Developing a System for Sectorization: An Overview

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Abstract. Sectorization is the partition of a set or region into smaller parts, taking into account certain objectives. Sectorization problems appear in real-life situations, such as school or health districting, logistic planning, maintenance operations or transportation. The diversity of applications, the complexity of the problems and the difficulty in finding good solutions warrant sectorization as a relevant research area. Decision Support Systems (DSS) are computerised information systems that may provide quick solutions to decision-makers and researchers and allow for observing differences between various scenarios. The paper is an overview of the development of a DSS for Sectorization, its extent, architecture, implementation steps and benefits. It constitutes a quite general system, for it handles various types of problems, which the authors grouped as (i) basic sectorization problems; (ii) sectorization problems with service centres; (iii) re-sectorization problems; and (iv) dynamic sectorization problems. The new DSS is expected to facilitate the resolution of various practitioners' problems and support researchers, academics and students in sectorization.

Keywords: Decision Support Systems, Sectorization, Evolutionary Algorithms

1 Introduction

Sectorization is a division of a large area, territory or network into smaller parts considering one or more objectives. Sectorization problems are diverse given the vast fields of application. Different applications arise due to the need for several real-life dilemmas. Examples include designing political districts, sales territories, schools, health and policing zones, forest planning, municipal waste collection or street cleaning zones and maintenance operations. Solution procedures are challenging given the wide range of applications and problem complexities.

A good sectorization creates economic, social, and financial benefits. However, the definition of a good sectorization can be very subjective and can change from one Decision Maker (DM) to another depending on different 'what if' scenarios (i.e. restrictions and objectives). A Decision Support System (DSS) designed for Sectorization can support analysing and resolving different problems under diverse conditions.

In general terms, DSS refers to an information system that provides computer help to DMs or its users to solve their specific problems. DSS are strong tools since they allow multiple users, supply data and provide analytics. Moreover, DSS are useful for policy-making. DSS users can easily prove their 'what if' scenarios using these tools to observe the differences in the solutions, compare, and decide. Thus, DSS play a vital role in increasing time and cost efficiency, providing better performance management, and empowering users' decisions even if the problem is not well-defined or immature [26].

The paper's main contribution is the brief description of a new DSS dedicated to Sectorization (D3S) problems. D3S deals with different multiple criteria problems grouped as (i) basic sectorization problems; (ii) sectorization problems with service centres; (iii) re-sectorization problems; and (iv) dynamic sectorization problems. This platform is designed in the format of a website with a user-friendly outline. The authors are not aware of any DSS for sectorization, which is so comprehensive. Thus, it is expected that the new D3S will help researchers in the sectorization field and contribute to dealing with real cases involving different criteria and scenarios.

The remainder of the paper is structured as follows. Section 2 provides a literature review on application fields of sectorization problems and DSS that aim to assist the solution procedure of these problems. Section 3 includes detailed information about D3S and the four steps that the user should follow to use the system. Solution methods used in D3S to solve sectorization problems are briefly presented in Section 4. Finally, Section 5 concludes with a discussion on future work.

2 Literature Review

The current section is a short review of the literature concerning Sectorization and DSS.

As mentioned, Sectorization problems appear in various real-world settings under different configurations. For instance, political districting is one of the oldest application fields. Political districting problems aim to divide the territory neutrally and avoid gerrymandering. It is possible to see several applications of political districting considering various criteria such as equilibrium, compactness, contiguity, or community interest in the literature [3,18]. Most of the time, political districting is subject to resectorization problems to adapt the current solution regarding the updates in the territory. Bozkaya et al. [4] built a spatial DSS as a built-in within ArcGIS called "DistrictBuilder". They used a tabu search algorithm and designed the system properly for several objectives. The authors tested their DSS to resectorize the political districts of Edmonton City in Canada.

Moreover, the design of sales and service territories is another field of sectorization. These problems include strategic logistic planning such as determining the locations of factory depots, distribution centres or sale facilities and designing service territories in terms of customer and/or technical facilities and maintenance operations [16,17,20]. Routing is usually a critical stage when the sectorization process is completed. Designing compact sectors for the salespersons or customer service workers to travel between clients most efficiently requires good sectorization first. Thus, most of the time, the solutions should guarantee aspects like connectivity within the sectors, balance in work hours, travel time or distance. It is common to consider predefined service centres or plan to determine some during the solution procedure in these problems. Moynihan et al. [22] developed a micro-computer based DSS for logistic/distribution network planning. They provided test alternatives for the DMs to observe the possible solutions under different scenarios and objectives. The solution methods implemented in the system are based on simulation and heuristics. Another effort was taken place by Noorian and Murphy [24] on territory design problems. The authors aimed to create optimally balanced sectors by simultaneously respecting region restrictions and multiple objectives. The solution method implemented was a Genetic Algorithm (GA) based on graph theory. This web-based DSS was shared with the user through the intermediate platform SaaS.

Furthermore, the distribution of energy and microcells are also relevant fields of sectorization. It is important to distribute the mobile network, internet and electricity in the most similar and fast way since they are limited and essential resources for human life [27,5,7]. In the solution procedure of these problems, microcell and energy towers can be viewed as service centres/facilities. Bergey et al. [1] built a DSS to support electric power districting (EPD). They create an EPD problem solver as a Microsoft Excel built-in. They implemented GA with a configuration that automatically guarantees the contiguity in the distribution network. This system allowed the DMs to visualise the frontier solutions and pick the most convenient one.

Other common fields to be studied are related to the problems of waste collection and water distribution. These applications play a fundamental role in improving cities' infrastructure and increasing living standards [21,28]. Pan et al. [25] developed a DSS to operate Milan, Italy's daily and long-term water distribution network. The authors aim to use this DSS for both pump scheduling and the sectorization of the system to make benefits in the daily and eventually long term operations in Milan city. They developed a web-based DSS with two metaheuristic methods as a solver, namely, the Non-dominated Sorting Genetic Algorithm (NSGA-II) and Archive-based Micro Genetic Algorithm (AMGA2).

Additionally, sectorization applications on forest planning aim to improve the ecological (by protecting the wildlife), economic (by reinforcing sustainability) and social (by promoting leisure and tourism) aspects of forest management [23,36,27]. Wilksröm et al. [11] built a DSS on forest planning. The system supported the stand, forest and regional analysis and planning. The platform was built in the format of a desktop app. They followed Analytical Hierarchy Process (AHP) to scale multiple criteria when it is the case.

A narrower field of sectorization necessary during winter in many cities is snow removal or disposal. Heavy snow shall negatively affect living standards by blocking traffic and diminishing mobility from one place to another. This situation may have social and economic consequences [19]. Thus, designing the cities and leading the municipal service to the necessary points in the most balanced and fastest way are the goals of this type of problem. Depending on the weather conditions or the countries' infrastructure, these problems may be considered dynamic or subject to resectorization. Labelle et al. [19] developed a DSS to sectorize the cities for snow removal quickly and efficiently. They used MapInfo GIS software to build their DSS, which was beneficial due to the possibility of instant interaction of the DM with the provided solution. This way, they aimed to give the most convenient solution to the DMs. They implemented the DSS in Montreal to observe the performance of their system.

Additionally, problems on schooling, police, health districting and transportation are common problems beneath sectorization [6,2,12,38]. School districting carries dynamic attributes. It is important to assign the same pupil to the same school from one year to another while distributing the new pupils to the most convenient schools by considering the transportation costs and the institution capacity [2]. Health districting mostly provides caregiving services to the patients in a most balanced way. These problems can be considered dynamic since the potential changes in the unmet health needs of the patients.

Given the need to update school districting every year, it is possible to observe various efforts to build DSS on this specific sectorization field to make the decisions as quickly as possible. For instance, Ferland and Guenette [14] designed a microcomputer-based DSS. They used heuristic methods and offered solutions regarding contiguity while considering school capacity, population and number of students in different schools. The platform allowed modification of the solution if needed, besides the user integration.

Camacho-Collados and Liberatore [6] built a DSS, called Predictive Police Patrolling DSS (P^3-DSS) to construct powerful and balanced police patrolling sectorization to distribute police officers efficiently and decrease the criminal actions.

Moreover, air-traffic services can be efficiently designed using sectorization methods. Essentially, airspace sectorization is one of the major application fields given its international and intranational importance in the line of transportation [9,34]. Weigang et al. [37] built a distributed DSS for air traffic flow management. The meta-level control approach and reinforcement-learning algorithms aim to decrease the possible risks in air traffic flow to the minimum. Stamatopoulos et al. [33] developed a DSS for strategic airport planning. They distinguished the drivers of the airport as dynamic and stochastic. This way, they created a structural model which could interact with the different areas of the airfield by considering the specific need of that area.

Finally, we refer to two classical books, which can still contribute to developing model-driven DSS, especially if supplemented with new computerised and communication means [35,32].

As is seen, there are various efforts to build DSS to solve different sectorization problems. Most DSS use Evolutionary Algorithms as solution methods. It is possible to use some of these systems for problems not intended for. However, the authors are unaware of any DSS dedicated to dealing with diversified sectorization problems. D3S was genuinely designed to represent such a generic system for sectorization practice and field literature.

3 System Design

As mentioned, the Decision System, which will be called D3S, is designed as a web-based DSS using Python base Web-framework Django since any device with a web browser can access it. It is a straightforward and user-friendly platform. Figure 1 shows the system architecture. The interaction with the system starts with the User Interface, through which the user's problems are proposed.

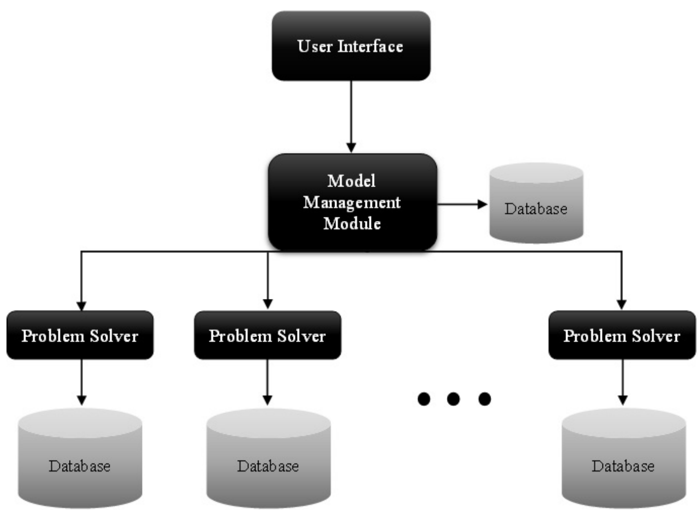

Fig. 1. System Architecture

The model management module keeps the inputs, namely, user preferences, problem information, problem instance (i.e. data) in the database. It then processes this information and sends it to the adequate problem solver. The model management module includes several problem-solvers for different scenarios. The final solutions obtained are stored in the database and can be accessed again through the user interface. This process can be seen in the flow diagram in Figure 2.

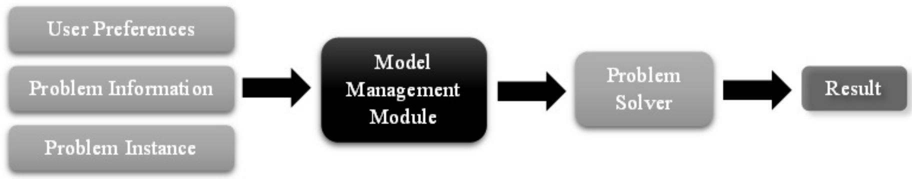

Fig. 2. Input-Output Diagram

The remainder of this section provides detailed information about the four steps a user should follow to benefit from D3S.

Step 1: Select the Service

D3S has been developed to deal with sectorization. Figure 3 shows the services that D3S provides within four groups, introduced by the authors when considering the general attributes of different sectorization problems, as articulated in Section 2. These groups are: (i) basic sectorization problems that do not consider any predetermined service centres nor plan to determine service centres; (ii) sectorization problems with service centres that consider predetermined or fixed service centres or plans to determine one; (iii) redistricting problems for redesigning a solution that is already valid; (iv) dynamic sectorization problems that represent more than one point in time and allow changes on the instances over time.

As the initial step of D3S, the users are expected to select one of these services proper for their problem.

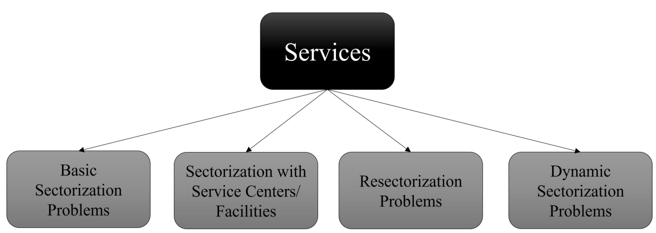

Fig. 3. Services Provided by D3S

Step 2: Fill in the Survey

After users select the related service, they are required to respond to a more detailed survey to input the specific attributes of the problem. This survey is structured to understand the nature of the problem, the basic characterisation of the problem, the type of solution wanted, and the criteria and objectives considered. Through the questions in these categories, D3S identifies the problem in specific.

For instance, the nature of the problem includes questions regarding the distance considered and the characterisation of the basic units. More precisely, users may prefer different distance types between the basic units, such as Euclidean or other. *Basic Units* can be defined as points or geographic areas. Furthermore, whether the basic units are subject to a weighting scheme (e.g. valorisation, demand, or the number of customers) is also beneath the nature of the problem.

Moreover, the basic characterisation of the problem includes questions that aim to understand the features in more detail. This category contains questions regarding the number of sectors and their capacity or whether the user wants to receive routing within each sector. When the problem consists of service centres/facilities, the questions aim to understand whether there are predefined service centres or whether the users plan to define them. If there are predefined service centres, whether all will be used or whether a service centre will serve only one sector or more. Furthermore, when resectorization is in question, whether the user looks for a completely new solution or asks for a solution similar to the one that already exists. At last, in the case of dynamic problems, the questionnaire also collects information regarding how many time horizons the user considers and the percentage changes in the instances that could occur from one moment to another.

The solution type aims to understand whether the user expects to obtain a single or multiple solutions. The answer to this question directly affects the solution method that D3S uses.

Finally, the category called criteria and objectives collects the information regarding the user's objectives, such as balance, connectivity, density, and time distance minimisation. Moreover, users can give information about if there are natural boundaries to be respected or, on the contrary, if some basic units need to be in the same sector.

As is seen, only the category regarding the basic characterisation of the problem changes from service to service. The rest of the questionnaire remains the same.

These surveys are essential since the answers of the users have a direct effect on the optimisation process. Every service has its specific query set for problem identification.

Step 3: Upload Data

The data uploading phase starts following the survey submission. The users are expected to present their instances according to a given structure of the system. The data expected by the system require some specific information to execute the optimisation. The required information shows some diversity from one service to another given the different nature of the services.

The information, which constitutes latitude, longitude, weights (i.e. quantity or demand), links, boundaries, and neighbours, is fixed in the data for all services. Besides, service centres and their capacities are also necessary when sectorization with service centres are considered. Furthermore, information regarding the old solution is expected in resectorization problems.

To avoid complications in this phase, given the distinctions in the expected data structures, the system first provides a downloadable template with detailed explanations about the data structure. The template can be downloaded and filled with the instances in the proper format.

Moreover, the system provides instances to test the D3S for valued objectives if the users do not have data. These instances can be found through the following link: https://drive.inesctec.pt/s/NS47qnZEmYPwEQP.

Submission of the data activates the model management module. The optimisation is executed according to the answers to the survey using the uploaded data.

Step 4: Get the Results and Visualise

After data submission, D3S takes the users to a 'Results' page to see all their submissions. Each submission is a link to a page that contains a detailed summary of that specific submission. In these summaries, users can observe the type of service they benefited from, their answers to each survey question, their data, computation time, and the result(s) provided by the D3S.

The users can observe the fitness scores of each solution before selecting. This score is a single value containing the overall performance (case of single solution) or multiple values that show the solution's fitness for different objectives separately (case of multiple solutions). Besides that, it is also possible to visualise the solution(s), which will facilitate any final user decision phase. Figure 4 shows a small print screen from D3S that represents the process explained in this section.

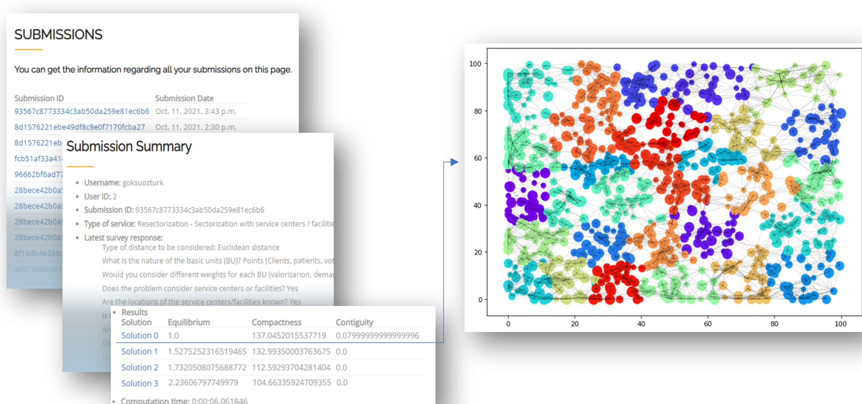

Fig. 4. Results provided by D3S

The user can see all the submissions with the dates. Each submission links and leads the user to the submission summary page with detailed information and the results provided. In the example presented in Figure 4, we observe multiple solutions with three objectives: equilibrium, compactness, and contiguity. By clicking on the "Solution N", one can visualise a map of the results provided by D3S.

4 Solution Methods

D3S is a platform that provides solutions according to different preferences. The solution methods that the D3S uses are based on Evolutionary Algorithms. As mentioned in Section 3, choosing the preferred solution method (i.e. single or multiple) is possible.

D3S follows a GA when the user asks for a single solution. GA, a well-known algorithm proposed by Goldberg and Holland [15], evaluates the solutions according to their performance on the fitness function through generations. The fitness of a solution represents the adequacy of a solution to the problem. It is also a commonly used and powerful algorithm to solve sectorization problems [5,10,24].

If more than one objective is in question, the fitness function must be built as a weighted composite single objective function in GA. Establishing this composite equation requires normalisation of the objectives with different measurement units and weighing processes. In D3S, AHP, presented by Saaty [29,30,31], is followed to build the weighting scheme based on the preferences of the DMs among the objectives. These preferences are detected by ordering them within the pairwise comparison scale, which contains elements from 1 to 9, and higher values show stronger importance of one objective over another. The DMs are expected to compare each objective unilaterally with any other.

On the other hand, the NSGA-II is used to solve the optimisation problem when the user demands multiple solutions. In that case, D3S provides Pareto frontier solutions to the user's decision.

NSGA-II is one of the most used multi-objective optimisation methods presented by Deb et al. [8]. In this method, Pareto frontier solutions are selected according to their performance in the solution space. A solution is superior if and only if that solution is better than the other solution in at least one objective while not being worse in the other objectives. Moreover, NSGA-II is selected to be implemented in the D3S as an adequate approach since several authors use it in sectorization and similar problems [13,39,40]. Furthermore, Pan et al. [25] applied NSGA-II as one of the solution methods in their web-based DSS on the water distribution network of Milan.

The necessary steps to complete a generation (i.e. iteration) are similar in GA and NSGA-II. This situation is visible in Figure 5. As is seen, the main difference between these methods is the evaluation process of the solutions. Thus, besides the selected solution type, objectives and user preferences are vital inputs for the solution methods used in D3S.

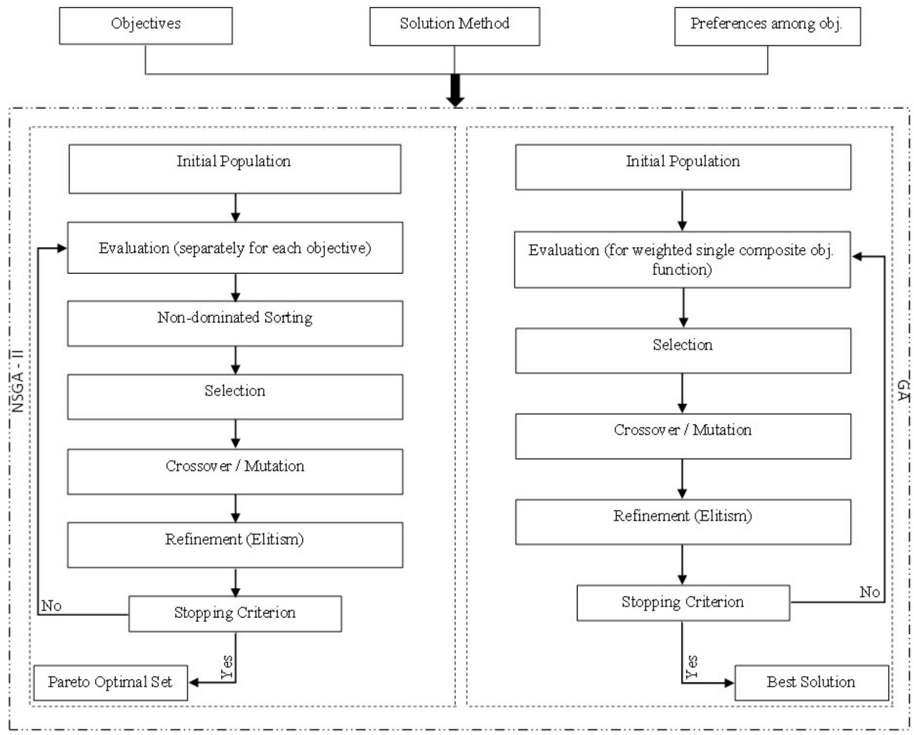

Fig. 5. Schematic of the Solution Procedures

Finally, the D3S platform uses a Greedy Algorithm for routing if the user asks for it. The routing moves to the closest basic unit in this algorithm. The Euclidean distances are considered unless the user presents data regarding the type of distances that s/he would like to take into account.

5 Conclusion and Future Work

Sectorization refers to dissolving a whole into subsets by respecting some objectives. Diversity in the application areas in real-life problems makes sectorization a very relevant field of study. For instance, design of sales or service territories, maintenance operations, health and school districting, police patrolling or transportation are some of the applications that may directly affect countries, economies, or human life itself.

Sectorization solution procedures can be difficult due to uncertainties in their characterisation, objectives' choice, and the frequent combinatorial nature of the associated problems. DSS are computer-based information systems that can provide solutions rapidly to test, adjust, and decide.

The current work presented D3S, a new web-based DSS designed to solve various sectorization problems, organised in the four revealed groups. D3S was developed to solve sectorization problems arranged within four main groups: basic sectorization, sectorization with service centres, resectorization and dynamic sectorization. Solution methods integrated into the system are NSGA-II or GA with AHP to build fitness functions. They will be used depending on the type of solution desired by users. One of the D3S advantages is its flexibility in terms of objectives and restrictions and the applicability to various sectorization problems.

D3S will evolve by improving existing algorithms, integrating new optimisation algorithms and dealing with more objectives. The system will soon be publicly available at www.sectorization.pt. We hope that the D3S will contribute to the resolution of various practitioners' sectorization problems and assist researchers, academics and students.

A short video of D3S can be found at https://www.researchgate.net/project/StoSS-Sectorization-to-Simplify-and-Solve/update/61c375edf5675b211b18c582.

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