Providing flexibility in the Vehicle Route Optimization for the AVL based Transport Monitoring System

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Abstract—Automated Vehicle Location (AVL) based Transport Monitoring System (TMS) has generated some interest within the research community since decades ago. The emergence of enabling technologies such as the Global Positioning System (GPS) and advanced cellular communication systems has opened up new opportunity to this area of research. Vehicle location is now determined in real time and data can be transferred instantaneously to either centralized or decentralized processors. Implementation of a full fledge TMS requires components such as communication module, Geographical Information System (GIS), databases and monitoring application to be incorporated into the system architecture. Once all the elements are gathered, the project will inevitably become very complex and difficult to deploy efficiently and in a timely manner. In this paper, we propose a new approach for the design and implementation of a TMS. The approach that we are proposing relies on the strength and modular nature of a language-based platform. The platform will not only make the project more manageable but will also enhance it by offering extended collaborative features. It will also allow modular experimentation of various optimization algorithms in different Vehicle Routing Problem (VRP) model to be designed and tested for better system performance. With the proposed framework, AVL based TMS can be built economically and efficiently. Analysis and comparison among current AVL based systems are also performed in order to investigate the feasibility of the project.

Key-Words: - Automated Vehicle Location (AVL), Collaborative environment, Multimedia communication, Vehicle Routing Problem (VRP), Route optimization, Scripting language.

1 Introduction

The basic ideas behind this research originally concerned about the problems in the logistic distribution process, which needs accurate decision on how to consign goods economically and reasonably to customers with high efficiency at the lowest cost possible. Vehicle Routing Problem (VRP) that directly influences customer service level and distribution cost is one of the major problem. It may involve finding the optimal routes for vehicle delivery under certain constraints such as vehicle location, capacity, time and customer demand. To reduce VRP domain, proper planning shall be done to the entire distribution process that mainly involves management of vehicles travelling along targeted routes.

Towards resolving this problem, Automated Vehicle Location (AVL) based Transport Monitoring System has created some interest to many researchers. According to [1], the recent advances of AVL based system on Global Positioning System (GPS) have provided the transit industry and public transport enterprises with tools to monitor and control operations of their vehicles and manage their fleet in both efficient and cost effective manner. This paper proposes the bus transit and arrival time prediction algorithm that uses GPS data on current vehicle location and speed. Beside that, the GPS data can also be used for a wide variety of applications for example service planning, transit operations monitoring, driving pattern tracking as well as for safety and security enhancement.

Studies on recent implementations of AVL based systems [2] reveal that common design traits in its architecture includes components such as databases, optimization module, monitoring and communication components supported by enabling technologies such as GPS, Geographical Information System (GIS), General Packet Radio Service (GPRS) and Short Messaging Service (SMS) technologies. Integration of these components and technologies happens at multiple layers, thus introducing complexity into the overall system. The level of complexity increases again when the system is required to work in a collaborative environment.

To date, the implementation of AVL based Transport Monitoring System in many developing countries, including Malaysia is still in its infancy. This is most probably because of the high development cost incurred by the requirement of expertise. To develop such system, one would require to have high level network programming skills. In the development process, the most important and difficult issue is to create mechanisms for controlling interaction among components, data, protocols and users simultaneously. By considering at least four important activities like zone monitoring, vehicle searching, map navigation and spatial data manipulation, there should be an incorporation of various interaction protocols. Each one will require different critical collaborative interaction management. In the case of shared data, it should have some proper management of interest on issues like data sharing, filtering and security.

The framework for developing an AVL based Transport Monitoring System proposed in this paper has been designed to overcome the difficulties mentioned above. In this proposed framework, the system can be implemented using special purpose scripting language, called JACIE (*Java-based Authoring language for Collaborative Interactive Environments)* [3, 4].

This paper is outlined as follows; Section II presents the related work including current AVL based system architecture, development tools and vehicle route optimization algorithms. Section III explains the definition and concept applied in Vehicle Routing Problem and section IV discusses the overall system framework and describes the software tool used for the implementation. Section V gives a comparative analysis on the current frameworks and proposed framework before the concluding remarks in Section VI.

2 Related works

In Transport Monitoring System (TMS), the Automated Vehicle Location (AVL) is very important in identifying the location of vehicles. Much research has been undertaken to study the AVL based systems and their development tools and languages.

2.1 Automated Vehicle Location (AVL)

The location of a vehicle can be traced through a number of different technologies. Currently, the most common technology used for AVL is the Global Positioning System (GPS), a constellation of 24 satellites around the earth that are constantly transmitting their positions [5, 6]. Generally, the architecture of the AVL based system proposed in [7-12] were included with some common components namely as command centre or management terminal, network and communication module, monitoring terminal, vehicle terminals and data server. The vehicle terminal has been considered as mobile terminal since it was installed in vehicle while the rest of the components have been located or setting up in the dispatch or command centre. Prior to AVL based system, SMS technology was used as a communication channel between vehicle terminals and dispatch centre. However, SMS communication is very text limited (only 140 bytes per SMS) and having uncertain delay (caused by short messaging service centre) [5]. In order to overcome the SMS shortcomings, General Packet Radio Services(GPRS) was introduced to replace the SMS for better AVL based system [8, 10, 12]. GPRS is a network computing solution which is compliant to Internet Protocol (IP). It has become de facto that Internet solution is the cheapest communication infrastructure and most reliable compared to other network solutions for example SMS or Public Switch Telephone Network (PSTN).

Most of the communication in the current systems are among systems or inter-system [8, 10, 12, 13], and none has been mentioned about the communication channel used among users in the system. Although the WEBGIS-based system model [12] provides interfaces via web browser for users to perform vehicle monitoring, it has not been defined in details about the communication medium among users. Hence, it can be concluded that all the systems mentioned above have limited means of collaboration between users. By utilizing the benefits of IP based network, users working in the collaborative environment, should be given flexibilities in multimedia communication. Moreover, multimedia communication especially through the web is well known as an independent platform, cost effective (using IP network) and high scalability medium of communication.

2.2 Development tools and languages

AVL based systems can be developed by using various development tools and languages. As for example, in the development of Vehicle Monitoring System (VMS) in [10], application of MapX 5.0 was used. Map X can be quickly integrated into client side applications using Visual Basic, PowerBuilder, Delphi, Visual C++ and other object-oriented languages.

Pathfinder Tools software development kit [14] is another tool that can be used for the realization of AVL based system. Pathfinder tools were included with four OCX (Active X) controls for configuring, controlling and monitoring of GPS receivers. It was enabled with functions for easy conversion of GPS coordinates and units. Developer could develop any AVL applications with their preferences languages such as Visual Basic and Java, and then incorporate the Pathfinder Active X controller into the application.

The two examples of AVL tools given above required programmers to use any general purpose programming languages for the development of a complete Transport Monitoring System. Furthermore, in developing collaborative multimedia environment for Transport Monitoring System, the programmer must have expertise in using powerful general purposes languages like C or Java and high level capabilities in using network programming elements like sockets, streams, thread and remote management interface (RMI).

In recent years, a variation of development tools also have been introduced to support the development of collaborative type applications. However, many of them targeted to be used for a small class of collaborative applications[3] and they provide software library for network programming in a very limited way [4]. Since the interaction management and data sharing are very important aspects in AVL based Transport Monitoring System, these current development tools by no means provide the developers with interaction and communication protocols. Moreover, these development tools are not specifically suited to be used for AVL based system development.

3 Vehicle Routing Problem

The VRP [15] is considered as one of the most challenging combinatorial optimization task. Basically, the problem in VRP concern about designing the optimal set of routes or schedulling for fleet of vehicles in serving a given set of customers.

Formally, the VRP can be designed as the following:

Let $K=(V,E)$ is a graph with set of nodes or vertex V connected with a set of arc or edges, E. In the vertec set, V_i ,$i=0..n$, V_0 is the depot and the other vertices (V_1 to V_n) are customers to be served. With every arc, $e(i,j)$ and $i\neq j$, has its own non-negative distance or cost matrix $C=(c_{ij})$, where can be a total of distance, travel time or travel cost. Different with VRP model in [16], the cost matrix calculation has been included with a fuel consumption for unit distance.

Each customer at V_i , $i=1..n$, is associated to a non-negative customer demand, d_i to be delivered or serviced. If there is set of vertex, $S \subseteq V$, the total demand of the set is:

$$d(S) = \sum_{S \in V} d_i .$$

The total demand must not exceed the vehicle capacity. Figure 1 illustrates an example of a routing path of 8 customer sites and one central depot.

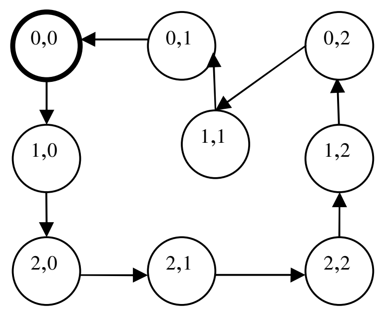


Figure 1: An example of a routing path

From Figure 1, the set of V,E and C can be represented as:

$$V = \begin{pmatrix} v_{(0,0)} & v_{(0,1)} & v_{(0,2)} \\ v_{(1,0)} & v_{(1,1)} & v_{(1,2)} \\ v_{(2,0)} & v_{(2,1)} & v_{(2,2)} \end{pmatrix}$$

$$E = \begin{pmatrix} e_{(0,0)(1,0)} & e_{(1,0)(2,0)} & e_{(2,0)(2,1)} \\ e_{(2,1)(2,2)} & e_{(2,2)(1,2)} & e_{(1,2)(0,2)} \\ e_{(0,2)(1,1)} & e_{(1,1)(0,1)} & e_{(0,1)(0,0)} \end{pmatrix}$$

$$C=\begin{pmatrix} C_{(0,0)(1,0)} & C_{(1,0)(2,0)} & C_{(2,0)(2,1)} \\ C_{(2,1)(2,2)} & C_{(2,2)(1,2)} & C_{(1,2)(0,2)} \\ C_{(0,2)(1,1)} & C_{(1,1)(0,1)} & C_{(0,1)(0,0)} \end{pmatrix}$$

In the VRP, the meaning of finding a set of least-cost vehicles routes is considered as:

- each vertec in V except V_0 is only served exactly once by exactly one vehicle.
- each vehicle route start and ends at the depot.
- during the serving, all side constraints need to be satisfied for example capacity, maximum travel distance or maximum travel time.

Usually, in real logistic distribution processes, there will be many side constraints need for consideration depending on the particular objectives. So, started from the classical VRP created by Dantzig and Ramser in 1959, several variations and specializations of the VRP have been extended nowadays. Among the popular are listed as in the following:

- VRP with time window (VRPTW)- every customer need to be serviced within a certain time window for example fresh food or bread delivery.
- Multiple Depot VRP(MDVRP)- when there are more than one depot used to supply goods or product to customers.
- VRP with Pick-Up and Delivering (VRPPD)- might be applied when there is a case customers may return some goods back to depot or post and parcel delivery.
- Split delivery VRP(SDVRP)- it is applied in some cases when vehicles might be possible or even necessary assigned to several routes rather than single as in original VRP.
- Stochastic VRP(SVRP) – an original VRP can be considered as SVRP when some constraints value like number of customer,their demand and travel time are random.
- Periodic VRP (PRVP) – it is an extension of VRP in which deliveries may be done in some days periodically according to a planning.
- Fleet size and Mix VRP (FSMVRP) – when the number of vehicles can be any numbers and the fleet is heterogeneous(having different size and capacity)
- Dynamic VRP (DVRP) – when some data or constraints value are not known beforehand or before the routes begin by vehicles. When new information is received during the vehicle on routes, for example new demands or cancelation from customer, new decision on the VRP might be required.
- Hybrid VRP - combinations of different VRP for example DVRPTW which combine Dynamic and Time window VRP.

3.1 Vehicle Route optimization algorithm

Route optimization algorithm is a method that constitute towards minimizing the travelling cost in vehicle routing problem. Some of current AVL based systems integrate route optimization functions. For example, the Ant Colony Algorithm has been adapted to improve vehicle route optimization, but the overall system framework was not explained in detail[7]. The focus is more on map manipulations in GIS application rather than the tool to plan and optimize the route. Dalia *et al.* [17] proposed a Nearest-Neighbour Trajectory (NNT) algorithm to predict the future movement of a vehicle. The prediction identifies historical path of vehicle locations that would generate trajectory pattern with the most similar path to the current pattern. This method is called *similarity based prediction*. In addition, a modified Particle Swarm Optimization is also used to control autonomous vehicles for solving VRP[18]. It is also possible to apply Simulated Annealing (ESA) algorithm to find an optimal routing path in modelling a package delivery problem, an extension of VRP[19]. Based on these four algorithms, heuristic methods are proven to be the most popular and suitable algorithm for solving complex combinatorial problems, like the VRP. According to Gendreau *et al.*[20], a good metaheuristic implementation can provide near-optimal solutions in reasonable computation times. The most popular metaheuristic used for VRP and its extensions include ant colony, genetic algorithm, greedy randomized adaptive search procedure, simulated annealing, tabu search and variable neighbourhood search. Among these metaheuristic methods, there is a lot of extension to improve their performances [21, 22] . In certain cases, one or more metaheuristic algorithms can be combined to get the best solution in shortest time possible [23, 24].

4. Framework

This section discusses the current and proposed framework of AVL based systems with the development platform. Therefore, the enhancements on current frameworks can be seen clearly.

4.1 Current framework

The system framework normally applied in the current AVL based system has been drawn as in Figure 2.

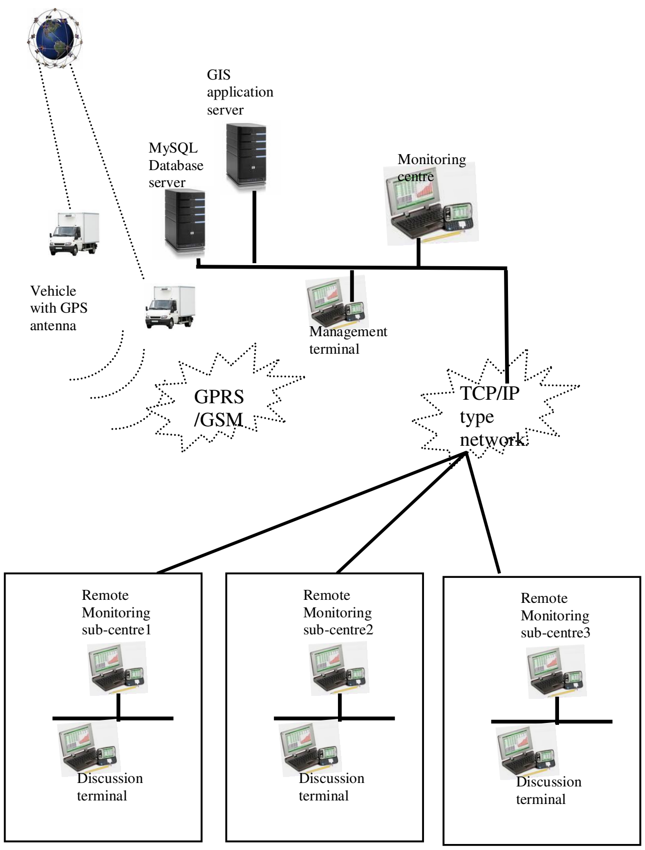
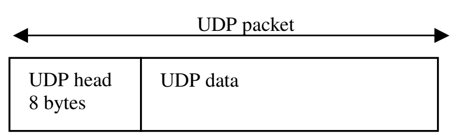


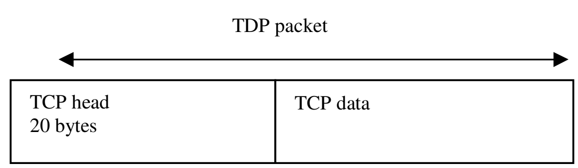
Figure 2. Overall current system framework

Normally, the system is based on a Client/Server (CS) model with TCP/IP type network to support reliable interaction data between main monitoring terminal at main office and remote terminals at branches or sub-centres. The GPS receivers installed in each vehicle terminal uses wireless type network in GPRS or GSM type network to communicate to the main system in the depot centre or main office, which normally included with database server, GIS application server, data management and monitoring centre terminal. In the database server, the table relationships have been designed precisely among the GPS data,vehicle and driver information so that information can be viewed and tracked effectively. A system administrator will be given authority to manage database data for example to add or delete vehicle and driver information. The management of collaborators' account, group and functional authorities can be done through the management terminal located at the operation centre. The process of managing map manipulations and displaying vehicle location will be handled by GIS application server.

All the GPS data such as longitude, latitude, time and speed of vehicle will be transferred to the central database server in a form of User Datagram Protocol (UDP) data packet and upon arrival at the destination server, the data packet will be extracted and stored into the database server. The reason to use UDP data packet is to reduce delay when congestion of network line occurs during transmission from GPRS network to central network. In order to provide more reliable and secure connections between local central network and remote monitoring sub-centre, the Transfer Control Protocol (TCP) normally has been used as the transport protocol. TCP which is known as connection-oriented protocol has the capability on controlling connection errors at service or port level of terminals [25]. Thus, only the right or upon agreement operations will be executed. Since TCP provides more reliable data flow, the packet size is longer than UDP. Figure 3(a) and Figure 3(b) illustrate the packet size of UDP and TCP respectively.



(a) UDP



(b) TCP

Figure 3: Packet Format

Based on this current setup, we can identify a number of drawbacks and limitations such as:

- Normally, in order to realize this kind of AVL system framework, it might involved long and complicated task in the development circle especially when using general purpose language for implementing network, client/server, map manipulation and vehicle route algorithm.
- Because of these difficulties, there is no flexibility in providing various vehicle route optimization algorithm to users for allowing modular experimentation in different type of situation and parameters. We believe that different algorithms may have different performances in various types of VRP.
- Only one VRP model is applied in AVL based system while in real logistic processes, an instant of VRP might not be suitable to be applied at different process or objective.
- There is also limited way of communications among users that mostly rely on text limited system such as SMS or email. Besides, the telephony system that is normally being used might be effective in certain circumstances but in most time, it is too expensive to be deployed.

4.2 Proposed framework

In the proposed framework, we applied the overall current architecture but with an enhancement in the integration of the monitoring centre into another new two modules namely as VRP server and collaboration server as shown in figure 4. This new proposed components (VRP Server, Monitoring Centre and Collaborative Server) will be implemented using a high level language, JACIE [1,2] for flexible VRP model, route optimization and collaborative environment.

Communication among collaborators from monitoring centre and sub-centres can be attained through a discussion terminal with a variety of build-in multimedia communication channels such as text, voice or video messaging. The management of handling interaction protocols among collaborators and sub-systems has been given to the collaborative server. One major part of the route optimization server is to interact with monitoring centre and provides flexibility for users to run or test various route optimization algorithms in different VRP model or extensions. Figure 5 shows the VRP server architecture.

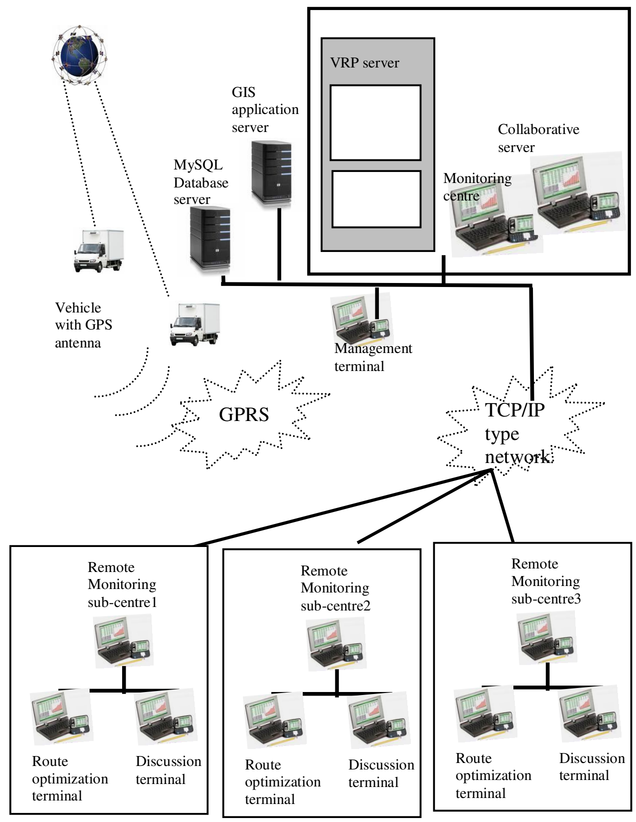


Figure 4: Overall system framework

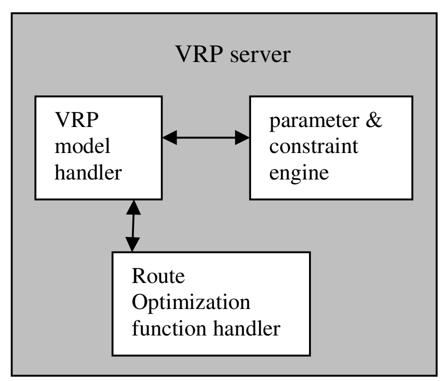


Figure 5: The architecture of VRP server

From the monitoring centre, users can choose one VRP model from the build-in VRP model and its extensions. For each VRP model selected, there is also another alternative for users to select any one of route optimization heuristic algorithms. At this stage, three different type of heuristics algorithms has been choosen. The popularity of genetic algorithm (GA), ant colony(AC) and particle swarm optimization(PCO) in major type of VRP models[20] have been considered to be selected as the build-in optimization algorithms.

4.3 Language-based platform - JACIE

JACIE is a software development tool that enables distributed collaborative applications to be developed at a very low development cost, within a short development period, and by possibly inexperienced programmers [3, 4]. The type of applications that are possible to be developed with JACIE may include virtual meeting, collaborative editing, e-learning, collaborative monitoring and many more. Figure 6 shows a collaborative system of E-Learning on Simulation of Network Trouble Shooting that has been developed from JACIE[4]. Every window in the figure represents different individual screen from the three collaborators involved in the network monitoring process.

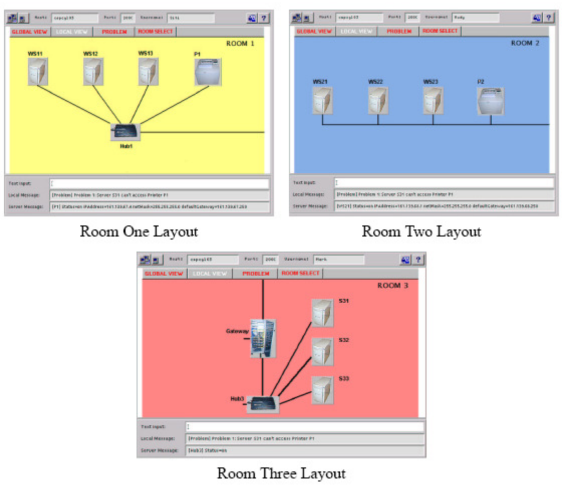


Figure 6: E-Learning on Simulation of Network Trouble Shooting[4]

A set of language constructs will be added into JACIE and the specifications have to be developed for providing:

- three build-in VRP models which are Vehicle Routing Pickup and Delivery (VRPP),Vehicle Routing Problem with Time Window(VRPTW) and Multiple Depot Vehicle Routing Problem(MDVRP).
- one hybrid model for integrating more than one build-in VRP models.
- a method for programmer to create new VRP model with new parameter and constraint setting that is not available from the predefined models.
- three vehicle route optimization algorithms namely as genetic algorithm (GA), ant colony (AC), particle swarm optimization (PSO).
- a method for programmer to create new vehicle route optimization rather than the predefined algorithms.

From the scripting language editor, programmer can implement and call the predefined functions that have been constructed in the JACIE platform. Programmers will also be able to define new extension of VRP model and route optimization algorithms that will specifically fulfill the requirements or problems needed. Figure 7 illustrates the functionality of the set of language constructs for VRP.

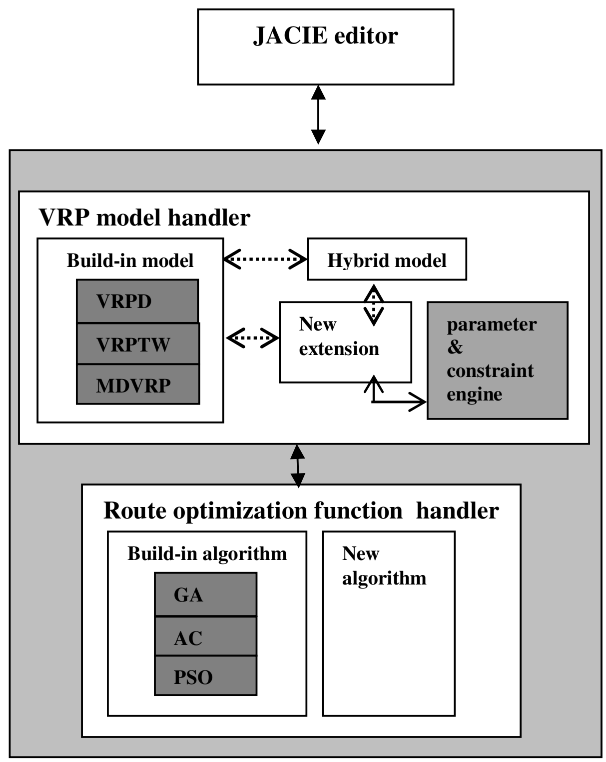


Figure 7: Functionality of the VRP language construct set in JACIE

In this research work, we choose JACIE as the development platform due to several reasons. First, JACIE contains a collection of built-in language constructs for supporting structured and unstructured communications. There are five built-in communication channels that can be used in JACIE and can be directly used to AVL based transport monitoring system. These channels are:

- canvas – is a shared workspace that can be used for displaying collaborative activities such as manipulating GIS images, transport monitoring, displaying vehicle or driver information and VRP modelling.

- message – is mainly used to deliver long message among client server communication.
- chat – can be optionally used for text based communication.
- voice- can be optionally used for voice based communication via computer network instead of telephony system. Telephony system is more expensive than computer network system.
- video – if requiring distance meeting, video conferencing is applicable through this channel.
- whiteboard - it is used for arbitrary drawing to sketch down problem scenarios on the dedicated canvas.

These communication channels will provide extra flexibility and ensure effective communication among collaborators in the AVL based Transport Monitoring System. Second, JACIE is originally designed as a scripting language and its compiler will automatically generate JAVA codes for the developer. The scripting language is generally easier to understand as compared to a full blown language such as JAVA or C++. JACIE also allows the inclusion of Java code as part of a JACIE program, enabling experienced programmers to use Java for the implementation of complex code segments [3]. The last reason but very important is because JACIE provides flexibility for developers to use the varieties of robust built-in collaborative interaction protocols[26, 27]. These interaction protocols may perform at different performance levels for different VRP model as well as its routing optimization algorithms. The JACIE architecture can be seen in Figure 8 [4].

3.4 New features in proposed framework

As described in the previous explanation, we have identified new elements and flexibilities in the proposed architecture:

- The methodology of the system development is considered as totally new but promising towards simplicity and effectiveness in the development process.
- The variaty of interaction protocols provided in JACIE will improve the performance of data communication process in VRP modelling. It will also create flexibility to users in choosing different interaction protocols in different VRP case study.
- There will be a lot of flexibility provided for programmer to create different VRP models and applied different route optimization algorithms for each model. By this flexibilities, many modular experiments can be done and analyzed so that better system performance can be achieved in the future.
- Since JACIE is a language-based platform and the VRP model can be dynamically shaped and reshaped, the inclusion of new algorithms is always permitted in case of misleading parameter and functions in the current language constructions.
- It is possible to provide multimedia collaborative environment to every users involved in the monitoring process because JACIE is a collaborative development tool enriched with multimedia channels for communication.

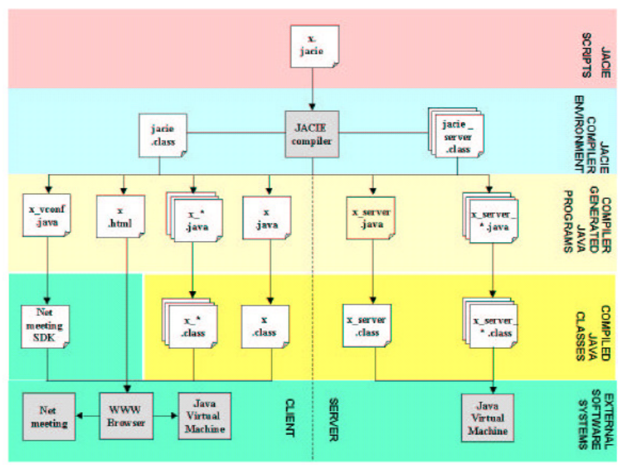


Figure 8: JACIE software architecture[4]

5 Analysis

The technology used in some AVL based Transport Monitoring System frameworks in most systems [7-12] have been compared with the new proposed framework in this research. Referring to Table 1, it clearly shows that the proposed framework is the only framework that provides multimedia collaborative environment to the system. Multimedia collaborative environment benefits in providing effective communications among collaborators such as arbitrary drawing in a shared workspace and video conferencing. Arbitrary drawing permits users to visualize problem scenario in more effective while video conferencing enhanced the collaborative features with more emphatic distance meeting.

Furthermore, there are flexibilities in choosing or developing VRP model and route optimization algorithms in making this new framework more efficient as compared to the others. Based on the six features selected in Table 1, we can see that the new framework introduced more than 50% new features to the current framework.

Table 1: Comparison analysis among current frameworks with the proposed framework

Feature	GIS-VRP[7]	VMS[8]	IVMMS[9]	VMS[10]	VMS[11]	WEB-GIS[12]	NEW FRAMEWORK
GPS	X	✔	✔	✔	✔	✔	✔
GIS	✔	X	X	✔	X	✔	✔
Route optimization flexibility	X Fixed to ant algo-rithm	X	X	X	X	X	✔
VRP models and it extension flexibility	X	X	X	X	X	X	✔
Multimedia collaborative environment	X	X	X	X	X	X	✔

6 Conclusion

It is predicted that the creation of the new framework will definitely benefit a lot to the current system architecture. With the integration of multimedia collaborative environment, tremendous research works can be carried out in the future. The accuracy of data conversion and reliability of the information generated will be different in collaborative environment especially in cases concerning GPS sensor data. These factors may also contribute to the performance of algorithms used for vehicle route optimization. Since collaborative applications require network resources and specifically design protocols, it is necessary to study on the data and network performances during the implementation of an AVL based system in collaborative environment.

The scripting language proposed in the design and implementation of this framework will reduce the difficulties in developing AVL based Transport Monitoring System. Although it is based on a scripting language, it will still provide flexibility for programmers to insert their own JAVA codes within JACIE. The new language constructs will be created in JACIE and especially tailored to solve VRP problems. Creation of new models and route optimization extensions will therefore become simpler and efficient as compared to code inclusions from other languages. With flexibility of models and route optimizations, a variety of experiments can be run, tested and analyzed so that system performance can efficiently fine tuned.

As a general rule, whenever we manage to simplify and optimize any steps in the system development process, it will inherently render the project more manageable. This fact by itself places our approach in a good light with regard to AVL based TMS projects requiring short development cycle.

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