A simulation based decision tool to coordinate emergency services in a road accident

D. Guimarans[§], J.J. Ramos[§], M.A.Piera[§], A.Guasch[‡]

[§] Department of Telecommunication and System Engineering - LogiSim
Universitat Autònoma de Barcelona, 08193 Bellaterra, Spain
Daniel.Guimarans@uab.es, JuanJose.Ramos@uab.es, MiquelAngel.Piera@uab.es
-
[‡] Department of System Engineering and Automatic Control - LogiSim
Universitat Politècnica de Catalunya, 08028 Barcelona, Spain
Toni.Guasch@upc.es

Abstract

The coordination of emergency services in road accidents is essential to ensure a quick intervention in critical situations. The number and kind of resources assigned must be determined dynamically, as not all the accident variables are known when an alert is received. In addition, some decisions can only be token at the accident scene and may affect emergency service's distribution.

This paper presents the model and the laboratory environment that is being developed for the design of real-time decision tools for the coordination of emergency services. Furthermore, it describes the major characteristics of an optimization algorithm proposed to tackle the emergency services coordination problem. This algorithm combines heuristic methods and Constraint Satisfaction Problem techniques in a two interactive phases procedure.

1 Introduction

The coordination of the three major emergency services, i.e. Police Service, Medical Service and Fire Service, is a key issue to ensure an effective intervention in road accidents. Thus, correct management of the three heterogeneous fleets is necessary to distribute units according to dynamically changing real needs.

Such a coordination is highly complex, since not all the information relative to accident variables is known from the very beginning and the available information usually contains uncertainty. Furthermore, although some collaboration protocols are defined they only regulate services interaction at the accident scene, but they not include general norms about resources' assignation [1]. Centralized communication, coordination and decision tasks would improve rescue services response, reducing rescue time and optimizing the available resources.

Time restrictions are naturally imposed since reaction time is primordial to save possible accident victims. Road network configuration and depots (fleet bases) distribution are important issues that determine the emergency fleets' capability to respond a concrete situation. These variables are specially relevant in rural communities, where some studies have demonstrated the inefficiency of current emergency services [2].

This paper presents a distributed environment which is being developed to assist in the design and validation of real-time decision tools. The main aim of this environment is to provide a detailed representation of real systems, so optimization algorithm can be developed and tested tackling realistic situations. Next section introduces the basic operative protocols and phases that make up an emergency intervention. The following section describes the software architecture where the simulation environment provides the information of accidents and fleet state. Section 4 introduces the system model based on Coloured Petri Nets formalism which will be used to simulate different problem approaches. Finally, section 5 describes basic characteristics of the proposed optimization algorithm to tackle the problem.

2 Operative Protocols

The complexity of tasks carried out in a road accident requires the intervention of multidisciplinary rescue services. The number and kind of resources which are mobilized in a particular situation depends on the accident variables such as the number of involved vehicles, traffic ratio on the road and time when the accident takes place or whether there are injured victims or not. Furthermore, resources are dynamically assigned since information flow is continuous from the moment the accident occurs until services finish their action.

Each rescue service can divide its intervention into four major phases [3]:

1. From call receipt to scene arrival.

2. From scene arrival to scene departure.

3. From scene departure to hospital arrival and registration.

4. From departure back to the station to the arrival at the station.

In the first stage, a call is received and all the available information is collected to determine which resources to mobilize. A minimum of a police unit is sent, since its primary task is to control traffic at the accident scene permitting an easy access to other rescue services. Number and kind of medical units (basic ambulance, ICU ambulance, etc) assigned depend on the number of injured victims, while Fire units are only mobilized in case of trapped victims.

In the next phase, rescue services arrive at the accident location and check accurately known and unknown information, transmitting their evaluation to the respective stations. If resources assigned to the accident are not enough, it will be necessary to reallocate new units. Victims' attention is the most complex part of the process [4], since many situations can be derived from a road accident and a well coordinated intervention is essential. In case that hospitalization is necessary, hospital destination is decided at this phase taking into account the seriousness of injuries and travel distance.

In the third stage, transport and registration at the selected hospital is performed. Hospitalization depends on injuries' seriousness, so not all accident victims will require it. Most of cases where hospitalization need is determined, only Medical and Police services will take part in the transport. In this stage, the patient should be registered at the hospital and seen by a physician, so the ambulance rescue unit must wait until the physician's diagnosis has been made and the patient is fully admitted. If the diagnosis requires treatment for the victim at any other hospital, the medical unit is responsible for transporting the patient.

In last phase, assigned units return back to the depot from the hospital or the accident scene. Different actions are done at the station after an intervention, including cleaning tasks, used material replacement and communication of fully operative state to the communications centre.

3 Distributed Platform Architecture

Because the project has a multidisciplinary approach, the computer program architecture designed to tackle the problem integrates different technologies, i.e. different software, programming languages and operative systems. Figure 1 illustrates the system architecture. The system involves four main modules: the Information System, the Fleet Simulator, the Decision Making Tools and the Visualization Tools.

The system has been designed as a distributed application based on CORBA [5] to simplify the coordination and communications between modules. The complete modularity of this architecture also permits to replace modules answering to simulation needs or case studies [6].

The *Geographical Information System (GIS)* module manages all the static and dynamical data in the system. The static data is composed by the geographical data, provided by a cartographic database, and the filtered geographical data, which is extracted from the former and generates a representation of the roads and streets network accord-

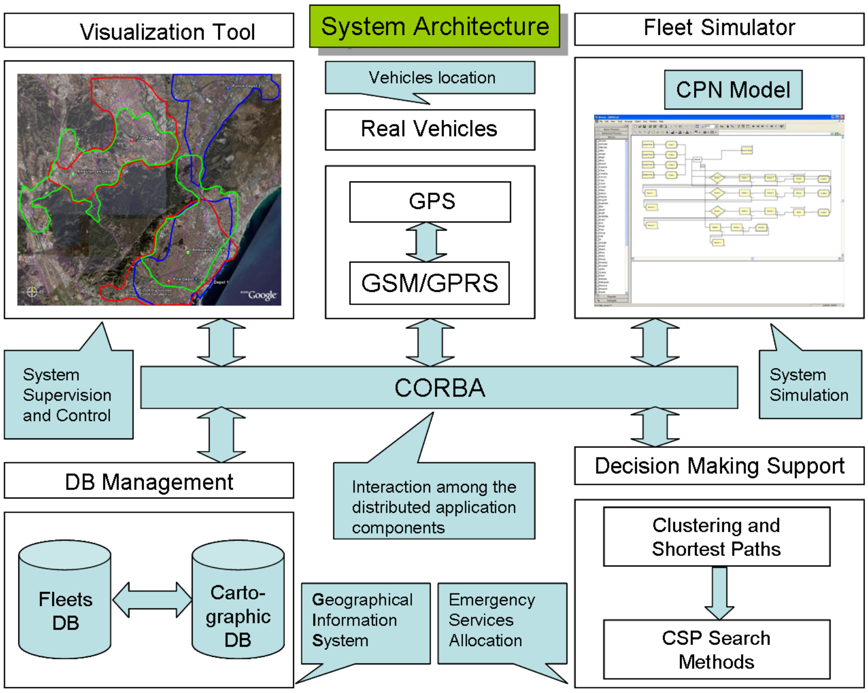

Figure 1: System architecture

ing to the need of the optimization module. The dynamical data is composed by the fleet structure information (vehicle characteristics, state of vehicles, etc), the georeferenced position of each vehicle and the georeferenced position of the road accidents, as well as the accident characteristics (vehicles involved, number of injured victims, time window constraints, etc).

The *Visualization* module is a graphic application where the vehicle movements and the configured routes are represented on the map. Vehicle positions are generated and registered at the database by the *Fleet Simulator* module, though a real vehicle positioning system could be easily integrated in the platform [7].

The *Decision Making Support* module has to find a solution for the problem, which falls into the VRP category. Near all the solution techniques for this problem are heuristics and metaheuristics because no exact algorithm can be guaranteed to find optimal solutions within reasonable computing time due to the NP-Hardness of the problem [11].

4 Emergency Services Model

The problem can be interpreted as a Vehicle Routing Problem (VRP) [8] with some additional constraints. First hand, a multi-depot consideration should be tackled since every rescue service owns different bases scattered along the territory. Moreover, several kinds of vehicles are located at each depot, constituting a heterogeneous fleet. On the other hand, rescue service time is usually tightly restricted since a quick actuation is required on road accidents. Traffic ratio on the road, seriously injured victims or the number of vehicles involved in the accident are some of the variables that determine the tightness of the time window restriction applied to a specific accident.

The routing problem to be solved is different for each rescue service though all represent a variation of a pickup/delivery problem. The Fire Service action could be interpreted as a single pickup/delivery service between two fixed nodes: vehicle's depot and the place where the accident has occurred. Medical and Police Services action presents more complexity since the delivery node is dynamically

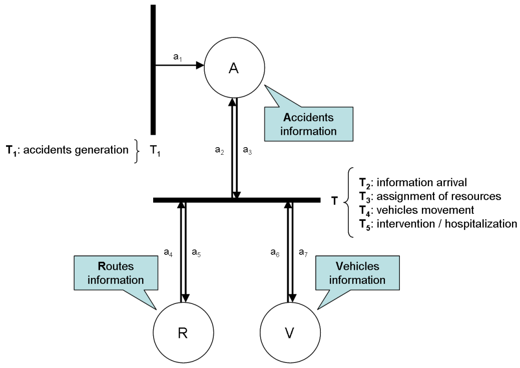

Figure 2: CPN Model

assigned taking into account accident variables, including the option that no delivery is needed. Thus, the complete route can only be decided once the service at the accident node has started, so the routing planning expended time becomes critical.

The fact that Medical and Fire Services must return to their origin depots before attending another accident simplifies the routing problem, so two-nodes or at most three-nodes routes should be calculated. On the other side, Police Service can perform different actions in several accidents before returning to their origin depot, although a new destination cannot been assigned until their service at the accident scene has ended. In this special case, a police vehicle returning to its base can be interpreted as a new depot with a single vehicle in order to reallocate services on runtime simulation.

The state of the system is determined by the fleet state (state and position of every vehicle), the routes planned and accidents state. Thus, two parts can be distinguished in the system dynamics represented by the model: the generation of the accidents and the simulation of different rescue services movements and actions. The CPN [9] model is shown in Figure 2.

Road accidents are generated according to a stochastic model along the simulation. In order to represent a real-time system, the information related to a specific token created when transition T_1 is fired should not be uniform. Thus, some attributes will remain unknown until the firing of another transition update them. These updates will represent the stochastic information arrival (T_2) or the perception of rescue services during their action performing at the accident scene (T_5).

Attending an accident basically consists of deciding which resources are assigned, taking into account all the known information and, so that, on which route the travel time will be reduced (T_3). The allocation task is performed using the fleet variables, including available units type and state, but not considering vehicles crew assignment.

The fleet movements are determined by transition T_4. When T_4 is fired the fleet state is changed and different actions begin as the vehicles arrive to the accident, hospital or depot points (T_5).

5 Decision Making Tool

A two phases approach is suggested to tackle the emergency services coordination problem. The objective is to assign resources to accidents according to the implicit restrictions of the problem, which falls into the Constraints Satisfaction Problem (CSP) category. These constraints define that the maximum fixed response time may not be violated by the problem solution and no area must rest uncovered, affecting resources' allocation. Therefore, all resources of a particular depot may not be assigned to a single accident, since the second restriction would not be satisfied.

5.1 Clustering process

In order to reduce the computation time at the solution stage, GIS information is preprocessed by classifying the GIS nodes according to distance and traveling time from the different depots. Thus, each node is only reachable by a vehicle whose base is located at the depot which minimizes distance and traveling time, creating a cluster-based structure, as shown in Figure 3.

The goal of this geographic data rearrangement is to reduce the multi-depot VRP problem to a set of single-depot problems, where only one for each service has to be solved when an accident takes place. Therefore, variables' domains are reduced, improving the response time of the optimal solution search algorithm.

At this phase, common heuristic A* procedure [10] is used to classify the geographic information into separated clusters. Moreover, a shortest path

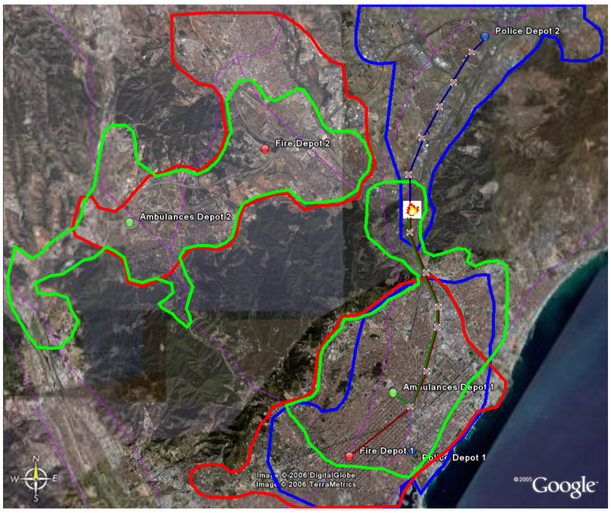

Figure 3: Accident simulation

determination task is performed, so nodes are reordered into the cluster structure. Thus, when an accident notification is received, a shortest path approach from the depot to the accident scene is known, achieving an important calculation reduction.

An uniform cost heuristic function is introduced in the clustering algorithm. The reason is that every single node is a potential accident node, so no particular direction may be pondered during the search. Each path is explored until the time service restrictions are not fulfilled, delimiting thus the cluster edge.

The uniform cost heuristic never overestimates the real cost of getting from one node to another. This property guarantees the optimality of all paths included in a cluster and ensure that no optimal solution may be discarded during the search [10].

As the algorithm always explores nodes with minimum associated cost at each iteration, it is possible to guarantee that the corresponding determined path from the depot to any node in the cluster is minimum. Since any suboptimal path to a particular node has a larger cost than the optimal one, it can be demonstrated that the suboptimal path will never be explored and the optimal solution will be returned.

5.2 Emergency services allocation

In solution's search stage, emergency resources are assigned when an accident occurs. Constraint Satisfaction Problem (CSP) techniques are used to find a feasible solution. System constraints are related to the available resources and specially to time windows.

The information obtained at clustering stage is used to reduce the solution search space. Furthermore, an accident may be associated to a particular depot with a minimal computational cost, since either the accident location belongs to a specific cluster or the distance from the accident node to close clusters' edge may be easily calculated. Thus, the solution search is simplified to explore only nearby clusters, reducing the search space.

In some cases (e.g. accident occurred in an isolated area, traffic jam, etc.), a solution fulfilling all the imposed constraints may not be reached. Thus, time constraints may be relaxed or weighted and minimizing the response time becomes an objective of the arising optimization problem. The main aim is to allocate resources satisfying all the imposed constraints except the response time restriction, which turns into an objective function.

The information available during solution's calculation is dynamically changing, since not all accident variables are known until the first unit arrives to the accident scene. Furthermore, the information may arrive from different sources, containing a large uncertainty. Therefore, the solver is forced to check resources' availability and problem's time constraints in a continuous process during the intervention. Moreover, roads state may change from the moment the accident takes place to service end, so shortest paths calculated at clustering stage may become non optimal. This situation may be determined using vehicles' GPS information, since their geographical position and movements are well-known. Thus, the corresponding route to the accident scene must be recalculated and, in some cases, resources should be reallocated. On the other hand, cluster's shortest paths information may be used in an heuristic approach to calculate the new route, reducing search's complexity. So, clusters can not be defined as rigid structures, but nodes included in foreign clusters may be reachable by vehicles belonging to a particular depot in order to find a feasible solution.

6 Conclusions

The paper presents a CORBA distributed environment which is being developed to assist in the design and validation of real-time decision tools in emergency services field. A fleet simulator is used to test the decision tools designed to tackle the problem.

These tools are based on a two phases algorithm, introduced in the present work: a preprocessing work where the search space is reduced, transforming a n-depot problem into n single-depot problems, and a second stage where individual single-depot problems are solved using Constraint Programming techniques. This approach allows to reduce calculation during the execution, since the clustering task is performed in a preprocessing stage. In the second phase, emergency resources are assigned and the corresponding routes are calculated considering the shortest path structures generated in the first stage.

Acknowledgements

This work has been supported by the Department of Universities, Research and Information Society of the Catalonia Autonomous Government, Ministerio de Fomento and by the Spanish Ministry of Science and Technology (projects DPI2004-08056-C03-01 and DPI2004-08056-C03-02).

References

[1] SAMUR (Servicio de Asistencia Municipal de Urgencia y Rescate) - Ayuntamiento de Madrid, *http: // www.munimadrid.es / Principal / ayuntamiento / ServMuni / seguridad / samurweb / menu_superior / procedimientos / Operativo.pdf*, Procedimientos Operativos

[2] T.Young, J.C.Torner, K.C.Sihler, A.R.Hansen, C.Peek-Asa, C.Zwerling, *Factors associated with mode of transport to acute care hospitals in rural communities*, The Journal of Emergency Medicine, 24#2:189-198, 2003

[3] A.S.Al-Ghamdi, *Emergency medical service rescue times in Riyadh*, Accident Analysis and Prevention 34: 499-505, 2002

[4] J.Urbano, J.D.Cortés, J.Busto, J.Lafuente, J.C.López, *Coordinación de los servicios de emergencia en accidentes de tráfico. Experiencia en Alcorcón*, Emergencias, vol. 10, #1, 1998

[5] Object Management Group, Inc., *Common Object Request Broker Architecture: Core Specification*, OMG, Inc., 2004

[6] J.J.Ramos, M.A.Piera, A.Guasch, J.Figueras, *A simulation based environment for designing real-time decision tools in the trucking industry*

[7] G.Derekenaris, J.Garofalakis, C.Makris, J.Prentzas, S.Sioutas, A.Tsakalidis, *Integrating GIS, GPS and GSM technologies for the effective management of ambulances*, Computers Environment and Urban Systems, 25:267-278, 2001

[8] The VRP Web, *http://neo.lcc.uma.es/radi-aeb/WebVRP/*, 2005

[9] K.Jensen, *Coloured Petri Nets: Basic Concepts, Analysis Methods and Practical Use*, vol. 1, 2, 3, Springer-Verlag, 1997

[10] S.Russell, P.Norvig, *Artificial Intelligence: a Modern Approach*, 2nd. edition, Prentice Hall, 2003

[11] T.Bektas, *The multiple traveling salesman problem: an overview of formulations and solutions procedures*, Omega (The International Journal of Management Science), 34:209-219, 2006

[12] G.Nagy, S.Salhi, *Heuristic algorithms for single and multiple depot Vehicle Routing Problems with pickups and deliveries*, European Journal of Operational Research, 162:126-141, 2005

[13] R.Dondo, J.Cerdá, *A cluster-based optimization approach for the multi-depot heterogeneous fleet Vehicle Routing Problem with time windows*, European Journal of Operational Research, 2006