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Control points deployment in an Intelligent Transportation System for monitoring inter-urban network roadway

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ABSTRACT

The constant evolution of transportation systems and traffic in developing countries is nowadays confronted with a problem of road safety and therefore of a high accident rate, especially in the context of inter-urban road transport. In this work, we propose a communication architecture for an Intelligent Transport System (ITS) to provide surveillance in an inter-urban transport network in the context of developing countries. We introduce two types of control points: Relay Control Points (RCP) and Treatment Control Points (TrCP). We also designed two multi-objective models for the deployment of these points. In order to ensure good coverage, to minimize the cost of installation and to put more emphasis in the areas having a high number of accidents. To ensure optimal deployment of these points, we have used the Non-Dominated Sorted Genetic Algorithm II (NSGA-II) that will allow to realize the Pareto front of non-dominated solutions. The results of the simulations show the effectiveness of our proposal.

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1. Introduction

1.1. Background

The effectiveness of road networks for monitoring traffic and user activities in the developing countries is not easy. Their implementation is generally confronted with the problems of connectivity, coverage, and networking. The lack of road infrastructure in these countries is a source of many accidents and deaths. For instance, Otou states that 1450 people died in 2012 in Cameroon following a traffic accident (Gokulakrishnan and Ganeshkumar, 2015; Otou-Essono, 2013). In developed countries, the emergence of Intelligent Transportation Systems (ITS) ensures good monitor-

ing of activities in the transport networks (road, air, rail, etc.). It would be very important for such a concept to be implemented in developing countries especially in the context of road networks. Despite the limited financial means available to these countries for setting up such projects.

Several works are being carried out with a view to set up an intelligent system that could monitor activities through road networks in these countries. In this light, Tom et al. (2016) recently proposed a futuristic and sustainable architecture for ITS for developing countries. The proposed architecture has sophisticated tools and technologies for poor countries (web application's or SMS, GPS or cell phones, IR sensors, Internet connectivity, WiFi, LED board, Motion sensors and Radar gun) (Rubin et al., 2019; Younes and Boukerche, 2015). Moreover, a methodology for the implementation of an ITS for monitoring the inter-urban road network that takes into account the lack of financial resources observed in these countries and using the available ICTs has been introduced by Mfenjou et al. (2018). Their methodology is based on three large modules: the first is for the management of control points, the second for the detection and diffusion of disturbances and the last for the dynamic route planning.

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1.2. Contributions

The purpose of this paper is to propose an architecture of communication with an optimal scheme for the deployment of the various control points (relay and treatment) in order to minimize deployment costs, maximize network coverage and, above all, favor areas with a high number of accidents. Indeed, the setting up of control points that we propose would reduce the regulatory problems encountered in inter-urban road networks according to the realities of the developing countries. Thus, initially, we propose a deployment formulation that gives priority to areas where accidents are often affected. Then we minimize the cost of deployment and also maximize the coverage.

We proceed to a multi-objective reformulation of the deployment. For performance evaluation, we define three instances of control points deployment. Several optimization methods are used nowadays to solve multi-objective optimization problems. Sometimes, some research addressed problems related to more than three objective functions such as: Dynamical Multi Objective Evolutionary Algorithm (DMOEA) (Zou et al., 2008), Multi-objective Colliding Bodies Optimization (MOCBO) (Kaveh and Mahdavi, 2019), Comprehensive Evolutionary Algorithm (CEA) (Seifollahi-Aghmiuni and Haddad, 2018), Multi Objective Particle Swarm Optimization (Lalwani et al., 2013) and Non-dominated Sorting Genetic Algorithm for Multi-objective Optimization (NSGA-II) (Deb et al., 2000), etc. In this work, we adopted the Multi-Objective Genetic Algorithm especially the NSGA-II. We exploit its search aspect of non-dominated solutions and its speed to realize the Pareto front which facilitates decision making at the level of any forum that will set priorities for one objective function or another.

1.3. Organization of the paper

The rest of this paper is organized as follows: In Section 2, we present works related to nodes placement and the related taxonomy. In Section 3, we present an architecture of communication in an inter-urban roadway networks for developing countries. Section 4 presents an overview of GA, which is to adopted optimization method. In Section 5, we describe the adopted system model. In Section 6, we present the proposed mathematical framework as well as the design goal. Section 7 presents the performance evaluation. Section 8 conclude the paper.

2. Related work

The set of issues that arise in the management of vehicles and other entities, which enter the road transport networks is assimilated as vehicle routing problem. Eksioglu et al. (2009) proposed a complete taxonomy for modeling of vehicle routing problems. Their work highlights all the parameters to be considered in activities related to road network management. The context of inter-urban roadway networks in developing countries is not excluded. In addition, Current and Marsh (1993) present a scheme that gather these problems in different axes that include: the shortest path problem, transportation problem, assignment problem, transshipment problem, vehicle routing problem, optimal network design problem, the spanning tree problem and the network for problem. Naturally, the problem of optimal deployment of control points in the inter-urban transport network of developing countries, therefore, falls within the axis of the optimal network design problem.

Usually, deployments in road transport networks include some equipment such as Road Side Units (RSUs), which are used in Vehicular Ad hoc NeTworks (VANETs). The literature groups the deployment plans into five categories (Elliott et al., 2019; Xue

et al., 2017; Wang et al., 2017). This is according to the objectives: network connectivity, traffic coverage, information dissemination, density based-approach, and centrality based-approach. The goal of network connectivity is to realize deployment plans focused on the improvement of the connectivity and the reducing of the disconnection intervals between a limited number of RSUs. Several works have been done in this case. Lochert et al. (2008) present a domain-specific aggregation scheme to minimize the overall bandwidth and to save the traveling time in traffic networks. They also proposed a GA that is able to identify good positions for static roadside units in order to cope with the highly partitioned nature of a VANET in an early deployment stage. A set of tools allows us to optimize the placement with respect to an application-centric objective function, based on travel time savings. Simulations have been done using VISSIM simulator. The proposed solution has been deployed and tested in a part of Brunswick in Germany.

Chi et al. (2013) provide an optimal RSU allocation algorithm with a concept of intersection connectivity between intersections. Firstly, they find optimal RSU candidate intersections which can cover the entire intersections, in the meantime minimizing the overlapped transmission coverage of RSUs. They eliminate repeatedly RSU candidates by the value of intersection-connectivity between RSU candidate intersections. The intersection-connectivity between two intersections is basically measured by the number of vehicles with the same moving pattern such that pass through both intersections. Thus, a high value of intersection-connectivity between two intersections stands for that the traffic information obtained at one intersection can be carried-and-forwarded to the other intersection with a high probability by those vehicles. Therefore, with this feature, they remove repeatedly RSUs having high intersection-connectivity with its neighbors. This model has been executed with real urban roadmaps of JungGu and Seochogu in Seoul (South Korea). Concerning the traffic coverage objectives, the proposed model aims at maximizing the number of vehicles that get in contact with the RSUs deployed in the considered region.

Coverage issues in mobile networks usually aim at finding strategies to satisfy the majority of entities that are there in terms of communication. In Naito et al. (2013), authors cover RSUs by Extension with Orthogonal Frequency Division Multiplexing (OFDM) cooperative transmission technology. Due to the dynamic of RSUs, Naito et al. (2013) employ multi-hop mechanisms to extend the transmission range of RSUs. Consequently, forwarder vehicles transmits a simultaneous OFDM signal to forward data from roadside units. For the simulations carried out, the interval between the RSUs is fixed, thus that of the RSUs and multi-hop transmission. The results show that this scheme can be extended without further degradation and redundant consumed wireless resource.

Zheng et al. (2009) propose a α -coverage for bounding the inter-connection gap for vehicular internet access. They introduced a notion of intermittent coverage for mobile users, called α -coverage that provides worst-case guarantees on the interconnection gap while using significantly fewer access points than needed for full coverage. Therefore, they give algorithms that verify whether a given deployment provides α -coverage and approximation algorithms for determining a deployment of the access point that will provide α -coverage.

Salvo et al. (2012) studied the extension of the RSU coverage area via a simple data dissemination defined for urban scenarios. They also proposed a forwarding algorithm that relies on information local to the forwarding On board unit (OBU). They showed that their case studies representing urban structures and the protocol, which is used in the order of 20 times the transmission area of the RSU, to guarantee a good RSU coverage with a very low percentage of vehicles not reached by the disseminated data.

Mehar et al. (2015) proposed an Optimized Roadside Units Placement for Delay-Sensitive Applications in Vehicular Networks (ODEL). It is a model of deployment of RSUs in which the main objective is to deploy the RSUs in order to ensure a good coverage and a good Quality of Service (QoS) in order to minimize the application delays between RSUs and vehicles. This model is based on two steps. The first is to select the possible positions where we could install the RSUs. As for the second step, they use the GA and the Dijkstra algorithm to reduce the number of RSUs while also minimizing application delays. The simulations carried out on certain scenarios with SUMO show that the cost of deployment is reduced up to 23% while application delays are reduced up to 84%.

For the information dissemination objectives, the purpose is to improve the information dissemination performance, such as reducing the end-to-end delay, increasing the packet throughput, or decreasing the packet loss ratio. Salvo et al. (2012) also shows that one can improve information dissemination by defining good coverage. Cavalcante et al. (2012) models the problem of RSU placement for information dissemination by model this problem as a Maximum Coverage with Time Threshold Problem (MCTTP). They used GA to solve the MCTTP. Their solution is compared to a greedy approach and the results show that their approach is better than the greedy in all scenarios (in four towns: Zurich, Baden, Baar, Winterthur), with gains up to 11 percentage points. This approach allows us to speed up the process and find solutions with acceptable. Nevertheless, there are no details about the modeling of communications between vehicles and RSUs.

With reference to density based-approach, the goal is to deploy the roadside unit with the lowest possible cost to alert emergency services in case of an accident. This approach uses an inverse proportion to the expected density of vehicles. The results obtained in Barrachina et al. (2013) shows that this approach reduces the required number of RSUs, as well as the accident notification time. They used wireless technologies to share warning messages to other vehicles and emergency via V2I communication via RSUs. The parameters that are considered here are the density of vehicles (veh./km²), number of RSUs, simulated city, simulated area, number of crashed vehicles, downtown size, downtown probability,

warning message size, packets sent by vehicles, warning message priority, normal message priority, mobility generator, mobility models, MAC/PHY, radio propagation model, maximum range, broadcast storm reduction scheme. Experiments have been made in a part of Madrid in Spain. Simulations have been achieved with the NS-2 simulator.

A centrality based-approach is defined in Wang et al. (2017) and its goal is to introduce the notion of centrality in a social network to RSU deployment, and used it to measure the importance of a given RSU position candidate in RSU deployment. The major metrics in the centrality approach are degree centrality and closeness centrality (Wang et al., 2017). The centrality approach is formulated as a 0 – 1 Knapsack problem. The algorithm of RSU deployment based on centrality which is defined by Wang et al. (2017) has as input parameters the cost of each RSU position candidate, the number of RSU positions candidates and the budget of deployment. The output is a set of RSU deployment positions. The simulation was done with C++ and the results show that it can improve the efficiency of the RSU in terms of the coverage time ratio as compared to the random deployment approach. Table 1 summarizes the proposed solutions for deployment plans. In the next section, we present a background on the inter-urban roadway and the related communication architecture.

3. Background on inter-urban roadway network architectures

3.1. Policies and positioning

In addition to the various deployment plans, there are policies to ensure a good deployment in terms of urbanization and costs (Barrachina et al., 2013). These policies are Minimum cost deployment policy, Mesh deployment policy, Downtown-based deployment policy, Security deployment policy. Concerning the minimum cost deployment policy, we note that the deployment of Control Points (RCPs or TrCPs), like that of RSUs, must take into account the financial cost. Sometimes the authorities responsible for doing so do not necessarily consider the objectives related to technical and realistic needs (connectivity, coverage, information

Table 1
Summary of RSUs the relevant deployment plan objectives in ITS compared to a given goal.

Deployment Objective	Solution	Approach	Goal	Simulator	City
Centrality	Wang et al. (2017)	Degree of centrality Closeness centrality 0–1 Knapsack Problem	Measure the importance of a RSU position candidate	C++	–
Network Connectivity	Lochert et al. (2008)	Genetic Algorithm	Define a domain specific aggregation scheme to minimize the overall bandwidth and save the traveling time in traffic	VISSIM	Brunswick (Germany)
	Chi et al. (2013)	*Floyd Algorithm *Optimization using weight constraints	Connectivity between intersections by ensuring the research of optimal RSU candidate intersections which can cover the entire intersections		JungGu, Seochogu (South Korea)
Traffic coverage	OFDM Naito et al. (2013)	Multi-hop mechanisms	To allow to the vehicle to demodulate multiple OFDM signals within guard Interval period without inter-symbol interference		–
	α -coverage Zheng et al. (2009)	Polynomial Time Algorithm	Introduce intermittent coverage between mobile users	NS-2 Mercator Projection	Franklin County USA
Information dissemination Density	ODEL Mehar et al. (2015) MCTTP Cavalcante et al. (2012) Barrachina et al. (2013)	Genetic Algorithm Dijkstra Algorithm Genetic Algorithm	Reduce the Number of RSUs Reduce the Application Delay Maximize coverage by information dissemination Share warning messages to other vehicles and emergency via V2I communication via RSUs	SUMO C++ NS-2 CityMob	– Zurich, Baden Baar, Winterthur Madrid

dissemination, density). Thus, most often (especially in the case of large cities) the RSUs are located in areas of high densities and good internet connection. The disadvantage here is that there are unconnected regions where vehicles will not be able to communicate.

For the mesh deployment policy case, there is another used policy. Deploying devices such as control points and RSUs through a transport network (urban or inter urban) can also be done in a mesh that can be either uniform or not. The uniform mesh consists of distributing these devices uniformly without considering neither density of the traffic, nor the roadmap topology. In the case of a mesh which is not uniform, other parameters must be taken into account. In the deployment of infrastructures in an ITS, meshing can be considered as a parameter for reducing the cost of deployment in the function of QoS offered by a network.

Furthermore, authors of Ligo et al. (2016) use vehicular mesh networks to carry Internet data traffic for mobile users. Real data from the vehicular network that is operating in Portugal is used in this case. They estimate the relationship between network throughput and offered a load of internet traffic, quantity of vehicles, quantity of infrastructure and the use of Request-to-Send/Clear-to-Send handshaking. Downtown-based deployment policy is a deployment of devices only in areas of high traffic densities.

Besides, security deployment is another policy that is important in the deployment of infrastructure in ITS is security. Generally, the security in a network concerns communication between entities or security of these entities. In Krishnan and Ram (2015), the authors exploit the infrastructure RSUs to efficiently and reliably route packets in VANETs. This system operates by using vehicles to carry and forward messages for a source vehicle to carry and forward messages from a source vehicle to a nearby RSU. Moreover, if needed the system routes these messages through the RSU to the destination vehicle. The placement of RSU, in this case, is formulated via an integer linear programming model. The performance of this system is evaluated using NS-2. Their results show that this solution leads to the best performance as compared with the uniformly distributed placement and the hot spot placement.

Now, what happens in ITS in terms of deployment? The case of the RSUs caught our attention because having some link in its working with the control points. In the context of monitoring of inter-urban roadway networks in developing countries, what deployment plan should be used for? Which policy should be exploited? As mentioned early in Section 2, the purpose of the control point is to relay information and monitor activities through the inter-urban roadway network. The choice of the deployment plan should take into account the objectives to be achieved as part of the monitoring of activities through the inter-urban transport roadway networks namely reducing the congestion and traffic accidents. The deployment here is a hybrid approach in terms of plan. In addition, the satisfactions are based on:

- *Network connectivity.* The technology used must allow maximum connectivity between control points.
- *Traffic coverage.* The proposed deployment model maximizes communication coverage across the inter-urban road network. It would be important that, whatever road a vehicle uses to access the inter-urban road network, it should be registered.
- *Density based approach.* Road sections with heavy traffic will necessarily have more control points than others.

Regarding the deployment policy, given the proposed hybrid plan, the deployment should allow us to minimize the cost of deployment because we are in the context of developing countries where there is no financial power. Downtown-based deployment policy must be considered in our context of surveillance of the inter-urban roadway network. In an inter-urban roadway network,

particularly in developing countries, the density of traffic is not uniform. Therefore, the deployment of control points cannot be uniform. Since the deployment plan is hybrid, the layout of the control points cannot be uniform.

In summary, it should be emphasized that for the control points, i.e., RCPs and TrCPs deployment model, our proposal relies on a hybrid plan that ensures good connectivity between control points, maximizing the communication coverage between these control points, and increasing control points in high-density traffic areas. In a context where many accidents and deaths are recorded in the inter-urban transport networks of the developing countries, it would be important to consider the density of traffic and the number of deaths through this network as factors that influence the deployment of control points.

3.2. Control points

Control points visible in Fig. 1 denote stations that, depending on their type, relay information, and monitor activities between cities in an inter-urban road network. The idea is to place them at cities' exits, at their entries, some adequate positions between cities, and certain places between the cities so as to favor a maximum coverage of the inter-urban network in terms of visibility and follow-up of the activities through the inter-urban transport network and according to the rate of accidents in an area. Also in the Fig. 1, the points A, B, and C designate cities in the inter-urban road network that we operate. Depending on their positions (entry or exit, between cities), we define two types of control points: Relay Control Points (RCP) and Treatment Control Points (TrCP).

Furthermore, Fig. 2 illustrates the approach that we define the operation of control points in an intelligent interurban transport network monitoring system. We define an autonomous management system of control points by region. In each region, an autonomous system is defined for monitoring control points and communicating with other control point managers. Whether among control points or between control points and users, the communication concerns the evolution of activities across the inter-urban road network such as disturbances, vehicle to be sanctioned, decisions sent to a user in relation to a fault committed. As for the control points, the communications performed between them are defined in the following subsections.

Indeed, the idea of the local manager is to decentralize the system to ensure administration at the regional level. Many challenges remain as modeling behavior of these control points. So as to ensure the security of information, fault tolerance on this system to ensure the responsiveness of the system at any time.

3.2.1. Treatment Control Point (TrCP)

In the considered system, this type of control point depicted in Fig. 3 is used to process the information collected by the Relay

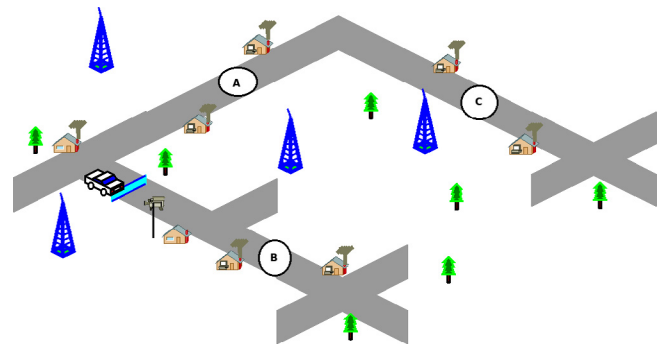


Fig. 1. Communication architecture of Control Points.

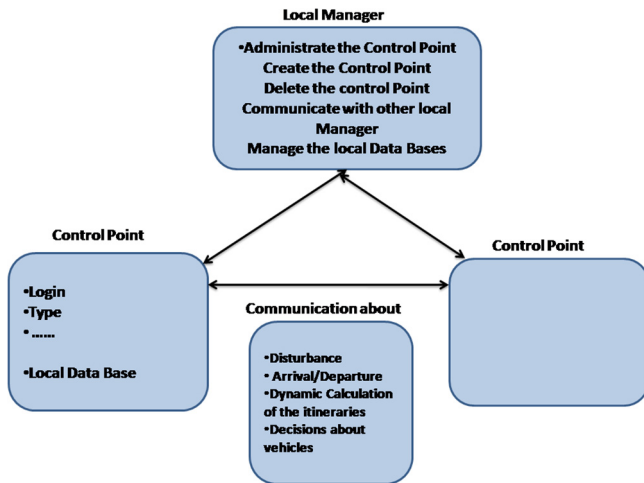


Fig. 2. Operating structure of Control Points.

Control Points (RCPs). These information are related to the behavior of vehicles traveling through the inter-urban transport network and disturbances that are observed through an inter-urban network in developing countries. Finally, for a vehicle entering the inter-urban road network, the first TrCP through which it passes must register it with the other TrCPs through which it should pass. For this reason, the deployment of the control points involved in this work must ensure coverage of the inter-urban road network.

3.2.2. Relay Control Point (RCP)

The Relay Control Points (RCPs) are structures that are installed between TrCPs at locations that experience the most congestion, which most commonly cause accidents (see Fig. 4). In our proposal, we, therefore, ensure the deployment by assuring coverage that will focus on areas where accidents are mostly caused by users. Moreover, detection technologies and sensors will be used to build these RCPs later in our research. What is important at the moment is to see how we will deploy them in order to control the distractions as well as disturbances of users of the inter-urban road network in developing countries.

3.3. Vehicles and crossroads

As kinds of vehicles in an inter-urban roadway, we have public transport vehicles, personal vehicles, freight trucks, logging trucks,



Fig. 3. An example of Treatment Control Point (TrCP).

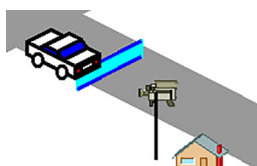


Fig. 4. An example of RCP.

convoys of vehicles. In order to manage control points in inter-urban road networks, the proposed system must enable communication among the control points and on the other hand between the control points and the terminals used by the road users. In the context of developing countries, smart vehicle technologies have been developed and are used in daily life urban transportation. With regard to developing countries, GPS is the most used technology in vehicles. Moreover, user mobile phones embarked with mobile technologies such as GSM, UMTS, and LTE radio modules are used to ensure some traffic services.

Crossroads are designed according to the type of road (highways, assimilated roads and express roads) on which they should be and the conditions of their use. The nature of the secondary road as well as the characteristics of the traffic and exchanges for which they are conceived are also to be taken into account. Fundamentally, crossroads are defined in two main families:

- **Interchanges:** are separated from each other and managed outside the main axes.
- **Crossroads plans:** group in a single plane all the exchanges between the routes concerned.

Beside these big crossroads families, we observe the “half-crossroads” which are a common crossroads. For the deployment of the control points, which is the main objective of this work, we consider the road network as being only that formed of paved roads. In most of developing countries such as those in sub-Saharan Africa, crossroads in inter-urban road networks often have routes to small towns, forest and finally industrial areas. These are entities that must be considered while designing the deployment scheme. In the next section, we present the used background framework in the design of our proposal.

4. Overview of genetic algorithm and multi-objective optimization

4.1. Genetic algorithm

The GA has been introduced by Holland (1992). It relies on techniques derived from genetic and natural evolution mechanisms namely: cross, mutation and solution. In Fig. 5 a flowchart of the structure of a GA is presented. Hereinafter the main step of a GA are presented.

4.1.1. Encoding

The encoding step allows to represent the information. There are six types of encoding: *the binary encoding, the octal encoding, the hexadecimal, the real value, the permutation (or order) encoding and tree encoding.*

4.1.2. Selection

This step consists of finding out the best individuals for mating process so that the offspring are better than the previous population. There are several methods of selection, the most known are:

1. **The roulette wheel selection.** The parent are selected according to their fitness values and the better chromosomes have more chances to be selected. Higher the fitness of individual, higher the chances of getting selected (Hancock, 1997; Jebari and Madiafi, 2013).
2. **The linear rank selection.** For this case, after sorting the individuals depending of their fitness, a rank is defined to them.
3. **The exponential rank selection.** This method is the same with the previous methods, but differs by the probability of selecting each individual (Hancock, 1997).

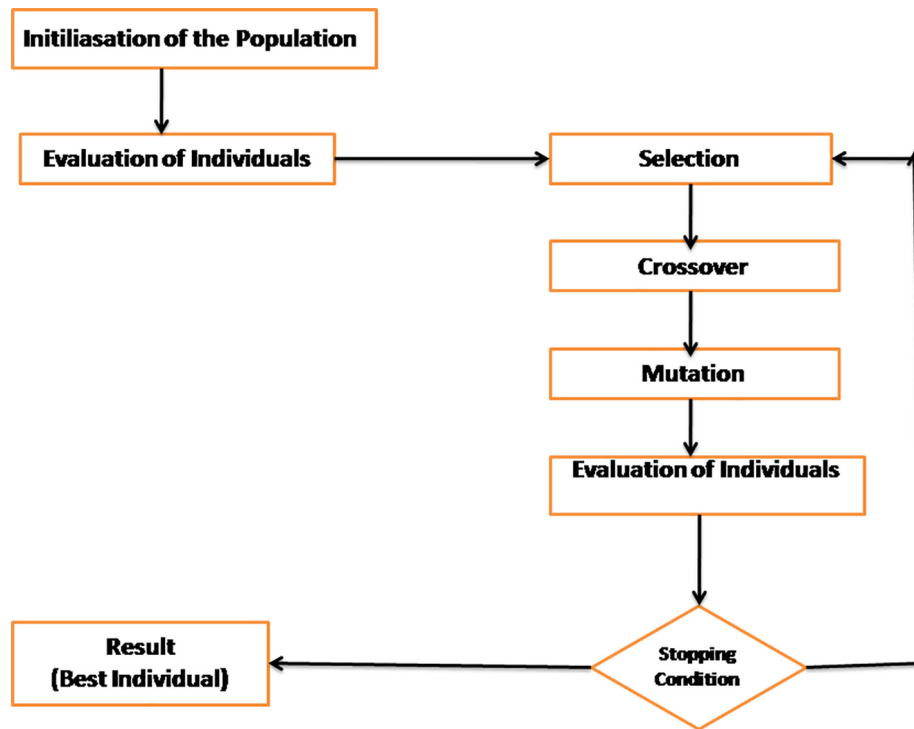


Fig. 5. Flowchart of GA.

4. *The tournament selection.* In this case, tournaments are played among a set of individuals (Little and Agarwal, 2005).
5. *The truncation selection.* This is the most easy technique that orders the candidate solutions of each population according to their fitness (Hancock, 1997). At end, only a certain portion p of the fittest individuals are selected and reproduced $\frac{1}{p}$ times.

4.1.3. Crossover or re-combination

This step relies on an operation that allow to merge two parents to generate a third new individual. It seriously accelerates research by early evolution of the population and leads to an effective recombination of solution schemes. The greater the number of crossing points and the higher the crossing probability, the more segments will be exchanged of exchange of parameters, information and the more the number of crossing points will be small and the greater the probability of crossing bring diversity. The main type of crossover operators in a genetic algorithm (Kora and Yadlapalli, 2017; Kora and Kalva, 2015) are:

1. *Mutation.* This operation allows to the algorithm to generate original solutions in the field of solutions (Sivanandam and Deepa, 2007).
2. *Evaluation.* It is precisely at this step that the objective function is used to check the individual optimizes the objective function.
3. *Replacement.* This is the last stage of the cycle of all GA. In addition to the individual to be the best, it would have to reflect the related problem initially posed in the reality (Sivanandam and Deepa, 2007).

4.2. Multi-objective optimization

The Multi-objective optimization schemes are the case of the resolution of problems with several objective functions. They are grouped into three classes: aggregating function, population-based approaches and Pareto Based approaches (Coello and Lamont, 2004).

4.2.1. Aggregating function

The goal of aggregating functions is to turn a multi-objective problem into a single goal problem through an equivalent objective function. It exists under several types but the best known is the *weighted average* that combines all the objective functions into one of the form given in Eq. (1).

$$\text{minimize } \sum_{i=1}^n w_i f_i(x) \text{ where } w_i \geq 0 \text{ and } \sum_{i=1}^n w_i = 1. \quad (1)$$

where $w_i \geq 0$ are the weighting coefficients. Their values are given according to the importance of the objective function with which it is associated.

4.2.2. Population-based approaches

This approach uses sub-populations to optimize each goal independently. Here, the research is diversify thanks to the population and the notion of Pareto is not directly taken into account in the selection process. The most known of this method is Vector Evaluated Genetic Algorithm (VEGA). The particularity of VEGA is in the way of selecting. A sub-population is generated at each generation from the initial population for each objective. For k objectives, k sub-populations of $\frac{p}{k}$ individuals are generated, where p is the number of individuals in the initial population. These sub-populations are then gathered together to obtain a new population on which the genetic operators will be applied.

4.2.3. Pareto-based approaches

The goal is to use Goldberg's (1989) Pareto-Dominance for solving the problems introduced by Schaffer (1985). The idea is to use the concept of optimality to respect all the criteria without comparing the values of different criteria. Let E be a set of possible multi-objective solutions. A point x is Pareto-optimal if it is not dominated by any point belonging to E . x belongs to the set of non-dominated solutions. This approach is grouped into two methods:

1. *Non elitist methods.* They are methods that do not preserve the “Pareto-optimal” individuals found over time. They hardly maintain the diversity on the Pareto border. Finally, the convergence of solutions towards the Pareto border is generally slow (Rabiee et al., 2012). Non-elitist methods include: Nondominated Sorting Genetic Algorithm (NSGA), Multi-Objective Genetic Algorithm (MOGA) and Niche Pareto Genetic Algorithms (NPGA).
2. *Elitist method.* The algorithms used in this approach solve the shortcomings found in non-elitist methods by introducing an external population or archive to keep Pareto-optimal individuals, the preference for non-dominated solutions and the use of efficient distribution of solutions on the Pareto borders. The elitist algorithms include: Strength Pareto Evolutionary Algorithm (SPEA), Pareto Archived Evolution Strategy (PAES) and Non-dominated Sorting Genetic Algorithm-II (NSGA-II),

4.3. Hybrid approaches

Some recent works try to improve the results that are obtained by genetic algorithms by combining it with other optimization methods or by modifying them by adding certain numerical method. In their work Nguyen et al. (2019) proposed a hybrid approach of finite element method, kriging metamodel, and multi-objective genetic algorithm (MOGA) for computational optimization of a flexure elbow joint for upper-limb assistive device. Moreover, Le Chau et al. (2019), proposed a new multi-objective optimization design for a new compliant planar spring of upper limb assistive device using a hybrid approach of RSM (response surface method)-FEM (finite element method) and multi objective genetic algorithm (MOGA). Furthermore, Quresh et al. (2019) applies a multi-objective optimization method, Generalized Differential Evolution (GDE3), to tune a Linear Quadratic Regulator (LQR) in the control algorithms for environmental disturbances. The comparison between the results of GDE3 with Non-Dominated Sorting Genetic Algorithm (NSGA-II) and conventional tuning is done. This comparison shows that GDE3 performs better than other methods.

At the end of the review on genetic algorithms, it appears that it is an optimization method that allows to have solutions on a known research space using the theory of evolution. Several authors have used its different variants in their works. Others combine genetic algorithms with other optimization methods to find the best results. According to the literature review, we adopt the Multi-Objective Genetic Algorithm especially the NSGA-II. We exploit its search aspect of non-dominated solutions and its speed to realize the Pareto front which facilitates decision making at the level of any forum that will set priorities for one objective function or another. This solution is used as a basic solution. In future works, we will make comparative studies with other optimization methods (simple or combined) to see if the results obtained improve those we obtain in this work.

5. System model

5.1. Assumptions

In this work, we consider the inter-urban road network as the network paved roads. An inter-urban roadway network is covered in this context, if whatever the junction a vehicle uses to enter in this network, it is registered by a TrCP. Indeed, as developing countries lack the infrastructure and the financial means to ensure full coverage, the proposed model we propose should allow them to maximize coverage. We suppose that, at a admissible location of some TrCP, we can have only one TrCP, i.e., $n_1 = 1$. We suppose

that, at a admissible location of some RCP, we can have only one TrCP, i.e., $n_3 = 1$.

Furthermore, it is useful to bring back the problem of deployment of control points to a graph problem. Indeed, the TrCPs and RCPs are installed through the inter-urban road network at fixed positions. It is, therefore, easier to work on these positions to optimize deployment by minimizing installation costs and also maximizing network coverage. We consider the admissible positions of TrCPs, RCPs and other junctions that arrive on the inter-urban road network as vertices of the graph they constitute. In our modeling, we assume that the TrCPs could be at the entrance or the exit of each city concerned, or at the level of large intersections that are found more often between cities. These are junctions connecting major highways to other areas of activity (agricultural, livestock, industrial) or other (small) cities.

5.2. Vocabulary

The consideration in the RCP's case has a few differences with TrCPs. We must note that in this case, the RCPs are installed between TrCPs and we aim to optimize their deployment. Let us define Q as the set of admissible RCP positions and P the number of RCP candidate. Let:

- E denote the set of vertices in this graph.
- S be the set of admissible positions to install TrCPs and c_{ij} be the $TrCP_i$ deployment cost at the position j .
- x_{ij} be the variable that indicates if the $TrCP_i$ is deployed at the location j or not.
- N be the number of TrCP candidates.
- n_1 and n_2 represents the thresholds limiting the number of TrCPs.
- $b_{u,v}$ be the cost associated to the placement of RCP_u at the location v .

Moreover, the decision variable to open or not the RCP_u at the location v is $y_{u,v}$. $H[card(Q)]$ in an array of number of accident of all of the RCP admissible position. At the end, p_1 is the threshold limiting the number of RCPs. Therefore, we summarized it in Tables 2 and 3.

Table 2
Notations used for modeling the optimization problem of TrCPs.

Variable	Notation
Deployment cost to build at location j $TrCP_i$	$c_{ij} > 0$
Decision variable to open or not the $TrCP_i$ at location j	$x_{ij} \in \{0, 1\}$
The number of TrCPs candidates	N
The set of admissible TrCP positions	$S \subseteq E$
Thresholds limiting the number of TrCPs	$n_1^*, n_2^* \in \mathbb{N} \cup \{+\infty\}$
The number of TrCP at a given location	$n_1^* \in \mathbb{N} \cup \{+\infty\}$

Table 3
Notations used for modeling the optimization problem of RCPs.

Variable	Notation
Deployment cost to build RCP_u at location v	$b_{u,v} > 0$
Decision variable to open or not the RCP_u at location v	$y_{u,v} \in \{0, 1\}$
The number of RCPs candidates	P
The set of admissible RCPs positions	$Q \subseteq E$
Thresholds limiting the number of RCPs	$n_3^*, n_4^* \in \mathbb{N} \cup \{+\infty\}$
The number of RCP at a given location	$n_3^* \in \mathbb{N} \cup \{+\infty\}$
The number of registered accidents from u to v	$a_{u,v} \in \mathbb{N}$

6. Formulation of the optimization problem and design goal

6.1. Multi-objectives derivation

In the context of the deployment of control points through inter-urban roadway network in developing countries and for a good follow-up of activities through this one, our goal is to find better deployment of relay and treatment control points. These deployments should minimize the number of control points to be deployed in order to ensure maximum coverage, connectivity of the inter-urban roadway network in term of communication and consider also the regions in this network which have a high traffic densities. On the other hand, our problem consists in placing a set of control points along the road of a given region, maximizing the network capabilities and minimizing the deployment costs. The others priorities in this deployment case are to consider the RCP positions which have most of accident around.

In this deployment formulation, there are several types of control points and depending on the area where they needs to be installed. It would be normal that the prices be different. Indeed, the supposed differences between the control points of the same resides on their basic characteristics. For instance, depending on the coverage radius, sectoral and omnidirectional aspect, the infrastructure that makes up one point the price will not be the same. The resolution of these problems of deployment of treatment control points and relay control point must be defined according to the defined objectives. Indeed, we are confronted to a multi-objective problem whose results of the first problem (the TrCPs solution's) allow us to define the inputs parameters for resolution of second problem (RCPs).

6.2. TrCPs modeling

The optimization work here is based on the choice of junctions to consider for the deployment of a TrCP. We thus consider F_1 given Eq. 2 as the objective function which represents the cost of deployment of TrCPS. This function is associated to another objective function Z_1 modeled in Eq. 3, which allows us to maximize the coverage of the inter-urban roadway network. In fact, Z_1 guarantees that whatever position is chosen, all vehicles passing through the road network will be visible and registered by at least one TrCP.

$$F_1 = \sum_{i \in N} \sum_{j \in S} c_{ij} \times x_{ij} \quad (2)$$

$$Z_1 = \sum_{i \in N} \sum_{j \in S} \sum_{\substack{k,l \in E \\ k,l \neq i}} m_{kj} \times m_{jl} \times x_{ij} \quad (3)$$

where m_{ij} is a boolean variable which is equal to 1 if there is an edge starting from i to j and 0 otherwise.

The associated constraints C_1 and C_2 are given in Eq. 4 and Eq. 5.

$$C_1 : \sum_{i \in N} x_{ij} \leq n_1^*, \forall j \in S \subseteq E \quad (4)$$

$$C_2 : \sum_{i \in N} \sum_{j \in S} x_{ij} \leq n_2^* \quad (5)$$

where, $x_{ij} \in \{0, 1\}, \forall i \in N, \forall j \in S \subseteq E$.

Therefore, we define it as a multiobjective optimization problem in Eq. (6).

$$\begin{cases} \text{Minimize } F_1 \\ \text{Maximize } Z_1 \\ \text{subject to} \\ C_1 \text{ and } C_2 \end{cases} \quad (6)$$

6.3. RCPs modeling

RCPs are deployed such a way that the deployment costs are minimized and the priority is given to areas where the number of accidents is high. In this case, we also associate a satisfaction constraint to prioritize RCPs that have a high number of accidents in a given region or a given section. The objective function F_2 for the deployment of RCPs is formulated by the model given in Eq. (7). Moreover, the objective Z_2 given in Eq. (8) allows us to prioritize the RCPs around which the most accidents occur in a given section while the objective Z_3 given in Eq. (9) guarantees that whatever position is chosen, all vehicles passing through the road network will be visible and registered by at least one RCP.

$$F_2 = \sum_{u \in P} \sum_{v \in Q} b_{u,v} \times y_{u,v} \quad (7)$$

$$Z_2 = \sum_{u \in P} \sum_{v \in Q} \sum_{k,l \in E} m_{k,v} \times m_{v,l} \times a_{u,v} \times y_{u,v} \quad (8)$$

$$Z_3 = \sum_{u \in P} \sum_{v \in Q} \sum_{k,l \in S} \bar{m}_{k,v} \times \bar{m}_{v,l} \times y_{u,v} \quad (9)$$

where:

- $m_{u,v}$ is a boolean variable which is equal to 1 if there is an edge starting from u to v and 0 otherwise;
- $\bar{m}_{ij}, i, j = \{k, l, v\}$ is a boolean variable which is equal to 1 if there is a way starting from i to j and 0 otherwise;
- $a_{u,v}$ denotes the number of accidents registered on an existing edge starting from u to v (it can be generalized to a function of the number of accidents);

The associated constraints C_3, C_4 and C_5 are given in Eqs. (10)–(12). The constraint C_3 requires at least one RCP between two TrCPS.

$$C_3 : \sum_{u \in P} \sum_{v \in Q} \bar{m}_{k,v} \bar{m}_{v,l} y_{u,v} \geq \min \left\{ 1, \sum_{u \in P} x_{u,k} \sum_{u \in P} x_{u,l} \sum_{v \in Q} \bar{m}_{k,v} \bar{m}_{v,l} \right\}, \forall k, l \in S \quad (10)$$

$$C_4 : \sum_{u \in P} y_{u,v} \leq n_3^*, \quad \forall v \in Q \quad (11)$$

$$C_5 : \sum_{u \in P} \sum_{v \in Q} y_{u,v} \leq n_4^*, \quad \forall y_{u,v} \in \{0, 1\}, \quad \forall u \in P, \quad \forall v \in Q \quad (12)$$

Hence, we formulate this problem in Eq. (13)

$$\begin{cases} \text{Minimize } F_2 \\ \text{Maximize } Z_2 \text{ and } Z_3 \\ \text{subject to} \\ C_3, C_4 \text{ and } C_5 \end{cases} \quad (13)$$

Beyond the constraints that are presented in the previous section, the problem of the deployment of infrastructures through a network is an NP-hard problem. For instance, Gilbert and Malewicz demonstrate that the deployment problem is an NP-hard problem (Gilbert and Malewicz, 2004). In its sensors deployment optimization work, Njoya et al. (2016) as well as Ari et al. (2016) and Hamidouche et al. (2019) already showed that the deployment of wireless sensors while taking into account the target and their vicinities is also NP-hard. Therefore, like Road Side Units, the deployment of control in an inter-urban roadway network in developing countries is also an NP-hard problem (Arora et al., 1995). Multi-objectives optimization problems formulated in Eqs(6) and (refeq11)–(13) are known to be linear programming

problems, which are known in the literature as NP-hard. Therefore, solving this problem of setting up a road transport network can be achieved either through exact algorithms or meta-heuristics (Eksioglu et al., 2009; Toro et al., 2016).

6.4. Design goal and scheme

As we showed in the previous section, the problem of determining the number of TrCPs and RCPs in order to minimize expenses can be formulated as a multi-objective optimization problem. Among the number of methods for multi-objective evaluations, we chose the NSGA-II. The Pareto front associated with each of these methods will allow us to ensure a good orientation for the users. Fig. 6 illustrates the adopted approach to propose a set of non-dominated solutions for the deployment of TrCPs in our context.

Indeed, the use of a solution based on the notion of Pareto dominance converges the population towards effective solutions. It offers significant help in decision making and does not allow to choose one alternative over another. To solve the formulated optimization problems, we use the NSGA-II depicted in the following six steps.

1. *Encoding.* We perform a binary encoding where each individual has a size of $M \times N$ (see Fig. 7). N represents the number of possible positions of TrCPs (respectively RCPs) and M represents the number of types of TrCPs (respectively RCPs).
2. *Selection.* We adopt the *Roulette Wheel Selection*.
3. *Crossover.* We use *N point Crossover*. In this case, $N = 2$.
4. *Mutation:* Gaussian Mutation.
5. *Population's Size:* 100.
6. *Number of iteration:* 100.

7. Performance evaluation

To evaluate the multi-objective formulation of the deployment of control points (TrCPs and RCPs), we defined three scenarios according to the number of eligible positions. The experiments have been conducted with Matlab simulator in three scenarios including five, ten and fifteen eligible positions. The number of positions has been limited given to the realities encountered in

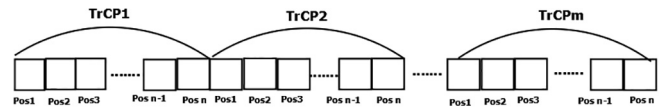


Fig. 7. Encoding of TrCPs and RCPs.

the context of developing countries. For example, in Cameroon, the Yaounde-Douala road, which is the main road of the country and the most monitored one, has no more than ten radars. These radars are deployed by the *gendarmerie* to ensure the floating car data. In each scenario, we work on three types of control points depending on the characteristics and performances.

- The matrix of cost $isc = random([1575], NbrTypCapt, Nbrpos)$.
- The matrix of adjacency has been set for each scenario.
- The matrix of accidenta $= random([025], Nbrpos, Nbrpos)$ with modifications like $a_{i,j} = a_{j,i}$.
- $NbrTypCapt$ is the number of types of control points and $Nbrpos$ represents the number of eligible control points for a given scenario.

The obtained curves visible in Figs. 8–10 represent the Pareto front of deployments of TrCPs for defined scenarios. On the x -

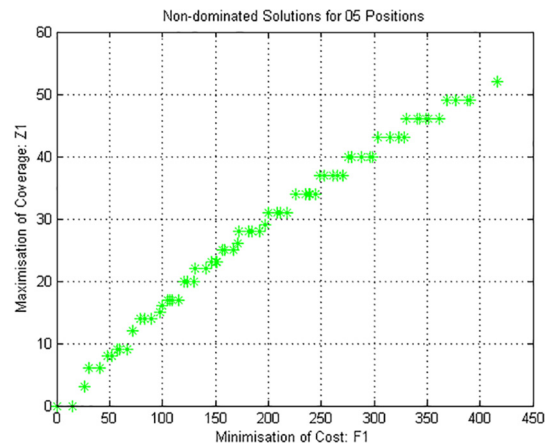


Fig. 8. Pareto Front of TrCP with 5 admissible positions.

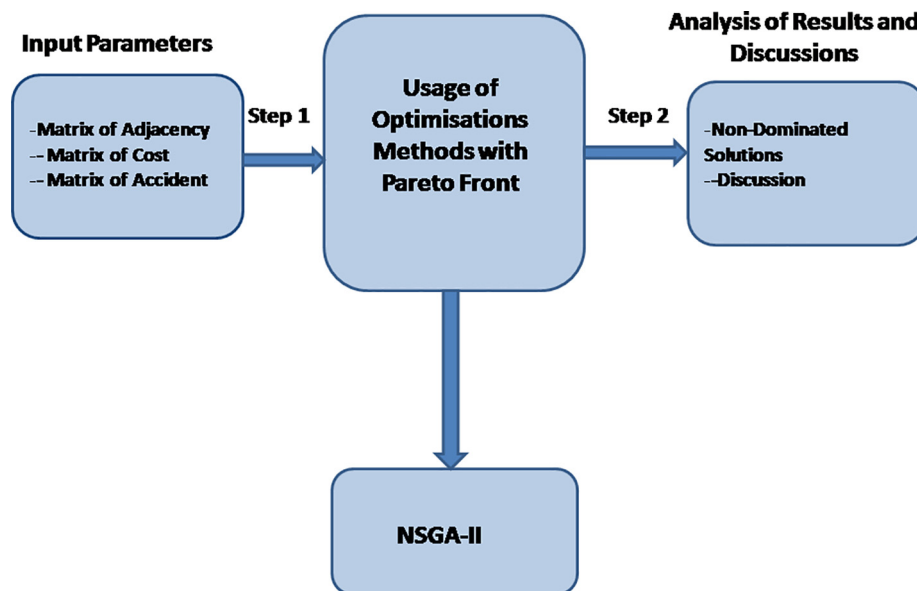


Fig. 6. Our Proposal Design.

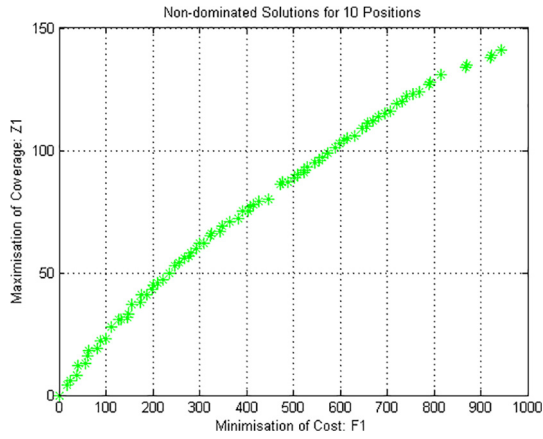


Fig. 9. Pareto Front of TrCP with 10 admissible positions.

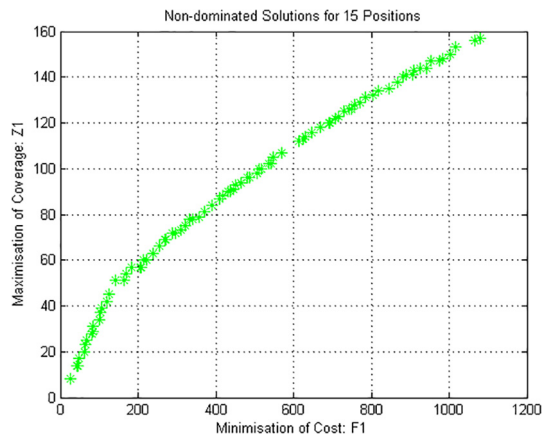


Fig. 10. Pareto Front with 15 admissible positions.

axis, we represent the costs of facilities and on the y-axis we come out of coverage. Non-dominated solutions that are closer to the x-axis give more coverage to the cost of installation. However, solutions that are closer to the y-axis favor the installation cost compared to the coverage.

As it can be observed in Figs. 11–13 for the Pareto front of the RCPs deployments in each defined scenarios. Here, we have three objectives functions. Decisions taken about the non-dominated solutions are taken according to the axis.

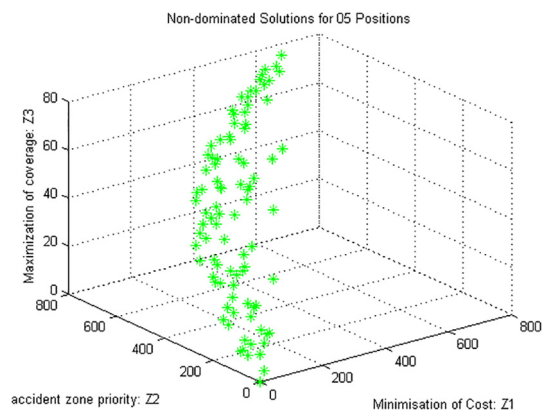


Fig. 11. Pareto Front of RCP with 5 admissible positions.

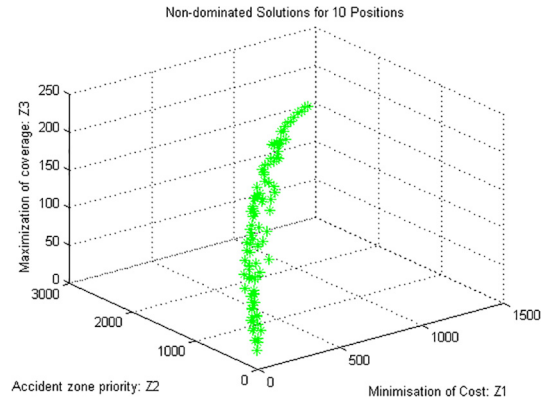


Fig. 12. Pareto Front with 10 admissible positions.

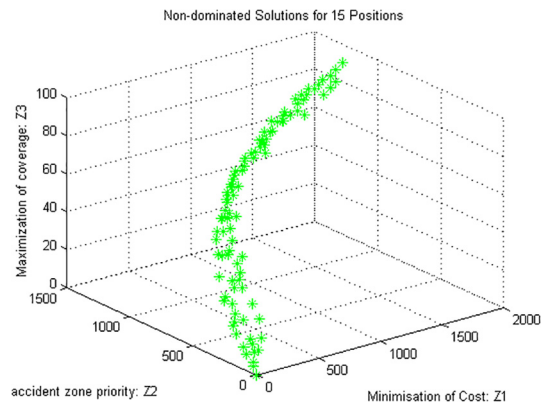


Fig. 13. Pareto Front of RCP with 15 admissible positions.

- *Coverage and accidents*: the solutions closest to the z-axis favor coverage, but solutions that are close to the y-axis favor areas with a high number of accidents
- *Coverage and costs of installations*: the solutions closest to the x-axis favor coverage, but solutions that are close to the y-axis favor the minimization of cost of installation.
- *Accidents and costs of installations*: the solutions closest to the x-axis favor areas with a high number of accidents. However, solutions that are close to the z-axis favor the minimization of the cost of installation.

8. Conclusion and future works

At the end of this work, it appears that the developing countries are facing difficulties that prevent them from setting up intelligent transport systems as in the developed countries. We offer treatment control points (TrCP) and relay (RCP). This aims to collect and process information related to activities in inter-urban road networks. We then propose an inter-urban road network surveillance communication architecture based on these control points. We define a deployment in order to minimize the cost of installation, maximize coverage and focus on areas with high accident rates. We then make a multi-objective formulation of this deployment. The NSGA-II method allows us to define the front of Pareto for three deployment scenarios which presents for the two types of control points, the non-dominated solutions. It offers the opportunity to decision-makers to consider solutions according to your priorities. In our future works, we plan to study the detection and diffusion of disturbances in our context and also perform a comparison between the NSGA-II method and other optimization methods by associating some performance indicators.

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