THE DEVELOPMENT OF A GENERIC STEP-WISE FRAMEWORK FOR ACHIEVING A MULTIMODAL PLATFORM IN A DEVELOPING COUNTRY ENVIRONEMENT

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ABSTRACT

With information and technology becoming such a vital commodity in everyday life, it can be argued that informed travellers are the key to successful future transport services. Fortunately, it is recognised that the development of a multimodal transport system is needed in providing integrated traveller information. The relating challenges and the applicable considerations in attaining such an integrated system were researched. Following from this, a generic sequential framework that facilitates multimodal data integration and traveller information as a precursor to a fully integrated multimodal system was developed. In this framework four focus areas, related to the implementation requirements of the application environment considered, were identified. These areas are based on the premise that current technological evolvements need to be exploited in order to breach the missing intelligent link between the various application environments. The focus areas are: 1) the multimodal transport network and the design and modelling thereof, 2) the role of Intelligent Transport Systems (ITS) in achieving a multimodal platform, 3) the need for and the design criteria of a centralised database, and 4) the need for and the travel information requirements of a multimodal Journey Planner (JP). The establishment of such a concise framework (along with its associated steps in attaining multimodal information) will go a long way towards providing the impetus, and eradicate the barriers, in achieving sustainable traveller information services. Ideally, South Africa (SA) will be able to empower a better transport service that spans across the nation's social barriers.

1   FOREWORD

This paper is of an investigative nature and is the second in a series of publications emanating from a research project by Struwig (2012) on integrated traveller information. In a recently published paper by Struwig and Andersen (2013), an introductory perspective regarding this subject matter is given. Here the reader is introduced to some of the relating challenges and the associated considerations in implementing and sustaining integrated traveller information in a developing country environment such as SA. The main conclusion drawn from this paper is that SA's transport situation not only impedes, but also complicates, the realisation of extensive traveller information. In thís subsequent paper, the sequential steps required in achieving a multimodal platform, which enables extensive traveller information services within the context of such a developing environment, are explored.

2   BACKGROUND

SA is a developing country that struggles with poverty and inequality. Currently, adequate levels of integration between modes are still problematic and the provision of (equal) access to basic transport amenities is difficult.

If a sustainable transport system is to be pursued, the deficiencies of SA's current heterogeneous non-integrated systems need to be overcome. Fortunately, with the evolvement of information technology, enormous scope for growth in the utilisation of information systems within the transport industry has been created. According to Vanderschuren and McKune (2011), SA needs to develop and standardise an ITS architecture. With an ITS architecture in place, the need to integrate- and standardise data will be addressed. Moreover, an ITS architecture, as a reference framework, will provide transport role-players a means of detecting gaps, overlaps and inconsistencies between the country's rising technology applications and their standards.

3   INTRODUCTION

3.1   An Intelligent Transport Approach

Currently, there is a realisation that an 'intelligent transport approach' needs to be adopted. That is, the development of a standardised ITS architecture. However, SA's tumultuous state of its transport industry exacerbates the comprehension of the multi-disciplinary environment addressed. In essence, the complexity of the application environment is a deterrent that impedes the implementation- and realisation of the sought after integrated system.

From the research conducted in Struwig and Andersen (2013), the need to develop a generic sequential framework that simplifies the implementation- and achievement of an integrated system is identified. That is, an all-encompassing step-wise approach that can be adopted to achieve multimodal data integration and traveller information as a precursor to a fully integrated multimodal system. The framework constitutes four focus areas related to the implementation requirements of the application environment considered. These focus areas are briefly mentioned in Struwig and Andersen (2013) and are based on the premise that current technological evolvements need to be exploited in order to breach the missing intelligent link between the various application environments. In the following section, these focus areas are discussed as implementation considerations.

3.2   An Intelligent Transport Management System

It is argued that, if an Integrated Transport Management System (ITMS) augmented with integrated traveller information services is pursued, the different aspects involved with achieving an ITMS need to be considered in detail. This not only helps to eradicate the varying levels of understanding the proposed integrated system, but accordingly also assists with the achievement thereof. Therefore, in order to clarify the requirements of an ITMS, the following four implementation considerations (in correlation with the focus areas) are identified.

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Firstly, the design- and modelling of the multimodal transport network need to be considered. This entails, among others, choosing specific individual networks to form part of the integrated transport network, determining the appropriate graph models to be used, merging- and linking the individual graphs, and applying a routing algorithm (which accommodates for user preferences) on the multimodal graph. Secondly, the appropriate ITS applications need to be utilised, standardised and integrated. If information- and technology integration are advocated, the local transport industry will be in the position to more effectively monitor what is going on, to more accurately predict what might happen in the future, and to manage transport systems proactively on an area-wide basis. Thirdly, a centralised database, which acts as a common data hub repository for all modes of land transport, needs to be in place. If such a database exists, both the development of a standardised ITS architecture and multimodal journey management can be facilitated. Fourthly, integrated Advanced Traveller Information Systems (ATIS) need to be provided. Transport data needs to be mined such that trip- and routing information can specifically be catered for each transport-user. With the utilisation of personalised ATIS, people will have the perception that they have more control over their lives. Therefore, even though they may be reluctant to change, their perception of multimodal transport may be influenced for the better and they may choose to break their habitual strictly dichotomous choice between private vehicle or public transport to rather favour multimodal transport. Ideally, traversing within a multimodal platform may become the norm.

4 THE GENERIC SEQUENTIAL FRAMEWORK

Struwig (2012) reported on comprehensive research regarding all the portraying aspects required in obtaining multimodal transport. The main focus areas considered are: 1) the multimodal transport network and the design and modelling thereof, 2) the role of ITS in achieving a multimodal platform, 3) the need for and the design criteria of a centralised database, and 4) the need for and the travel information requirements of a multimodal JP. These focus areas each originates from different disciplines, with each encompassing different aspects, based on unique considerations and foundations.

In this section the general line of thought needed in accomplishing multimodal transport is depicted by investigating each of the relevant contributing aspects individually. In the next section, these aspects are integrated in order to develop the generic sequential framework that simplifies the implementation- and achievement of a multimodal platform.

4.1 The Multimodal Transport Network

4.1.1 The Network Design Considerations
According to Zhang, J. *et al*. (2011), if the individual networks are viewed separately as either a Public Transport Network (PTN) or a Private Vehicle Network (PVN), the multimodal transport network can be adequately modelled as a supernetwork. Nagurney and Smith (2011) state that, by utilising a supernetwork representation, the individuals' travel alternatives can be appropriately captured and the design complexity of multimodal travelling can, accordingly, also be reduced.

The transport supernetwork is an abstract concatenation of unimodal transport networks interconnected by transfer links, where the origins and the destinations correspond to appropriately defined vertices, the edges (having associated disutilities: e.g. time or distance) connect the vertices, and the paths comprise of (directed) edges that connect the origins and the destinations (Nagurney and Smith 2011).

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This process of combining the individual networks is based on the concept of the Nearest Neighbour Problem (NNP) and can be described as an application of two operations: the merge- and the link operation (Pajor 2009). While the merge operation essentially unifies the vertex- and the edge sets of the multiple individual graphs; the link operation inserts the appropriate link edges (i.e. transfer edges) needed to interconnect the individual networks together into a multimodal supernetwork.

4.1.2 The Graph Modelling Considerations

The modelling considerations include, among others, the following: 1) the selection of the appropriate graph models, 2) determining the appropriate and then defining the vertex- and edge type, 3) the applicable weight metric to be used for optimisation, and 4) the modelling of user constraints with aid of Nondeterministic Finite Automata (NFA).

The three main PTN graph models that need to be considered are: 1) the condensed model, 2) the time expanded model and 3) the time dependent model. According to Pajor (2009), the realistic time dependent model with constant transfer times should be used in modelling the PTN. The PTN should then consist of station/stop vertices connected to route vertices, with the transport modes modelled between these route vertices via time dependent edges representing the separate public transport lines and -schedules (Dibbelt *et al.* 2012). Furthermore, based on finite state automata (i.e. NFA) and language theory (i.e. regular language), user preferences can be modelled by labelling the edges in the PTN with transit mode. That is, the PTN's graph, apart from having vertices and edges, also comprises two additional functions: a cost function c for the travel time and a label function ℓ for the transit mode; $G = (V, E, c, \ell)$.

The recognised way to build a road graph is to use time independent modelling in which each edge is weighted with a constant value. Pajor (2009) states that, even though the PVN is influenced by the time of travel (i.e. congestion imposed in peak hours), the absence of time-dependency still yields useful queries. According to Dibbelt *et al.* (2012), with a time independent road model, the intersections should be modelled as vertices and the edges, depicting road segments, should connect these vertices. Moreover, in order to be consistent with the PTN, the road network should be weighted by the monetary average travel time of the road segment. It should also be noted that, in multimodal routing, it is a realistic assumption that a traveller does not necessarily have a car available to him/her everywhere along his/her journey. Therefore, Pajor (2009) states that, in order to still be able to make point to point queries in the road network, some sort of foot edges (i.e. pedestrian network) should also be incorporated into the graph. The edges in the PVN should thus be either labelled with car for roads or foot for pedestrians. Consequently, the PVN's graph constitutes the same functions as a PTN's graph. That is, a cost function c for the travel time and a label function ℓ for the transit mode; $G = (V, E, c, \ell)$.

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4.1.3 The Routing Algorithm

The classic algorithm for solving shortest routes is Dijkstra's algorithm. However, in multimodal routing the itineraries inherent to the PTN also need to be included. Therefore, in order to include this time dependency within multimodal routing, the concept of the Earliest Arrival Problem (EAP) needs to be considered in conjunction with Dijkstra's algorithm.

If the EAP is incorporated, the classic Shortest Path Problem (SPP) essentially transforms to the many-to-many SPP. This approach however requires linear computation time and may hence be too slow for practical applications in today's real world transport networks. Furthermore, Dijkstra's algorithm, when applied to multimodal graphs, may also result in undesirable routes (Pajor 2009). The fact that the traveller probably does not have a car available to him/her in the middle of his/her journey needs to be taken into account. In such a case, even though the computed path might be the fastest, it is not applicable.

One way to incorporate the constraints (that restrict the set of feasible paths in multimodal routing) is to augment Dijkstra's classic SPP to the Label Constrained SPP in which finite state automata and language theory are encompassed. That is, Dijksra's Regular Language Constrained (DRegLC) SPP.

The general idea of DRegLC SPP is to find a shortest path from a source vertex s to a target vertex t, with starting time τ, on a labelled- and directed multimodal graph G, by minimising some cost function (time or distance), with the concatenated labels along the shortest path satisfying a word of a given regular language L. The regular language is used to model the travellers' constraints on the sequence of the labels (e.g. exclusion of labels (i.e. mode preference), predefined order of labels, etc.) (Kirchler *et al.* 2012).

4.1.4 Speed-up Techniques

In order to compensate for today's large scale transport networks, research in the past few years have also focussed on developing speed-up techniques to accommodate for routing problems evident in today's life. These speed-up techniques all have the same goal; that is, reducing the search space of routing algorithms such as Dijkstra's SPP, while still yielding demonstrable optimal results. The three most recognised techniques that need to be considered are: the bi-directional search, the goal-directed search and pre-processing contraction hierarchies.

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4.2 ITS Applications

4.2.1 The role ITS play

According to Neudorff *et al.* (2006) the quality of day to day transit operations are classified by the following considerations: congestion, safety, mobility, accessibility and reliability/predictability.

Congestion means there are more people trying to use a given transport facility during a specific period of time (i.e. demand) than the facility can handle (i.e. capacity), with what are considered to be acceptable levels of delay. *Safety* is concerned with reducing the number of crashes and minimising any injuries (as well as the probability of a fatality occurring) associated with crashes. *Mobility* is related to the ability and knowledge to travel from one location to another by using a multimodal approach. *Accessibility* is the means and ease by which an individual can accomplish some economic- and/or social activity. And *reliability/predictability* refers to how much the ease of movement varies from day to day, and the extent to which the traveller can predict these temporal variations (Neudorff *et al.* 2006).

If the appropriate ITS applications are in place, situations with a potential to, among others, cause congestion, unsafe conditions and reduced mobility can be promptly detected. As a result, appropriate strategies and plans for mitigating these problems, and their duration and impacts on travel, can be implemented in a timely manner. Moreover, if travellers are provided with a convenient, reliable and safe transport system, while being informed about their travel options, it can: stimulate knowledge and confidence, foster positive attitudes towards the service provider and create favourable perceptions of efficiency and security. ITS is the cement that sets everything else in place.

4.2.2 Challenges in implementing ITS

In Ezell (2010), the following challenges are underlined.

Firstly, the vast majorities of ITS applications are subject to system interdependency challenges; require system coordination to deploy, and at the same time, the adoption by the individual users; and should operate at scale to be effective. Secondly, the uncertain marketplaces for ITS applications (due to the higher risk associated with new systems) impede its development. Thirdly, ITS face a range of institutional barriers, and these organisational challenges determine how the performing organisations, often across jurisdictions, establish and maintain common plans and schedules; how they allocate funding priorities; and how information is shared. Other ITS challenges include, among others, the lack of expertise within local- and regional transport agencies with regard to the technologies underlying ITS applications and the implementation thereof. Lastly, the lack of technical standards for ITS technologies inhibits the integration of ITS applications pursued by different organisations.

As for SA, almost no common ITS architecture and hence little common technical standard, for the technologies underlying ITS applications, exist. However, with the realisation of an integrated multimodal transport system, institution- and thus information integration may be encouraged. Accordingly, the development of a standardised ITS architecture may follow, and hence the meeting of the challenges mentioned, will be possible.

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4.3   Database Design Considerations

The development of the database can be construed as the back-end and front-end design thereof.

4.3.1   The back-end Design

The basic back-end design considerations for the development of a centralised database follow. Firstly, the security, authentication and access to the database need to be decided. That is, who has access to the database and what privileges they have (e.g. read, write or read-and-write). Secondly, the appropriate server- and network type need to be decided. For the realisation of a multimodal information system, the usage of a database and a web Graphic User Interface (GUI) as the server type, with a hierarchical network topology, are deemed appropriate. Thirdly, the required size of the database- and server, based on the workload expected, need to be determined. Fourthly, the data structure, according to the database type, need to be determined. And lastly, the data standards, that is, the data type, naming type conventions, and so on, need to be decided. Based on the application of a multimodal information system, the development of a relational database was chosen, with the data standards and -structures following from the relational tables developed therein.

4.3.2   The front-end Design

It is recommended that the multimodal information system be modelled by a 3-tier client-server architecture since it accommodates for the provision of a web-based JP.

As mentioned previously, it is proposed to use a web GUI, e.g. Internet Explorer, as the front-end medium for accessing the relevant data, in a relational database, with an Online Transaction Processing (OLAP) application type, and a hierarchical network as the network topology.

A user who, for example, wishes to commute between point 1 and 2 within the multimodal platform will sign onto the website (i.e. web interface). Here, it is proposed that he/she be prompted to give: the origin, the destination, his/her mode preference and his/her optimisation preference (e.g. time or distance). Then, from here via HyperText Transfer Protocol (HTTP) the information submitted by the user need to be send over the network using Transmission Control Protocol/Internet Protocol (TCP/IP) to the application server.

The application server will package the information submitted by the user into the correct format to then send it to the Database Management System (DBMS) over the TCP/IP network. Furthermore, the application server will need to, on a regular (adjustable) interval, query, via the Internet using HTTP, real time data updates from the various mode operators. This information can then be written back to the DBMS in order to maintain real time accuracy.

The DBMS then returns the information the user has requested to the applications server. The application server then again needs to via TCP/IP present the information to the web server. Lastly, via HTTP over the Internet, the requested information can be presented on the web-based JP to be used by the user.

4.4   Multimodal Information System Considerations

The basic design considerations for the development of a multimodal information system follow.

Firstly, the travellers' information needs are dependent on (and vary between) the phases of transit. Therefore, their needs should be determined by whether they are in the pre-trip, on-trip or end-trip phase. If the wrong type of information is provided, the value of information inherently decreases. For example, in Aguiar *et al.* (2011), a Personal Digital Assistant (PDA) that utilises the available existing geographically widespread networks of Radio Frequency Identification (RFID) readers to deploy location-based (i.e. positioning) services, is developed.

Secondly, the information services travellers deem as important need to be determined. For example, in Chorus *et al.* (2010), it was found that travellers generally have intrinsic preferences for some types of information over others, preferences that do not necessarily coincide with the economic value of information. More specifically, it was found that having unknown alternatives generated, is preferred over assessing known alternatives. Furthermore, based on the analysis conducted in Zografos *et al.* (2010), the following types of traveller information services were rated with the highest weight of relative importance:

- Traveller-centred (i.e. customised) door-to-door journey planning.
- Personalised real time alerts and travel reminders.
- Dissemination of travel information through the Internet and mobile phones.

Thirdly, the travellers' choice behaviour on information service media also needs to be investigated. For example, in Zhang, X. *et al.* (2009) it was found that the travellers' demand for urban-oriented information maps enhances the probability of travellers' choice of Internet. Similarly, since mobile phones can assist travellers with the provision of real time information (e.g. timetables and traffic information), the demand for this type of information enhances the probability of the travellers' choice of mobile phones. Zhang, X. *et al.* (2009) also concluded that travellers' vocation have the most significant influence on the choice of service media, especially regarding the choice of Internet and mobile phones.

5   RESULTS

The sequential steps required in achieving a multimodal platform, based on the main focus areas discussed, the subcomponents relating thereto, their corresponding considerations as well as their associated foundations, are all highlighted in Table 1 (Struwig 2012). For a holistic view of Table 1 (Struwig 2012), first refer to **Error! Reference source not found.**.

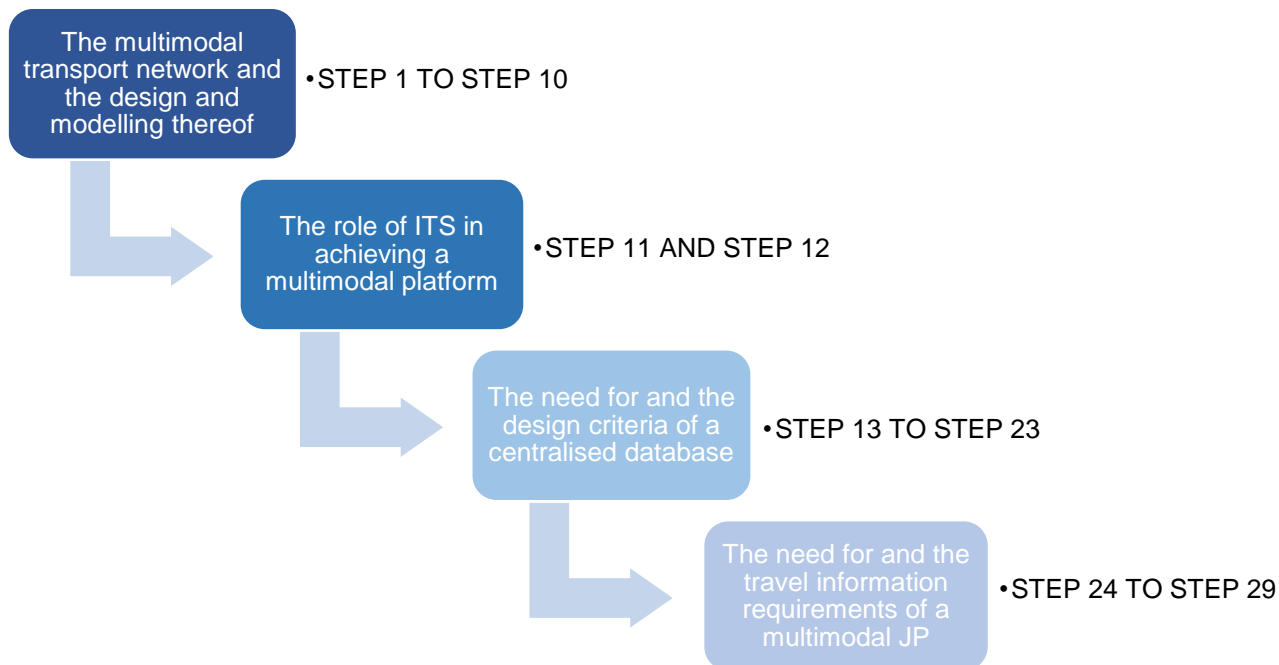**Figure 1: A Holistic view of the proposed Generic Framework**

Table 1: The proposed Generic Framework for attaining a Multimodal Platform

STEPS	ASPECTS	CONSIDERATIONS	FOUNDATIONS
1	Mode Selection	MyCiti, Metrorail, GABS, privately owned vehicles, (minibus taxis, metered-taxis)	
2	The Multimodal Transport Network Design	Supernetwork, Hierarchical Network	Graph Theory
3	Modelling User Constraints	Deterministic Finite State Automaton, Nondeterministic Finite State Automaton	Finite State Automata, Language Theory
4	The Networks	Private Vehicle Network, Public Transport Network, Foot (Pedestrian) Network	
5	The Graph Models	The Condensed Model, The Time Expanded Model, The Time Dependent Model	Time Independent, Time Dependent
6	Vertex- and Edge Type	Physical-, Event-, Transfer- and Route vertices; Physical-, Transfer- and Trip sequence Edges	
7	Weight Metric for Optimisation	Travel Time, Geographical Distance (Euclidean Method, Great Circle Method), Generalised-Cost approach	

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8	Merge- and Link Operations	Linear Search, K-D trees	Nearest Neighbour Problem
9	Routing Algorithm	Shortest Path Problem (SPP), Many-to-Many SPP, One-to-All SPP, All-pairs SPP	Earliest Arrival Problem, Dijkstra's Regular Language Constrained SPP
10	Network Size	Bi-directional Search, Goal-directed Search, Pre-processing Contraction Hierarchies	Speed-up Techniques
11	Advanced Traffic Management Systems	FMS, AMS, UTC	ITS
12	Advanced Public Transport Systems	Automated Vehicle Location, Electronic Fare Payment (i.e. AFC and IFM), ATIS	ITS
13	Data Repository Type	Database, Data Warehouse	
14	The Database Management System	Online Transaction Processing, Operational Data Store, Online Analytical Processing, Data Warehouse/Data Mart	
15	Sharing the Database	Security, Authentication and Access to the Database	The Database Management System
16	Data Models	High-level, Low-level, Representational (i.e. Legacy and Relational)	
17	Defining the Relational Database	Domains, Attributes, Tuples, Relations, Relation Schemas, Relational Database Schema and –State	
18	Managing the Relational Database	Relational Database Schema Constraints: Domain constraints, constraints on NULL values, Primary key constraints and Integrity constraints (i.e. Entity and Referential)	Relational Database Management
19	Database Type	Microsoft SQL Server, Microsoft Access, Oracle	
20	Data Standards	Data Type, Data Structure, Naming Conventions	Normalisation Principles
21	Server Type	Database, Web Graphic User Interface (GUI)	User Interface
22	Server Architecture	2-Tier Client-Server, 3-Tier Client Server	
23	Network Type	Hierarchical, Star, Ring, Bus	Network Topologies
24	The Value of Information	The Information Quality Attributes, The Information Valuator, The Information	Information Theory, Value

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		Service Value Chain	Theory, Utility Theory
25	Passenger Travel Information Needs	Pre-trip, on-trip, end-trip phase	
26	Information Services deemed important by the Travellers	JP criteria: 1) transport modes covered 2) sufficiency of static journey information provided 3) geographical coverage 4) quality of information display 5) sufficiency of itineraries offered 6) real time information capability 7) sufficiency of on-trip information provision 8) ticket booking capability 9) the means for information service accessibility	The Value of Information
27	Travellers' Choice Behaviour on Information Service Media	Personal Attributes, Information Attributes, Usage of Internet and Mobile Phone	
28	The provision of personalised Information	AFC, RFID	Personalised ITS
29	A Multimodal Framework Architecture	Overall Conceptual Aspects, Logical Aspects, Conceptual Aspects	

In essence, Table 1 (Struwig 2012) thus facilitates multimodal data integration and traveller information as a precursor to a fully integrated multimodal system.

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6   CONCLUSIONS AND RECOMMENDATIONS

The generic sequential framework for achieving a multimodal platform gives 1) perspective on the extensity and 2) provides for a simplistic and thus more controllable implementation of an ITMS.

This author submits that, even though the deployment of multimodal transport is in its infancy, the need for a multimodal platform and the subsequent positive outcomes that await those that embark on this path, are evident. Furthermore, with the generic sequential step-wise approach in achieving such a platform stipulated, an integrated sustainable transport system, possibly nation-wide, can be encouraged. Once again, SA offers the entrepreneur many opportunities and subsequent riches as they are identified and developed.

7   FUTURE RESEARCH

As mentioned previously, this paper is the second in a series of publications emanating from a research project by Struwig (2012) on integrated traveller information. In the third paper, the practical application of the generic sequential framework developed is tested within the context of the City of Cape Town's (CoCT's) land transport modes. That is, the succeeding paper will stipulate what was used for the execution of each aspect based on the challenges and considerations identified herein.

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