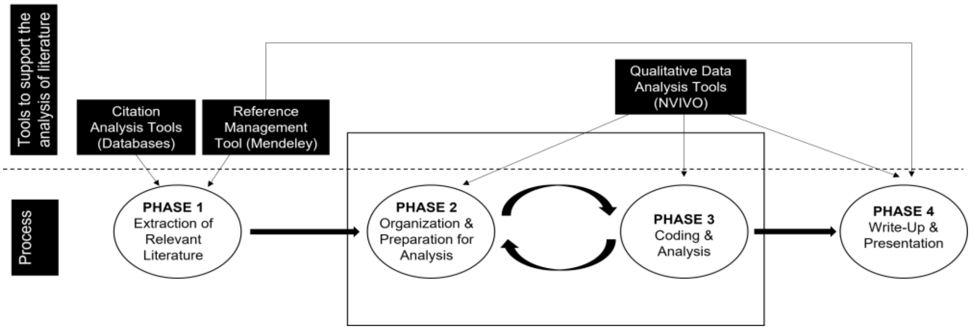

Figure 2 : Overview of the methodology followed

The tool-supported four-phase literature review approach, suggested by Bandara et al [41], was adopted (depicted in the Figure 2), as the review methodology for this research, based on a thorough review of existing literature reviewing methodologies.

As the initial step keywords were identified under the two main aspects of the research which are supply chain related keywords and business process improvement related keywords. Four search strings were developed using the identified keywords. ABI/INFORM, Scopus, Taylor and Francis and ProQuest databases were used to extract research papers, and 81 papers were considered for the final analysis based on the relevance to the review scope. Literature papers that have discussed benefits, success factors and challenges of different supply chain process improvement initiatives were selected for the final analysis which was done using NVivo software.

Main NVivo codes were made under three categories: benefits, critical success factors and challenges. Under the benefits category, additional sub-categories were made: namely, procurement process improvement, manufacturing process improvement, warehousing and distribution process improvement and miscellaneous improvements. Each sub-category was further categorised according to different initiatives such as Lean, Six-Sigma, Lean Six Sigma, ERP, Redesign and RFID, etc. This coded literature was reviewed and analysed while identifying similar benefit patterns. Critical success factors and challenges categories were further sub categorised and analysed based on similar patterns in literature.

The summary of the methodology adopted is depicted in the Figure 3.

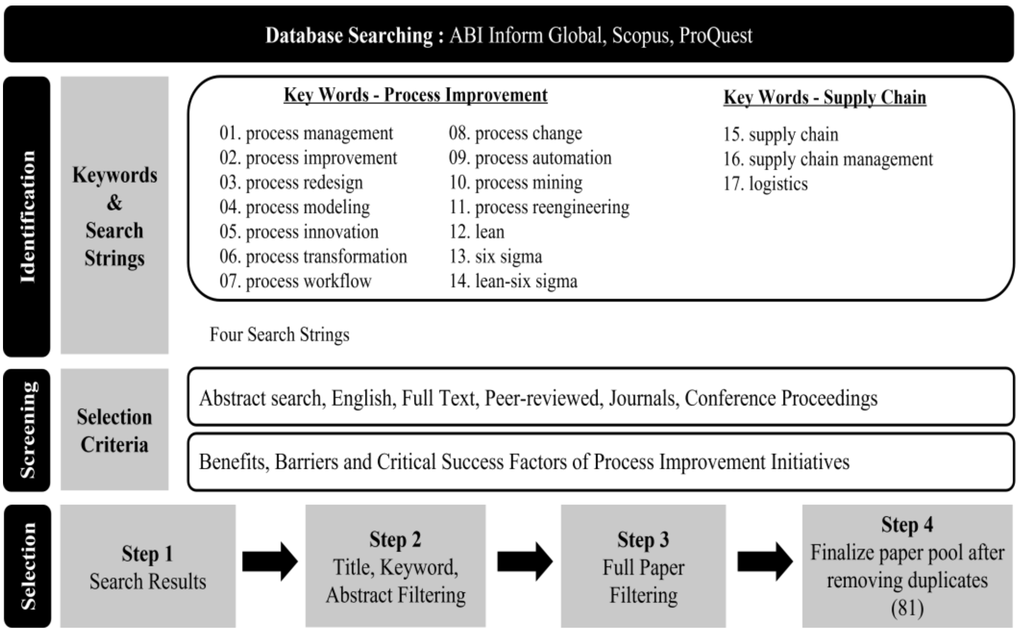

Figure 3 : Methodology summary

3.1. Profiling the Literature

This section contains a descriptive overview of existing literature. According to Figure 4, publications related to this topic can be found since 1997, and random fluctuations can be observed until 2021. The highest number of papers emerged during the year 2020, with nine papers.

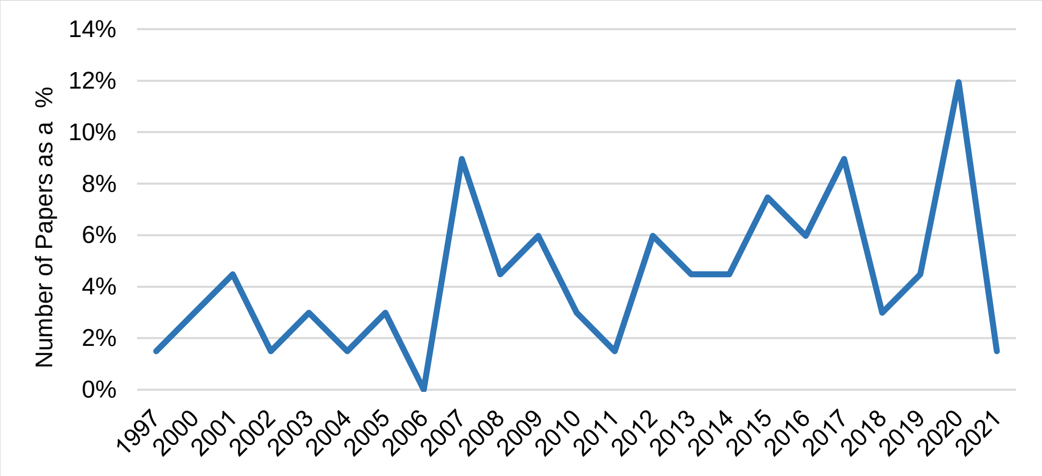

Figure 4 : Distribution of papers over the years

Figure 5 represents the industry distribution of BPI initiatives as stated by authors. Most of the research describing BPI initiatives were adopted in the manufacturing (25%) industry, followed by the logistics and distribution (16%) industry. All these industries were categorised based on authors' statements found in reviewed literature.

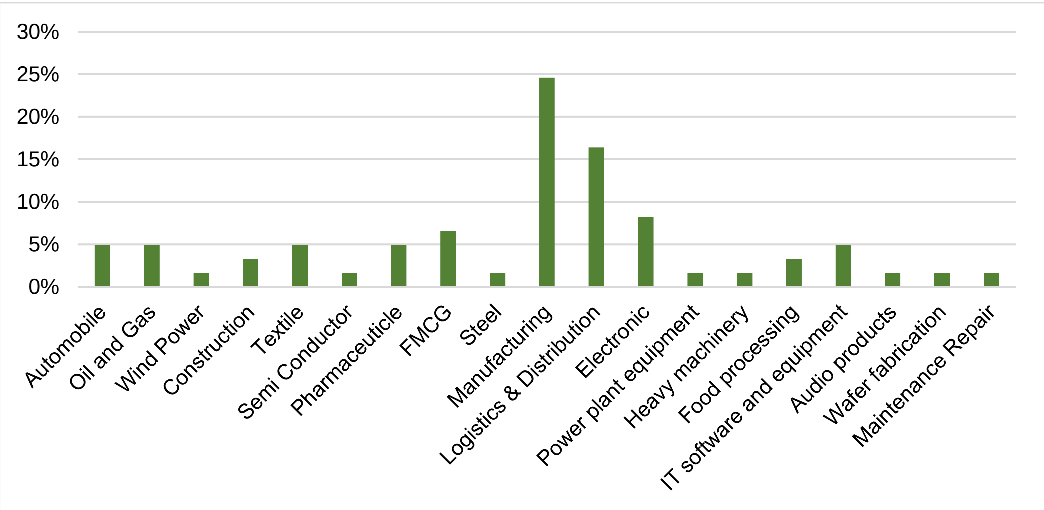

Figure 5 : Analysis of literature based on the type of industry denoted by the respective authors

Literature analysis according to the BPI paradigms used by different organisations can be found in Figure 6. It is observed that most organisations have used business process reengineering when making improvements (more than 42%) to their processes. BPI related to process redesign and Lean are accounted for around 24%.

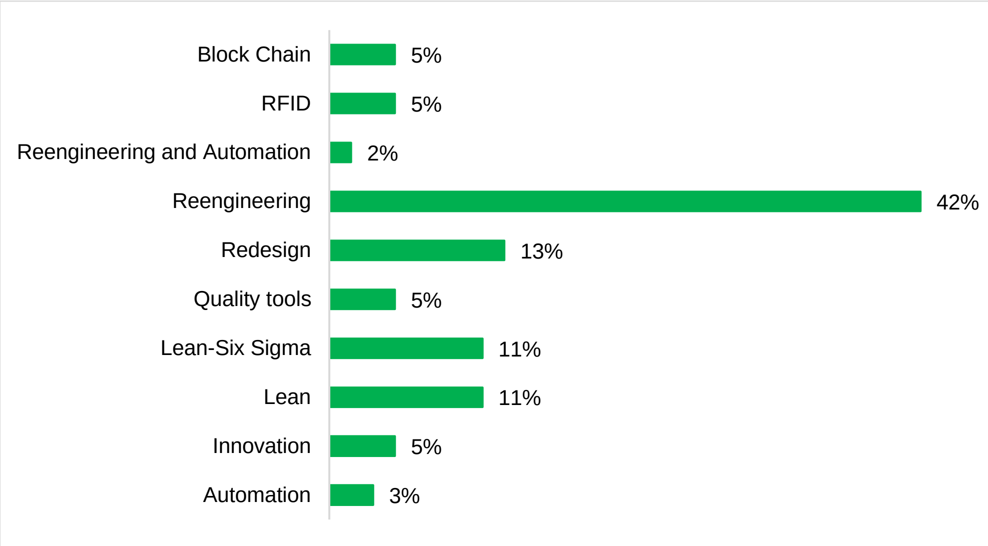

Figure 6 : Analysis of papers reviewed on the BPI paradigms

4. RESULTS AND FINDINGS

This section contains the results and findings under three main categories: benefits of supply chain process improvement initiatives, critical success factors of supply chain process improvement initiatives and barriers for supply chain process improvement initiatives.

4.1. Benefits of Supply Chain Process Improvement Initiatives

This section includes an analysis of review findings for the benefits of process improvement initiatives. Analysis was done by categorising benefits of different process improvement initiatives implemented under procurement process, manufacturing process and warehousing and distribution process. All other initiatives that are not coming under the above three categories are interpreted under a separate category named miscellaneous improvements.

4.1.1. Procurement Process Improvement Initiatives

It was observed that BPI initiatives emerged under the procurement function more focused on inter-organisational collaboration with real-time information sharing with suppliers. Based on procurement activity, Yen & Ng [25] discuss the benefits of a government-funded E-Procurement facility called HKTAIGA (Hong Kong Textile and Apparel Industry Global Applications) for small and medium-sized enterprises in the Hong Kong textile industry. This facility provides inter-organisation communication and a portal to interact with financial institutions and logistics service providers. It reported cost reduction benefits for suppliers and buyers regarding fewer storage spaces requirements, reduced physical visits to clients, and on-time order deliveries and material supplies. In a similar study, a one-third reduction in administrative costs due to reductions in costs associated with searching for order, placing the order, and paying for an order has been identified by Croom [43] through a comparison of E-procurement and manual procurement. Accordingly, increased information for customers, reductions in stationary cost, and excluded supply chain links such as travel agents' benefits were denoted as benefits of the proposed E-Procurement system.

On the flip side, Groznik & Maslaric [26] examine the relationship between process modelling and process reengineering. In this paper, two alternatives of process reengineering were simulated for the procurement process of petrol stations through a Serbian petrol company: Information Technology (IT) facility introduction with organisational structure change (to-be A) and IT facility introduction without organisational structure change (to-be B). Both methods reported benefits through reductions in transactional cost and average lead time. However, the reduction gained through (to-be A) is larger than the (to-be B). Thus, it indicates the importance of change in organisational structure to yield more process reengineering benefits. Trkman et al. [7] also confirm that benefits such as average lead time reduction, labour cost reduction, inventory cost reduction, and process cost reduction can be achieved for the procurement process by facilitating external integration through IT implementation and process renovation. It recorded a 70% process cost reduction and 62% average lead time reduction while showing how supply chains can be improved by integrating supply chain activities.

Sammon & Hanley [44] have researched two electronic-based improvement initiatives to procurement management and payments handling, and it included a web-based option and a Business to Business (B2B) E-solution. These two options automate order sending and receiving tasks. Furthermore, B2B E-Solution provides additional benefits such as touchless transactions and fewer data entry errors on automated transactions processed by the suppliers' system. Similarly, Viale & Zouari [14] researched the impact of digitalisation of the procurement process using two companies. The technique Robotic Process Automation (RPA) has been applied as the digitalisation technique. As Viale and Zouari identified, benefits can be obtained under six categories: transaction time, productivity, compliance, accuracy, labour hours, and costs. Thus, it resulted in reduced request completion time, increased employee satisfaction, reduced safety stocks of materials, reduced human errors, increased data accuracy, cost savings due to reduced poor production and reduced overtime workload, and increased customer satisfaction.

Ongoing negotiations with suppliers are also an important supply chain task that businesses should consider. One category of that is handling of auctions. Online auctions are a B2B E-solution that can be performed in a shorter time than traditional auctions. As Emiliani [45] confirmed, this method gives benefits not only for buyers but also for suppliers. Benefits for buyers include a much disciplined auction process, the ability to evaluate many capable suppliers, and the ability to develop negotiated prices within a few hours. Benefits for suppliers include the equal chance for all interested suppliers, reduces marketing costs, the ability to validate competitiveness among competitors, and long-term agreements. Moreover, quality associated with materials supplied is an important aspect that must be considered during supplier selection process, mainly because low-quality materials result in increasing production cost [46], [47]. In order to consider the quality aspects for supplier selection, a special model has been developed by Chen et al. [47] with reference to the process capability index. Using this model, a user can visualise each supplier's capabilities for a considered process quality characteristic, and it helps to select the best supplier and to provide quality-related recommendations for others.

4.1.2. Manufacturing and Manufacturing Supportive Processes Improvement Initiatives

A study conducted by Westhuizen & West [48] reveals that cross-function integration through ERP systems provides multiple benefits. It focuses on integrating warehousing and work order planning and warehousing activities. As it proved, the integration mentioned above provides benefits such as on-time delivery of materials, utilisation of available information via ERP system, picking time reduction, and facilitating external integration.

This has been further proven by the research conducted by Arlbjørn et al. [49] which emphasise the importance of enhancing the internal integration through ERP implementation to improve competitiveness. They focus on integrating sales and delivery, production, production planning and procurement processes through ERP implementation through integrating the company’s several IT systems into one system. It resulted in reduced employee requirement, reduced capacity requirement resulting from reduced inventory, improved delivery quality resulting from reduced delivery delays and reduced wastages. In contrast, cross-functional integration through ERP implementation results in financial, operational, internal relational and external relational benefits.

Moreover, the study conducted by Yan et al. [50] identify the benefits of process redesign through developing a process resequencing model. This model re-sequences and merges the activities in the production process. It reduces safety stock, the step-up time required for different products, and improved product quality.

Lean implementation focuses on reducing wastes associated with processes by reducing non-value added activities [51], [52], [53]. Each business needs an information management method to run operations without errors and disruptions. Therefore, it is important to use available information by communicating effectively. Soares & Teixeira [54] describe the benefits of adopting a Lean information management system in logistics. The study focused on redesigning the existing information management procedures related to production orders and sales forecasts by joining them to automate data crossing and calculations. This study further reported reductions in human resources and time required to perform the task. Parry and Turner [53] describe how the manufacturing industry can benefit from adopting a Lean information management system through a case study research conducted with three aerospace leaders. This Andon-based information system has been integrated with ERP so that production details such as units, pending tasks and anticipated finishing time can be communicated to workers in the plant. This results in improved transparency in production and eliminates bottlenecks; the eventual results include cost reductions, increase in productivity and waste reductions. A similar study conducted by Senkuviene et al. [50] discussed the manufacturing process improvement initiative of combining IT and Lean concepts. This initiative is about real-time monitoring of the production process progress and equipment workload. As a result, this method improves timely production and staff effectiveness.

An empirical study conducted by Ward and Zhou [12] suggested that implementing Lean/Just in Time (JIT) reduces the customer lead time (order receipt to order delivery to the customer). Moreover, they emphasise the mediating role of Lean/JIT on IT integration. According to the findings, both internal IT integration and external IT integration do not have a direct effect on reducing customer lead time. However, this effect will be mediated if implemented with Lean/JIT practices. Further, it elaborates that the above results are in the same manner for manufacturing lead time. The study conducted by Kovács [52] tries to emphasise the importance of combining facility redesign initiatives with Lean initiatives while proving the integrated initiative gives more benefits than implementing two initiatives separately. Facility redesign aims to optimise arrangements of facilities and material flows in the plant. Kovács applied 13 methods under Lean with facility redesign which gave 15 benefits including improved productivity, reduced travel distances, improved process transparency, ergonomics and employee satisfaction.

Several authors tried to show benefits that can be gained by combining Lean with Six Sigma (LSS). This amalgamated initiative helps to improve quality while eliminating wastages associated with processes [42], [55]. Thus, it gives more benefits than implementing separately [56]. Further, Zhang et al. [32], reveal that benefits such as cost savings, reduced cycle time, improved delivery performance, improved employee utilisation, eliminated or reduced process wastages, and improved inventory turnover can be achieved through implementing LSS tools as process improvement initiatives. This study was conducted for the logistics sector in Singapore as a survey. Similarly, the study conducted by Hill et al. [33] discusses the use of the LSS framework to identify and reduce the issues related to an Aerospace engine repair and maintenance facility. The developed framework identified causes for late calls for materials and non-value-added activities of the facility operations. This model benefits the facility by reducing late calls and reducing order-to-receipt time. Thus, it helps to improve the overall efficiency of the facility.

The case study research conducted by Vinodh et al. [55] also proves that lead time can be reduced by implementing LSS. LSS has been adopted to reduce the work-in-progress inventory and defective products which eventually gives a cleaner working environment while reducing customer complaints.

The study conducted by Thomas et al. [57] propose a new framework for LSS implementation by combining DMAIC (Define, Measure, Analyse, Improve and Control) cycle to the standard lean thinking cycle. This is somewhat at odds with the LSS implementation cases as all of them directly follow DMAIC and adopt Lean tools whenever necessary (examples: value stream maps (VSM), Kanban, total productive maintenance (TPM), etc.). As Thomas et al. state, Six Sigma centric LSS adoption contains two issues: Lean thinking is not strategically applied as Lean tools are adopted under DMAIC whenever necessary, dual impact of Lean and Six Sigma is eliminated with the use of DMAIC as the structure. Thus, it results in more quality improvement-based projects. The applicability of this framework has been proven by applying it to the aircraft manufacturing industry with the reduction of cost per aircraft manufacturing [57].

Machinery performance significantly impacts process performances such as cost, quality, productivity, and time consumption [58], [59], [60]. Therefore, it is necessary to pay attention to the timely maintenance of machinery. Total Productive Maintenance (TPM) emerged during the 1970s in Japan, considering the maximisation of equipment effectiveness. It covers productivity, inventory, cost, safety, production output, and quality depending on equipment performance [58]. Accordingly, TPM prevails to eliminate machinery breakdowns or defects caused by the production process. TPM is not the same as any other maintenance approach but is also a critical supplement to Lean production [46]. Case study research conducted by Singh & Ahuja [29] identified the benefits of TPM such as improved productivity, improved quality, reduced labour cost.

4.1.3. Distribution and Warehousing Process Improvement Initiatives

The distribution function plays a vital role in reducing lead times embedded in an organisation. Based on that assumption, much research has discussed the role of BPI initiatives in escalating overall performance. Research shows that reducing lead time on perishable supply chains is critical. For example, in healthcare supply chain, platelet distribution is a very time-sensitive task due to the short shelf-life [61]. After the shelf life, the platelet becomes outdated and cannot be used on patients for treatments. A case study research carried out in US by Fontaine et al. [62] addresses this issue of distribution network by redesigning supply chain through better collaborations between blood centres and transfusion services . A newly designed network results in reducing expenses due to minimised safety stock and outdated stocks.

The importance of electronic information sharing is discussed by Clark & Lee [63], where they reveal that both manufacturers and retailers can benefit from improving the replenishment process to make it continuous by adopting the EDI (Electronic Data Interchange) system. This improvement initiative which combines process change with technology (EDI), results in higher inventory turnovers and reduced data entry errors. Another study conducted by Shen & Chou [61] reveal that logistics companies that apply Business Process Re-engineering (BPR) to their processes perform better than those that do not. Performance can be identified in activities or functions such as: order receiving, order picking, order processing, shipping, information processing, coordination, human resource management, organisational culture, and structure.

The application of Lean based value stream mapping method to improve the reverse logistics process has been studied by Rabnawaz Ahmed & Zhang [62], considering steps associated with inert construction waste management. As the study reveals, different future waste management strategies can be developed by comparing the value stream maps (VSM) for current state and future state of the value chain. It helps to eliminate wastages and non-value-added tasks to get an optimal solution. This method calculates and reveals benefits such as total process time reduction, fuel consumption reduction, facility and non-facility-based cost reductions, travel distance reduction, vehicle capacity utilisation, and pollution reductions [62].

A study conducted by Gutierrez-Gutierrez et al. [56] identified the benefits of process standardisation for two logistics processes: payment process and order request to shipment process through implementing LSS. With this improvement cycle time for the process has been reduced. Specially, they tried to elaborate on how a logistics company can benefit by applying DMAIC and VSM to improve logistics processes. Besides, case study research conducted by Dzubakova & Koptak [64] about the logistics process standardisation also provides evidence regarding the benefits of standardisation. Dzubakova & Koptak mentioned benefits such as cycle time reduction, variability reduction, waste reduction, and efficiency improvement through process standardisation.

Agreements for quotations between logistics service providers and customers, including negotiations, are time-consuming activities. Therefore, logistics service providers need to take action to improve mutual understanding and mutual benefits. Liu & Li [63] suggest a Quality Function Deployment (QFD), a tool-based argumentation model, to address this issue. This solution provides benefits such as quick response time and more transparent negotiations while improving overall business efficiency for both parties.

Managing relationships with customers is a very important aspect of a make-to-order business. Therefore, it is important to take initiatives to improve the customer relationship management process. Brashear Alejandro et al. [65] suggest a novel approach by considering customers' lifetime value, which gives an improved delivery performance as a benefit. The presented model in [65] considers past, future, and customer loyalty to decide the lifetime value. The model has been validated using a case study approach, and results show an increase in customer satisfaction.

RFID (Radio Frequency Identification) technology and Electronic Product Code (EPC) systems are two other IT technology dimensions adopted by most businesses. RFID enabled Walmart stores, which recorded significant cost savings through stock shortage reduction, is one of the best examples [66], [67]. A study conducted by Wamba & Boeck [68] regarding the RFID and EPC adoption in the retail industry also validated the cost savings. The study reveals benefits such as time savings in the receiving process due to automated information flow, reduced labour cost, reduced human errors, and reduced information tracking due to an automated tracking system. Moreover, as Wamba and Chatfield [69] have demonstrated, this would help to identify the variations in customer orders and receiving or dispatch quantities automatically as it can be connected with the warehouse management system (WMS)/ERP system of the organisation. Further, it can be used to give indications for drivers regarding whether the order has been completely loaded or not [70]. Generally, this tracking system gives significant cost savings by automating information flows, reducing human errors, reducing labour requirements and reducing process costs [68], [66], [70], [71].

4.1.4. Miscellaneous Supply Chain Process Improvement Initiatives

Supply Chain Management (SCM) is a cross-functional activity that considers integrating materials, information/data, and money between different functions such as sales, marketing, finance, procurement, manufacturing, and IT [72], [73]. Thus, much research developed across SCM elaborates the role of BPI initiatives in curtailing discrepancies through managing technology holistically. Auramo et al. [34] confirm that improved service level, operational efficiency, information quality, and agility can be obtained through IT implementation for supply chain activities. This study used 18 IT implementation cases in different industries to identify the benefits mentioned above through propositions validation. However, the study has been focused on ERP, electronic data interchange (EDI), internet, system web portals (B2B web portals), and third-party B2B web portals. Besides, benefits of cost-saving resulting from reduced human errors, better information flow resulting from better inter and intra-organisational communication, shorter response time, and improved profit have been identified as Electronic Supply Chain Management's (E-SCM) benefits by [74]. These benefits have been obtained through a study conducted on the Electronic Manufacturing Services (EMS) industry of North America.

Furthermore, efficiency benefits of labour cost reduction, inventory management cost reduction, and material order process cost reduction have been identified by Barsauskas et al. [36] through a study conducted to explore the impact of E-SCM on business efficiency. However, this study has been considered only the B2B E-SCM activities. This case study conducted for Lithuanian computer equipment wholesale company mentioned that there is a 57% increment in business efficiency with using B2B E-SCM. Moreover, Hwang & Lu [30] discuss the benefits of an E-SCM implementation project in Taiwan's Semi-Conductor industry to integrate all supply chain partners. According to Hwang & Lu, this project provided several benefits, including reduced data transfer time, on-time delivery of information, improved data transparency, and improved data accuracy. Akyuz & Rehan [75] also identified several other benefits of E-SCM such as the integration of internal and external supply chain functions, real-time collaboration, automated business activities.

A Green Lean Six Sigma (GLSS) model for public sector supply chains has been introduced by Sreedharan V et al. [76], considering the procurement, production, and distribution supply chain functions. This module evaluates suppliers using eco-friendly standards while ensuring the procurement process in linear and green conditions. The production process of the module has been prepared to ensure the application voice of the customer, eco-friendly production, and total productive maintenance. The distribution process identifies and evaluates the non-value adding tasks and finally eliminates non-value adding tasks' impact. Overall, this model reduces wastes while reducing the burden on the environment and humans. In addition, De Giovanni & Cariola [77] confirms that three categories of benefits: improved environmental performances, operational performance, and economic performances can be obtained through adopting Green Supply Chain Management (GSCM) practices. This paper concludes the fact that the adoption of lean also contributes to the benefits mentioned above. These results have been validated using data from several industries from multiple countries.

In addition, improved operational performance on process and product innovation has been proved by Tarigan [78] through a study conducted using 42 small and medium-sized shoe firms in Indonesia. As a result, innovation firms can reduce labour costs and burden costs while lowering the product price. Additionally, firms can improve competitiveness with the industry through customer attractiveness and affordable products through product innovation. Nguyen & Harrison [79] prove that benefits related to financial performance and cost reductions can be reached through process innovation. Besides, process innovation benefits such as flexible production processes, improved product quality, expanded production capacity, and reduced labour costs and production costs have been reported by Macurova et al. [28] using a cross-industry analysis for firms in the Czech Republic.

A study conducted by Jayaram et al. [80] confirm the impact of information systems infrastructure on on-time performance. Information systems infrastructure plays a significant role in supply chain process improvement as it facilitates the integration of different supply chain activities. The study tested the impact of the three sectors of information systems infrastructure: IT, Design Manufacturing Integration (DMI), and manufacturing technology on-time performance. As the study reveals, DMI reduces product development time and delivery time. The other two sectors also reduce the product development time while improving the responsiveness to customers. Thus, it clearly shows the impact of information systems infrastructure on cycle time reduction of processes. A study conducted by Dehning et al. [35] confirm that IT-based SCM practices benefit both inbound and outbound supply chain practices while enabling better relationships with customers and suppliers. Thus, it reduces the required inventory levels for a firm and results in cost savings. This study further reveals that benefits related to the firm's internal process can only be gained through redesign and IT implementation. Saygin & Sarangapani [81] mentioned the supply chain level benefits of RFID system implementation through a study conducted for time-sensitive inventory tracking in the manufacturing industry. Mainly, it facilitates the vendor-managed inventory concept as it helps to eliminate the requirement of middle parties such as distributors through direct information sharing between supplier and buyer. It gives additional benefits including reduced labour intensiveness due to automated data tracking and monitoring, utilisation of workers due to automated repetitive tasks, improved productivity and quality due to high data visibility, and mobile database facility. Gorla et al. [82] introduced an IT-based Business Process Re-engineering (BPR) model for process improvement. This model includes eight steps and shows the importance of organisational structure change and continuous improvement in BPR projects. Besides, the study records a 43.3% net profit increment in a year after the case study project completion.

In a study conducted by Mohanty & Deshmukh [10], lead time reduction, labour requirement reduction, inventory reduction, and risk reduction were identified as BPR benefits resulting from eliminating non-value-added processes. Mcadam & Mccormack [16] argue that benefits such as long-term and stronger relationships with customers and inter-connected logistics and production processes can be gained through business process redesign. This redesign was about restructuring the organisation from production plants to supply chain activity centres. Banerjee [83] identified the benefits of process reengineering by introducing new three IT software related to procurement management, order planning, and order fulfilment. IT adoption to order fulfilment facilitates real-time order processing and transmission while eliminating orders via time-consuming media such as fax, telephones, and emails, requiring manual order entries. Its adoption to the procurement process gives benefits, including reduced lead time causing better connections with suppliers, increased data accuracy, and reduced inventory requirement due to reduced re-order points. More accurate forecasts and timely information for replenishment requirements benefit from the software adopted order planning process. Radosevic et al. [84] explore benefits gained using the lean-based value stream analysis tool as a process improvement initiative. Existing supply chain management practices have been improved after analysing it, and the following are the benefits received from it: reduced stock holding cost, reduced time for production line changes due to well-maintained planning activities, reduced write-offs of finished goods and raw materials due to better alignment of procurement and production planning activities, reduced warehousing cost, reduced transport cost and increased customer satisfaction due to quality service.

Jahre et al. [85] conducted a study to find reasons for stock shortage in the drug supply chain in a city of Uganda. Jahre suggests a supply chain redesign model which eliminates and reduces the identified reasons such as lack of storage facilities, transport facilities, proper ordering method, and staff competency levels. Jahre et al. [48] identified benefits by addressing these issues via the developed model, including lead time reduction, uncertainty reductions, and reduced stocks due to improved order frequency. Improvement initiatives to address these issues include introducing a postponement strategy, implementing proper information flow, and strengthening the supply chain through internal and external integration and simplified structure. A new dimension to BPI initiatives was discussed in a case study research conducted by Arlbjorn et al. [49], where it discussed the benefits of integrating finance, logistics, production, procurement, sales and logistics through the ERP system integration. As mentioned, benefits including productivity improvement, delivery quality improvement, inventory cost reduction, labour requirement reduction, annual capacity cost reduction and energy cost reduction were achieved through this implementation.

Block chain is an emerging technology in the supply chain domain due to its track and trace ability and security [86], [87]. Block chain technology facilitates the ability to come up with smart contracts while building trust among strangers. This will reduce paper-based processing costs and traveling costs [87]. As Perboli et al. [88] state, block chain being a decentralised system prevents issues on trust, fraud and corruption that arise in relation to current centralised logistics management systems. Using a food supply chain as an example, Perboli shows how blockchains facilitate supply chain visibility while providing accurate and secure information and reducing human errors. Thus, it provides accurate information for forecasts which eventually help producers to reduce the bullwhip effect and stock-out situations through optimised and efficient production and capacity plans. Moreover, it enables prompt actions against food contamination and delivery delays that cause additional costs [88], [86]. Further, it provides accurate data regarding expiration dates and quality for food safety auditors. [88].

4.2. Critical Success Factors of Process Improvement Initiatives

This section describes the success factors identified through the literature reviewing process.

Top management is the utmost level of organisational hierarchy and has great influential power over the decisions. Even though top management typically does not participate in the improvement implementation stage, their guidance, motivation, appreciation, commitment, timely decisions, and resource providence positively impact project success [56] [30]. Moreover, there can be several processes with inefficiencies in an organisation. Therefore, a thorough analysis must be done to identify the supply chain process which has the most negative impact on organisational performance.

After a thorough review of selected papers, the factors summarised in the Table 1 (below) were identified as general success factors that could be considered for any process improvement initiative.

Table 1: General critical success factors obtained from the analysis

• Top management involvement	[89], [14], [54], [90], [91], [78], [30], [56], [55], [52]
• Proper identification of the process to be improved	[14], [55]
• Analysing the existing state of the process in the pre-implementation stage	[81], [92]
• Conducting a pilot project before the actual implementation	[81], [68], [26], [7], [93], [94]
• Conducting a feasibility study in the pre-implementation stage	[81], [15], [71]
• Prior implementation of quality standards.	[95], [96]
• Employee training and awareness regarding the improvement initiative	[74], [26], [97], [57], [13]
• Commitment, motivation and involvement of all stakeholders who are involving and affecting the implementation	[16], [81], [15], [79], [10], [26], [82], [97], [54]
• Establishment of a cross-functional team as the initiative team	[10], [82], [56], [55], [13], [88]
• Information sharing among stakeholders	[11], [13]
• Organisational structure changes	[26], [7]
• Continuous monitoring of results and progress	[82]
• Clearly identifying the importance of process improvement initiative for organisation's vision and strategy	[56], [14]

Proper identification of the improvement project will benefit the organisation in both financial and operational aspects. In addition, analysing the existing state of the process will help consider all the non-value-added activities. Flow charts, value stream maps and SWOT analysis can be used to analyse the existing state.

Moreover, some process improvement initiatives like IT implementation and machinery replacement require huge financial investments. Improper implementation of such initiatives will not provide actual benefits as estimated. Therefore, it is necessary to conduct a pilot project before implementing the improvement initiative (Example - Simulation). Besides, performing a feasibility study before the implementation helps to understand the relationship between costs and benefits of the initiative. Thus, it acts as a guide to decide whether to invest and implement or not. Process improvement initiatives change some tasks performed by employees. As an example, the implementation of ERP systems eliminates reduces manual tasks performed by employees. Therefore, it is necessary to train employees regarding the new operational procedures and software interfaces, etc. Role plays, process-oriented learning, user manuals, and workshops can be used to train employees [74], [26].

Implementing quality standards help to maintain well-disciplined organisational processes. Therefore, such implementations influence the process improvement capabilities making it easy to improve [95]. Commitment, motivation and involvement of all stakeholders who are involving and affecting through the implementation is much required to direct the initiative towards the right path and to ensure success through continuity. Appointing a cross-functional team comprised of employees with multiple skills and knowledge areas is also acts as a success factor as it ensures the multidisciplinary aspects required for the initiative's success [82]. Information sharing among stakeholders provides opportunities to identify and take actions whenever necessary against possible risks. Further, sharing of information such as benefits and process changes among process users is important as it facilitates project continuation and continuous improvement.

4.3. Challenges for Process Improvement Initiatives

This section describes the challenges identified through the literature review process. After a thorough review of selected papers, those presented in the Table 2 were identified as general challenges for any process improvement initiative.

Table 2: General challenges for BPI initiatives obtained from the analysis

• Resistant to change and adopt for new process	[25], [14], [98], [32], [82], [42]
• Resource allocation issues	[36], [98], [42], [99], [25], [15], [69]
• Lack of top management commitment	[100], [42], [85], [10], [57]
• Lack of availability of customer data	[100], [65]
• Lack of employee training	[56], [42], [74]
• Issues related to information sharing	[7], [42], [101], [90], [15]
• Organisational culture barriers	[42], [102], [15]
• Implementing the process improvement initiative without organisational structure change	[26]

Resistance to change may arise from employees who perform the newly improved tasks [25]. Therefore, it is necessary to make them aware of the benefits they can gain and motivate them to adopt new changes. Resource allocation issues such as lack of financial resources, lack of machinery, lack of human resources and lack of technical knowledge is another barrier that must be taken into consideration when taking supply chain process improvement initiatives. Lack of top management involvement was found to be another important barrier [103]. Without top management's active commitment, guidance, and enthusiasm improvement initiatives are impossible to become a success.

Issues related to information sharing include lack of information, the accuracy of the information, and confidentiality of information. Some improvement initiatives expand the degree of information sharing requirement with other internal and external parties (Example – suppliers, consultants, etc.). Thus, it creates problems with the confidentiality of information. On the other hand, employees must be aware of initiatives' benefits and objectives through proper communication methods. Lack of training causes for unawareness of employees regarding the tasks [56]. Thus, it may affect productivity through wastages and time consumption.

5. DISCUSSION AND CONCLUDING REMARKS

The most recent literature review on BPI initiatives dates back to over two decades ago [63]. This paper presented the first systematic review of its kind. The study started keywords formulation without being restricted to any time limit. When compiling the documents based on their relevance to our scope, this study only reviewed papers from 1997. This rigorous iterative process provided a pool of 81 research papers spanning end-to-end supply chain disciplines.

This study aimed to set the context in determining the nature of BPI initiatives in terms of benefits, challenges, and critical success factors. Benefits of process improvement initiatives can be identified under four basic categories. These include operational benefits such as waste reductions, financial benefits such as cost reductions, internal relational benefits such as integration with internal divisions or parties and external relational benefits such as integrations with external parties (suppliers and customers).

Moreover, two types of trends can be observed among critical success factors and challenges. It was observed that success factors in the first type eventually become challenges if an organisation is unable to facilitate it. As an example, better top management involvement and adequate employee training regarding the new initiative are success factors for a supply chain process improvement initiative. On the other hand, lack of top management involvement and lack of employee training become challenges for a supply chain process improvement initiative. This implies they are interchangeable. The second type of success factors act as leveraging factors and therefore they do not become challenges for a process improvement initiative. For example, prior implementation of quality standards influences supply chain process improvement initiatives by providing more disciplined organisational processes. However, it is not a mandatory requirement as it can be facilitated even through the process improvement initiative. Hence, they are not interchangeable.

The analysis arrived at several key findings and potential research directions as noted below. The present state of the literature reviewed in this paper has mostly considered process reengineering initiatives. Software developments including ERP, B2B web portals, EDI, special procurement software, and planning and scheduling software were considered part of process reengineering initiatives in this study. RFID technology became indispensable to researchers as an IT-related technology. This has become widely accepted in storage & distribution facility improvement projects assessing inventory tracking. Process redesign initiatives are common in the industry, yet academic research has not extensively explored this phenomenon. The prevalence of resequencing, restructuring, merging and route network redesigning was attached to this particular research discipline. More evidence-based studies that explain the applicability of RPA and Blockchain technology as process improvement initiatives for supply chain processes can be identified as a future research direction. Given the global trends in Lean, including value stream mapping, TPM, and lean information management initiatives, various aspects of culture and risk attitudes in implementation could be an important emerging research area in this domain. This notion has inevitably inspired academic studies to discern how LSS initiatives contribute to end-to-end supply chain practices. Even though process improvement initiatives are considered, they may fail if anti-systematic approaches are followed [104]. Exploring systematic approaches or systematic models for supply chain process improvement initiatives embedded in systems thinking can be identified as a future research direction.

Moreover, benefits realisation management provides opportunities for an organisation to evaluate and measure how improvement projects or initiatives add actual values to organisations [105]. However, there is a lack of literature which discusses benefits realisation frameworks and practices which leverage the process improvement success. Therefore, exploring benefits realisation frameworks and practices associated with achieving target benefits of the supply chain process improvement initiatives can be identified as a future research direction. Literature proves that combined Lean-Six Sigma and Lean-process redesign improvement initiatives which simultaneously apply two process improvement initiatives can give more benefits than applying them individually [52], [26], [13]. However, there is a lack of research that shows the dependencies between different types of technology-based process improvement initiatives from the organisation's strategic objectives achievement perspective. Therefore, identify the dependencies between benefits and overall contributions towards organisation's strategic objectives can be identified as a potential future research direction.

While BPI initiatives have a rich history in academic research, most preceding work looks at overall benefits/performance improvement without connecting to the general challenges and critical success factors. BPI initiatives can open the path for this success through removing wastages, utilising resources and optimising processes [11]. However, it is necessary to identify the suitable process improvement initiatives with reference to the benefits that can be gained and success factors and challenges that have to be faced.

Therefore, this research was able to synthesise industry perceived benefits, challenges, and critical success factors; as summarised in the Table 1, Table 2, Table 3, Table 4, Table 5 and Table 6. The findings of this research therefore enable future researchers and industry practitioners to better comprehend the state of the literature and identify opportunities for future works.

Table 3: Summary of supply chain process improvement initiatives under procurement category

Improvement Initiative	Main Focus	Additional Benefits
E-procurement facilities	Enhancing inter-organisational collaboration with real-time information sharing with suppliers.	• A portal to interact with financial institutions and logistics service providers • Process cost and time reduction
Robotic Process Automation (RPA)	Automating repetitive tasks like order sending and receiving.	• Reduced data entry errors • Reduced overtime workload
Online auctions	Reducing the time associated with selecting suppliers.	• Ability to evaluate more suppliers and equal chance for all of them • Gives a more disciplined auction process
Quality based supplier selection model	Selecting suppliers based on their process capability	• Ability to provide quality-related recommendations for suppliers

Table 4: Summary of supply chain process improvement initiatives under manufacturing and manufacturing supportive category

Improvement Initiative	Main Focus	Additional Benefits
Cross-functional integration through ERP systems	Enhancing internal integration among supply chain processes.	• Facilitate external integration • Utilisation of available information • Reduced lead time associated with decision making • Reduced employee requirement • Reduced capacity requirement resulting from reduced inventory • Improved delivery quality resulting from reduced delivery delays • Reduced wastages
Process Redesign	Re-sequencing and merging of production activities	• Reducing the set-up time required for different products. • Improved product quality resulting from reduced defects • Reduced safety stock
Lean		
1) Value stream maps	Identifying wastages associated with 7 waste types.	
2) Total Productive Maintenance (TPM)	Leveraging production process through reduced machinery breakdowns.	• Improved product quality • Improved productivity • Reduced human resources requirement
3) Lean information management	a) Reduced time waste by redesigning and automating data crossing and calculations.	• Reduced human resources requirement • Reduced task time
	b) Use of Andon method to monitor real-time progress.	• Enhanced response to customers and suppliers • Improved process discipline • Improved production process transparency • Easy identification bottlenecks • Waste reduction
4) Lean-Six Sigma	Improving quality while reducing wastes	• Cost savings resulting from reduced wastages and improved quality

Table 5: Summary of supply chain process improvement initiatives under distribution and warehousing category

Improvement Initiative	Main Focus	Additional Benefits
Distribution process redesign	Reducing the lead time associated with time-sensitive product distribution.	• Minimised outdated stock • Minimised safety stock
Electronic Data Interchange (EDI)	Real-time information sharing that will result in higher inventory turns.	• Reduced data entry error • Higher inventory turns
RFID implementation	Saving the time resulting from automated information tracking/ product verification.	• Reduced human error • Reduced labour requirement • Eliminated paperwork related to the process (eg: product counts) • Increased visibility throughout product movement.
IT–based transparent quotation for logistics services	Reducing the time associated to come-up with customer agreements.	• Improved mutual understanding resulting from increased transparency • Quick response time
Lean	Reducing cycle time associated with processes.	• Variability reduction • Efficiency improvement

Table 6: Summary of supply chain process improvement initiatives under miscellaneous category

Improvement Initiative	Main Focus	Additional Benefits
Process innovation	Reducing costs associated with existing processes.	• Flexible production processes • Expanded production capacity • Improved product innovation capability • Improved product quality and competitiveness
E-Supply Chain Management (E-SCM)	Integrating all supply chain partners.	• Enhanced information flow • Shorter response time • Improved data transparency
Blockchain Technology	Enhancing trust, accuracy and traceability	• Reduced paper-based processing cost and time resulting from smart contracts • Reduced human errors • Reduced bullwhip effect due to accurate information • Optimised and efficient production and capacity plan resulting from accurate information • Ability to take prompt actions and decisions due to traceability

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STRATEGIC PERSPECTIVE

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REVIEW OF THE "SISU SERIYA" SCHOOL BUS SERVICE

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ABSTRACT

School Transport is considered an essential service that provides equitable access to school children who have difficulties in accessing their respective schools. Different school transport systems in countries differ from each other based on their resources and topography.

This paper presents a case study conducted on the Sri Lankan School Bus service "Sisu Seriya" initiated in 2005 to provide a sustainable, reliable and safe mechanism for providing State assistance for school transport. It provides bus service at a concessionary rate through a state subsidy to schoolchildren across the country, contracting bus operators in both public and private sectors, engaged for regularly scheduled services through a specific contractual arrangement in which a set of regulatory and safety conditions are stipulated. Sisu Seriya engages over 1,565 buses serving more than 100,000 school children daily. The paper has benchmarked the Sisu Seriya service through a systematic review of global best practices. Initiation of the system, design features, implementation mechanism and monitoring procedures of the Sisu Seriya service and areas for potential improvement are discussed based on its 15 years of operation, while elucidating the distinctive characteristics of the system. It further highlights how the service design has addressed the challenge of resource limitations, inherent to developing countries, through effective utilization of the existing fleet.

Keywords: *Sisu Seriya, Transport, School Children, Dedicated, Concession, Sri Lanka*

1. INTRODUCTION

Transport plays a crucial role in the economic, social and cultural development although it is considered as a product fetching derived demand. Efficient and effective transport systems are directly attributable to the development of a country. A sustainable transport system addresses social and cultural needs while respecting economic and environmental imperatives. School transport is an area that society should focus on as it relates to an age group that bears responsibility for the future of a particular society [1],[2],[3].

Sri Lanka is a middle-income developing country with 21 million people, out of whom 4.2 million are students attending 10,000 schools. Of these schools, 96.5% are classified as provincial schools and the others as national schools [4]. Only 10% of the total student population in the most populous and economically-advanced Western Province use buses in commuting to school. In other provinces, most students attend schools located within walking distance from their residences, due at least in part to the absence of bus services. It has been found that more than 50% of students in the Western Province use either cars or vans, resulting in increased traffic congestion in the vicinity of schools in urban areas[5].

One of the responsibilities of the Government, especially in a developing country with significant income disparities, is the social and cultural development of its people by ensuring equitable access to education. Affordable and accessible transport services for school children are often provided with government support or subsidies; perceived as investments owing to their benefits being accrued in the long run. [1],[6].

This case study illustrates the design and implementation of a concessionary school bus service called *Sisu Seriya* that has continued successfully since its inception in 2005. *Sisu* Seriya, meaning "students' travel" in Sinhala, was inaugurated by the National Transport Commission on 12th September 2005 with 180 buses at Temple Trees, Colombo; the service has since expanded island-wide, providing 1,418 daily services to nearly 100,000 students [7],[8].

2. LITERATURE REVIEW

This literature review summarises global school transport service arrangements while noting their special features. These provide insights into global best practices in the selected countries throughout the world. The provision of school transport varies globally, from students having to share scheduled public transport to having a dedicated school bus service operated free of charge by the Government or the respective education authorities [9]. Safety and reliability have been identified as essential combinations of school transportation given the nature and need of commuters [1],[2]. Compared to other modes available for school transport operations, relatively larger seating capacity, safety, reliability, and flexibility make the bus mode the top choice [10].

The United States of America (USA), Australia, Canada, New Zealand, the United Kingdom (UK) and Japan are all high-income countries with well-developed school transport systems. The USA, Australia, the UK and Russia provide free school transport to all students or at a minimum to those eligible for free transport. Eligibility criteria include being enrolled at the nearest appropriate school, receiving a minimum compulsory education, residing no further than 3-5 km from school, or residing outside of an area where public transport services are unavailable [9],[11]. In Australia and most of the European continent, dedicated transport services are provided to students with special needs, free of charge or at a concessionary rate [12],[13],[14]. In addition, it is common to observe dedicated school buses with a specified colour and customised hazard lighting: a practice that originated in the USA. Countries with large geographic areas delegate school transport provision to the respective Provincial Transport Authorities (PTA): this creates practices that often differ within the same country [6]. In the U.S. and Australia, such services are usually provided by school districts, who provide dedicated services through buses or contract out service delivery to bus operating companies [15].

However, only a few Asian countries have dedicated school bus services, and some are yet to be extended into full-scale programmes. China, Hong Kong, the Philippines, Singapore and South Korea are some countries that have implemented dedicated school bus services [9],[16],[17],[18]. However, except for Singapore, all other countries are still far behind in improving safety standards and fulfilling the demand [9],[17].The lack of suitable public transport for students often results in parents making arrangements with private operators of passenger vans or buses at a premium rate. The absence of proper regulatory guidelines and the lack of ownership and operational controls of such services result in many delivery problems and issues [18],[19]. In addition, countries like Japan, the Netherlands, Hong Kong, the United Kingdom, South Korea and Italy have encouraged non-motorised transport to school, such as walking and cycling. Such policies are supported by urban development policies and school admission policies which urge students to be enrolled at nearby schools so that non-motorised access is feasible [8],[20],[21],[22]. Table 1 compares school transport systems in different countries according to their design features.

The most common problem faced by countries lacking public school transport services is that parents have to provide transport for their children, leading to a loss of workforce productivity. Studies have shown that parents are more concerned about safety and convenience than cost, sustainability, and reliability of transport arrangements, resulting in them personally driving their children to school [1],[4].

Table 1: Comparison of the features of global school transport services

Characteristic		China	Japan	HongKong	Singapore	South Korea	Russia	Australia	New Zealand	United Kingdom	Germany	Italy	Netherlands	Poland	USA	Canada	Mexico	Argentina	Sisu Seriya
Providers	Government				✓		✓	✓	✓					✓	✓	✓	✓		✓
	Private	✓	✓	✓	✓	✓				✓	✓	✓						✓	
	School	✓		✓				✓						✓			✓		
Service	Exist. public transport							✓		✓									✓
	Additional provision										✓								
	Dedicated service				✓		✓	✓	✓	✓		✓		✓	✓	✓	✓		✓
	Special needs						✓	✓	✓	✓			✓	✓	✓	✓			
Main mode	Bus	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓		✓
	Van	✓		✓		✓		✓										✓	
	Walk / Bikes		✓	✓		✓				✓			✓						
Consession	Free of charge						✓	✓		✓			✓	✓	✓	✓			
	Discounted								✓	✓	✓						✓	✓	✓
	Season tickets					✓													✓
	Allowance					✓		✓	✓		✓								
	Eligibility criteria						✓	✓		✓				✓	✓		✓		
	Symbol / Wording	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓		✓					✓
Vehicle features	Colour	✓	✓			✓	✓	✓	✓	✓		✓		✓	✓	✓	✓		✓
	Lights	✓	✓			✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓		
	GPS	✓	✓			✓	✓	✓	✓	✓		✓		✓	✓	✓	✓		
	Video surveillance	✓			✓		✓	✓											
Rules and regulations	Speed limits	✓	✓			✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓		✓
	Traffic priority	✓				✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓		
	crews	✓				✓	✓	✓	✓	✓		✓		✓	✓	✓	✓		✓
Routes	Existing routes										✓							✓	
	Dedicated routes				✓		✓	✓	✓	✓				✓	✓	✓	✓		✓

Safety is a vital element of school transport, given the involvement of a sensitive group of riders. Europe, the USA and Australia can be identified as pioneers in implementing dedicated safety standards for school transport [3],[21],[23],[24]. Many Asian countries have followed suit, engaging in different arrangements between regulators and users. These are often triggered by accidents and social pressures after accidents [18],[22]. Many countries have implemented traffic priority measures that provide dedicated school bus services: for example, restrictions on overtaking school buses, on children boarding or alighting, prohibiting or permitting certain action only at a reduced speed [11]. A study to measure and analyse the school bus service quality level in Malang City, Indonesia used Importance Performance Analysis (IPA) to rate the service's features. It included adequate space, seating capacity, availability of trash can, availability of information boards at the bus stops, availability of public telephones at bus stops, and CCTV [25]. In the City of Lisbon, Portugal, a transport mechanism integrating different routing problems arrived at a Mixed Integer Linear programming (MILP) solution for a multi-route school bus service. The system was capable of developing solutions for a single medium-sized school. However, in the case of multiple schools and multiple cities, there were some complexities in arriving at an efficient and effective solution [26].

In the case of developing countries, financial, technological and infrastructural capacity need to be evaluated to design a sustainable and productive school transport mechanism. Systems designed with inadequate consideration of these factors have collapsed or incurred high costs to the Government [27],[28].

3. DESIGN OF SISU SERIYA SCHOOL BUS SERVICE

3.1. School Bus Transport before Sisu Seriya

Sri Lanka had been implementing different concessionary schemes to encourage children to attend school by facilitating travel between home and school since as early as the 1950s. It started well before the nationalisation of the bus industry to establish the State monopoly operator, the Ceylon Transport Board (CTB) [29],[30],[31]. Such schemes can be identified and elaborated as follows:

Season Tickets – A season ticket is a printed card issued at the beginning of each month. The CTB, formed in 1958 after the private operators were nationalised, initially issued season tickets at a 67.5% discount for students under 12 years and a 35% discount for those above that. These season tickets allow students two trips between home and school every school day in a school uniform. These concessions were further increased to 85% discount in 1993; the CTB’s financial losses increased when those discounts allowed were not reimbursed to the CTB by the State [30],[31].

School Bus Service provided by CTB – This was a mechanism where the CTB provided a fare-paying dedicated school bus service for schoolchildren attending a specific or any cluster of schools. Students who possessed a monthly season ticket could travel in these dedicated buses without paying extra, which was considered an excellent service at its initiation in the 1960s [32]. However, there was no incentive for the CTB to keep operating such dedicated bus services, which were not accessible to daily fare-paying ordinary passengers. However, there was no incentive for the CTB to keep operating concessionary services. Therefore, it often neglected these services, favouring more remunerative services, making the school bus service unreliable. This practice led to the CTB losing student passengers who consequently moved out to reliable modes of transport, reducing the school bus service to around 70 operations a day by 2005 when there were 200 scheduled operations island-wide. This situation was a direct consequence of expecting the CTB to cross-subsidise the loss-making service, which the Government should have assisted given the social and economic benefits delivered through such a service.

Even though the economic benefit to users through this initiative was considered significant at the beginning [29],[31], school buses' quality, reliability, and safety gradually became unsatisfactory [29],[32],[33],[34]. Besides, the share of public bus transport services provided by the Sri Lanka Transport Board (SLTB), the successor to the CTB, dropped to around 30-40% after private bus operators re-entered the market in 1978. As a result, schoolchildren had to wait longer for the arrival of an SLTB bus and, when it arrived, had to struggle to get on board as the bus would invariably be overloaded [29],[33]. This type of high concessionary mechanism could rarely be observed in the international context without subsiding the operator for such provision. Most countries provide school transport services either entirely freely, either through a dedicated service provider who is being paid for the service provided or by paying an allowance for eligible students, which removes the financial burden from the operator.

This practice led to both types of services, namely school season tickets and dedicated school buses, becoming less reliable and less attractive by 2005 even though the State was spending over Rs 225 million every year on season ticket concessions. Schoolchildren often had to depend on other modes of transport, usually paying much higher fees and sometimes in addition to what was paid for their season tickets. The result was an emergence of large numbers of privately-operated school vans that provided school transport services for a premium rate, generally around 20 times the season ticket rate.

On top of this, the high concession rates granted for schoolchildren created a considerable loss to the SLTB. Thus, the SLTB prioritised general commuter service in the morning peak, which was more lucrative than the school service, resulting in a shortage of buses made available for school children. Gradually, the system became commercially unviable for SLTB due to the absence of a sustainable financing mechanism, which led to the system's collapse by 2005 [35].

Some schoolchildren in remote areas are seen as having abandoned studies due to these difficulties. Table 2 summarises the issues and repercussions of the systems that existed prior to *Sisu Seriya* being introduced.

Table 2: Issues and repercussions in the school bus system prior to Sisu Seriya

No.	Issue	Repercussion
1	Buses not operating on schedule, leading to poor service reliability	Higher absenteeism, children were returning home without attending school, children unable to return home, leading to parents' anxiety. Some students dropped out of school as more reliable transport was expensive.
2	Inadequate service provision underpinned by the limited number of buses assigned to dedicated school services	Congested school buses and students not being able to travel in comfort. Other disciplinary issues arose within buses, resulting in violent student behaviour, with buses being taken to the police station.
3	Due to the captive market and losses in providing the service, the operator assigned some of the oldest buses for school transport.	High exposure of students to breakdowns, accidents etc.
4	There was no regulator as it was an arrangement between the Government and state bus operators.	The inability of the self-regulatory mechanism to maintain quality of service led to gradual deterioration of services.
5	Due to the high concession of even up to 85% provided to the students, most of which was not reimbursed by the Government, the operator has to bear heavy losses, making such services financially unviable.	The quality and reliability of the service deteriorated due to the operator's lack of eagerness to provide a loss-making service. Students bought seasons tickets as they were highly discounted, but often travelled in private buses as they were more frequent and regular.
6	The emergence of private transport providers providing school service at a rate 20 times the regular transport fare	The system was unaffordable for the majority of the school children. In addition, school vans entering and parked near the schools were creating congestion interrupting the urban vehicle flow.

3.2. Concept of *Sisu Seriya*

The inefficiency of the prevailing system by 2005 raised the need to design a better system [29],[32],[33],[36]. The concept of *Sisu Seriya* was initiated with the idea of addressing the above-discussed deficiencies through a standardised and regulated service. The paramount need was to create an environment where the children could go to school well in time and return home safely without being inconvenienced mentally or physically.

The school transport concept was restructured considering that the private sector provided around 70% of the buses deployed for regular route operations, most individual bus operators. The SLTB supplied the balance through around 100 bus depots scattered across the country.

The National Transport Commission (NTC), the regulator of the public bus industry, and mainly the inter-provincial private bus services, took the lead in innovating a new system of school bus service provision. Upon detailed assessment of the conjuncture, lessons learnt from the hitherto existing systems, and the objectives, the *Sisu Seriya* service was developed with the following objectives and features:

(a) Objectives of Sisu Seriya Service

The objectives of the Sisu Seriya school bus service, as set out in the aim of the service at the inception, can be listed as follows [37]:

- (i) Provision of a reliable and quality transport service for students from school to home and back, reliable and on time to provide them with a pleasant mind in readiness to engage in educational activities that would contribute towards a fruitful new generation.
- (ii) Charge only 50% of the ticket price from students who use this service to reduce the economic burden of schooling to families.
- (iii) To create a pleasant social environment for students to interact during the commute to school.
- (iv) Substitute a large bus instead of a large number of small vehicles to reduce fuel consumption and environmental pollution and to reduce traffic congestion;
- (v) Incorporate both SLTB and private bus operators to provide more supply.

(b) Features of the Design of Sisu Seriya

The following key features were incorporated to ensure success and sustainability:

- (i) **Reliability** by imposing penalties for non-operation of buses and delays compelling regular operations;

(ii) **Security** by stipulating that two teachers be carried free of charge and safety guidelines issued for the operators;

(iii) **Affordability** by charging only 50% of the regular fare while allowing the use of the Season Tickets remain unchanged on SLTB buses;

(iv) **Ownership** by setting up School Transport Committees (STCs) made up of teachers and students;

(v) **Continuity** by reimbursing estimated operator losses through a dedicated budget allocation for Sisu Seriya and incorporation of both State and private operators;

(vi) **Quality** by setting standards required for safe and convenient carriage of children including the minimum age for bus crews, uniforms, EPF/ETF etc. in the contract and termination clauses as required;

(vii) **Monitoring** by requiring the accreditation by STCs and the regulatory agencies (NTC and PTAs) about the service before payments are made and allocating free tickets for two teachers and one senior student to certify the services provided every month.

The *Sisu Seriya* proposal, developed incorporating the above attributes, was submitted to the Cabinet of Ministers in 2005 through the Ministry of Transport. Upon approval and receipt of the necessary funding from the Treasury, the *Sisu Seriya* school bus service was inaugurated on 12th September 2005, commencing the operation with 180 buses in 7 districts serving 152 schools across the country.

The systematic planning and incorporation of the necessary attributes listed above have enabled the *Sisu Seriya* to be endowed with a service model that stood well above the prevailing systems despite being developed and operated in a developing country.

3.3. Selection of Sisu Seriya Buses

The selection of a Sisu Seriya bus service begins with a school (the “trip attractor”) making a written request to the NTC for a school bus service. After evaluating the requirement, the NTC directs the request either to the SLTB or to the relevant Provincial Transport Authority (PTA) to nominate an existing private bus operator on the same or nearby route to serve the school most easily. Once the supplier details are verified and matched with the school requirements, a service agreement is generated between the NTC and the operator with the necessary terms and conditions for three years. After the NTC approves the service, the respective school must form an STC to be held responsible for the smooth operation of the service. This appears to be a unique user quality assurance feature that has worked very well.

Figure 1 depicts the processes of service assignment in the *Sisu Seriya* programme.

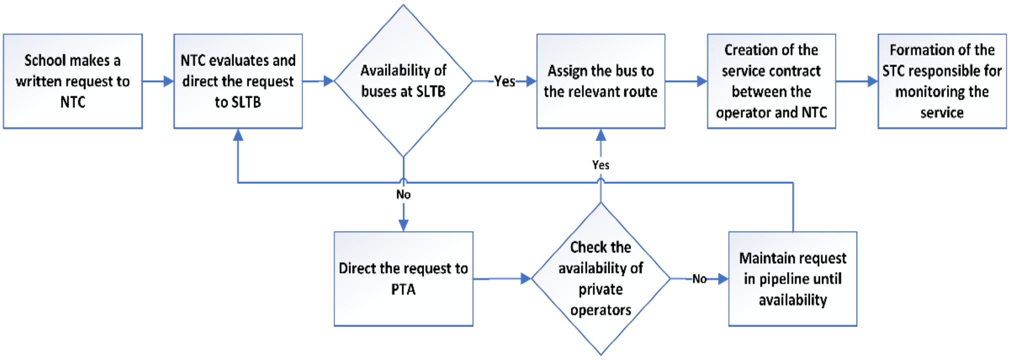

Figure 1: Process of bus assignment in Sisu Seriya service

3.4. Scheduling of Services

The bus chosen is taken from its existing schedule and assigned for the two trips required by the *Sisu Seriya* service. Other buses are rescheduled as necessary. The bus remains in public scheduled service at all other times of a school day. On weekends and school holidays, it provides regular public services.

3.5. Financing Model

Under this model, the operator collects 50% of the fare. The Government provides a subsidy for the balance provided that the service is delivered under the guidelines regarding availability, reliability, crew conduct, quality of bus, etc. The subsidy also pays the operator for the empty haul in both directions at the bus operating cost rate calculated annually by the NTC. Thus, a bus operating from x to y, a distance of 24 km, for instance, will be paid for 2 x 24 km. If the bus operating cost for a 40-seater bus is calculated at Rs 100 per km, then the subsidy provided will be at 50% of the operating cost, Rs 50 per km x 48 km, making a total of Rs 2,400 per day for approximately 200 days a year that schools function. However, the maximum number of km the subsidy is provided is 90kms in the Western Province and 110 km in other provinces. The NTC uses the index applicable to the annual fare revision to revise the bus operating cost annually. The SLTB, as it offers the season ticket subsidy to students on top of the 50% fare concession, will also get that portion of subsidised from the Treasury.

3.6. Payment Process

The bus operators qualify for the payment only if they provide at least 90% of the monthly scheduled trips. In 2010, this was raised to 95% but subsequently lowered back to 90% due to the inability of the providers to comply. An unserved trip is penalised with a monetary penalty twice the subsidy provided for that trip. A penalty equal to the subsidy assigned for the relevant ride is charged if a bus gets delayed. The NTC issues a log-sheet for a bus every month, where the actual delivery and times of the two school trips should be certified by the assigned staff member/student each day. This sheet is to be kept inside the bus for inspection by NTC officers when providing the *Sisu Seriya* service. The NTC makes payment after the log sheet is submitted to the NTC through the SLTB Depot Manager or the PTA in the case of a private operator. The price per trip in the contract is renewed by applying the percentage of the annual fare revision, which takes place in July every year. The price has increased and decreased with changes in input prices, mainly affected by changes in fuel price.

Source: National Transport Commission, Sri Lanka - Annual Report, 2018

Figure 2: Images of Sisu Seriya Service

3.7. Stakeholder Duties and Responsibilities

The *Sisu Seriya* service requires the participation of several stakeholders for successful implementation.

School Transport Committee (STC)

All schools to which many children arrive by means other than walking are encouraged by the NTC to form an STC after assigning a Sisu Seriya bus service. The Principal of the school appoints this committee. It consists of two senior teachers, two responsible parents, the Officer in Charge of the Police of the area and the General Manager of the PTA if the bus is provided by a private operator and the representative who is in charge of the operations in the respective SLTB depot. Other members are co-opted where necessary. This committee should meet at least once every month. If one bus is shared among students of several schools, a lead school may take the initiative to ensure adequate representation of other relevant schools in the committee.

The responsibilities of the committee are:

- To plan new services and amend existing services to provide maximum benefits to the students;
- Inform the parents regarding the services and securing the support for the service provision;
- To discuss with the bus company to provide and maintain a regular school bus service and to monitor such service;
- To appoint a Warden for each school bus to maintain discipline and to liaise with the bus company daily;
- To plan and manage the parking, traffic control and road safety in the vicinity of the school, especially at times of starting and closing of the school;
- To monitor school van services according to guidelines that may be prepared and issued by the Ministry of Education or NTC;
- To certify the provision of bus services for endorsing payment to SLTB and private companies for services provided;
- To maintain the "log sheet" with proper updates mentioning the dates when the service was not provided and specifying any quality concerns in the same sheet.

Service Conditions

The buses employed for the programme have to be labelled with the logo developed for the programme. The name Sisu Seriya is marked in both Sinhala and Tamil, as depicted in Figure 3.

Figure 3: Logos used in Sisu Seriya

A dedicated bus is allocated for the service by the operating company, which is responsible for providing a replacement if the designated bus is not available. Since the Sisu Seriya buses are used in regular service at other times, another advantage of Sisu Seriya is that buses in the regular public transport service are used instead of dedicated buses that are colour coded, as in some other countries. This feature enables the bus service to be provided at the regular ticket price, and the State only subsidises the relevant concession discounted from the regular fare. This case study depicts how a developing country successfully provided a service mainly seen in developed countries.

Following requirements need to be fulfilled by the private operators to be eligible for the service provision.

- In the case of a private bus, it should possess a valid route permit for the general route on which the bus would operate.
- Priority is given to the operators who reside close to the point of origin.
- An operator possessing more than one bus is considered preferable.
- The minimum capacity of the bus should be 40 seats, and the carrying capacity should be 80.
- The bus employed for this service should be less than ten years old.
- The operator should register to pay social security payments for the crew.
- The driver and the conductor should be registered either under NTC or PTA.
- Operators are required to maintain communication facilities inside the bus.

In addition, there are specified requirements for the crew.

- Should wear the uniform while on duty
- Should be more than 30 years of age
- Should possess sound knowledge on the route
- Should be free of charges of having been found unkind or impolite to passengers
- The driver should not have been involved in fatal accidents during his career.

3.8. Implementation Issues

Though well-received by the public, the Government and other stakeholders, there were considerable protests from the school van owners whose business and incomes were impacted due to *Sisu Seriya*. Given the benefits of *Sisu Seriya* through reduced congestion and the resulting economic benefits to society, these objections were not strong enough to disrupt the service. However, the option was given for school van operators to get the *Sisu Seriya* service after converting to bus permits. As a result, some former school van owners now operate only a *Sisu Seriya* Service as it is perceived that operators who provide a good school bus service receive social recognition as a provider of meritorious and altruistic service.

3.9. Monitoring

Monitoring is an essential element for the success of any new programme. Countries with dedicated school bus systems make the respective regulatory authorities responsible for monitoring. However, the *Sisu Seriya* service is monitored primarily by its users. The two teachers and a student leader aboard the bus, who represent the STC, certify the log sheets daily and implement the penalty system for absence, delays and failure to adhere to the contract conditions.

This auditable and corruption-free mechanism is needed to complete payments for bus operators made from public funds. Hence the operators are motivated to get the log sheets signed every day. The log sheets also require the Principal's signature before being sent to the transport authorities for payment. In addition, the NTC conducts unannounced spot checks from time to time to evaluate the compliance of the service providers, especially when a complaint of a breach of conditions is received.

3.10. Current status of Sisu Seriya

Table 3: Progress of Sisu Seriya School Bus Service by Province (2009-18)

Year	Western	North Central	Central	Sabaragamuwa	Uva	Southern	North Western	Eastern	Northern	Inter-provincial	Total
2009	216	70	32	105	57	105	76	31	0	0	692
2010	216	70	32	105	57	105	76	31	0	0	692
2011	220	76	33	118	60	118	77	52	29	0	783
2012	317	72	47	111	83	224	99	77	29	0	1059
2013	296	111	35	122	68	240	130	100	23	10	1135
2014	310	96	62	86	69	225	133	119	25	10	1135
2015	410	111	42	122	67	231	131	108	23	10	1255
2016	337	99	51	98	89	226	136	140	26	10	1212
2017	424	121	48	126	82	272	147	109	32	09	1370
2018	431	118	51	127	92	286	155	115	36	07	1418
2019	422	163	51	122	100	104	298	117	36	07	1420
2020	426	168	53	122	111	107	321	117	36	07	1468
2021	432	187	55	123	141	107	351	122	36	12	1565

The province-wise expansion of the *Sisu Seriya* service is given in Table 3 [38],[39],[40]. The highest number of services is provided in the Western Province. However, the highest growth is recorded by the North Western Province. The only provinces where the services are proportionately less are the Eastern and Central Provinces.

The annual subsidy provided over the last 14 years, together with the growth of the fleet, is depicted in Figure 4. It could be observed that the growth rate of the subsidy, even at a nominal value, is less than the growth in the number of services. In 2018, the subsidy amounted to Rs 552 million, entirely distributed among the respective operators. The NTC absorbs the administration cost of this programme as an assigned regulatory role.

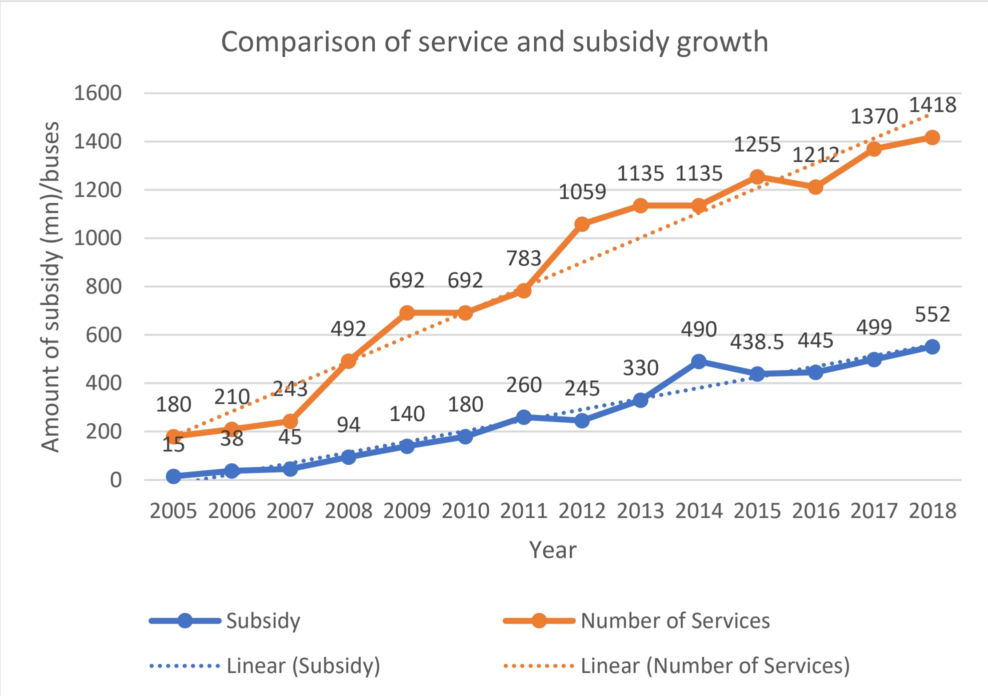

Figure 4: Comparison of Service and Subsidy Growth

4. CONCLUSIONS AND INSIGHTS FOR FUTURE DEVELOPMENTS

Sisu Seriya has many notable features which allow it to be compared with other leading and noteworthy global school transport systems, especially given that Sri Lanka is still a developing middle-income country. Its design that integrates both the State-owned and private providers in delivery without conflicts is noteworthy and crucial. The demand-driven process and the setting up of STCs have empowered the schools to ensure several key success parameters, namely (a) ownership by the users,

(b) certification of services and (c) continuity. The cost-based service provision and the annual fare revision formula helps to retain and continue with successful operators. The penalty systems and on-board monitoring reduce the occurrence of irresponsible behaviour of operators and their incomes being pruned, at the limit even making them exit from operations. Such operators have a fall-back position as they could return to their regular route service and, as such, could leave voluntarily.

The experience so far reveals that the number of buses deployed for *Sisu Seriya* has grown by 16% p.a. without Government investment or assistance to operators—the rapid growth being due to the use of regular route operators for school trips. School trips make up just two trips a day out of their total of eight to ten trips. Counting also the days on which schools do not operate, this works out to around 12% of the total kilometres operated by such a bus being used for *Sisu Seriya*.

The programme has reduced the operation of school vans, especially in large urban areas. The school buses have reduced congestion on urban roads as these vans were parking on roadsides near the schools [33]. Hence the schools have encouraged buses to minimise traffic congestion and parking around schools. It is also reported that school children prefer to use a bus against a school van and even those driven by their parents in some cases, as the social climate in a school bus is considered enjoyable- an area for future research.

Even though major accidents have not been reported to date, there is room for improving safety with the use of hazard lights during alighting and boarding school children and implementing GPS-based monitoring of speed.

There have been protests by the school van operators arising from loss of patronage [41], which provides an opportunity for concessions to be provided to existing privately provided school buses and vans to upgrade their services to become "school buses". The subsidy can be tied to introducing higher-quality buses with air conditioning to get students out of parent-driven vehicles. Moreover, traffic priority measures have not been legislated in favour of the *Sisu Seriya* school bus service. It is suggested that the upcoming developments in Sri Lanka in Bus Priority Lanes and bus modernising systems could further enhance both the quality and quantity of *Sisu Seriya* school bus services.

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Figures and photographs should be fitted into the body area in portrait orientation. Photographs should be preferably scanned with a resolution of 100 dpi in .jpg or .tif format and sized before placement in the manuscript. Each figure should be sequentially numbered, and caption should be located below the Figure. The font size of the caption should be not less than 11 pt. All figures should be in sharp contrasting colours so that it can easily be legible even in black and white prints.

References

This comprises a list of all sources used in the paper located at the end of the paper using IEEE referencing style. They should contain full bibliographical details in numerical order at the end of the manuscript. In the reference list, all authors should be included. (Times New Roman, 11pt, full aligned).

Appendices

Sometimes appendices help readers to further study the issue presented. Submit appendices separately after attaching tables and figures. If more than one appendix is featured, use capital letters to refer to them in the text: Appendix A, Appendix B, etc. Follow guidelines for tables or figures, as appropriate, when formatting appendices.

Queries

For clarifications, Editor-in-Chief may be consulted via e-mail: editor-jsalt@slstl.lk.

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