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Modeling Methodologies for Optimization and Decision Support on Coastal Transport Information System (Co.Tr.I.S.)

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***Abstract*—**The aim of this paper is to present the optimization methodology developed in the frame of a Coastal Transport Information System. The system will be used for the effective design of coastal transportation lines and incorporates subsystems that implement models, tools and techniques that may support the design of improved networks. The role of the optimization and decision subsystem is to provide the user with better and optimal scenarios that will best fulfill any constrains, goals or requirements posed. The complexity of the problem and the large number of parameters and objectives involved led to the adoption of an evolutionary method (Genetic Algorithms). The problem model and the subsystem structure are presented in detail, and, its support for simulation is also discussed.

***Keywords*—**Coastal transport, modeling, optimization.

I. Introduction

CO.TR.I.S. is developed in the frame of a research project co-funded by the European Union and the Greek Government. This system will be tested in Aegean Sea, Greece, for the effective design of coastal transportation lines but it could be used in any island environment taking into account topics like geography, fleet composition, volume of traffic, network design, port infrastructure, and other system parameters [1], [2]. Co.Tr.I.S. includes six subsystems (see Fig. 1).

This paper focuses on S5 and S6 Co.Tr.I.S. subsystems. The next section presents the Optimization module, the third section refers to the optimization tools and the last section presents some concluding remarks.

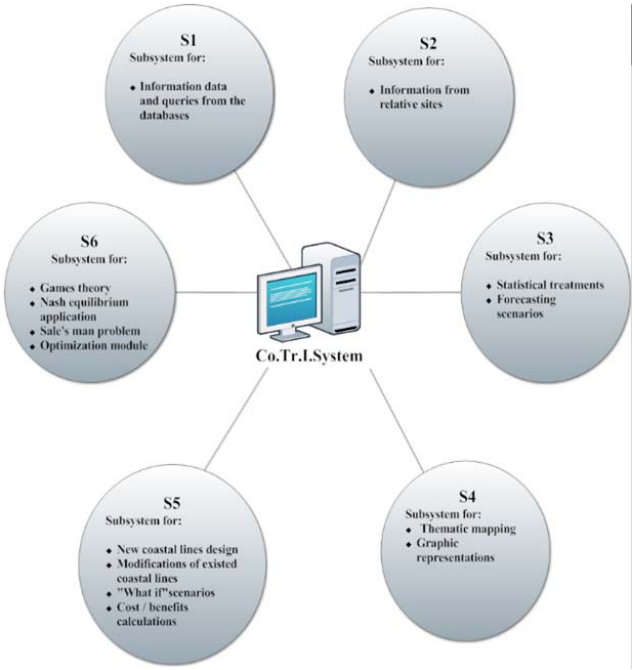


Fig. 1 Co.Tr.I.S. subsystems

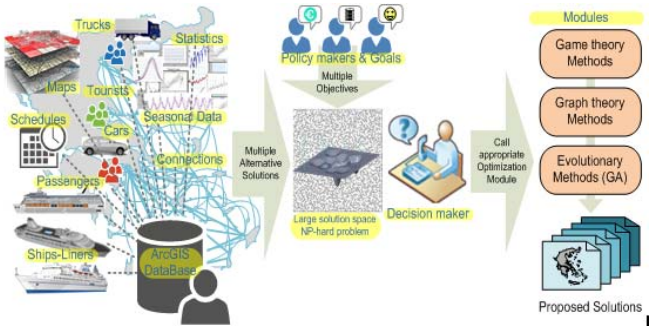


Fig. 2 The Role of Optimization in Co.Tr.I.S.

II. Optimization Module of CO.TR.I.S. Subsystems S5 and S6

One of the main aim of Co.Tr.I.S is to support the decision making process of the policy makers and the involved players (Ministry, Maritime companies, Local Authorities), towards an improved Coastal Transport System in the area. The size and complexity of the entire Aegean costal transport system prohibit any manual or interactive search for better or optimal solutions to support functionality of Co.Tr.I.S will use

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specialized modules for network generation, scenario validation, solution optimization and decision support. All these modules will have access to the vast amount of data classified and modeled by Co.Tr.I.S and, therefore, will offer globally improved solution proposals.

The overall Coastal Transport System complexity increases exponentially with the number of lines, destinations and realistic parameters included, and any typical enumeration or Branch and Bound method would require an unacceptable long time to reach an optimal solution. As a result, a tool using evolutionary methods was needed to provide optimization support on user demand and provide a ranked list according to the user's requirements and priorities of the best alternative scenarios.

Several methods for coastal transport optimization [3], [4] and simulation [5] have been proposed in the literature, but they usually tackle only a small part or a reduced version of the complex problem of the Aegean Sea coastal transport system. Many works on coastal network optimization can also be found in the literature, where, the use of evolutionary/heuristic techniques was successful. Most of them try to solve the container ship fleet problems by optimizing cost, consumption, distance travelled and/or delivery deadlines [6], [7] and a few also investigate the hub positioning problem or consider environmental issues [8], [9]. Evolutionary techniques were found especially capable to liner shipping problems [10], [11]. Other works combine them with methods from Graph theory or Game theory especially in a search of equilibrium during network design with competing goals [12], [13].

In Co.Tr.I.S. the optimization module is designed to solve the complete, complex and multi-objective problem where the user wants **to** optimize the full scenario and has several goals such as: minimize cost, minimize travel time, maximize ship utilization, maximize demand coverage, maximize passenger satisfaction, minimize fares, minimize effect of weather conditions, maximize schedule accuracy, minimize delays, increase reliability, and their combinations. Co.Tr.I.S. interface and the optimization modules aim to help potential users (such as the Ministry, the Maritime companies or the Local Authorities), to select the appropriate system parameters, examine/compare several alternative solutions and finally reach a globally optimal one, based on specific information at hand, and, the restrictions and goals they wish to satisfy.

III. Modeling for the Co.Tr.I.S. Optimization Tools

The role of the optimization tools in Co.Tr.I.S. and the overall work flow is depicted in Fig. 2. Co.Tr.I.S. database is hosted by ArcGIS and offers all kinds of current and past information about the Aegean Sea transport system, i.e.: connection lines, company fleets, time schedules, geographical and thematic maps, passenger and vehicle demand, statistical, seasonal, weather and price data, etc. These multifold and detailed data and their numerous alternative values create a huge solution space that contains the potential coastal transport scenarios.

The decision maker must find the best solution that satisfies specific goals such as cost, consumption, user satisfaction, etc. Depending on each specific request the decision maker uses one or more of the decision/optimization modules offered by Co.Tr.I.S comes up with a proposal containing a ranked set of complete solutions using Co.Tr.I.S framework for the entire procedure will conclude in a fraction of the time usually required.

The high information volume and detail offered by Co.Tr.I.S., the large number of realistic parameters, their complex relationships and the different goals and restrictions posed by all actors involved, create a Non-deterministic Polynomial (NP-hard) optimization problem that cannot always be solved within acceptable computer time by exact algorithms. Therefore, the main Optimization Module will be based on heuristics/evolutionary techniques in order to search only a part of the vast solution space and converge much faster near the optimal solution. The evolutionary technique selected is based on the Genetic Algorithms (GA) method and its extensions.

A. Optimization Methodology

The problem of Coastal Transport System can be seen as a multi-level or multi-stage problem consisting of several interconnected stages such as: 1) The Geometry of the network with all the nodes (ports) and their connections, 2) The Routes serviced. The routes and trips as well as the sequence of ports per trip are defined here, 3) The Schedule and Frequency of Service. The frequency of service is defined by the Routes and their corresponding demand, 4) The Ship Allocation. For each route/schedule defined in 2 and 3 the company must assign a ship with the appropriate characteristics, 5) Operational issues. This stage is based on the results of 3 and 4. By taking in to account all possible variations in each of the five stages, the resulting alternative scenario combinations create a huge solution space that can be efficiently searched only by an evolutionary technique.

The optimization tool employed is based on the Genetic Algorithm method and the implemented structure is shown in Fig. 3. An Input processing module validates all user inputs and collects any required information from the database, a scenario generation module creates valid scenario solutions, a scenario evaluation module evaluates the scenario performance based on selected performance indices, and the GA module implements the GA algorithm until convergence is reached. In every GA evolution, each solution of the problem (phenotype) is produced by the genotype that contains an individual (chromosome) represented by a string of bits or integers (genes). Every instance of this string corresponds to a solution for the Aegean Coastal Transport System design.

The genotype contents are created by the retrieved spatial, statistical and other information from the database, on the ranged variables set by the user, on any restrictions, goals and priorities applied by the involved parties and on any other factor required such as season, weather or prices. The objective and penalty functions constitute the overall fitness

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measure that is used to: evaluate the population (solutions), keep the fittest solutions, and discard the worst ones. They are based on transportation demand, routes length, travel duration, trip cost and quality, ship delays, demand coverage, service frequency, etc. Quadratic functions are mainly used as penalties for unfeasible solutions and constrain violation. The GA's new generations are created using cloning, crossover and mutation on the parent population of the feasible solutions. The GA concludes after a number of generations or when convergence is reached.

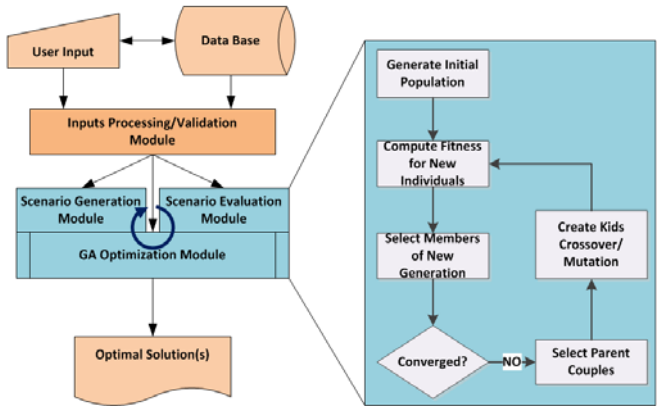


Fig. 3 Optimization tool structure

B. Coastal System Modeling For Optimization

In order to achieve globally optimal solutions and search flexibility, the system model contains a large number of coastal transportation parameters and variables. All together they build a set of Measured Values (MV) of our system. An indicative list of the model variables follows:

- Island characteristics (such as, population, autonomy, hospitals and public services, airports, local population transportation demand, visitors demand),
- Port characteristics (such as, capacity for ships – size and number, infrastructure for refueling, waste, passenger accommodation, load/unload delays),
- Connections (geographical distance, nautical distance, shuttle line or cyclic route, forced route, number of stops, alternative routes),
- Demand per route (passengers, cars, trucks, seasonality, statistics),
- Schedule (frequency of each route, departure, travel time, delays, time windows, bad weather delays, winter/summer adjustments, waiting queues),
- Ships (type, capacity, speed, various costs, various fares),
- Demand statistics and forecasts, Weather statistics, etc.

For a typical user request most of the above quantities are fixed (constant value), others are free to change inside an acceptable range (discrete or continuous) and the rest are set/adjusted/restricted by the user. All the non-fixed variables are creating the GA chromosome that defines the search space with all the alternative solutions (scenarios). From the full set of MVs another set of Calculated Values (CV) is also produced. In the proposed coastal transport system model the CVs set includes, per implemented route the:

- Total time, productivity, overtake, delay, as well as,
- Demand and the capacity of coverage, cost, income, etc

Altogether MVs and CVs create a phenotype a system solution/scenario. Phenotype contents are then combined to form the Performance Indices (PI) for each scenario. In the proposed model, the major PIs for each scenario include:

- Total travelling distance and delay,
- Total cost, total revenues,
- Total demand coverage and total fleet coverage,
- Coverage of local demand and state demands

Finally, all the PIs are combined to a single KPI (Key Performance Index). The KPI (1) corresponds to the overall score of the fitness function of the optimization algorithm. There is no unique KPI, as it is a weighted sum of all PIs and the corresponding weights are not fixed but they are defined by the user (KPIu).

$$KPI_u = \sum_{k=1}^{n} w_{u/k} \cdot PI_k \quad (1)$$

Each user may have a separate set of weights Wu that best represent is user objectives and goals. Currently four different KPIs have been designed, corresponding to three different actors i.e., the ministry, the maritime companies and the local authorities.

In addition to the above variables a large number of constrain is always imposed to the designer. For the coastal transport system under development, an indicative list of typical constrains follows: available fleet (set of ships) and companies, min/max capacity per route, min/max speed per route, min wind speed, max over-length, max time per route, max number of stops, min allowed frequency of service, aver/max load/unload delay, aver/max waiting for connection line, min demand coverage, min capacity coverage, max number of hubs, etc.

C. Example

Co.Tr.I.S. optimization subsystem work flow is shown using a sample from the Aegean containing seven islands of the Cyclades and the Piraeus main port, as shown in Fig. 4. According to the user criteria, different results are obtained.

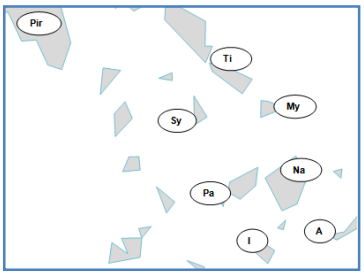


Fig. 4 A sample case with a main port and some of the Cyclades islands

If the user wants to e.g., minimize the number of ships, the total distance, maximize ship utilization and minimize consumption, then Scenario A in Fig. 5 will obtain a higher score (KPI) than B. If the user wants to e.g., minimize the travel time, maximize visitors and population satisfaction,

increase redundancy and reliability, then Scenario B will obtain a higher score (KPI) than A (Fig. 5). Of course, the optimization subsystem returns many more scenarios and the user is free to select one that may be not the best, but it may fulfill other needs not included/defined in the submitted job.

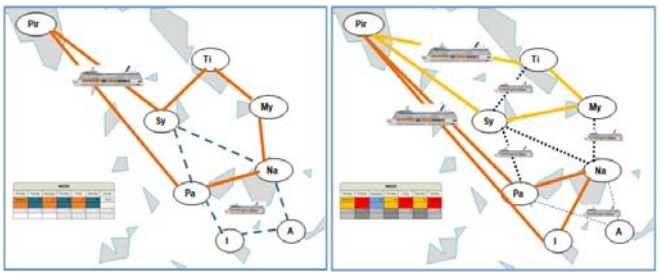


Fig. 5 Example of different solutions from different criteria: Scenario A (left) and Scenario B (right)

IV. Concluding Remarks

In this paper the modeling methodologies and the optimization tool of Co.Tr.I.S. are presented. The complexity of the problem and the large number of parameters and objectives involved led to the adoption of an evolutionary method (Genetic Algorithms). Specialized methods from graph and games theories are also included for specific cases. The GA chromosome representation was presented, as well as, the functionalities offered to the Co.Tr.I.S user.

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