# ISOLDE XI

international symposium on locational decisions

June 26 - July 1, 2008

Santa Barbara, California

# Abstracts

*Editors:*

Matthew R. Niblett

Micah Brachman

Hugo Repolho

Richard Church

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# Past Symposiums

ISOLDE is the triennial symposium devoted to the subject of Location Analysis. This symposium involves researchers from many fields including Civil and Industrial Engineering, Management Science, Economics, Operations Research, Geography, and Computer Science, as well as practitioners in government and industry. The previous ISOLDE symposia have been held at the following locations:

- ISOLDE I: Banff, Alberta, Canada. April, 1978.
  Chairman: J. Halpern
- ISOLDE II: Skodsborg, Denmark. June, 1981.
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- ISOLDE VII: Edmonton, Alberta, Canada. June-July, 1996
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- ISOLDE VIII: Coimbra and Estoril, Portugal. June, 1999
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# Sensitivity in Competitive Location Models

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## Abstract

Since its inception in 1929, researchers have investigated a large variety of modifications of Hotelling's competitive location model. The models that were investigated included competitive location models with more than two competitors, models in spaces other than the original line segment (e.g., the two-dimensional Euclidean plane & networks), models with different pricing policies, & many others. Typical analyses either attempt to determine Nash equilibria, or try to find a von Stackelberg solution. The general consensus is that Hotelling models are very sensitive with respect to the assumptions of the model. Typical examples are models with fixed and equal prices on a line segment that have an equilibrium, while an arbitrarily small change of one of the prices results in the nonexistence of equilibria. Similarly, while models with quadratic transportation costs have equilibria at the ends of the line segment, the introduction of an arbitrarily small linear component in the cost function destroys Nash equilibria.

This research intends to further explore the sensitivity of competitive location models. Particular attention will be paid to models that include more realistic choice rules for customer behavior and those that allow competitors to apply different objective functions. Again, we are interested in the existence of Nash equilibria and von Stackelberg solutions.

# Improving Commercial Territory Design for a Distribution Firm with Scatter Search

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## Abstract

In this work a commercial territory design problem motivated by a real-world application in a beverage distribution firm is addressed. A territory design problem (TDP) consists of grouping small geographical areas into larger geographic clusters called territories according to relevant planning criteria. See Kalcsics et.al., [3] for a review of many TDP applications.

In particular, planning criteria such as multiple node activity balance, contiguity, and compactness is sought. Two node activities are considered: product demand and number of customers. Node activity balance expresses a relation of territories among each other about an activity. Territories must be similar in size with respect to each activity (i.e., it is desirable to evenly spread out the product demand over the territories). Contiguity means that territories should be geographically connected, that is, all areas should be accessible by travelling within the territory. A district or territory is said to be compact if its assigned units are relatively close to each other. In a sense, having compact territories is associated with shorter travel times when physically routing the product. Our approach focuses on the territory design.

This problem was introduced by Ríos-Mercado and Fernández [6] with three node activities. The authors present a reactive GRASP approach with a filtering mechanism in the local search phase. The method outperforms the solutions obtained by the firm method. They also establish that this combinatorial optimization problem is NP-hard. GRASP [2] is a multi start method. A GRASP iteration consist of a randomized greedy solution followed by an improvement. Our work aims at improving the results obtained in the above mentioned work [6].

Typical real-world instances are very large. Existing exact methods can solve instances of relatively small size. In the present work a Scatter Search heuristic is proposed. Scatter Search [4] is a population based metaheuristic, which apply diversification and

intensification strategies that have shown to be effective in a variety of combinatorial optimization problems [5].

Basically, a standard implementation of scatter search considers five elements: Diversification generation method (DG), improvement method (I), reference set update method (RSU), subset generation method (SG), and solution combination method (SC). In the more general way, Scatter Search is based on the combination of good solutions contained in the Reference Set. This set stores solutions found along the search process considering both, quality and diversity. The DG generates a collection of diverse solutions. (I) improve the solutions generated in DG. Normally, (I) can deal with both, feasible and infeasible solutions. RSU is in charge of building and maintaining a set of the b best solutions found along the search. The SG identifies a subset of the reference set for creating combined solutions. The SC method is in charge of transforming solutions in the reference set into combined solutions. In Scatter Search, both the design and implementation of the diversification generation method, the improvement method and the combination method depend on the application context. We focus our proposal in the generation of diverse solutions and in the combinations of the solutions in the Reference Set.

Diverse solutions are generated according to a location-allocation heuristic. In the location phase, three GRASP-based procedures are proposed. Each of these attempts, in a different way, to find p seed points that are as far apart as possible from each other. This phase can also be seen as a p-dispersion problem. Our proposed GRASP procedures extend some ideas presented in [1] to generate diverse sets of seeds. Heuristic 1 starts by choosing the two farthest units as the initial two seeds. Iteratively, a new unit is selected to be a seed. The unit is chosen from a restricted candidate list (RCL). The desirability of a unit j to become a seed is measured by the minimum distance from j to all previously located seeds. Heuristic 2 is similar to Heuristic 1, but with a look-ahead policy, i.e., the procedure evaluates the next two units to be included simultaneously. The idea behind Heuristic 3 is the following: given a set of units in the space, if a pair of the nearest basic units is identified and one of these basic units is eliminated, each time the remaining units in the space may tend to be dispersed in the space. Again, the procedure incorpores a RCL. In the allocation phase the remaining geographical units are allocated to one territory within GRASP framework. In this phase, a greedy function which is a weighted convex combination of the original distance-based objective and the violation of the balancing constraints is used. In general, the DG method may obtain infeasible solutions with respect to the balancing constraints. Thus an improvement method for attempting both to recover feasibility and improve the objective is applied.

Another contribution of the work is the design of a combination method. In the combination proposals two solutions are combined in order to get one new solution. The combination method must identify the common characteristics of the solutions selected to be combined. In the proposed method, the new solution keeps assigned to the same territory each pair of units that are assigned together in both of the combining parent solutions. The remaining unassigned units are then allocated by using a merit function that takes into account dispersion and violation of the balancing constraints, and taking contiguity into account.

At this moment these procedures are being implemented. In previous work, the longest instance solved by an exact method has 100 nodes and 10 territories. Our aim is targeted at 1000- and 2000-node instances. Full computational experience will include the algorithmic evaluation of the Scatter Search scheme and a detailed comparison with the current approach reported in [6].

## References


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[6] R. Z. Ríos-Mercado and E. A. Fernández. A reactive grasp for a commercial territory design problem with multiple balancing requirements. Computers & Operations Research. Forthcoming.

# Emergent Location Patterns in Competitive Retail Markets

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## Abstract

Given recent changes in consumer behaviour, the spatial structure of competitive retail markets is undergoing changes. In the last years - among others - the increased focus on consumer individuality and diversity results in different consumer spatial behavior than traditionally assumed. Since location patterns of competitive retail markets are dynamically interrelated with the spatial structure of the demand side, we propose an agent-based model to integrate the recent trends in consumer behaviour in the study of location patterns at the supply side. An agent-based model allows one to examine how micro-based rules can explain macroscopic regularities. This implies that we presuppose individual behaviour rules for both consumer and retailer agents and simulate a competitive retail market as a dynamic system of interacting agents. Then, the investigation of the emerging location patterns in the competitive retail market at the macro level is done by means of the set of interacting agents at the micro level.

# Incorporating Inventory Decisions in Competitive Location Models

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## Abstract

Competitive Location Models seek positions and prices which maximize the market captured by an entrant firm from previously positioned competitors. Nevertheless, strategic location decisions may have a significant impact on future inventory and shipment costs thus affecting the firm's competitive advantages. In this paper we introduce a heuristic algorithm which considers both market capture and replenishment costs in order to choose the firm's locations. Viswanathan's (1996) algorithm is used to solve the replenishment problem whereas a Greedy Randomized Adaptive Search Procedure is used to solve the location problem.

# Organizing Hospital Services into Networks: A Hierarchical and Multiproduct Location Model with Application to the Portuguese Health Care System

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## Abstract

In countries with health systems based on a National Health Service decisions about where to locate and how to organize hospital services should be planned and should consider the policy objectives of pursuing geographic equity in access, efficiency and cost containment in health care delivery. Planning requires decision support tools that are built upon location models and that are able to inform which network configurations of hospital units and services best serve the system objectives. Previous methods to inform hospital planning have not always considered key features of hospital networks which are deemed as crucial for organising services, namely the hierarchical and multiproduct nature of hospital networks.

This study develops a two-tier hierarchical and multiproduct mathematical programming model to define location and supply of hospital services that maximize patients' accessibility to health services and consider other policy objectives. The echelons cooperate in a successively inclusive hierarchy where the higher level units offer all the lower level services additionally to their specialised services. Lower level hospitals are expected to be closer to populations, whereas higher level units provide more differentiated services to larger catchment population areas. The articulation between these two echelons accounts for the referral system. The models consider that hospitals provide three types of services: inpatient care, external consultation and emergency care. Models are formulated as mixed integer linear programs, where the integer variables define the opening and the number of units chosen and the continuous variables establish the flows of patients. Some operating key features of hospital networks –ascendant and descendent flows between hospitals at different levels of the hierarchical network, and multiple flows connecting the various services within and across hospital units- are considered. Finally, capacity constraints on minimum and maximum levels of supply for each service are used so as to encapsulate efficiency information. Some variants of the model take into account other political constraints and cost considerations when running some alternative location models and while testing the acceptability of some model solutions.

The model is implemented in the Generic Algebraic Modelling System (GAMS) and solved through the use of a commercial solver CPLEX. A Portuguese case study that includes the South administrative health regions is shown. This application has lead to a complex problem due to the combinatory nature of the location problem and due to the structure of the hierarchical model. A solution strategy involving multi-stage decisions was defined: in the first stage, the model is solved for a single product (the most costly service, inpatient care); in the second stage the hierarchical multiproduct model is used to optimise the flow redistribution. The implementation show that the model is highly demanding in terms of required data, but results are robust and provide very useful information for planning: referral networks, hospital catchments' areas, structure of hospital supply, and accessibility indicators by population area.

Results encourage to extend the study to other regions and to develop other strategies for solving the hierarchical multiproduct model. Currently the development of a decomposition method for improve efficiency is explored.

# Transportation Design: Location and Planning

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## Abstract

Location theory is used to design transportation networks. There, usually the goal is to make it easy for users to reach the facilities of the network, i.e. to facilitate accessibility to stations. On the other hand, line planning (which is aimed to determine routes and frequencies) goals can be classified in two types: company oriented goals (minimizing construction and operation costs) and customer oriented (minimizing total traveling time, maximizing direct trips.)

We consider both user constraints and company constraints in our model, which combines location theory criteria with line planning criteria. It chooses a line which minimizes the costs and maximizes the demand covered, among all possible alternatives.

# Locating Lottery Retail Stores in Barcelona: A Consumer Oriented Approach

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## Abstract

The optimal location of retail stores is one of the most important factors that affects both service quality in terms of consumer access and business profitability. In this paper a model is presented that locates multiproduct retail stores such as lottery stores maximizing demand capture. The model formulation is extended to consider hierarchical facilities and consumer preferences. Then the model is applied to the location of lottery retail stores in the city of Barcelona.

# Fuzzy Approach to Optimal Manipulation with Empty Containers within a (Mediterranean) Feeder System

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## Abstract

The implementation of hub-and-spoke networks model for optimal decision making in container Intermodal transport in Mediterranean container transport is suggested as one of the potential solutions for helping to reduce the total transportation costs. In past two decades new type of Intermodal terminals, specifically designed for fast transhipment at ports as nodes in hub-and-spoke networks, have been introduced in European ports. It increases also the quantity of empty containers and costs of manipulation with these empty items. But the optimal manipulation with empty containers has not been completely solved up to now especially because they have been considered separately from nonempty items.

In Mediterranean port systems there are ports where more cargo is discharged than loaded and consequently empty containers remain in ports. On the other hand there are ports where demand for containers is greater than container space. So ship operators are forced to transport empty containers from first ports to the second ones. Such cases, obviously, are economically inefficient. Full containers have absolute priority because operators are fully paid for loaded containers only. Consequently, operators must increase feeder ship capacity or increase the number of containers in the system or use other ships to transport empty containers to ports. All these measure incur additional costs.

Linear algorithm and fuzzy approach to hub-and-spoke model for optimal manipulation with empty containers was developed here to study reduction of total costs in Mediterranean see.
At the same time, reduction of the number of empty containers at terminals contributes to the optimal investment policy in the container terminal area. The solution suggests also a now approach to cooperation among the owners of ports and users of port activities.

# Integer Planar Location Problems

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## Abstract

Planar location problems (see e.g. [2, 3]) ask for one or more points in the plane minimizing the distances to a set of existing facilities. In this talk we will add an additional restriction and require that the coordinates of the new locations must be integer numbers. Applications of the resulting integer location problems include location problems on grid graphs which are embedded in the plane. One example is to find a location on a crossroad in Manhattan. The model can hence be interpreted as an approach towards integrating planar and network aspects in location theory.

Adding the integrality constraint to continuous location models results in integer nonlinear programs which are, in general, known to be NP-hard. Enumerating all possible candidates is too time-consuming in most instances. However, the specific structure of location problems allows efficient solution approaches for many cases, even if we require integer coordinates for the new locations. First, we make use of the fact that the location of a single facility is a low dimensional problem. Moreover, we exploit specific properties of the objective functions of location models. In particular, we rely on the convexity of the objective function for unrestricted models and on the piecewise linearity in location problems with block norm distances.

In location problems with block norm distances or polyhedral gauges we use that the objective function is piecewise linear in polyhedral regions in the plane. On each of these regions we are hence left with an integer linear programming problem with only two variables. Such problems can be solved efficiently, see [1]. In some special cases it is possible to construct the convex hull of the allowed integer points directly in each of these polyhedral regions. This yields a finite candidate set which is much smaller than all possible points on the grid. For the Manhattan distance the integer problem can be solved with the same complexity as for the classical Weber problem with Manhattan distance.

The convexity of the objective function yields convex level sets. The shape of these sets is well known for many location problems and will also be exploited to find an optimal integer solution. For the squared Euclidean distance, e.g., the integer version of the problem can be solved efficiently with the same complexity as for the corresponding classical location problem.

Moreover, by relaxing the integrality constraints and rounding the optimal solution of the relaxed problem, quality guarantees can be derived which will be evaluated and discussed for different types of objective functions.

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# The Big Cube Small Cube Method for Location Problems with Multi Parameters

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## Abstract

We will present the big cube small cube (BCSC) solution method, a combination of the big square small square technique (BSSS) and the interval branch-and-bound algorithm. Using this approach, we are able to solve continuous, non-convex, and even non-differentiable location problems with more than two parameters. We demonstrate our approach at some location problem, among them the median circle location problem and the 2-median problem.

Hansen et al. (1985) suggested the big square small square (BSSS) technique for some location problems on the plane with two variables. Plastria (1992) generalized this method to the generalized big square small square (GBSSS) technique. Using triangles instead of squares, Drezner and Suzuki (2004) proposed the big triangle small triangle (BTST) method. Note that all these techniques are branch-and-bound solution methods for problems on the plane with two variables and that every location problem requires lower bounds for each square or triangle.

The interval branch-and-bound algorithm is a more general optimization technique that can be applied to problems in every dimension using interval analysis; see, for example, Hansen (1980). Here, lower bounds are obtained by inclusion functions and the main concept is to find good discarding tests. Note that for both lower bounds using inclusion functions and most of the discarding tests, a differentiable objective function and information about the gradient are required.

Since our objective functions are not differentiable and they are dealing with more than two variables, we propose a general solution method for (non-differentiable) facility location problems with multi-parameters. We adopt the idea to create specific lower bounds from the BSSS method and the idea for higher dimensions and discarding tests from the interval branch-and-bound algorithm.

The median circle location problem

Considering irrigation pipes or ring roads, the median circle problem is to locate a circle on the plane which minimizes the sum of weighted distances between the circle and a set of $n$ existing facilities $\{A_1,\ldots,A_n\} \subset \mathbf{R}^2$ with $A_k = (a_k, b_k)$. With positive weights $w_k > 0$, with $r \geq 0$, and with $X = (x, y) \in \mathbf{R}^2$, the problem can be formulated as

$$f(X,r) = \sum_{k=1}^{n} w_k \cdot |d_2(A_k, X) - r| = \sum_{k=1}^{n} w_k \cdot \left| \sqrt{(a_k - x)^2 + (b_k - y)^2} - r \right|.$$

Using the BCSC solution method, we will show that on average the run time is almost proportional to the number of existing facilities.

The 2-median problem

The 2-median problem is to find two new locations $X_1 = (x_1, y_1)$ and $X_2 = (x_2, y_2)$ on the plane. With positive weights $w_k > 0$ we have to minimize

$$f(X1, X2) = \sum_{k=1}^{n} w_k \cdot \min\{d_2(A_k, X_1), d_2(A_k, X_2)\}.$$

We can solve this problem with the BCSC approach using specific lower bounds and discarding tests. Further problems include the Fermat-Weber problem with positive and negative weights, the center circle problem, and the median sphere problem.

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# More (d.c.) bounds for planar location models *

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## Abstract

The BTST (Big Triangle Small Triangle) introduced by Drezner and Suzuki, [2], has shown to be a very satisfactory strategy to solve continuous location models. BTST is a branch-and-bound procedure, and thus a crucial step is the generation of sharp bounds. In this talk we will present new bounding strategies, applicable to many continuous location problems, based on exploiting the structure of the objective as a difference of d.c. functions with certain properties.

The numerical experience reported shows that the bounding strategy is rather competitive against benchmark procedures, such as those given in [1].

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# A dual algorithm for the weighted Euclidean distance min-max location in $IR^n$

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## Abstract

In 2003, Fisher, Gartner and Kutz presented a primal type (Crystal and Pierce) algorithm for the un-weighted Euclidean distance min-max location problem in $IR^n$. In 2007, Dearing and Zeck presented a dual type (Elinga and Hearn) algorithm for the un-weighted Euclidean distance min-max location problem. This paper reviews the dual algorithm approach, and extends it to the weighted Euclidean distance min-max location problem in $IR^n$.

The dual algorithm generates a sequence of subsets $S_k$, containing no more than $n + 1$ affinely independent points from the given set of points, and solves the weighted Euclidean distance min-max location problem over each $S_k$. If the solution for $S_k$ covers all points, then it is optimal. Otherwise, a new set $S_{k+1}$ is generated by adding an uncovered point to $S_k$, or by having it replace some point in $S_k$.

The algorithm sequences between updating the set $S_k$ to $S_{k+1}$ and in solving the weighted Euclidean distance min-max location problem over the new set $S_{k+1}$. Updating the set by replacing a point requires the solution of an $n+1 \times n+1$ linear system of equations, and a minimum ratio rule that is similar to the simplex algorithm. Solving the min-max problem over the set $S_{k+1}$ involves searching in a direction that follows the arc of a circle in $IR^n$. Computational results will be presented.

# The impact of site location in C-Stores Sales under the New Paradigm of the Portuguese Fuel Retail Market

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## Abstract

Since the year 2000, the Portuguese fuel market became very competitive and companies with high financial capacity invested in related non-fuel businesses with higher unit margins. The Portuguese market leader, GALP, developed a new concept of c-stores, branded M24.
GALP is the leading investor in this non-fuel business. GALP's C-stores offer a wide range of products, ranging from grocery and prepared food to hygiene products, newspapers, magazines and tobacco. Despite the huge investments in non-fuel business, in fuel stations with c-stores, fuel sales represent, on average, 88% of total turnover.

The location is a critical success factor for retailers. In retail business it is essential to attract more customers, improve market share and maximize profits in a competitive scenario.
The main purpose of this study is to find relations between the C-stores sales and location characteristics (macro and micro location). For 67 c-stores the relations between location characteristics and groups of products are discussed. Differences between highway sites and urban sites and between sites located in highly populated regions with a high number of vehicles and sites located in rural areas are evaluated.

Previous studies show c-stores' sales are highly correlated with fuel sales and that the ratio food/non-food products differs from site to site.
For the non-food products most sold in the c-stores first results suggest highway sites sell more than urban sites, on average, for the following categories: car, books and maps, magazines and personal hygiene. The urban c-stores sell more than highway sites, on average, tobacco, newspapers and services like tickets.

Analysing the most sold food products, non-urban c-stores sell, on average, more than the urban ones sweets, cookies, yogurts, water, beverages, dairy, frozen food and coffee and cakes. They sell almost the same volume of beer and wine and sell less bakery products. The same results are obtained considering sales by square meter and median sales instead of average sales. Other location variables are studied but the results are less conclusive, despite some tendencies encountered. Managers have to study their customers'

preferences and according to site location should adapt their portfolio of products and services offered in order to increase profitability.

# Capacitated Facility Location for Disbursement of Supplies in a Large-Scale Emergency

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## Abstract

In this paper, we consider the problem of locating points of disbursement (POD) for medicines in response to a large scale emergency. Large-scale emergencies are those rare events that overwhelm local emergency responders and require regional and/or national assistance, such as a bioterrorist attack in a large metropolitan city. To address the tremendous magnitude and low frequency of large-scale emergencies we obtain a solution that maximizes the number of people serviced under such uncertain and limited resources/time conditions.

In the problem we consider here, first, the facilities are capacitated by the service rate of a POD. Second, the demand satisfied depends on the distance to the facility. This is because in a large-scale emergency scenario, the number of people turning up at a particular POD decreases as their distance to that POD increases. Thirdly, given the unpredictability as to when and where such an emergency scenario could occur and how many people would be affected, there is significant uncertainty in demand values.

We model the problem as a maximal covering problem with capacitated facilities and a distance dependent demand. The number of facilities to be opened is dependent upon the type of emergency scenario, and the number of people affected. In our model, we assume that the demand that can be serviced at a facility from a particular demand point is a fraction of the demand that decreases as a function of the distance between the demand point and the facility. This assumption is made to reflect the inability of people to travel large distances (due to possible damage to infrastructure such as roads, health conditions etc.) in an emergency scenario. For this purpose, we use a loss function, as shown in the figure below.

In this figure, only a fraction $f_1$ of the demand from demand points within a distance $\delta_1$ from the facility (represented by a triangle at the center) is felt at the facility. Similarly, for demand points within a distance greater than $\delta_1$ but lesser than $\delta_2$ from the facility, at most a fraction $f_2$ of their demand is felt at the facility. In addition to this, we allow more than a single facility to serve a demand point. We use chance constraints for the uncertainty in demand arising in the various demand points. For a given distribution of *D,* we write the chance constrained equations as given below:

$$\Pr\left( \sum_{j:\ d_{ij} \le \delta_1} u_{ij} \le D_i \right) \ge 1-\varepsilon \quad \forall i \in I$$

$$\Pr\left( \sum_{j:\ \delta_{k-1} < d_{ij} \le \delta_k} u_{ij} \le f_k * D_i \right) \ge 1-\varepsilon \quad \forall i \in I,\ k = 2,\dots,K$$

A locate-allocate heuristic combined with LP-rounding techniques is developed to efficiently solve this problem. We run the heuristic for various combinations of open facilities, N and service factors, $\gamma$. We test the performance of this heuristic in locating medical supplies for an anthrax attack scenario in Los Angeles County, with approximately 2000 demand points and over 200 potential facilities, with the supply of vaccines in each facility to be at least equal to 140,000 units per week.

# The Army Reserve Stationing Study

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## Abstract

The Army Reserve Stationing Study was a year-long effort to analyze where to station 340 new units representing 17,000 soldiers and to develop a standard methodology for future stationing decisions. The Center for Army Analysis study team made recommendations on where to station the new units and developed a decision support methodology that can be used for years to come.

The Army Reserve needed a standardized process to determine where to station the new troop program units it is adding between 2008 and 2011 as part of the Grow the Army and Army Reserve Rebalancing initiatives. These critical efforts add Army Reserve force structure to fix shortfalls identified after the increase in tempo related to the Global War on Terror. These new units represent the single largest block of new force structure in the Army Reserve in several decades. Because of Army Reserve command and control transformation, their historically decentralized stationing process had to be centralized. The Army Reserve also wanted to take this opportunity to add analytic rigor to what had historically been a personality driven stationing process.

The Army Reserve approached CAA in September of 2006 and requested a study that would consider such important factors as recruitable local population, occupational demographics, Army Reserve career progression opportunities, and the inventory of existing facilities. They wanted a process that would produce auditable decisions, and they needed the analysis and the process complete by summer 2007.

The study team surveyed stationing experts within the Army Reserve to determine the factors which are important to effectively station units. They then collected data on these factors from pre-existing free or low-cost data sources. They developed a multiple-objective decision model with geographic display capability to combine the data and to

score and rank-order potential stationing locations for the new units. This decision model includes population and demographic measures, measures of career progression opportunity for reserve Soldiers, measures of existing local training areas, and measures of facility capacity and quality. The team assessed value scales for each of the measures and developed a weighting scheme to combine them in the model using standard decision analysis methods

By combining these often competing objectives into one tool that provides traceable, auditable analysis to support decisions, the team improved the quality of this year's stationing decisions. In addition to supporting important immediate decisions, the Army Reserve Stationing Study provided a decision methodology that the Army Reserve is institutionalizing for use into the future. The Chief Army Reserve called this study the most important analysis done for the Army Reserve in many years.

# Solving an Actual Optimization Routing Problem for an Agricultural Cooperative

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## Abstract

In this paper we study an actual problem proposed by an agricultural cooperative devoted to harvest corn and grass. The cooperative uses combine-haversters for harvesting the crop and trucks for transporting it from the smallholdings to the silos of the landowners. Then, the cooperative needs to plan both, the combine-harversters and trucks routing in order to minimize the total working time. A mixed integer linear programming model is proposed to solve this problem. However, since approaches dealing directly with such formulation lead to extensive computation times, we propose a heuristic alternative solution approach for the problem. We are making an experimental analysis to show that the proposed heuristic approach can solve large problems effectively with reasonable computational effort.

# GRASP Heuristics for the Capacitated Multi-source Weber Problem

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## Abstract

We investigate the continuous capacitated location-allocation problem which is also known as the capacitated multi-source Weber problem. A greedy randomised adaptive search procedure (GRASP) guided by a region-rejection scheme is proposed to tackle the problem. An ADD procedure based on a small subset of customers only is adopted to constructively build the restricted candidate list (RCL). The RCL is updated at each iteration by introducing a self adjusted threshold. This threshold parameter is dynamically obtained by using linear, convex and concave functions. These variants are tested on two classes of instances with constant and variable capacities of the facilities. The computational results shows that the proposed methods provide encouraging results when compared to recently published papers. Benchmark results for larger instances which we have also recently created are also provided.

# Bio-Inspired Approaches for Large Scale Hub Location Problems

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## Abstract

Hub location research is an important area of location theory due to the use of hub networks in modern transportation and telecommunication systems. These systems serve for travel or communication between many demand points (origin/destination). Rather than serving every demand point with a direct link, a hub network provides service via a subset of link between demand points and hubs, and between hubs. The use of a subset of links in the network allows economies of scale to be exploited, since allows a large set of demand points to be connected with relatively few links and concentrates flows via central hub facilities. Thus, hub location problems involve locating hub facilities and designing hub networks.

Transportation and communication applications of hub location include air passenger travel, express shipments, postal operations and a wide variety of distributed data networks in areas such as computer communications, telephone networks, video teleconferences, etc.
An important differences between classical facility location and hub location is that multiple and single allocation versions exist for hub location problems. In a single allocation hub location problem, each demand point is allocated to exactly one hub, and in a multiple allocation hub location problem each demand point may be allocated to more than one hub.

Good reviews of hub location research are through the 1990's. Campbell [2] presented a classification scheme for the different models and problems considered. O'Kelly and Miller [10] focused on the topological alternatives in hub networks. Klincewicz [9] reviewed the design of hub networks in the telecommunications area. Bryan and O'Kelly [1] surveyed works in the field of air transportation. Campbell et al. [3] focused on the location of hubs in new models.

Hub location problems are difficult to solve exactly. The best methods available so far cannot solve instances with a large number of demand points unless the number of potential hubs is significantly restricted. The most common approach for solving hub location problems is using linear programming. Traditional formulations uses O(n4)

variables and requires O(n3) constraints. The fact that both the number of variables and constraints increases rapidly with problem size means that these formulations are not amenable to exact techniques. In order to make hub location problems more tractable, it is important to reduce the problem size. This has led to a proliferation of heuristics and new reduced formulations to solve large scale hub location problems.
Solving NP-hard optimization problems, such as hub location problems, has been a core area in research for many communities in engineering, operations research and computer science. The interdisciplinary features of most NP-hard optimization problems have caused a large amount of papers from many researches that have proposed numerous and different algorithms to overcome the many difficulties of such problems. Several researches used algorithms based on the model of organic evolution as an attempt to solve hard optimization problems [7]. Due to their representation scheme for search points, genetic algorithms [6] are one of the most easily applicable representatives of evolutionary algorithms.

The idea of using neural networks to provide solutions to NP-hard optimization problems have been pursued for over decades. Hopfield and Tank [8] showed that the travelling salesman problem (TSP) could be solved using a Hopfield neural network. This technique requires minimization of an energy function containing several terms and parameters. Due to this technique was shown to often yield infeasible solutions, researchers tried to either modify the energy function or optimally tune the numerous parameters involved so that the neural network would converge to a feasible solution.

In this work a framework for making reduced hub location formulations is provided. The proposed framework is based on the formulation provided by Dominguez et al. [4] for solving the p-hub problem. Moreover, several bio-inspired techniques successfully applied to other location problems [5] are presented for solving hub location problems.

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# Parallel Variable Neighborhood Search for the Capacitated p-Median Problem

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## Abstract

The capacitated p-median problem (CpMP) seeks to solve the optimal location of p facilities, considering distances and capacities for the service to be given by each median. This problem which goes also under the name of Capacitated Warehouse Location Problem, Sum-of-Stars Clustering Problem and others, is NP-hard.

In this paper we coded and analyze the parallelization strategies for the Variable Neighborhood Search (VNS) meta-heuristic applied to the NP-hard capacitated p-median problem (CpMP) which has a significant number of applications in practice. Our implementation incorporates innovative mechanisms to include memory structures within the VNS methodology. We report excellent solutions that are qualitatively comparable to the best published results. The Cooperative multisearch method takes a clear advantage respect to the other strategies.

Four different parallelization strategies for the VNS have been reported in the literature in two papers, and both were linked in a chapter of a book [4]. All of them were coded for the p-median problem. In the Crainic et. al. [1] classification, one of them belongs to the type 1, and the other three strategies belong to the type 3: Multiple Search Strategies, two of them with an independent search and the other one with a cooperative search approach..

In 2002, García et.al. [3] proposed three different parallelization strategies, two of them were simple and the other one was more complex. The first of the two simple parallelization strategies is a type 1 and attempts to reduce the computational time by parallelizing the local search in the sequential VNS, and is denoted SPVNS (Synchronous Parallel VNS). The parallel local search is implemented trying to get a balanced load among the processors. The procedure divides the set of p(n-p) solutions of the neighborhood of the current solution among the available processors to look for the best one. The other simple one is a type 3 with independent search, called Replicated Parallel VNS (RPVNS) that tries to search for a better solution by means of the exploration of a wider zone of the solution space, using multistart strategies. It is done by increasing the number of neighbor solutions to start a local search (several starting solutions in the same neighborhood or in different ones). This method is like a multistart procedure where each local search is replaced by the VNS. Therefore our implementation includes: i) communication between the threads, also ii) the current solution of each thread is not updated after a better solution than the incumbent is reached. iii) In order to intensify the search we introduced another modification when the solution cannot be improved, in this case, the overall best is requested from the master and sends it to all the threads, this version with all the modifications is called Intensive-RPVNS.

Finally, the third strategy applies a synchronous cooperation mechanism through a classical master-slave approach, and was called the Replicated Shaking VNS parallelization, RSVNS, is an implementation of cooperative VNS search. In this case, the master processor runs a sequential VNS but the current solution is sent to each slave processor that shakes it to obtain an initial solution from which the local search is started. The solutions obtained by the slaves are passed on to the master that selects the best and continues the algorithm. The independence between the local searches in the VNS allows their execution in independent processors and updating the information about the joint best solution found. This information must be available for all the processors in order to improve the intensification of the search. Therefore in our implementation RSVNS was modified cutting the communication among the threads, in order to reduced the intensification. This version is called Non-Intensive-RSVNS.

In 2004, Crainic et al.[2] proposed another type 3 parallelization strategy that applies a cooperative multisearch method based on a central memory mechanism, called the Cooperative Neighbourhood VNS (CNVNS). In this approach, several independent VNS cooperate exchanging information about the best solution. Here, they work asynchronously and the master saves the best solution found by the threads. Instead of this, we considered that the master saves an ordination of the best solutions obtained by the threads using a queue. The master sends to the first useless thread, the first value of the queue and removes it from the queue. Then, the second useless thread receives from the master the next value of the queue and removes it from the queue, and so on until the queue becomes empty or all the threads become useless. The size of the queue in our implementation is equal to the number of threads. This version is called Diversified-CNVNS

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# Duality For Multiobjective Location Problems

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## Abstract

A very important feature in convex optimization is the duality theory. It means to associate to a given primal minimization problem an appropriate so-called dual maximization problem such that the optimal objective value of the dual problem is less than or equal to the optimal objective value of the primal problem. In general there can be a duality gap between the both optimal objective values. This situation is called weak duality. If the both optimal objective values coincide one speaks of strong duality. Strong duality allows to derive a lot of useful and important assertions and properties for the primal and the dual problem such as necessary and sufficient optimality conditions, upper and lower bounds for the optimal values, saddle point assertions, Farkas-type results (so-called theorems of the alternative), design of numerical algorithms etc.

In the present talk we consider some convex multiobjective location problems with respect to multiobjective duality, i.e. the dual problems turn out to be multiobjective problems, too. We show weak as well as strong duality for different notions of solutions to the multiobjective problems. In particular, we deal with efficient, weakly and properly efficient solutions.

Furthermore, also so-called converse duality results will be established. Based on the multiobjective strong duality optimality conditions are derived for the multiobjective location problems.

Our duality for the location problems is supported by conjugate duality using the tool box of convex analysis and, in particular, conjugate function theory.

# Hardening Facilities against Random Numbers of Losses

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## Abstract

This paper presents a stochastic generalization of the R-Interdiction Median Problem with Fortification (RIMF) introduced in [1]. The RIMF problem aims at identifying the optimal allocation of protective resources among the P facilities of a median system so as to minimize the worst-case impact of loosing a specified number of facilities. Protection models such as RIMF can be formulated as bilevel mixed integer programs where interdiction problems are used in the lower level to evaluate the worst case losses in response to the defensive strategies identified in the upper level [2]. These protection models generally assume that the number of possible losses is fixed and perfectly known to the defender. Given the large degree of uncertainty characterizing terrorist attacks and other external system disruptions, this assumption should naturally be relaxed. In this paper, we extend RIMF to include random numbers of possible losses. We assume that a potential attacker is able to interdict at most R facilities and associate with each r = 1,…,R, a probability pr which expresses the likelihood that the attacker will interdict exactly r facilities. The objective of the stochastic RIMF (S-RIMF) is to identify the protection strategy which minimizes the expected cost of worst-case interdictions across all possible values of r.

Although the bilevel formulation of the S-RIMF is a straightforward generalization of its deterministic counterpart, the solution methods proposed in [2] and [3] to solve RIMF cannot be easily adapted to solve the stochastic problem. In this paper, we present a novel single level, max-covering type formulation for S-RIMF. The formulation entails the complete enumeration of all possible interdiction patterns for each value of r. It is clear that the size of these models grows very rapidly with increasing values of P and R. In

order to solve problem instances of realistic size, we propose some model reduction techniques which are based on the computation of lower and upper bounds to the stochastic objective function value. These bounds provide valuable information which can be used to eliminate some of the problem constraints and to fix some model variables to their optimal values. Overall, the use of the proposed bounds can reduce the models' dimension by nearly 99%. This notable reduction allows us to find optimal protection strategies against millions of possible interdiction responses. We also present a heuristic concentration type approach to solve S-RIMF. The heuristic consists of two phases. In the first stage a deterministic RIMF is solved for every r in order to identify a core set of candidate facilities for protection. In the second stage, an implicit enumeration scheme circumscribed to the core set of facilities is used to generate potentially optimal solutions. Different variants of this two-phase heuristic are tested and compared against the exact solution approach. Results of extensive computational experiments conducted on several data sets, with different combinations of the problem parameters and for different probabilities distributions of the number of potential losses are also presented. The heuristic approach is able to find the optimal solution for almost every problem solved. The computing time of the exact approach is very competitive and of the same order of magnitude of the time required to solve the deterministic problems. Overall problem instances of significant size can be solved in modest computing time by the two approaches. Some remarks and comparison between the solutions of the deterministic problem and the ones of the stochastic problem conclude the presentation.

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# Designing Robust Coverage Networks to Hedge against Worst-Case Facility Losses

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## Abstract

The potential for long-term facility loss has important implications for the reliability of service/supply networks. In order to design a coverage-type service network that is robust to the worst instances of facility loss, we develop a location-interdiction covering model that maximizes a combination of 1) initial coverage given p facilities and 2) the minimum coverage level following the loss of any subset of facilities $r < p$. The problem is formulated both as a mixed integer program and as a bilevel mixed integer program. To solve the bilevel program optimally, a decomposition algorithm is presented, whereby the original bilevel program is decoupled into an upper level master problem and a lower level subproblem. After sequentially solving these problems, information is fed back to the upper level master by appending supervalid inequalities, which attempt to force the upper level master away from clearly dominated solutions. Supervalid inequalities, unlike standard valid inequalities used in cutting plane algorithms, cut away parts of the feasible region but are guaranteed not to remove all optimal solutions unless an optimal solution has already been found. Computational results show that when solved to optimality, bilevel decomposition is up to several orders of magnitude faster than performing branch and bound on the mixed integer program. Finally, various extensions, including optimizing over multiple values of r facility losses as well as a stochastic version of the problem in which facilities can vary in terms of their susceptibility to destruction, are also considered.

# Risk Management in Uncapacitated Facility Location Models with Random Demands

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## Abstract

In this talk we consider the classical uncapacitated facility location model with probabilistic and correlated demands at different nodes. Motivated by the mean-variance approach borrowed from the finance literature, the model is recast in a stochastic environment with several risk factors that effectively captures the probabilistic and correlated nature of the demand. Thereafter, by using a new solution methodology that adopts the "Value-at-Risk" (VaR)" measure within the framework of a location problem (by seeking location sites that maximize the lower limit of future earnings based on a stated confidence level), the problem is formulated as a non-linear integer program. The primary focus of the talk will be to describe the development and implementation of a branch-and-bound algorithm that utilizes a second-order cone program (SOCP) solver as a subroutine to solve this problem. Computational results will also be provided for small to medium sized problems.

# Facility Reliability Models:
# Preparing random and non-random failures

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## Abstract

In the aftermath of some recent high profile events such as Hurricane Katrina or the terrorist attacks of September 11, 2001, attention has focused on hardening critical infrastructures. There is a clear trade-off between the level of investment in hardening and the degree of disruption costs associated with facility failures. Failure costs can be measured by the increase in operating costs after a disruption that my result in major parts of the infrastructure becoming inoperable; larger investments in hardening will result in smaller increases in operating costs after a disruption. In this work, we discuss two versions of facility reliability models to hedge against the events of random and non-random facility disruptions, respectively.

In the first model, we consider a facility location problem in the presence of random failures (such as a natural disaster) where the facilities can be hardened with additional investments. For example, increased investments in the levies surrounding New Orleans will protect the city from more severe hurricanes. To solve the resulting mixed integer programming problem, we develop a Lagrangian Relaxation-based solution algorithm that is effective and quick. In addition, we derive structural properties of the model and show that for some values of the failure probability, the problem reduces to the classical uncapacitated fixed charge location problem (UFLP). Finally, we summarize the managerial guidelines suggested by the model.

In the second model, we consider a defender/interdictor location problem for preparing against the terrorist attacks. The problem results in a bi-level optimization problem which is very difficult to solve for the large problem instances. In our model, the outer problem represents the defender, and the inner level problem represents the actions of the interdictor or terrorist. We outline a genetic algorithm for solving such problems by capturing the actions of the two opposing parties in two separate populations. Computational results will be presented for this problem and some other key issues will be addressed.

# Profit-Maximizing Service System Design with Elastic Demand and Congestion

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## Abstract

The service system design problem seeks to locate a set of service facilities, allocate enough capacity for the customer demand to each of them so as to maximize facilities overall profits. Demands for service that originate from the nodes are assumed to be Poisson distributed and the servers provide service time that is exponentially distributed. Average demand rate at each node is assumed to be a decay function of travel time and waiting time in the facility. Price offered by the facilities are considered to be uniform and known in advance. Facilities revenue is the product of price and the overall demand captured by facilities and facilities cost is the sum of fixed costs of opening facilities and acquiring service capacity. Each facility is expected to ensure that the waiting time in each facility will not increase an acceptable level. This problem (without elastic demand assumption) is commonly known in the location literature as the facility location problem with immobile servers, stochastic demand and congestion. It is often set-up as a network of M/M/1 queues and modeled as a nonlinear mixed-integer program. The problem is formulated and analyzed and exact and approximate solution approaches are developed.

# Commercial Territory Design with Joint Assignment Constraints: A Heuristic Approach

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## Abstract

The *territory design problem* is concerned with grouping small geographic areas into larger geographic clusters called territories in such a way that the latter fulfill certain planning criteria. In commercial companies, the aim of territory design is to partition the set of customers they serve into manageable-sized territories and is motivated by changes in the number of their customers or the demand of these customers. It is often required to balance the demand among the territories in order to delegate responsibility fairly (Kalcsics, Nickel, and Schröder, 2005). The problem addressed in this paper is motivated by a real-world application in the city of Monterrey, Mexico. A beverage distribution firm wishes to partition the city area into disjoint territories that are suitable for their commercial purposes. In particular, the firm is concerned with the following criteria: (i) *balancing* with respect to two different *activity measures* (number of customers and demand), (ii) *contiguity* of each territory, so that each *basic unit* (BU) can reach each other by traveling within the territory; (iii) territory *compactness*, so that customers within a territory are relatively close to each other; and (iv) *joint assignment* of BUs, so that specified pairs of BUs must be assigned to the same territory in the design.

Although several commercial territory design approaches have appeared in the literature, the specific features present in this concrete problem make it very unique, and it has not been addressed before to the best of our knowledge. Vargas-Suárez, Ríos-Mercado, and López (2005) studied a similar problem without compactness and joint assignment constraints and where the objective was to minimize the unbalance among territories. More recently, Ríos-Mercado and Fernández (2008) studied the problem considering compactness and contiguity but without joint assignment constrains. A more extensive survey on many territorial design applications and methods can be found in Kalcsics, Nickel, and Schröder (2005).

The problem can be modeled using a graph $G = (V, E)$, where each BU (geographical block) is represented by a node $i \in V$ and an arc connecting nodes $i$ and $j$ exists in $E$ if

units *i* and *j* are adjacent blocks. Each node has three properties: geographical coordinates (*cix, ciy*), and two measurable activities. Let □*ia* be the value of activity *a* at node *i*, where the first activity, *a = 1,* represents the number of customers within that BU and the second activity, *a = 2,* represents the total demand of the BU. The number of territories *p* is fixed and given as a parameter. Each BU must be assigned to only one territory.

One of the desired properties in a solution is that the territories be balanced with respect to each of the activity measures, nevertheless, the discrete structure of the problem and the unique assignment constraint make it practically impossible. To overcome this difficulty we measure the degree of balance by computing the *relative deviation* of each territory from its average value μ*a* of activity *a* that is $\mu^a = \omega^a(V)/p, a = 1,2$. We are also given a collection *H* of pairs of nodes such that [*i, j*] ∈ *H* implies that node *i* and node *j* must be assigned to the same territory. One way to handle the requirement of compactness is to assign one node in each territory to be the territory center, denoting the center of territory *k* by *c*(*k*) and then define a distance measure such as $f(V_1, V_2, \ldots, V_p) = \max_{\substack{k=1,\ldots,p \\ j \in V_k}} \{d_{c(k)j}\}$, referred as (1), over the *p* territories, *dc*(*k*)*j* represents the Euclidean distance from node *j* to center of territory *k*. The problem can be thus described as finding a *p*-partition of *V* that satisfies the specified planning criteria of balancing: $(1-\tau^a)\mu^a \leq \omega^a(V_k) \leq (1+\tau^a)\mu^a \quad \forall k$, referred as (2), contiguity, and joint assignment, that minimizes the above distance measure (1). This problem can also be modeled in terms of integer programming as a *p*-center problem with additional constraints on capacity, contiguity and joint assignment.

The proposed GRASP algorithm starts with an infeasible territory assignment in which each BU is assigned to a singleton territory, $V^0 = (V_1, \ldots, V_n)$ with $V_i = \{i\}$. We now describe each of the components of the algorithm:
*Pre-processing:* The aim of this phase is to assure first the joint assignment of basic units. One way to do this is to find, for each (*v, w*) in *H*, a path *P* in *G* between *v* and *w* and then by merging all territories that contain one or more nodes in the path *P*. For additional diversity of solutions, in the spirit of GRASP, instead of using always the shortest path, we compute *k* shortest paths (Martins, Pascoal, and Santos, 1999) between the BUs and randomly select one of these paths.

*Construction:* After the pre-processing phase, the number of territories is larger than *p*. We decrease the number of territories by iteratively merging adjacent territories two at a time until *p* territories remain. However, this solution might not be feasible with respect to the balance constraints (2). The two territories to merge are chosen using a greedy function that weighs both a *distance-based dispersion measure* $f(V_k) = \max_{i,j \in V_k}\{d_{ij}\}$ and the relative violation of the balance constraints (2). Let us define $\omega^a(V_k) = \sum_{i \in V_k} \omega_i^a$ as the *size* of the $V_k$ with respect to activity *a*. Let $V_i$ and $V_j$ be two adjacent territories (territories connected by at least one edge in *G*), let us define their *greedy function* as $\phi(V_i, V_j) = \lambda\, f(V_i \cup V_j) + (1-\lambda) G(V_i \cup V_j)$, where λ is a user-defined parameter, and

$G(V_i \cup V_j) = \sum_{a \in A} g^a(V_i \cup V_j),$ with $g^a(V_k) = (1/\mu^a)\max\{\omega^a(V_k) - (1+\tau^a)\mu^a, 0\}$ as the sum of the relative infeasibilities with respect to the upper bound of the balance constraint of activity *a*. The candidate list is restricted (RCL) by a quality parameter α, so in a given iteration a pair ($V_i$, $V_j$) is chosen randomly from the RCL and the partial solutions is updated.

*Post-processing:* This phase consists of a local search procedure. The goal of this phase is both to reduce the (possible) infeasibility with respect to the balance constraints and to improve the value of the objective function. The local search uses a *merit function* that weighs both the infeasibility of the balance constraints and the objective function. For a partition $S = \{V_1, \ldots, V_p\}$, the merit function is given by $\psi(S) = \gamma F(S) + (1-\gamma)I(S)$ , where *F*(*S*) is the dispersion measure given by $F(S) = \max_{k=1,\ldots,p}\left\{\max_{j \in V_k} d_{c(k)j}\right\}$ and *I*(*S*) is the sum of the relative infeasibilities of the balance constraints. The *I(S)* function is similar to the function $G(V_k)$ used in the construction phase but it considers the violation of the balance constraints over the *p* territories. We define two neighborhoods: *N1*(*S*) consists of all partitions *S'* reachable from *S* by moving a basic unit *i* from its current territory *t*(*i*) to the territory of another BU *j* such that the edge $(i, j) \in E$ and $t(j) \neq t(i)$. *N2(S)* consists of all partitions *S''* reachable from *S* by swapping two basic units between their respective territories.

For the experiments, we generated problem instances based on real-world data provided by the industrial partner. Planar maps were randomly generated in the [0; 500] x [0; 500] plane. The node activities and the joint assignment constraints were generated as suggested by the industrial partner. We experimented with data sets consisting of 30 instances with size $n = 500$ and $n = 1000$, in both cases we use $p = 20$. For each data set we evaluate tolerances of deviation for the balancing constraints with values of 5, 10, and 20 % (i.e., $\tau^a = 0.05, 0.1, 0.2$). Among the most significant conclusions we highlight the following. About the GRASP quality parameter, α, our experiments show that among the values evaluated (0.0, 0.01, 0.02, 0.03, 0.04) the values of 0.01 and 0.02 yield the best results in quality of solution and number of feasible solution found. We also run the method for different number of iterations, and it was found that major improvements in the value of the objective function tend to occur during the first 500 iterations, i.e., solution improvement afterwards is very marginal. About the local search procedures, we found that a best strategy is to use *N1* first and then *N2*, particularly when the solution found in the construction phase is infeasible with respect to the balancing constraints. An explanation for this is due to the fact that balancing violation changes more rapidly when a unit is reassigned to a different territory than when two units are swapped. The overall procedure turned out to be very effective, finding feasible solutions to all instances tested, something hard to achieve with existing methods employed by the firm.

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# Cannibalization in a Competitive Franchise Environment

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## Abstract

In this paper the issue of cannibalization in franchises is investigated. We analyze maximizing corporate market share while minimizing franchisees cannibalization using the gravity (Huff) model. The efficient frontier according to these two non-compatible objectives is constructed and illustrated on an example problem.

# A Continuous Time Dynamic Model of Competitive Facility Location

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## Abstract

In this paper, we present a continuous time dynamic Stackelberg game-theoretic model of location of a firm on a network previously populated by Cournot-Nash oligopolistic competitors producing a homogeneous product consumed at distinct population centers (nodes). We show how different varieties of this problem may be formulated as optimal control problems and as mathematical programs with equilibrium constraints in an appropriate Hilbert space. We suggest some algorithms based on finite difference approximations, hierarchical mathematical programming, and commercial MPEC software. A numerical example of one or more of these algorithms is provided.

# A continuous analysis framework for the solution of location-allocation problems with dense demand

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## Abstract

The standard approach to solving location-allocation problems is to model alternative location sites and customers as discrete entities. Many problem instances in practice involve dense demand data and uncertainties about the cost and locations of the potential sites. The use of discrete models is often ineffective in such cases. We present an alternative methodology where the market demand is modeled as a continuous density function over a market region and the resulting formulation is solved by means of calculus techniques. The method prioritizes the allocation decisions rather than location decisions, which is the common practice in the location literature. Extensive computational experiments confirm the efficiency of the proposed methodology.

# Designing Connected Territories for a Beverage Distribution Firm with a Location-Allocation Scheme

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## Abstract

Territory design may be described as the problem of grouping small geographical units into larger geographical clusters called territories. This kind of problems has many different applications such as sales and service territory design, political districting, design of school districts, social facilities, and emergency services. For an extensive survey on applications, models, and algorithms for territory design see Kalcsics, Nickel, and Schröder [3].

The problem studied in this paper is motivated by a real-world case from a beverage distribution company. This company needs to group geographically its customers in the city according to some planning criteria. The company requires balanced territories (similar in size) with respect to each of two different activity measures (number of customers and sales volume). Territory contiguity is also necessary, that is basic units (in this case these units are city blocks) can reach each other by traveling within the territory. In addition, compact territories are desired, that is, customers within a territory are relatively close to each other; and finally it is desired a fixed number of territories $p$.

A similar problem was proposed by Ríos-Mercado and Fernández [4], but in this work, a different function for measuring dispersity is considered. A relaxation of this problem has been optimally solved in instances with size of 300 basic units as maximum, larger instances have not been solved in reasonable time. The real instances are larger than 500 basic units, so the use of heuristics and other approximate methods is necessary.

In the literature a technique called location-allocation has been studied and applied with relative success to solve problems with similar features. This scheme consists of a two-stage iterative process where territory centers are first located and then customers are allocated to centers. However, this technique has been designed to solve only problems

involving single balancing constraints. In our work this location-allocation idea is extended and an algorithm to handle both multiple balancing and contiguity constraints simultaneously is proposed. The proposed location-allocation-based heuristic is followed by a local search phase designed to improve solution quality. These phases (location, allocation and local search) are iteratively performed until a stopping criterion is met. The overall description of proposed algorithm is as follows:

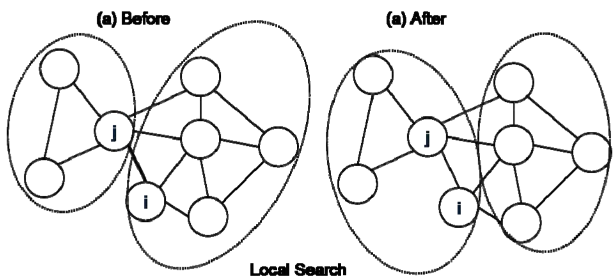
- Location Phase. In this phase a new configuration of territory centers is obtained based on the solution found in the previous iteration. The best center for each current territory is easily recalculated as the node with the minimum of the maximum distances to each other node within the territory. This means, a 1-median problem is solved for each territory. It is important to emphasize that at the beginning we do not have a configuration of territory centers. To obtain the required initial configuration, a GRASP heuristic proposed by Caballero-Hernández et al. [1] for a similar territory design problem was used.

- Allocation Phase. The configuration of the centers located in the previous phase are used as input to this phase. The number of variables and constraints in the original problem is considerably reduced because the configuration of the center is known, but the resultant problem is still a hard problem. Then, a new formulation is proposed to take advantage of the problem structure and also to get better balanced territories. So, by relaxing the integrality constraints the resulting model used in this phase is basically a linear transportation problem. This model is efficiently solved by the Simplex method. It is necesary to mention that there are two subproblems, one for each activity. In the optimal solution of each subproblem the territories are perfectly balanced. However, it is possible that the unique assignment constraint is not longer satisfied due to the use of a relaxation of the integer variables. This means that some basic areas could be assigned to two or more territories. These basic areas are called split areas or just splits.

- Split Resolution problem. The split problem consists of deciding wich territory the split area will be assigned to. The following ordered criteria are used:

  - Connectivity repairing: First, every split node is inserted to a non connected territory where the addition of this node repairs the connectivity of a possible nonconnected territory.
  - Prevention of nonconnectivity: A split node that causes the territory to become not connected is avoided.
  - Balancing: The node is assigned to a territory that causes the least violation to the balancing constraints. If no violation occurs, go to the next rule.
  - Compactness: Finally, the node is assigned to the territory causing the lowest increase in dispersion.

- Local Search. A neighborhood N(S) consists of all solutions reachable from S by moving a basic unit i from its current territory t(i) to a neighbor territory t(j), where j is the corresponding basic unit in territory t(j) adjacent to i, without creating a non-contiguous solution. Such a move is denoted by move(i, j) and is illustrated in the figure, where move(i, j) is represented by arc (i, j) (depicted in bold). Note that move(i, j) is allowed only if the resultant territory is connected (which is always the case if arc (i, j) exists). In practice an additional stopping criterion, such as limit_moves, is added to avoid performing the search for a relatively large amount of time. So the procedure stops as soon as a local optimal is found or the number of moves exceeds limit_moves. For evaluating the move benefit a weigthed merit function given by $\psi(move(i,j)) = \lambda F(move(i,j)) + (1-\lambda)G(move(i,j))$ is used, where $F(move(i,j))$ is the dispersity function cost variation and $G(move(i,j))$ is the balance constraint violation associated with move(i, j).




- The algorithm was implemented in C++, using the CPLEX callable library [2], and tested on randomly generated instances based on data from our industrial partner. The size of the instances tested is 500, 1000, and 2000 basic units with tolerance levels of 10 and 5%. We highlight the following results:

- The location-allocation phase works very efficiently, finding good solutions in relatively fast computation times. The local search phase was an excellent addition to the procedure since it was able to significantly improve the solutions obtained from the allocation phase. It was observed that the overall execution time did not significantly increase even when larger instances were tested. This is due to the nature of the procedure, that is, the most expensive part in the algorithm is the resolution of the splits, but the number of splits is determined by the number of desired territories p. So, this technique has a good behavior when the number of desired territories is small compared to the number of basic areas, even in large instances.

- In a given iteration, the method does not guarantee a feasible solution respect to the connectivity constraints. However, it was observed that the procedure designed to solve the splits was very effective since over 90% of the times it gave connected solutions. So, in practice, given the algorithm takes around 40-50 iterations to converge, it was always possible to find a feasible solution to each instance tested.

- The results show the efectiviness of the proposed approach, as it was able to obtain solutions of good quality (in terms of its compactness measure and feasibility with respect to the balancing constraints).

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# Multi-Facility Weber Problems with Facility Clusters

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## Abstract

We consider the multi-Weber location problem with allocation interdependencies. In addition to the problem of locating the new facilities in the plane and allocating the existing facilities to minimize the total transportation costs, allocation constraints induced by a pre-clustering of subsets of the existing facilities must be respected. Consequently, instead of allocating existing facilities individually to their closest new facility, the demand of complete subsets of existing facilities must be covered simultaneously by the same new facility.

Besides the classical multi-Weber problem, also the connection location-allocation problem is an example covered by this model. Here, flows between pairs of existing facilities must be routed through connection facilities. Relations can also be drawn, for example, to location problems with regional demand. Applications include the location of distribution facilities where each facility cluster represents, for example, the branches of one particular company or groups of customers demanding the same product. Similar problems occur in the design of telecommunication networks where clusters of clients must be connected via one single server.

# The Capacitated p-Center Problem with Multiple Allocation

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## Abstract

In p-center problems we have to partition a set of customers into exactly p clusters. A cluster is defined both by the location of its facility and by the set of its customers. There is a given cost for assigning each customer to each facility, and we want to minimize the maximum assignment cost among all the customers. These are discrete location problems, since facilities must be located within a given set of potential locations. In the Capacitated p-Center Problem (CpCP) each customer has also a known demand and each potential location a known capacity. Each cluster must be such that the total demand of all its customers does not exceed the capacity of its facility. Thus, CpCP is the problem of finding the set of p locations and the assignment pattern that satisfies the capacity constraints where the maximum assignment cost is as small as possible. Usually, in p-center problems it is required that the demand of each customer is served from one single open plant. However, there are potential applications where it is possible to satisfy the

customers demand from more than one open plant. These include, for instance, the location of blood banks or the planning of public school districts. Also, capacity constraints can be considered in the location of emergency facilities to avoid server unavailability. In capacitated versions of p-center problems, this issue can lead to different optimal solutions than when single allocation is required. Thus, in the Capacitated p-Center Problem with Multiple Allocation (CpCPM) we assume that service to each customer is not required to be provided from one single center; i.e., it is allowed that different plants serve fractions of its demand. As opposed to the single source version of the problem, to the best of our knowledge, the CpCPM has not been studied in the literature.

In this work, we propose a formulation for the CpCPM that is related to that proposed in [1] for the Uncapacitated p-Center Problem, since together with the classical location variables, auxiliary radius variables are used to indicate what is the maximum distance between a customer and its associated plants. The particularity of our model is that we do not use additional decision variables and, in particular, we do not use the classical assignment variables for location problems with multiple sourcing that indicate the proportion of the customer's demand that is satisfied from an open plant. Actually, the solutions of our model only provide sets of facilities to open for which feasible assignments (with respect to the capacity constraints) exist. Nevertheless, in the considered setting, once the optimal set of facilities is found, a feasible assignment of customers within this set can be obtained by solving a transportation problem.

The formulation that we propose contains an exponential number of inequalities to model the capacity constraints that ensure that the demand of all customers can be satisfied from the set of open facilities. In this setting it is important to prove that the capacity inequalities can be separated by solving a Knapsack Problem. Therefore, we address the solution to the CpCPM (and its LP relaxation) by means of an iterative cut generation algorithm. Finally, we present an exact branch and cut algorithm for the CpCPM that combines the above cut generation procedure for the LP relaxation to the CpCPM and an enumeration tree.

The results of some preliminary computational experiments are reported. These experiments are twofold, on the one hand, we test the efficiency of the proposed algorithm and, on the other hand, we compare the structure of the solutions of the CpCPM with those of the Capacitated p-Center Problem.

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# Analysis of Facility Location Using Order Rectilinear Distance in Regular Point Patterns

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## Abstract

This paper deals with a facility location problem with closing of facilities. When some existing facilities are closed, not only the distance to the nearest facility but also the distances to the *k*th nearest facility are important. For example, when locating emergency facilities such as hospitals, fire stations, and refuges, the second and third nearest distances should be taken into consideration. This paper analyses facility locations using the *k*th nearest distance.

We focus on the *k*th nearest rectilinear distance for regular and random point patterns. The regular patterns that we consider are the square and diamond lattices. The actual distribution of public facilities can be regarded as the intermediate pattern between regular and random patterns. The theoretical results of the extremes of regular and random will give useful information to empirical studies.

The problem is to find the optimal pattern that minimizes the average rectilinear distance from residents to their nearest open facility when some existing facilities are closed. To obtain the average distance, the probability density functions of the kth nearest rectilinear distance are theoretically derived for $k$ =1, 2,..., 8 for two regular point patterns. Upper and lower bounds of the kth nearest distance are also derived. Assuming that facilities are closed independently and at random, we show that the diamond lattice is optimal if at least 73% of facilities are open.

# Line Location And Robust Regression

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## Abstract

The line location problems consists of finding an optimal line shaped facility in the two-dimensional space. It was first considered by Wesolowsky (1). Nowadays it is a well analyzed extension of classical facility location theory, see (4) for a survey. Possible applications include the planning of new railways or motorways or the location of pipelines, drainage or irrigation ditches. Line location problems are also known in computational geometry. Here they are called *linear* $L_1$ or $L_\infty$ *approximation problems*. Another field in which line location problems appear are statistics. Catchwords are *absolute errors regression*, $L_1$ *regression* or *vertical* $L_1$*-fit problems*, for example.

Although line location problems are important in location theory and statistics, there is no common way to treat such problems. A reason is that location theory focuses on low dimensional problems (mostly 2-d) and statistics are also interested in higher dimensions. Nevertheless, the locational point of view provides some fruitful approaches to statistical problems. In this talk we present such an approach. We discuss how location tools can be used to compute robust estimators for regression models.

In simple regression one assumes a relation of the type

$$y_i = \beta_0 + \beta_1 x_i + \varepsilon_i$$

in which $x_i$ is called the explanatory variable, $y_i$ is the response variable and $\varepsilon_i$ is the error term. The intercept $\beta_0$ and the slope $\beta_1$ have to be estimated from the data

$$\{(x_1, y_1), \ldots, (x_n, y_n)\}.$$

If the error terms are normal distributed, then the popular least squares method (LS)

$$\min_{\beta_0, \beta_1} \sum_{i=1}^{n} (y_i - \beta_0 - \beta_1 x_i)^2$$

works very well. But LS has a lack of robustness. If the error terms do not satisfy the normal distribution, it happens that LS computes very bad solutions (3). In order to treat such contaminated data, estimators were developed that are not much affected by violations of the normal distribution assumption. Such estimators are called *robust*. A robust estimator is least trimmed squares (LTS) given by

$$\min_{\beta_0,\beta_1} \sum_{i=1}^{n} \left[ (y_i - \beta_0 - \beta_1 x_i)^2 \right]_{(i)} ,$$

where $1 \leq k \leq n$ and $[\cdot]_{(i)}$ denotes the $i$-th order statistic. It was introduced by Rousseeuw (2). LTS has some nice statistical properties but one disadvantage - it is hard to compute. As far as the authors are aware, there is no polynomial time algorithm known to compute a LTS regression line.

In this talk we study the k-closest median line location problem, which contains the LTS problem as special case. The k-closest median line location problem consists of finding a straight line that minimizes the distance to the k-closest demand points. This problem is equivalent to solving

$$\min_{A \in \mathrm{A}, l \in L} g(A,l) \quad \text{with} \quad g(A,l) := \sum_{m \in A} d(D_m, l),$$

where $\mathrm{A} = \{A \subset \{1,...,M\} \ : \ |A| = k\}$. The k-closest median line location problem can be solved efficiently if the distance $d$ is induced by a norm. But in order to handle LTS as k-closest median line location problem, we are interested in the squared vertical distance. In case of this distance more effort is needed to solve the problem. It is possible to solve the problem for all subsets $A \in \mathrm{A}$. This leads to a finite dominating set (FDS for short) consisting of all optimal solutions of the k-closest median line location problem with fixed $A \in \mathrm{A}$. But the size of this set is $O(M^k)$, hence evaluating all elements is inefficient for large $M$. Therefore we use geometric duality in order to compute a smaller FDS: We derive a necessary condition for $A \in \mathrm{A}$ ensuring that the solution of the k-closest median line location problem with fixed $A$ coincides with the solution of the unrestricted problem. Using this condition we are able to compute an FDS of size $O(M^2)$. For the case of the weighted k-closest median line location problem we derive an FDS of size $O(M^4)$. Moreover, we discuss how to extend the presented approach to line location problems with ordered median objective [5], [6].

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# On the location of circles with type k-centrum criteria

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## Abstract

Given a set $P$ of $n$ points in the plane, the median circle problem consist in finding a circle minimizing the sum of distances to the points of $P$. The radius of such a circle is the median of all distances and the center is the point at which the mean absolute deviation of the distances to the points is minimized [1]. As a consequence, the median circle problem is a non-combinatorial problem. On the other hand the center circle problem is equivalent to the minimum width enclosing annulus problem, for which an optimal solution exists verifying that at least two demand points are on the inner circle and two on the outer circle [2]. As a consequence for the center circle problem a finite dominating set exists, yielding to a combinatorial problem.

The k-centrum circle problem consists in finding a circle minimizing the sum of the $k$ largest distances to the points of $P$ and generalizes the median circle problem (resulting when $k = n$) and the center circle problem (resulting when $k = 1$). In this paper we examine the combinatorial and non-combinatorial properties of the k-centrum circle problem and procedures to solve this problem are also discussed.

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# Locating a minisum circle in the plane

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## Abstract

We consider the problem of locating a circle with respect to existing facilities in the plane such that the sum of weighted distances between the circle and the facilities is minimized, i.e., we approximate a set of given points by a circle regarding the sum of weighted distances. If the radius of the circle is a variable we show that there always exists an optimal circle passing through two of the existing facilities. For the case of fixed radius we provide characterizations of optimal circles in special cases. Solution procedures are suggested and some computational experience is reported.

# A model for urban hierarchy and transportation network planning

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## Abstract

Regional development planning is usually concerned with the integration of policies and actions determined at a higher administration level (e.g., central administration) with specific local development interests (at the municipality level). In this context, spatial development plans are seen as integrated plans where the investment decisions on education, health, justice, transportation (roads), etc, are combined into a whole so as to assure sustainable and coherent regional development.

This presentation addresses a kind of problem that arises frequently in regional development planning. The setting for the problem is as follows. Suppose a region with N urban centers and M links connecting the centers. The centers differ in the class of facilities they accommodate (there are L classes of facilities). A different level of service in education, health care, justice, etc, is associated with each class of facilities (lower-level services may always be obtained from the higher-level facilities). People require all levels of service and travel to the closest level-l center to obtain level-l services. The links differ in the cost per length unit to traverse them. There are T types of links and a smaller cost is associated with higher-level links. The problem is to decide which centers and which links should be upgraded to a higher level so as to maximize the accessibility of population to service.

For addressing the problem we developed an integrated multi-level location and network design model. The objective of the model is to minimize the weighted total distance that people have to travel to obtain the various levels of services. Two fixed points in time are considered – the present and the planning horizon. Different weights for different levels of service and for different time periods may be used to reflect the different usage frequencies (higher frequency would normally be associated with lower levels of service) and the different importance assigned to present or future accessibility gains. The model takes into account the fact that decisions have a significant influence on the spatial distribution of population growth. Thus, the demand for service in the planning horizon is determined endogenously. The model is extremely difficult to solve to optimality. VNS and TS heuristic methods are developed and compared from the standpoint of solution

quality and computing effort on a representative set of test instances. The usefulness of the model is illustrated for a case study involving real-world data.

# Dynamic School Network Planning in Urban Areas

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## Abstract

Long term school network planning in urban areas is a difficult task because of unstable number of students over time and space. This becomes even more difficult if students are free to choose the school to enroll on. In most parts of Germany students are free to choose the secondary school to enroll on and thus there exist no school districts. Moreover, it is assumable that there exist substitution patterns between school locations. Therefore, a deterministic student assignment is not appropriate. The paper presents a mathematical programming approach to deal with the Dynamic School Network Planning Problem (DSNPP) with free school choice. The most striking difference of this new approach compared to the literature is that the decision on the student allocation and the decision which school to open or close in a given period could not be modeled simultaneously. This is because students are not allocated to schools in a deterministic way. In fact, students are allocated to available (open) schools according to empirical expected choice probabilities based on utility maximization. The school choice probabilities are determined by a mixed multinomial logit model (MMNL) since this formulation is the most convenient way to model flexible substitution patterns between choice alternatives (schools). Concerning the mathematical program the school choice probability is a model parameter by definition. Unfortunately, they depend on the available (open) schools, denoted by a model variable. To solve this conflict we have to consider a two step large scale optimization approach:

1. First, we enumerate all possible combinations of opened and closed schools (scenarios). For all feasible[1] depending on total number of students and capacity of all open schools combinations of periods and scenarios we compute the school choice probabilities. For these combinations we allocate the students to available schools minimizing the deviation from the empirical expected school choice probabilities and the overrun of schools. In order to avoid cohorts we just consider newly enrolled students ('freshers') for this Quadratic Constrained Program (QCP) and deduce total student numbers. Considering cohorts would complicate the problem in the way that we have to consider every scenario for each cohort. The QCP has to be solved for all feasible combinations of scenarios and periods. The result of the first step are the discounted scenario costs per period (including location and transport costs).

2. We select one scenario for each period in the way that the total costs over the

[1] depending on total number of students and capacity of all open schools

whole planning horizon and the costs for opening or closing a school are minimized. To consider the opening and closing costs in the objective function of this Mixed Integer Program (MIP) explicitly we have to implement the corresponding binary variables in the constraints. These constraints force the according variables to equal one (close or open a school), if in two successive periods different scenarios are selected and if only one of these scenarios contains the considered school.

We apply this approach on the college network of the City of Dresden, Germany. We consider more than 32 000 scenarios. Using two parallel tasks on a dual-core AMD Opteron 880 (2.4 GHz and 8 GB RAM) with GAMS/Cplex 22.2, the computational time of step 1 is more than 5 days considering 25 periods, 26 college locations and more than 4000 demand points (blocks). The time of CPU usage for step 2 is 13 hours. Our example shows a cost saving of 10 per cent (2 million Euro per period).

# Crossdocking Network Design with Load Balancing and Operational Considerations

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## Abstract

Crossdocking strategy has become an attractive distribution option as it could potentially reduce the overall inventory in a supply chain. It eliminates inventory at intermediate distribution facilities by moving products from suppliers to destinations through distribution centers in which products are not stored and only minimal handling takes place. However, the lead time experienced by a customer could be higher in crossdocking systems than in warehousing systems. Since the lead time experienced by customers is a key determinant in the successful implementation of crossdocking and is a function of the network topology, lead time considerations should be included at the strategic planning stage.

In addition to lead time management, both inventory management across the supply chain and load balancing at crossdocking centers are critical to realize the benefits of crossdocking. Since not only the amount of in-transit inventory but also the overall system inventory depends on the network topology, operational and tactical issues such as inventory management and load balancing should be considered in designing the distribution network.
In this research, we study an integrated crossdocking network design problem for a two-stage and single product supply chain. We locate crossdocking centers each of which serves a set of retailers while minimizing the sum of the location costs for crossdocking centers and inventory and transportation related costs across the supply chain ensuring that the limited service rate of each crossdocking center is not violated. Our model incorporates lead time and inventory management including load balancing at crossdocking centers into the design of distribution networks.

Products are shipped from a single production facility to regional crossdocking centers according to their final destination. After arriving at a crossdocking center, products go through the required processes such as sorting, packaging, and final assembly at that crossdocking center, and then are immediately distributed to each retailer where the deterministic demand for the product occurs. Thus, the total logistics cost includes the cost of locating crossdocking centers, pipeline inventory cost during transportation as well as wait time for a batch, transportation cost from the plant to the retailers via crossdocking centers, the cost associated with every order at the crossdocking centers, and the working inventory cost at the retailers.

Further, we introduce the maximum lead time restrictions so that lead time will be determined by not only the economical efficiency on pipeline inventory cost, but also customers' expectation of receiving the product within an acceptable period. We also require single sourcing. The detailed modeling of the lead time, which turns out to be a function of both the network topology and the size of the transportation batch from the plant to crossdocking centers, makes the model highly nonlinear.

We formulate the problem as a non-linear integer program. Given that the model is a generalization of the standard capacitated facility location problem, it is NP-Hard and thus we have developed a Lagrangian relaxation based heuristic to obtain near-optimal solutions with reasonable computational requirements for large problem instances. We also provide sensitivity analyses for each operational / tactical cost component which show the relationship between the operational / tactical decisions and the network design.

# The Connection Location-Allocation Problem

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## Abstract

Modeling the transportation of goods, material flows are given in the connection location-allocation problem between pairs of existing facilities. On their transport, the goods must pass a new facility which may represent a transshipment terminal or a processing facility. To minimize the total transportation costs, the allocation of the flows to the new facilities and the location of the new facilities must be determined.

We analyze this multi-facility location problem both from a theoretical and numerical perspective. Similarities and differences to the well-known multi-Weber problem are highlighted, an overview over exact solution methods and heuristic approaches is provided, and interesting model extensions are outlined.

# Equity in Semiobnoxious Facility Location Models

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## Abstract

When locating semiobnoxious facilities (facilities such as water treatment facilities, waste disposals or airports) we must take into account the two inherent contradictory characteristics of these facilities. They provide useful service to the surrounding communities but at the same time its proximity is noxious or at least disagreeable. Therefore, the location of semiobnoxious facilities is considered as a biobjective location problem. Both communities and potential facility sites are considered as nodes in a network where links represent the roads connecting communities and potential facility sites.

The semiobnoxious facility location problem is considered as a discrete biobjective location problem. Several biobjective discrete location models are presented for the semiobnoxious location problem. Capacitated and modular location models were considered. In the modular case the facility to be open in each potential site can be chosen from a set of possible facilities varying in the size and the impact in the environment due to the amount of pollution produced. The models presented differ also in the two objective functions considered. In some capacitated or modular models the two contradictory objectives are the minimization of the obnoxious effect and the maximization of the accessibility. The obnoxious effect is considered either as the total obnoxious effect produced by open facilities or as the maximum obnoxious effect suffered by some individual. Accessibility is also considered in terms of average and worst-case values. The obnoxious effect is measured considering the Euclidian distance and the accessibility considering the shortest path distance. Since costs are not considered in these models, in either of the objective functions, they are included as an additional constraint. We study the changes produced in the solutions obtained when an investment constraint is added to the models. In other models we consider as objectives the

minimization of the obnoxious effect and the minimization of total costs (transportation costs, fixed opening costs, fixed maintenance costs and service costs).

To obtain the non-dominated solutions for our biobjective problem an interactive method developed by Ferreira, Clímaco and Paixão (1994) was used. First the two lexicographic minima are calculated, delimiting, this way, the region where to find non-dominated solutions. Any non-dominated solution, either supported or non-supported, can be found by solving a location problem with only one objective (the weighted sum of the original objectives) and two additional constraints imposing some upper bound on the values of the original objectives. These bounds are chosen by the user, either explicitly by giving a sub-region in the objective space where to find non-dominated solutions, or implicitly by choosing a pair of non-dominated solutions candidate to be adjacent. Either this problem has an optimal solution and therefore a new non-dominated solution is obtained or it is unfeasible. In both cases it is possible to reduce the area where to search for new non-dominated solutions. The general solver CPLEX was used to solve the single criterion problem. The models that have non-linear objective functions are converted into linear models in order to use CPLEX.

The equity of the solutions obtained is an important issue since we are dealing with facilities with an inherent risk for the communities or at least providing a disagreeable environment. Therefore, the models presented were compared in terms of equity using two well-known equity measures: Gini's Coefficient and Hoover's Coefficient. Both coefficients were calculated considering that the equity of the solutions can be analysed by the average accessibility, or by the total obnoxious effect.

Computational results were obtained for randomly generated examples in an attempt to simulate two distinct real cases: location of waste treatment facilities that provide service for a large metropolitan area divided in sectors. In this case the facility location sites are external to the area where communities are located; location of semiobnoxious facilities in a given geographical area with several communities that will use the service provided by the facilities and will, at the same time, suffer its obnoxious effect. In this case the facility location sites are in the same pre-defined area among the communities they serve. Differences in equity were studied in both cases. The effect on equity when the function that measures the obnoxious effect varies was also studied. Two cases were considered: obnoxious effect proportional to the population and inversely proportional to the Euclidian distance; obnoxious effect proportional to the population and inversely proportional to the Euclidian distance square.

# Districting and Location in the Courts: The Making of the New Judiciary Map of Portugal

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## Abstract

Throughout the years, districting and location modeling techniques have been applied to an extremely wide variety of public facility types. However, to the best of our knowledge, they have never been used before to help making decisions on the spatial organization of a judicial system. In this paper, we describe the location component of a study made under contract with the Ministry of Justice to define a proposal for the new judiciary map of Portugal. This map is considered to be an essential constituent of the vast judicial reforms currently underway in Portugal. Indeed, the current map is the result of a long evolution with deep roots in the Middle Ages. It is based on very small jurisdictions ("comarcas") which in many cases are not consistent with the jurisdictions of institutions closely related with justice (such as local administration, police, or social security), and which do not favor the specialization of justice.

With the new judiciary map, the Ministry of Justice wanted to address the following main objectives: (1) respond to the judicial litigation levels expected to occur in the future (2015 was chosen to be the reference year); (2) adjust the jurisdictions of judicial institutions to the jurisdictions of related institutions; (3) promote the specialization of the judicial system; and (4) guarantee a good level of accessibility to courts.

For tackling the problems involved in the accomplishment of these objectives, we developed two optimization models – a districting model, to determine the borders of new, large jurisdictions for the organization of the judicial system; and a location model, to determine the location, type, size (measured in number of judges), and coverage area of the courts included in each new jurisdiction.

The solution given by the models signify a profound transformation of the Portuguese judicial system. Indeed, the existing 231 jurisdictions would be transformed into 40, 51 specialized courts would be open (but 17 labor courts would be closed), and 28 common courts would be closed. The number of judges would increase by 43, and 97 judge posts would have to change to a different tribunal. This solution was explicitly acknowledge as being at the basis of the proposal of new judiciary map recently submitted by the Government to the Parliament. If approved there, districting and location modeling techniques would have given a significant contribution to the reorganization of the judicial system of Portugal.

# Location with preferences

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## Abstract

A facility location problem consists in, given a set of potential facility locations and a set of customers who are to be served from the facilities, deciding which facilities are the most suitable to be opened and which customers should be served from which facilities so as to optimize a certain objective function.

A key element in facility location problems is how clients should be allocated to the facilities. Sometimes, the answer comes with the model itself. For example, in the well-known studied p-median facility location problem, the objective is to minimize the total distance the customers travel to the facilities; since there are no other requirements, every customer is always assigned to his nearest open facility.

Although most of facility location models do not have this closest assignment property, it is a reasonable assumption in many of them. Therefore, when it is desired or it is an external imperative that the nearest available unit serves the client, this property must be embedded in the model through some closest assignment constraints. Examples in public sector where customers are assigned to a facility and are denied access to any other via a law or fiat are schools, recycling centers and polling stations.

Conflict arises when the clients behave in a way which is not the most profitable for the locator element. The behaviour of a given client depends on many factors: client traits (age, sex, educational background, economic status...), characteristic of the site (production cost, availability of products...) and the route between the client and the site (freight cost, hazards in the route...). All this information can be translated into a set of constraints that are added to the original location model.

The Simple Plant Location Problem (SPLP) is a problem of common knowledge and which has been broadly studied because of its high interest: a set of customers has to be allocated to a set of facilities which offer a certain service in such a way that the total cost is minimized.

Therefore, it is a problem with two different components: one of location and another one of allocation. The location work is done by the firm which locates the plants. If the firm has the control of the allocation process or if the customers know the optimality criterium from the firm and they agree with it, then it is a SPLP situation. However, the firm may not be able to force the customers to obey this criterium and it is easy that customers' preferences do not match with the firm optimal allocation. This is the reason why these customers' preferences must be considered in the model, obtaining the so-called Simple Plant Location Problem with Order (SPLPO).

Unlike the SPLP, the SPLPO is a model which has been barely studied. The SPLPO formulation is the SPLP one together with the constraints which represent customers' preferences. This more accurate model is also much more difficult than the SPLP, whose NP-hardness is well-known.

This work will show some results on valid inequalities for solving the problem in a more efficient way.

# Optimal Placement of a Facility in Presence of a Probabilistic Barrier

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## Abstract

This paper considers the problem of locating a single facility in the presence of a line barrier or a rectangular barrier that occurs randomly on a given route on the plane. The objective is to locate this new facility such that the sum of the expected rectilinear distances from the facility to the demand points in the presence of the probabilistic barrier is minimized. Some properties of the problem are reported and a solution algorithm is provided with an example problem. As future research we propose to investigate the minimax version of the problem.

# An agent based approach for modelling location problems

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## Abstract

Agent based systems consist of a set of elements (agents) characterized by attributes which interact each other through the definition of appropriate rules in a given environment. In particular, agents can be passive if they do not change over the time or active if some rules can dynamically modify their attributes. These aspects suggest the possibility of using an Agent Based Systems (ABS) to model location problems. If we represent demand points with passive agents (assuming that the demand will not change over time) and facilities to be located with active agents, the results of the interaction between demand and facilities can provide the evolution of the positioning of active agents searching for optimal locations according to given criteria. In this way ABSs present a similar behavior to those of meta-heuristic procedure.

We can show that this approach appears to be particularly interesting when the location space is of geographical nature and, hence, the demand associated to facilities can be considered continuously distributed over portions of space: in this case the process of aggregation of demand through the association with passive agents can be performed in an effective way.
In this paper we present a general framework of an ABS oriented to the solution of location problems. The framework is based on a group of attributes and rules that can easily adapt to represent different kinds of location problems (i.e. p-median, p-centre, maximal and minimal covering).

The illustration of several practical examples shows the potential of this approach in order to build flexible decision support systems for the individuation of solutions for location problems.

We also provide experimental results on test problems to compare performance with other heuristic approach.

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# An exact algorithm for the Capacity and Distance Constrained Plant Location Problem: Valid inequalities and separation problems.

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## Abstract

The Capacity and Distance Constrained Plant Location Problem (CDCPLP) was introduced in [1]. The CDCPLP is a location-routing problem where a set of plants must be located (opened) in a discrete space, and customers are serviced form the open plants. To this end, a fleet of homogeneous vehicles has to be available for each open plant. There are three different assignment decisions in this problem. The first assignment decision refers to the assignment of customers to open plants: i) each customer is assigned to one plant, and ii) the total demand assigned to a plant does not exceed its capacity. The second assignment decision refers to the allocation of vehicles to plants. That is, each vehicle used in the solution is assigned to one plant. The number of vehicles assigned to each plant is not known in advance, and depends on the customers assigned to

the plant. Each such vehicle can serve several customers, so that a third assignment decision must be made. Each customer assigned to an open plant is also assigned to one of the vehicles assigned to its plant. It is assumed that each service requires a full truckload. Thus, each vehicle will perform as many trips as there are customers assigned to it. For any open plant, the total service load of each of its assigned vehicles is given by the sum, over all the customers assigned to the vehicle, of the individual service loads. The load of a vehicle cannot exceed a preset value. This value may represent, for instance, the total distance of all the individual routes performed by one vehicle. The objective function includes a cost for each of the decisions: set-up cost for the open facilities, assignment costs of customers to plants, and set-up costs for the vehicles.

In [1] a model was proposed for the CDCPLP, and lower and upper bounds were obtained via a relaxed model and a tabu search heuristic, respectively. Our goal is to develop an exact algorithm for the CDCPLP. To this end we will provide descriptions of its feasible domain in order to obtain smaller optimality gaps. First, we consider an alternative formulation that uses the so-called step variables for defining the assignments of vehicles to plants. Since the fleet of vehicles is homogeneous, our previous model was generating different representations of solutions that were in fact equivalent. The new step variables are better suited for avoiding symmetries, since, instead of denoting the "index'' of the vehicle assigned to a plant, they indicate the number of vehicles associated to the plant. Second, we consider two different types of valid inequalities, derived from the capacity constraints on the plants and from the constraints on the total load for the vehicles, respectively. Third, we develop two different types of inequalities derived from the capacity constraints on the plants and from the constraints on the total vehicle load, respectively. These inequalities are stated in terms of both the original variables and the step variables, giving rise to two families of valid inequalities for both models. For each of the two types of inequalities we formulate the corresponding separation problem that can be used for each model. The exact solution to the separation problem for the inequalities derived from the capacity constraints is solved as a series of knapsack problems; the separation problem for the inequalities derived from the maximum load constraints can be solved quite efficiently by any commercial solver. Both types of inequalities can be further strengthened by taking into account the structure of the CDCPLP. In particular, symmetric solutions can be avoided by imposing that vehicle k+1 is not used unless vehicle k cannot be loaded further. The expression of the resulting separation problems becomes now much more involved. We propose heuristic methods to separate these strengthened inequalities. Preliminary computational results will be presented.

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# Simultaneous Scheduling and Location (ScheLoc)

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## Abstract

Scheduling and location theory are equally important areas of operations research with a wealth of applications, e.g. in logistics, production planning, and supply chain management. For many of these applications it is obvious that dealing with these problems in the usual sequential manner (i.e., taking the output of one of the problems as input to the other) weakens the model and should be replaced by an integrated approach (i.e., solving both problems simultaneously). In this talk we introduce a unified theory as well as algorithms for a broad class of ScheLoc problems.

# Dynamic Location Problems with Discrete Expansion and Reduction Sizes of Available Capacities: model and algorithms

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## Abstract

We formulate a dynamic location problem that considers the possibility of expanding or reducing the maximum available capacity at any given location during the planning horizon. The expansion (or reduction) of available capacity at a given location is achieved through the opening (or closure) of one or more facilities with equal or different discrete capacities. The mixed-integer linear model developed considers fixed costs for opening the first facility at any location, plus additional fixed costs for every open facility in a location with already existing facilities. It is possible to open, close and reopen any facility at any location more than once during the planning horizon. It is also possible to consider different assignment costs depending on the size of the facility that is assigned to each client. This is important, because, in general, smaller facilities have smaller fixed costs but greater unitary operating costs.

It is interesting to note that a capacitated dynamic location problem is, in essence, a capacity expansion problem: facilities are open in different time periods, increasing the total available capacity, in order to serve a (generally) increasing demand. We study a problem where the expansion of capacity is explicitly considered and is achieved not only through the location of facilities at new sites but also through the location of facilities that will increase the already existing capacity at a given site (as in Shulman, 1991). Each facility capacity has to be chosen from a finite (small) set of feasible capacities, similar to what is described in Lee (1991) and Mazzola and Neebe (1999).

The major differences between the problem here presented and the problems studied in the literature are the possibility of reducing the capacity at any time period (most of the problems studied only consider the possibility of capacity increasing), the possibility of locating several facilities of different sizes in the same location and also the possibility of a facility being opened, closed and reopened more than once during the planning horizon. Canel et al. (2001) consider the possibility of a service being opened, closed and reopened more than once. Nevertheless, the authors do not differentiate between open and reopen fixed costs (which, in most cases, are clearly different), and present a non-linear objective function. In the model here presented it is also possible to differentiate the operating costs of the different facilities.

This work was motivated by the problem of locating transfer stations in a solid waste treatment system (see, for instance, Wirasinghe and Waters, 1983). Most transfer stations are composed by one or more equipments that can take one of a small set of different sizes. Each equipment has fixed and operating costs that are, usually, directly and inversely proportional (respectively) to its capacity.

The problem described is formulated as a mixed-integer linear problem, and three alternative resolution methods are compared: the use of a general solver (CPLEX), the use of a dedicated primal-dual heuristic and the use of a memetic algorithm, both developed by the authors.

The primal-dual heuristic tries to build complementary primal and dual solutions. The results already obtained through the execution of several computational tests show that the heuristic is capable of finding good quality solutions within reasonable computational times.

The authors have already successfully used metaheuristics in solving dynamic location problems (Dias et al., 2007). The problem described has several characteristics that increase the difficulty of applying genetic algorithms, and it is not straightforward to find a good genetic representation. The memetic algorithm developed represents each individual using two chromosomes composed of genes that can take values 0 and 1. The usual genetic operators (selection, crossover, mutation) are used, and a dedicated local search procedure was developed. The computational results already available show that the memetic algorithm is capable of finding good feasible solutions but at the expense of huge computational times, when compared with the two other resolution approaches. These results motivate the study of other genetic representations that can better tackle the specific characteristics of this problem.

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# Flexible Discrete Facility Location: A Generalized Model and Associated Solution Approaches

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## Abstract

One of the most important aspects of discrete facility location problems is the objective function that measures the quality of different solutions. In this regard, the main focus in literature has been on problems considering one or more particular objectives, and the proposed models typically take the special features of these objectives into account. As a consequence, for different objectives, different models have to be developed.

To incorporate a large number of objectives into one model, the so-called ordered median function (OMF) has been introduced (see e.g. [1]). Moreover, the corresponding discrete location problem is called discrete ordered median problem (DOMP). Given the OMF, different objectives are obtained by choosing different values for a vector of parameters $\lambda=(\lambda_1,...,\lambda_M)$, whereas $M$ is the number of clients which have to be served. The quality of a location solution is then measured by multiplying $\lambda_i$ with the $i$-th smallest allocation cost value and taking the sum of these values. It can be shown, that nearly all "classical" objectives, which have been employed in location theory, like median, center, etc., are special cases of the OMF.

In this talk, we present a general model for the DOMP, which is valid for all $\lambda \in R^M$. This model is an extension of the one proposed by [2], which is constraint to increasing values of $\lambda$, i.e. $\lambda_1 \leq ... \leq \lambda_M$ . Furthermore, two solution approaches for this model are discussed and computational results are reported. At last, it shown that the proposed model can easily be extended by capacities, which is not the case discussed in [3].

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# A Portfolio Approach to MNE Location Choices

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## Abstract

We extend the theory of MNE location choices by conceptualizing individual location moves as being conceived in the context of the MNE entire location portfolio. This approach entails that location choices are path dependent and determined by forces that are endogenous to the firm making them, in addition to exogenous characteristics of countries or the moves of other firms. We model the characteristics of the portfolio and their fit with those of subsequent location alternatives in affecting the likelihood of a location being selected for investment or being relinquished. We test the theory on a dataset of US law MNEs that details all the international location moves undertaken by these firms. Our findings show that after controlling for the country- and firm-characteristics that affect location choices, the characteristics of the portfolio and the fit between them and the characteristics of subsequent locations significantly affect the location choices of MNEs.

# A new discrete competitive multi-store location model

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## Abstract

In this presentation we introduce a new model for planning the stores of a company under a competitive environment. The behaviour of the customers is mapped by a multinomial logit model from which we obtain the probability a customer is selecting a specific store from a set of given stores. As the locations of the stores are subject of our model we have to integrate the specification of the probabilities in our model. In general, this results a very difficult non-linear approach. But it is well-known that the ratios of the discrete choice probabilities, derived by a logit analysis, are constant. This feature can be used to formulate a linear mixed-integer problem but with a huge number of constraints. For overcoming the huge number of constraints a simple solution approach has been developed. In a kind of case-study we consider the parcel shop networks of the main two competitors in the City of Dresden.

# Location of a Facility which Sells Goods

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## Abstract

A facility needs to be located in the plane to sell goods to a set of demand points. The facility charges the customers for the product a fixed price and a transportation cost per unit distance. The cost for producing an item and the actual transportation cost to the company, which may be different from the transportation cost charged to the customer, are given. Demand by customers is elastic and assumed linear. For each customer two parameters are given: the demand at price zero and the decline of demand per unit charge. The objective is to find a location for the facility in the plane, the fixed price charged to customers, and the unit transportation cost charged to customers such that the company's profit is maximized. The problem is formulated and an algorithm that finds the optimal solution is designed and tested on randomly generated problems.

# Network Location: A Survey of Models, Theory, and Methods

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## Abstract

The literature on network location problems has been proliferating over the past forty plus years since the initial of work of Hakimi back in 1964 on centers and medians. We review the existing literature based on a select set of more than 500 papers with primary emphasis on analytical models, theory, and methods. Our review covers p-centers, p medians, minimax and minisum problems with mutual communication, bi-objective and multi-objective problems, undesirable facility location problems, structure location problems, competitive location, robust location, and aggregation models.

# Multiobjective Source Location Problem

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## Abstract

The source location problem (SLP) is a rather new variant of facility location problem. In classical facility location theory, the objective function is typically measured by the sum or maximum (weighted) distances between a facility and a node. In source location, the arc-connectivity, node-connectivity, or flow-amount is taken into consideration rather than the distance between facilities and customers. In spite of its importance with regard to real-world applications, this class of problems has received much less attention than classical location problems. In this paper, we consider multicriteria versions of SLP.

In SLP we are given a flow network defined on some undirected graph $G = (V,E)$ with a capacity function $u : E \to \mathbf{R}_+$, demand function $d : V \to \mathbf{R}_+$, and criteria function $\mathbf{f} : V \to \mathbf{R}_+^K$. We want to determine a source subset $S \subseteq V$ such that the flow value $\lambda(S, v)$ between $S$ and $v$ is at least $d(v)$ for each $v \in V$ and such that its multicriteria value

$$\sum_{s \in S} \mathbf{f}(s) := \left( \sum_{s \in S} f_1(s), \ldots, \sum_{s \in S} f_K(s) \right)$$

is minimized.

We will first show that the number of Pareto solutions grows exponentially in the number of nodes of the underlying graph. Moreover, we derive sufficient and necessary conditions for Pareto optimality. Based on this characterization, a polynomial algorithm is proposed, to investigate whether a given feasible subset $S \subseteq V$ is a Pareto solution. Finally, we give an algorithm to find a representative system of Pareto points using the $\varepsilon$-constraint and box method of Hamacher, Pedersen and Ruzika (2007).

# Discretized reformulations for capacitated location problems with modular distribution costs.

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## Abstract

We study a discretization reformulation technique in the context of capacitated facility location problems with modular set-up distribution costs. We present a so-called 'traditional' model and a straightforward discretized model with a general objective function and whose linear programming relaxation dominates the linear programming relaxation of the original model. In order to explain this dominance, we show that a restricted version of the discretized model gives an extended description of the convex hull of a "small" polytope that arises in the original model and usually arises in network design problems with modular costs. Computational tests based on randomly generated data are presented showing that a lot can be gained by making use of the proposed discretized models instead of the 'traditional' models.

# Different formulations for ordered median hub location problems


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## Abstract

The discrete ordered median location model is a powerful tool in modelling classic and alternative location problems that has been applied with success to several discrete location problems as capacitated and uncapacitated location-allocation (with a fixed number of facilities) or plant location (without specifying a fixed number of facilities), among others. Nevertheless, although hub location models have been analyzed from the sum, maximum and coverage point of views, as far as we know, they have never been considered under a more general unifying point of view. In this paper we consider new formulations, based on the ordered median objective function, for hub location problems with or without capacities and with single o multiple allocation. This approach introduces some penalty cost associated with the position of an allocation cost with respect to the sorted sequence of allocation costs. This allows modeling among other: $p$-median-and-$p$-center hub location, uncapacitated and capacitated median-and-center hub location, lexicographic hub location, as well as many other objective functions as trimmed-mean hub location, centdian hub location ... We derive some basic properties of the models and compare their performance by means of an initial computational experiment.

# Location Models for Motorway Interchanges

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## Abstract

"Easy access to motorways" is usually ranked very high among the factors influencing city development. Because of this, the location of motorway interchanges is often the subject of harsh disputes between local political powers. In order to attenuate them, it is important that the decisions made in this regard by road authorities are carefully justified.

In this paper, we present a set of optimization models for helping making efficient decisions on the location of motorway interchanges. The specific problem dealt with is as follows. A motorway will be introduced over an existing road network that connects a given number of population centers. The motorway intercepts the road network in multiple points, but it is only possible to locate interchanges in some of the interceptions (to avoid the important costs involved in the construction of interchanges). The area crossed by the motorway is assumed to be predominantly rural and therefore traffic congestion is unlikely to occur either in the motorway or in the existing road network. The objective is to determine the interchange locations that minimize the total generalized travel cost in the area crossed by the motorway. Traffic is assumed to follow the least-cost route. This means that drivers will only use some segment or segments of the motorway when traveling between two population centers if this allows them to reduce travel costs. By allowing access to or exit from the motorway, interchanges perform an essential role when calculating the total travel cost between all population centers.

The first model included in the paper is a deterministic model – that is, parameters such as travel demands (O/D matrix) and travel costs are both assumed to be known with certainty. Then we introduce two robust models for dealing with the uncertainty inherent to those parameters: a stochastic model and an alpha-reliable model. Within these models, the uncertainty inherent to the parameters is dealt with scenarios for representing

evolution trends or potential changes in the parameters. The decisions are assumed to be made in two stages: strategic decisions (motorway interchange location) must be made now, before it is known which scenario will occur, while tactical decisions (travel route choice) are made later, after the uncertainty has been resolved.

The application of the models is illustrated through small academic examples and a case study involving a real-world situation (motorway A25, in central Portugal).

# Assessing the Robustness in Topological Configurations of Rapid Transit Systems

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## Abstract

Growing traffic congestion, urban sprawl and increasing mobility are some of the reasons why many agglomerations are extending, constructing or planning rapid transit systems. Most of the metro and commuter systems can be broadly classified into some simple topological patterns, such as single lines, two lines with one or two crosses, circle lines, stars, grids, cart wheels and triangles.

Loosely speaking a network is robust if basically keeps its functionality under failure of some of its components. Different measures and indices of robustness are gradually considered for each setting with the purpose of knowing which topological configurations are more robust.
Moreover, the formulation of railway network design and line planning problems by adding the analysed indices to the optimization model is dealt with in the paper.

# Locating Sensors of Traffic Network: an Overview

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## Abstract

The problem of optimally locating sensors on a traffic network to monitor flows has been object of growing interest in the past few years, due to its relevance in traffic monitoring and management. Different configurations of sensors, in terms of types, numbers, and spatial locations, allow the collection of data useful for different purposes within the general areas of traffic monitoring and control.

Many different models have been proposed in the literature as well as corresponding solution approaches. These existing models can be classified according to two main criteria: (i) the typology of sensors to be located on the network (e.g., speed/movement sensors, simple counting sensors, image sensors, and Automatic Vehicle Identification (AVI) readers), and, (ii) the objective function being considered for the applications (e.g., for OD estimation, for estimation of arc and route flows, measuring travel times, for traffic control, etc.).

This paper develops a classification scheme for the various sensor location problems that have appeared in the literature as well as some new ones that the authors have recently developed. The paper describes the computational complexity of the models and solution approaches that have been proposed, the computational experience that has been reported, and critically reviews the applications for which the models may be appropriate or inappropriate. The paper concludes with discussion of several promising directions for further study, including describing some open problems for future research.

# Mathematical Models for Reverse Logistics: An Algorithm for a Two-Level Problem

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## Abstract

Distribution planning in reverse logistics involves the physical transportation of a reusable item from the final user to a refurbishing facility. This is part of the "reverse distribution" process, analogous to "physical distribution" in conventional logistics. The reconditioning/recycling process involves refurbishing a used item and returning it to the cycle of usable products.

The management of reverse flows has received increasing attention in the last decades. Society's increasing concern with the environment has made the subject of recycling and re-uses a top priority. The effort in reducing wastage of natural resources promotes the idea of several cycles for a given material/product, as opposed to the "one-way" economy. This is not a new phenomenon; the re-use of paper, bottles and scrap metals has been around for a long time. In the latter case the re-use of these products has proved to be more economical than their disposal.

The main subject of reverse logistics is therefore the management of reverse flows. The context of reverse logistics may be better appreciated if we attempt to classify the circumstances under which re-use occurs, according to the following criteria: (i) Motifs for re-use; (ii) Types of recovered items; (iii) Forms of re-use; (iv) Agents involved. Each of these aspects has important implications on the type of the planning problem to be tackled and the formulation of adequate models to solve the corresponding problem.

Motifs for re-use: The recovery of materials/products has received increasing attention in the industrialized countries due, among other reasons, the concern with the depletion of non-renewable natural resources. Many countries have also enacted environmental legislation that penalizes wastage and increases the responsibility of enterprises to cover the complete life cycle of certain products (for example batteries and printer cartridges,

whose complete life cycle includes the disposal of these items as a responsibility of their manufacturers). On the other hand there exists economic motivation for recycling certain products. A typical example is the re-manufacturing of parts and components of machinery. Economic and ecological motivations are often linked. Ideally, these should be combined under the concept of a self-sustainable economy.

Types of recovered items: The main categories to be considered are: containers (for example: pallets, bottles), reserve components (for example: components of machinery, TV tubes) and consumer goods (for example: copiers, refrigerators). These categories differ in relation to when and why the items are returned. Reserve components are returned due to failure or for preventive maintenance, within a large life cycle. Consumer goods are returned at the end of their life cycle. Another possibility is items returned at the expiration of leasing contracts. In this case the timing of their return is known a priori and the corresponding activities may be planned.

Forms of re-use/reconditioning: Many authors adapted a classification by Salomon & Thierry (1995). The forms of re-use differ in relation to the production activities that must be planned and may involve different levels of coordination. In the present paper reconditioning will have a wider meaning, indicating any type of re-use.

Agents: Agents possess specific functions such as, for example, collection, test and re-use/reconditioning. An example of distinction among agents is re-use under the original manufacturer and re-use under third parties. Re-use under third parties may imply important restrictions on the possibility of integrating direct and reverse logistic activities.

The present work focuses on mathematical formulations that model the reverse distribution system. We study a linear-mixed integer programming model that considers the location of capacitated facilities in a two-level system: collection facilities in level 1 and refurbishing/remanufacturing facilities in level 2. We propose a genetic algorithm to solve the two-level problem. Tests are conducted using data generated according to a methodology available in the literature, with the heuristic solutions being compared with exact solutions obtained via a commercially available solver.

# The Maximal Dispersion Territory Design Problem

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## Abstract

Territory design is the problem of grouping small geographic areas called basic areas (e.g., counties, zip code areas) into larger geographic clusters called territories such that the latter ful_ll relevant planning criteria. These criteria can either be economically motivated (e.g., average sales potentials, workload or number of customers) or have a demographic background (e.g., number of inhabitants, voting population). Moreover, spatial restrictions are often demanded.

The problem we discus is motivated by the new recycling directive WEEE of the EC. The core of this law is, that each company which sells electronic products in a European country has the obligation to recollect and recycle an amount of returned items which is proportional to the market share of the company. In Germany, for one type of products, the so called “white goods", e.g., dry-cleaners, washing machines, fridges, a territory design approach is followed. However, as the EC wants to avoid that a recycling corporation gains a monopoly in some region of Germany, all basic areas which are allocated to the same corporation should be geographically as dispersed as possible. That is, one of the classical criteria for territory design problems, compactness, is completely inverted. To measure the dispersion of a territory we adopt an idea from facility location for placing mutually obnoxious facilities.

For this new problem, we present our initial mathematical programming model, together with some straight forward improvements and possibilities for fixing variables. Moreover, we discuss a simplified version of the problem which allows us to obtain tight and easy to compute bounds for the original problem. Finally, preliminary computational results will be presented.

# The Reliable maximin-maxisum Location Problem on a Tree Network

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## Abstract

We present the problem of finding the location of a facility on a tree network having unreliable edges. Two objectives are considered: (1) maximizing the minimum expected number of successful traversals from the facility to the demand nodes (maximin problem, termed *reli-maxmin*), and (2) maximizing the total expected number of successful traversals from the facility to all demand nodes (maxisum problem, termed *relisum*. We will analyze the properties of the bi-criteria problem in the decision and objective spaces and propose a solution methodology to generate the efficient and the non-dominated sets.

The tree network is described by a connected, undirected graph $T(V,E)$, where $V=\{1, 2,\dots, n\}$ is the node set and $E = \{e = (i,h): i,h \in V\}$ is the edge set, with $|E| = m$. The nodes are assumed to be perfectly reliable. Associated with any node $j \in V$, there is a finite positive integer attribute $w_j$, representing the node weight or demand frequency. This attribute can be understood as the frequency of traversals requested by node $j$. The edges are assumed to be unreliable, that is, at some random point in time, when a demand for service occurs, the edges are in such a state that prohibits their use for traversal. Associated with each edge $e \in E$ are two attributes: (1) the edge length, $d_e > 0$ and (2) the failure rate $\lambda_e$, representing the average number of failures per unit length. As a result of these two attributes, associated with each edge $e$ there is a probability $0 < p_e < 1$ that when attempting to traverse edge $e$ it is found in an operational state. Using an exponential model, we represent the relationship between edge length, operational probability and failure rate, as $p_e = e^{-\lambda_e d_e}$.

The bi-criteria model consists of two objectives. The first objective, a maximin *reliable* objective termed *reli-maxmin*, minimizes the effect of the worst performance of the network, which is analogous to the center approach. The second objective, a maxisum *reliable* objective termed *relisum*, optimizes the average performance of the network, which is analogous to the median approach. The bi-criteria *reli-maxmin/relisum* problem finds the set of *efficient* (Pareto-optimal) points, $X_T \subset T$.

We analyze the properties of the bi-criteria problem in the decision in an effort order to reduce the set of candidate points for efficient solutions. Then, by a combination of elimination and construction, we determine the non-dominated set (in objective space) and the efficient set (in decision space). Our solution procedure can be summarized as follows:

1. Find a candidate solution set $X_T$: we provide with an analytical procedure to fathom inefficient subsets of *T*. By taking advantage of the symmetric behavior of both objectives we develop a simple procedure to find a candidate solution set.

2. Fathom edges or parts of edges to reduce the candidate solution set. Conditions to fathom edges or sections of edges are developed based on dominance of the objectives functions when comparing different edges or parts of edges.

3. Construct the non-dominated set in objective space and convert it to the efficient set in the decision space. After mapping the candidate efficient set into objective space we eliminate dominated subsets using dominance properties between the images of two edge sub-segments and between the image of an edge sub-segment and the image of a point of *T*. We show that there is at most one intersection between the images of any two edge sub-segments. The non-dominated set is obtained as the union of non-dominated edge sub-segments and the efficient set is found by mapping the non-dominated set back to decision space.

A numerical example is provided to illustrate the solution procedure.

# Minimax Regret Path Location on Trees

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## Abstract

This paper deals with those networks location problems under uncertainty that are characterized by a situation in which the actual weights of the vertices and of the edges of the network are not known, but, for each vertex and each edge, only an interval of possible values is given. In location problems such a situation arises for example when, for each demand point, an interval estimate of its demand is known. For a given objective function -that obviously depends on the demands - a facility must be located in order to minimize the worst-case loss in the objective function that may occur because the weight of each client is not known exactly. In the literature, these problems are known as ‘‘minimax regret’’ location problems. In the recent years, the attention was mainly focused on problems related to facilities that correspond to single points and a variety of results was provided for tree networks Aver2000_1, Aver2000_2, Aver2003, Burkard2002, Chen1998, Conde2007. In the different papers the uncertainty is related to the weights of the vertices of the network and/or to the weights of its edges. In this paper we study the minimax regret path location problem on trees. In particular, we consider a tree with nonnegative lengths assigned to its edges, while it is known that the weight of each vertex belongs to a given interval of values, that is, we have an upper and a lower bound on such weight. We study the following two problems: the {\em Minimax Regret Path Center Problem} (MRPCP) and the Minimax Regret Median Path Problem (MRMPP). These problems refer to the minimization of the maximum regret function when the path is located w.r.t. the center and to the median criterion, respectively. To the best of our knowledge these problems have not been considered yet in the literature; for both we provide polynomial time algorithms.

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# Coverage Optimization for Deploying an Emergency Wireless Network

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## Abstract

Deployment of wireless network to support emergency service is important to achieve efficiency of allocated resources for lifesaving. With limited resources, it is desirable to provide suitable coverage to the greatest demand possible. In this paper, maximal wireless coverage is investigated, where demand for coverage is considered as continuously distributed. Application to site emergency wireless routes in Tucson, Arizona is examined.

# The minimal cost/maximal covering p-forest problem

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## Abstract

The objective of the minimal cost, maximal covering p-forest problem (MC2pF) is to design a forest of p-subtrees on an underlying network. The solution is evaluated on two criteria: the first is to minimize the cost of the arcs chosen for the forest, and the second is to maximize the number amount of demand covered or satisfied by the forest. A demand node on the underlying network is considered covered if an arc in the forest is within some pre-specified distance, S, of a subtree. This problem can be considered a generalization of the maximal covering minimum cost subtree problem of Hutson and ReVelle.

Many potential applications of the MC2pF exist. For example, in pipeline networks, such as water or natural gas distribution systems, the desired distribution network is a tree. However, several sources (e.g. wells) are possible and they need not be interconnected connected. Consequently, one can serve the demand via a forest, or several subtrees each with a well. In this paper we develop a specialized algorithm for the MC2pF problem defined on a tree network, as well as discuss possible approaches for the more general problem defined upon a network. Computation results of the tree-based algorithm will also be presented with a comparison using a general formulation and Cplex.

# Market Coverage and Service Quality in Digital Subscriber Lines Infrastructure Planning

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## Abstract

Digital subscriber lines (xDSL) belong to a family of technologies that provide the ability to transmit digital data over local telephone (copper) infrastructure. As the second most popular broadband platform in the United States, it is estimated that over 25 million xDSL lines are in service, capturing nearly 30% of the U.S. broadband market. While the service range of xDSL is somewhat limited, often extending to a maximum of 18,000 feet from a central office, available bandwidth also decays as distance increases from the central office. As a result, there are often marked disparities in the quality of xDSL service within market areas. This paper proposes a multi-objective location model for maximizing service quality and coverage in siting digital subscriber line access multiplexers. An application of the developed model highlights important implications for telecommunication policy.

# The Location Set Covering Problem with Service Quality: User Choice of Facility


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## Abstract

The location set covering problem as introduced by Toregas and ReVelle (1971) minimizes the number of facilities necessary to completely cover a set of customers in some given region, where covering means providing service within a predetermined distance or time. In other words, customers that are within a certain predefined "standard distance" D from a facility are adequately served, while those that are located beyond this distance are not served at all. This coverage concept can be represented by a single step function, which has value 1 for distances of up to D, and zero for distances greater than D.

Recently, Eiselt and Marianov (2008) summarized a class of Location Set Covering Problem models that use either stepwise or smooth quality functions, as opposed to the usual covered/not covered dichotomy. In this class of problems, quality of service is a function of the distance. Furthermore, they proposed a model that requires identifiable facilities. We can distinguish between two types of models. In the first type, all customers are covered with a basic quality, while the firm or the central planner can also provide higher quality levels on a selective basis. Quality levels are described by a stepwise quality function. In this case, the allocation problem is not solved, i.e. it must be solved a posteriori. The second type uses general quality functions (as opposed to stepwise), and each potential facility location can provide a specific quality of service to a particular customer. The models that use this approach both locate facilities and allocate the customers to them.

The individual quality of service can be measured in different ways. Among the rules that have been suggested that go beyond the "closest" rule, are gravity models as those

proposed by Reilly (1931). In addition to a customer's proximity to a facility, they include some "attractiveness" of the facility, which, in terms of applications in the retail industry, if often seen as variety of products available or, as a proxy, the facility's floor space.

In this paper we consider a probability approach. It is based on the probabilistic gravity rules first proposed by Huff (1964, 1966) that expresses the probability of a customer choosing a facility as the proportion of the attractiveness of a facility in relation to some power of the distance between facility and customer. Another distribution is the Logit function originally proposed by McFadden (1974), which expresses the probability of a customer choosing a facility proportional to an exponentially decaying function of the facility-customer distance. Our model can use any of these distributions.

The resulting optimization problem has a nonlinear objective function. We transform this nonlinear problem into a converging sequence of linear problems, whose solution can be found by inspection. The resulting solution is optimal.

We present numerical experience with several instances of the problem.

# Location Analysis and GIS

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## Abstract

In this presentation we describe what we believe is a significant shift in the application of location models, where new applications make greater use of geographical data provided by Geographical Information Systems. GIS platforms are designed to store, manipulate, retrieve, analyze and map geographic data. Such systems are now routinely employed by most State agencies and municipalities, creating a relatively rich amount of accessible geographic and demographic data. In fact many companies are embracing the use of GISs to store customer data and analyze system performance, as well as make site selection decisions for new retail locations. This shift toward the use of GIS in site selection is significant for several major factors. For example, data is often collected from a wide variety of sources and levels, presenting issues of the Modifiable Area Unit problem. Also the level of detail that data is collected and stored is often represented at a finer scale and in a different format than in used in many past location models. This trend presents a host of new challenges.

The objective of this paper is to describe why this trend is significant and the challenges and opportunities that this trend presents. Finally, we discuss some of the educational needs associated with training students wanting to use GIS in location modeling and research.

# A Location-Routing Model and a GIS Framework for a Competitive Multi-Facility Location Problem

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## Abstract

In this paper we propose a location-routing model for the facility location problem within a two- and three- dimensional geographical framework. The locations we consider in this regard are grocery stores or bank branches which typically have a presumed trade area around them with demand decaying as a function of distance from the facility. Our goal is to investigate the spatial interaction of the existing, new (candidate) and competitor sets of facilities with the demand points in a pre-defined geographic area, and make decisions regarding what new facilities to open and what existing facilities to close or consolidate, given a limited budget. We also take into account logistics aspect of such decisions and propose a model that integrates location and routing decisions.

The business problem we consider in this paper is quite a typical scenario in an emerging and hence extremely dynamic market. Grocery store chains that constantly monitor changing market conditions, shifting population demographics and competitors' moves are faced with such location decisions. In this paper, we aim to formalize the decision making process by developing and solving a non-linear integer programming model through a GIS-based decision support system interface. We seek optimal and α-optimal solutions for this problem using constraint programming and a heuristic algorithm.

Earlier work done in this context primarily operates with the assumption that the number of consumers who patronize a facility varies with distance and population. The gravity-based models that have been proposed also indicate that the aggregate demand captured by a facility from a nearby demand point is a function of the utility of the consumers which is proportional to the attractiveness of the facility and inversely proportional to the distance. In this paper, we expand upon these ideas and develop a generalized model that take into account routing issues as well.

In our model, market share captured by each facility depends on consumer characteristics (purchasing power, segmented population), facility attributes (floor space, parking space, product variety, accessibility, atmosphere, attractions nearby) and the spatial separation of customers from facilities. Demand generated at a demand point is assumed to vary with the population, the pattern of expenditure of the type of the service offered by the facility and the income level of the demand point. The pattern of expenditure is assumed to be a concave non-decreasing function of the consumer income level and the total utility served to the consumer by the facilities. The demand generated at a demand point can only be captured by a facility with a probability proportional to the total utility offered to the demand point. Here it is assumed that consumers want to maximize their utility which increases with the higher attractiveness and closeness of a facility.

In our model, we also attempt to formulize attractiveness of a facility as a multiplicative function of the facility characteristics. We consider the following attributes: facility area, parking space, product variety, accessibility, atmosphere, nearby attractions. We assume that these attributes are deterministically known once a candidate store location has been identified. Furthermore, each attribute is weighted with an exponential power which controls its impact to an overall attractiveness score. The overall attractiveness of a store is formulated by including the multiplicative surplus brought in by each attribute over the minimum possible attractiveness value.

One goal of this study is to incorporate vehicle routing decisions into the problem we study. The routing problem we consider in this study is a single-depot multi-vehicle capacitated routing problem. Each vehicle used in the distribution has a fixed usage cost. The transportation cost is calculated as the cost of travel between open facilities and the depot. This cost is included in the objective function in addition to fixed costs of opening and closing facilities. The objective function also includes expected revenues that are realized as demand is probabilistically captured from demand points. The overall objective function is minimized to achieve a balanced solution between compact routes and demographically attractive locations.

The resulting problem is solved by constraint programming for an optimal solution. We also propose a heuristic algorithm and compare the heuristic results with the optimal results. We test our algorithm with sample real data in the Istanbul region for a major retail chain. We use a GIS framework to facilitate problem solving as well as visualization of results. In our GIS data model, we also use the underlying 3-dimensional terrain topography of Istanbul to evaluate on-foot accessibility of facilities from demand points and its impact on facility location decisions.

# Transportation for Seniors: Planning a Senior Shuttle Service with GIS

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## Abstract

A lack of transportation services for the increasing numbers of senior citizens in Calgary presents a challenge for planners and decision makers alike. Transportation services offered by Access Calgary, Calgary Transit and volunteers are unable to meet the current needs of this growing segment of society. Difficulties accessing transportation services mean that many seniors find it challenging to meet such basic needs as grocery shopping, or to visit libraries, parks, fitness and recreation centres or to attend medical appointments. This research focused on providing a unique alternative transportation service that would be acceptable and accessible for seniors in Calgary using GIS as a planning tool for a senior shuttle service provided by the Calgary Motor Dealers Association (CMDA).

The CMDA has agreed to provide shuttle buses to transport seniors for the aforementioned needs. Each dealer agreed to provide a shuttle bus for one hour per week from 10:00 a.m. to 2:30 p.m. Monday to Friday. The initial target for this service was seniors living in lodges. Different statistical analyses were used to analyze the distribution of senior's lodges, the destination facilities and the motor dealers. Furthermore the shortest possible routes were designed using a GIS for the triangle of supply (dealers), demand (lodges) and target facilities (shopping centres and others). It was shown that even given the constraints of only one hour of donated time from each dealer that this shuttle service could be helpful in allowing the seniors to take an active role in their community.

# Location Planning using Geographic and Demographic Data

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## Abstract

In this talk we consider a multi-period location problem using geographic as well as demographic data. In particular we look at the problem of locating petrol stations in Germany. Since the demand for petrol (and thus also petrol stations) is changing over time, a time dynamic model is considered. We estimate the demand from geographic and demographic data. Future demographic data is forecasted by an ARIMA(p,r,q) process. For the location problem itself, the planning region is divided into smaller subregions and the optimization procedure decides whether to open or close stations in a subregion. Territories are designed using a line partitioning approach. To get a balanced territory design with respect to demand we use geographic data, such as crossroads together with the length of the incident streets (the length of the streets is assumed to correlate with the demand). The whole demand generated in a subregion is partially reassigned to adjacent regions by a gravity model, which takes the number of existing locations and the distance between the regions into account. Finally the resulting demand for each region is split evenly between the own and the competing facilities. The talk ends with some conclusions on how demographic data can support a location decision in the case of insufficient direct data.

# Rectilinear minimax hub location problems

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## Abstract

A hub is a strategically located facility which serves as a switching point for flows between a number of fixed nodes. It was shown in O'Kelly (1986) that a planar minisum objective is optimized by solving versions of the Weber problem. Since then, new research has extended many aspects of the planar location problem (though perhaps not as much as for discrete models which are dealt with extensively in the current literature). The present paper considers the problem of placing a facility in a grid such that the materials moving between all the sources and sinks in the system pass through the hub so that the maximum weighted distance traveled is as small as possible. Recent work by Berman et al (2007) made the interesting connection from the hub location problem to the task of linking dispersed demand points to a fixed given facility location, so in a sense their hub is a staging point or a transshipment point – for example, as a place where patients could be transferred from one mode of transport to another. This paper extends earlier research by formulating and solving the minimax hub location problem by geometric arguments.

A minimax hub location problem involves siting a hub facility so as to minimize the cost of the most costly interaction between a set of fixed nodes. In this model, distances are represented by a rectilinear norm and may be suited to factory layout or street network problems. The rationale for the solution method is based on an extension of geometric arguments used to solve the Euclidean minimax single facility location problem. Suppose a budget is provided for interactions, and that each interaction must be accomplished for no more than this cost. The algorithm uses a bi-section search for the feasible budget until it finds the precise amount of expenditure needed to provide for these flows. The models and solution techniques developed in the paper are illustrated using 10, 25, 40 and 55 node problems, derived from Swain's 55 node data set.

Suppose that flows between N = (m (m-1)/2) pairs of nodes are known; denote these flows by $W_{ij}$, for j > i, where $W_{ii} = 0$. If flows are asymmetric, then set $W_{ij} = \max(W_{ij}, W_{ji})$, since only the larger of the two flows needs to be considered. Denote the location of the hub by Q. The locations of the m origins and destinations for interactions (or flows) are denoted by $p_i$ for all i=1,...,m. Consider the problem of choosing the location for a single hub facility such that the most costly flow is as cheap as possible, given that the flows between i and j are routed from i to the hub, and then from the hub to j. Mathematically, the objective is to choose the facility location so as to:

MIN by choosing (Q)

$$G(Q) = MAX\{i, j\} : W_{ij}[C(p_i, Q) + C(Q, p_j)] \tag{1}$$

where C(p, Q) is a distance measure between p and Q. At a fixed hub location Q, the interaction costs of all the flows are simply evaluated: the product of the flow volume times the distance, via the hub, between the interacting nodes. The interacting pair with the largest cost is noted. The objective is to move the hub to a site which makes the maximum cost as small as possible. It is important to note that the objective is not concerned with an aggregate cost of transportation, only with the most expensive of these interactions, reflecting the desire to make the hub handle all the pairwise traffic for no more than some maximum threshold. As the hub location is varied, the pair of nodes with the maximum interaction cost varies, and so the objective function surface has a large number of local minima. The minimax objective is not separable into inflow and outflow components, since the combined cost of getting to and from the hub must be considered.

The purpose of this paper is to apply practical solution strategies for the minimax hub location model, and to suggest some interesting layout and location extensions. First is a three dimensional aspect of the interactions between the nodes, in that the interacting locations might be stacked up at various levels (such as layers in a warehouse, or floor/depths in a subway station). In that case, a hub on each floor (i.e. multiple hubs) would be a central place through which movements in the systems are channeled. A possible security application would be the location of a central scanner or surveillance point. A second and perhaps less obvious application occurs as a result of the extensions of the concept of space time activity prisms; the conventional "ellipse" shows the set of all points that can be reached from a fixed pair of points for within a fixed time budget. That time can be useful to delimit action spaces. The space time approach fixes anchor points and asks where those pairs of locations could reach within a time budget: an idea similar to the use of a budget for the minimax hub problem. The goal would be to find a place that can be in as many action spaces as possible, assuming that the budget is provided to cover the most expensive or distant of the interacting pairs. Such a site would make an ideal terminal for interactions, or a point through which social networks might be connected. A library comes to mind as type of facility that perhaps would adhere to this ideal.

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# Solving the Capacitated Hub Location Problem with Single Assignment with Branch-and-Price.

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## Abstract

In this work we consider the Capacitated Hub Location Problem with Single Assignment (CHLPSA). The CHLPSA is the problem of selecting a set of hubs to be established and an allocation pattern, that fully assigns each node to one of the chosen hubs, in order to minimize the cost of hub installation and the cost of sending the flow through the network, subject to capacity constraints on the amount of flow that can be routed by hubs.

One of the main difficulties for solving HLPs is the huge number of variables and constraints that typically appear in the considered models. From this point of view, formulations with fewer variables and constraints should be preferred to formulations with a bigger number of variables and constraints. However, in some cases bigger formulations lead to tighter lower bounds associated with the LP relaxation. In this work we propose a branch-and-price algorithm for solving exactly the CHLPSA. Our proposed method uses column generation and exploits the particular structure of the four index formulation to obtain at each node of the search tree tight lower and upper bounds in small computational times.

Lower bounds are obtained by means of a Lagrangean Relaxation approach that generates near-optimal dual variables (needed for the pricing) and feasible solutions for the original problem. The Lagrangean relaxation of the four index formulation for the CHLPSA, results from relaxing the constraints that link the assignment variables with the flow variables. As a consequence, the Lagrangean function can be decomposed into subproblems that can be solved efficiently. In particular, only one of the subproblems contains four index variables, and this subproblem can be solved by inspection. The other

subproblems are knapsack problems with two index variables. The upper bounds are obtained with a fast primal heuristic to obtain good quality feasible solutions that is applied at some iterations of the subgradient optimization that is used for solving the Lagrangean dual.

In order to speed up the convergence of the algorithm we reinforce it with two additional features that are applied at some iterations of subgradient optimization. The first one is a simple reduction test that is able to determine if a hub should be closed in an optimal solution. This reduction test allows reducing considerably the computational burden needed for obtaining the upper and lower bounds, and it may improve the lower bounds. The second element that speeds up the convergence of the algorithm is a stabilization procedure for the dual multipliers. With this procedure we adjust the dual multipliers at some iterations of subgradient optimization so as to reduce the number of columns to generate by reducing dual infeasibility of un-generated columns. This is achieved by solving auxiliary linear problems. Another positive aspect of this stabilization procedure is that after applying it the adjusted dual multipliers produce a valid lower bound.

We have run a series of computational experiments with benchmark instances from the literature and new larger instances that we have generated up to 300 nodes. We report on the obtained results that assess the efficiency of the proposal.

# A two-phase algorithm for solving p-hub location problems

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## Abstract

The single allocation p-hub problem with center and median objectives is an NP-hard location-allocation problem which consists of locating hub facilities in a network and allocating non-hub nodes to hub nodes such that a given objective is minimized. In this paper we present an exact two-phase algorithm where in the first phase we compute a set of potential optimal hub combinations using a shortest-path based Branch and Bound. For this set the allocation problem is then solved separately with a reduced size formulation in the second phase. We apply this approach to both the p-hub center and the p-hub median problems. The algorithm needs significantly less memory than other known algorithms and therefore it was able to find new optimal solutions for large-sized problems. We use three different data sets to demonstrate the effectiveness of the 2-phase algorithm.

# Release Time Scheduling in Hub Location Problems

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## Abstract

Hub location problems are special location-allocation problems in which flows between origin/destination pairs are distributed via special centers called hubs. Hubs are consolidation and dissemination centers at which flows from the origin with different destinations are consolidated on their route at a hub node; and they are then combined with flows from different origins but same destinations. The hub location problem involves the location decisions of the hubs and the allocation decision of the demand centers to these hubs. The hub location problem appears in a variety of applications including airline systems, cargo delivery systems, and telecommunication network design. When we analyze the application areas separately, we observe that each area has its own characteristics.

In this research we focus on cargo delivery systems. Our interviews with various cargo delivery firms operating in Turkey enabled us to determine the constraints, requirements, and criteria of the hub location problem specific to the cargo delivery sector. During our investigations, we observe that delivery times are very crucial in logistics decisions of cargo companies. The main reason under this is the fact that, they define the "service quality" as the time between a drop off at a branch office and its arrival at the consignee. From the customer's point of view, the main issue in the cargo delivery market is the service quality and nowadays most of the cargo companies are working to decrease their delivery times. We observe that, the cargo delivery companies want to give delivery time guarantees to their customers; i.e. serve them within certain threshold values. More precisely, the companies want to promise next-day deliveries. One way of achieveing this goal is to assign more than one truck between hubs which depart at different times. In that case, the cargo traveling on the earlier truck can be delivered within 24 hours (by scheduling the departure times appropriately). Another way, which is cheaper since the hub-to-hub trucks are specialized and expensive, is to utilize the truck departure times from originating branch offices towards hubs. The truck departure times from origins towards hubs are actually the ready times of the origins. Customarily, these ready times are taken as fixed parameters in hub location models. However, scheduling of these ready times could improve the delivery time guarantees and that is the main motivation of this study. We will treat the ready times as model variables and search for the best ready times at which the cargoserved within the threshold value is maximized.

We define the release-time-setting-for-next-day -delivery problem in which the total flow served within the fixed threshold value is maximized. Observe that, the total flow arriving till the release time is a function of release time. We first propose a mathematical model with an arbitrary arrival function. We then work out for uniform and piecewise linear demand functions. We derive certain valid inequalities and test the performance of the proposed models over Turkish network. The results for picewise linear and uniform demand functions are also discussed.

# Prioritizing Network Service Restoration

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## Abstract

For any networked infrastructure, damage to component facilities (arcs and nodes) and associated disruption of network services is always an important planning concern. Regardless of the source of damage (e.g., accidental or intentional), recovery/response plans need to be devised in order to prioritize restoration of service to impacted locations. Efforts to restore service in disrupted networks often require lengthy and costly repair or reconfiguration and hence, efficient and effective strategies must be identified in support of the restoration process. Therefore a strategic goal of service restoration is to ensure that facility restoration is prioritized such that system operation is maximized provided budgetary restrictions. This presentation proposes a location model for maximizing network service recovery in support of restoration planning. An application of the developed model is then used to illustrate the proposed approach.

# A multi-level modeling approach for the capacitated p-median interdiction problem with fortification.

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## Abstract

A crucial issue in today's distribution, supply and emergency response systems is to guarantee continuity and efficiency in service provision in the face of a variety of potential disruptions. Planning against possible disruptive acts of nature or sabotage is an enormous financial and logistical challenge, especially if one considers the scale and complexity of today's logistic systems. Since it is generally impractical to secure all assets, it is important to devise systematic approaches for identifying critical elements and optimize the protection of key system components.

In this work, we consider a service-supply system where the facilities have finite capacities and develop an optimization model for identifying the most cost-effective way of protecting the facilities against worst-case scenario disruptions. More specifically, we consider a system with $P$ capacitated facilities serving a set of $N$ customers. We assume that malicious attacks can disrupt (interdict) up to $R$ facilities and that interdicted facilities become completely inoperable. After interdiction, the remaining facilities operate in the most efficient manner, where efficiency is measured in terms of supply costs and lost-sale costs. The objective is to identify the optimal allocation of a limited amount of protective resources among the $P$ facilities so as to minimize the total costs in the event of a worst-case loss of $R$ facilities. The model assumes that exactly $Q$ facilities can be hardened (where $R + Q$ £ $P$) and that protected facilities cannot be interdicted.

We formulate the problems as a tri-level mixed-integer program: the top level problem involves the system planner's, or defender's, decisions about which facilities to secure; the intermediate level problem models the worst-case scenario loss of $R$ unprotected facilities; the bottom level problem reflects the fact that the system users try to operate within the system in an optimal way after interdiction. We show that the resulting defender-attacker-user tri-level problem can be reduced to a bi-level non-linear model. The bi-level model can subsequently be linearized through a suitable variable

replacement and solved to optimality by an implicit enumeration approach, similar to the one proposed in Scaparra and Church (2008) for the uncapacitated version of the problem. Computational results are presented for a benchmark problem with 150 customers, 30 facilities, and $R$ and $Q$ ranging between 1 and 5.

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# Models and algorithms for location and relocation of ambulances

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## Abstract

We present two optimization problems related to optimal location and dynamic relocation of ambulances, arisen in the context of a larger project we are developing for the emergency health care system in Milan, Italy.

The first problem is a strategic one and involves the selection of suitable parking areas to be built in the city in order to allow the ambulances to cover the urban territory. When the spatial distribution of the population changes, the optimal location of the ambulances should also change accordingly, but the constraint is that this reallocation must be possible exploiting a constrained number of parking areas.

The second problem is meant as an ideal approximation of the re-location problem encountered at the operational level. When the number of the available ambulances changes, their optimal location also changes, but here the constraint is on the number of allowed re-locations.

Both problems are solved with branch-and-bound and Lagrangian relaxation. In the former case the problem is decomposed into several independent sub-problems, one for each time period (a time period corresponds to a stable distribution of the population: night, working hours, week-ends...). In the latter case the problem is decomposed into several sub-problems, one for each number of available ambulances. In both cases the optimal solutions of the sub-problems are synchronized by Lagrange multipliers in order to make them consistent as parts of an overall optimal solution.

We present computational results on real instances taken from the above mentioned project under development in Milan.

We also describe the integration of these location models into a hypercube-like model, which takes into account the temporal distribution of the calls for service as well as the integration of the resulting decision support system into a geographical information system in use a the operating center of the emergency health care system in Milan.

# The Historical Allocation and Location (HAL) Model for Static EMS Location Problems

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## Abstract

Selecting optimal ambulance locations for the provision of emergency medical services (EMS) poses a difficult set of challenges. To begin with, the combinatorical structure of the problem means that the number of potential solutions grows exponentially with factors such as the number of ambulances to locate and the number of sites from which to choose. To further complicate matters, the random elements of EMS systems – such as the location, timing, and duration of calls for service – make it difficult to predict in advance how well a particular solution will work under realistic conditions. Researchers have to date focused on two main strategies for wresting with these challenges. The first has been to develop mixed integer optimization models which attempt to approximate certain probabilistic elements of EMS systems within their linear structure. Such models are quite effective at traversing the vast solution space to identify an optimal location pattern, but the treatment of probabilistic elements within a mixed integer formulation requires a set of simplifying assumptions that may skew the evaluation of each alternative considered. As a result, the solution identified as "optimal" according to the model's objective function may in fact be inferior to other alternatives. The second approach has been to develop sophisticated evaluation models – typically relying on some form of spatial queueing – intended to determine more accurately the expected performance of a given solution. The evaluative models are then embedded within a search heuristic designed to consider alternate solutions and identify the most promising. Because the evaluation step in this approach treats the probabilistic elements of EMS systems more fully, the predicted performance for any given solution is likely to be more accurate than that provided by a mixed integer model. That said, the evaluative model requires significant processing time for each solution considered, so it is computationally impractical to allow the search heuristic to consider a large number of alternatives. As a result, the predicted performance for the best solution identified may be quite accurate, but the search heuristic is unlikely to find the best possible solution. In this paper, we

develop a model for optimizing EMS location problems, referred to as the Historical Allocation and Location (HAL) model, which follows the second paradigm. Rather than relying upon spatial queueing for the evaluative step, however, we develop a simulation model instead. One advantage of this decision is that simulation models can run quite quickly, which enables us to develop a more robust search strategy. A second advantage is that simulation models can be custom-tailored to the specifics of any real-world EMS location problem (encompassing, for instance, multiple levels of service, multiple vehicle types, etc.). Spatial queueing models, though elegant, are less flexible in this regard. To test the effectiveness of HAL, we first develop a set of simple EMS problems and compare the quality of solutions identified by HAL against those identified by the most promising mixed integer model developed to date. In this preliminary set of tests, HAL finds the best solution in a majority of cases (66 out of 74), and its results are quite close (within a fraction of a percent) in the remaining cases. We next develop a slightly more complex set of problems incorporating multiple levels of service and again test HAL against the most promising mixed-integer formulation. Because the simulation routine embedded in HAL can be tailored to reflect the slightly more complicated problem structure, whereas the mixed-integer formulation cannot be so modified, HAL finds the best solution for all of the test cases in this second set of trials. While we have not tested HAL against comparable EMS optimization strategies that rely on spatial queueing, we suspect that the speed and flexibility enabled by the use of simulation would enable HAL to perform favorably in this context as well.

# A Two-Phase Multicriteria DSS Dedicated to Location Problems

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## Abstract

Most location models deal with desirable facilities, such as warehouses, service and transportation centers, emergency services, etc., which interacts with the customers and where usually travel is involved. The typical criteria for such decisions include minimizing some function of the distances between facilities and/or clients.

However, during the last two or three decades, undesirable facility location problems have emerged and those responsible for the area's overall development, where the new equipment is going to be located (i.e., central government, local authorities) as well as those living there, are showing an increasing interest in preserving the area's quality of life.

The traditionally optimality criterion of ‘closeness’ (to locate the facility as close as possible to the customers) is replaced by the opposite criterion (how far away from the customers can the facility be placed ensuring accessibility to the demand points).
The modeling of environmental issues as objectives, as opposed to constraints, would generate more information regarding the cost and other implications of environmental considerations (Current et al., 1990).

To deal with this type of models we believe that interactive methods are the best choice, especially if they are thought as learning procedures (improving the knowledge about the problem) and not as procedures seeking some ‘optimal’ solution. They should also be designed so as to be useful in a group decision and/or negotiation environment.

The interactive process looks for a progressive and selective learning of the nondominated solutions set, clarifying the criteria values aggregation meaning and consequences. Although in some situations it is possible to opt for one alternative in many others the interactive process just enables the elimination of great part of the feasible solutions reducing the final choice to a small part of the nondominated ones. In this case, if necessary, these alternatives can be scrutinized using another multicriteria analysis tool dedicated to discrete problems, where the alternatives are known explicitly and in small number. Of course, this stage looks for a more detailed analysis of this sub-set of the nondominated alternatives. In many cases it is justified to extend the analysis to slightly dominated solutions, in terms of the two objective function values considered in the first phase, very close to the previously selected solutions in the first phase. However, this second phase analysis does not enable the combinatorial nature of feasible solutions to be explored. So, it just should be used for a deeper study of alternatives filtered by the phase one of the process.

In this paper we propose the use of a bicriteria decision support system dedicated to the above referred to two phases process.

The bicriteria location problems already included in the tool used in the firs phase are:

- the bicriteria simple plant location problem;
- the bicriteria p- location problem,
- the bicriteria capacitated plant location problem.

In all these models one of the objectives usually represents total costs and the other one total risk or noxiousness resulting from open services and transportation between communities and services.

There is a calculation phase where nondominated solutions are calculated, and a dialogue phase where the nondominated solutions are presented to the DM giving the opportunity of expressing preferences, which will guide the next calculation phase and so forth. This process stops when the DM finds the preferred solution or feels satisfied with the knowledge gained about the problem.

An interactive decision support tool (SABILOC) incorporating all the procedures was implemented in Visual C++ (Fernandes et al., 2007). It was developed in a modular way, allowing for the introduction of more models relevant in practical situations and/or procedures to solve them. The type of graphical tools used in SABILOC seems adequate to look for compromises in situations where group decision occurs, eventually in presence of hierarchical relations between some of the decision-makers, stimulating negotiation among all the actors of the decision process.

Once the preferred efficient solution or a set of compromise alternatives is known (some of them, eventually slightly dominated as referred to above, a second phase consisting in an "a posteriori analysis" procedure should be carried out, for a more detailed analysis of this sub-set of the alternatives. For this second phase, another tool, VIP Analysis - Variable Interdependent Parameters Analysis for Multicriteria Choice Problems (Dias and Clímaco, 2000) is used. It supports the selection of the most preferred alternative from those selected in the first phase. VIP-analysis is a multiattribute decision adding tool supporting interactively the choice of the "best" compromise option. It uses the additive aggregation model but avoids fixing sharp scaling constants. Instead, one just needs to elicit imprecise information regarding the scaling constants (for instance, ordering them according to the relative importance of the corresponding criteria). Then a box of adequate tools and tabular/graphical interfaces are provided to help in the interactive support of the choice…

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# Constructing a DC Decomposition for the Ordered Median Problem

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## Abstract

In this paper we show how to express every ordered median problem as a difference between two convex functions. Once such a decomposition is available, DC optimization techniques can be applied to optimally solve ordered median problems. The approach is demonstrated on solving ordered one median problems in the plane. General lower bounds are constructed and eleven such problems (such as minimizing the truncated mean, range, inter-quartile range, mean distances difference and others) are optimally solved by applying the "Big Triangle Small Triangle" approach. Computational experiments demonstrate the superiority of this approach over other algorithms for the solution of the majority of these problems.

# Improved Algorithms for Covering a Family of Paths in a Rooted Tree

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## Abstract

Let $T = (V,E)$ be a tree with node set $V = \{v_1,...,v_n\}$ and edge set $E$. Each edge $e \in E$ has a positive integer capacity (cost) $u_e$. Let $\{(s_k, t_k): s_k \neq tk, k = 1,...,K\}$ be a list of $K$ distinct pairs of nodes. Associate a commodity $k$ with the pair ($s_k$, $t_k$), and designate $s_k$ as the source and $t_k$ as the sink of this commodity. Let $p_k$ be the unique path from $s_k$ to $t_k$. The integral multiflow problem is to maximize the sum of the integral simultaneous flows corresponding to the $K$ commodities, subject to the capacity and flow conservation constraints. The respective multicut problem is to find a minimum cost set of edges whose removal separates each pair $(s_k, t_k), k = 1,..., K$ . Equivalently, the latter problem is to find a minimum cost covering of all paths $\{p_k : k = 1,..., K\}$.

Consider the formulation of the integral multiow problem as a packing problem. For $k = 1,..., K$ let $f_k$ denote the integral flow on $p_k$. For $k = 1,..., K$ , and $e \in E$ , define $a_{ek} = 1$ if $e \in p_k$ and
$a_{ek} = 0$ when $e \notin p_k$ . Let $\mathbf{N}$ denote the set of all nonnegative integer numbers.

$$\max \sum_{k=1}^{K} f_k$$

Subject To,

$$\sum_{k=1}^{K} a_{ek} f_k \leq u_e, \quad \forall e \in E$$

$$fk \in \mathbf{N}, \quad \forall \mathrm{k} = 1,..., \mathrm{K}.$$

(1)

Similarly, the formulation of the integral multicut problem as a covering problem is

$$\min \sum_{e \in E} u_e x_e$$

subject to,

$$\sum_{e \in E} a_{ek} x_e \geq 1, \quad \forall k = 1,...,K,$$
$$x_e \in \{0,1\}, \quad \forall e \in E.$$

(2)

For general undirected trees, both the covering (multicut) and the integral multiflow problems are NP-hard, as shown respectively by Kolen and Tamir (1990) and Garg, Vazirani and Yannakakis (1997). When $T$ is directed and for each $k = 1,\dots,K$, the path $p_k$ is directed from $s_k$ to $t_k$, using total unimodularity properties, the above pair of packing-covering integer programs have been shown to be a pair of primal-dual linear programs. They are both polynomially solvable by using standard network flow algorithms.

Costa, Letocart and Roupin (2003) focused on the case where the tree $T$ is rooted. In this case there is a distinguished root, say $v_1$, and the edges are directed such that there is a unique directed path from $v_1$ to any other node. In this model, for each $k = 1,\dots,K$, $s_k$ is an ancestor of $t_k$ on the rooted tree, and $p_k$ is a directed path from the source $s_k$ to the sink $t_k$. They presented a greedy procedure to find an optimal multiflow and use duality properties to obtain an optimal multicut. In fact, their algorithm is a specialization of the quadratic time greedy type algorithm of Kolen (1982), (see also Kolen 1986, Hoffman, Kolen and Sakarovitch 1985, Kolen and Tamir 1990), to solve weighted covering and packing problems defined by general totally balanced and greedy matrices. The complexity of the algorithm in Costa, Letocart and Roupin (2003) is $O(\min(Kn, n^2))$.

In this paper we also concentrate on the multicut and multiflow problems in rooted trees. Our main objective is to show that this model can be solved in subquadratic time. We identify additional properties of this model which lead to a subquadratic transformation into greedy form, and apply more sophisticated data structures, to show that the above greedy algorithm of Kolen can be implemented in subquadratic $O(K + n + \min(K, n)\log n)$ time. Since $K \leq n(n-1)/2$ for any rooted tree, we conclude that our modified complexity bound coincides with the quadratic bound in Costa, Letocart and Roupin (2003) if and only if $K = O(1)$ or $K = \theta(n^2)$. Our modified bound strictly improves upon the bound in Costa, Letocart and Roupin (2003) in all other cases. For example, when $K = \theta(n^\delta)$, the improvement is from $O(n^{1+\delta})$ to $O(n)$ if $0 < \delta < 1$, from $O(n^2)$ to $O(n \log n)$ if $\delta = 1$, and from $O(n^2)$ to $O(n^\delta)$ if $1 < \delta < 2$.

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# Revenue-Optimizing Location Model with Equilibrium-driven Demand and Congestion

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## Abstract

In this paper we focus on several of the most important strategic decisions for service facilities facing uncertain customer demand, including finding the locations of the facilities, determining the service capacity, and choosing the price to charge for service. Utility-maximizing customers are assumed to reside at the nodes of the network, generating Poisson demand streams. Customer utility is affected by the price, travel distance and the waiting time at the facility selected by the customer. The unique feature of our model is that we explicitly recognize that the total demand generated by each customer, as well as the choice of which facility to use for obtaining service (in the multi-facility case), is affected by the congestion at the facilities, which, in turn, is affected by the choices made by other customers. Thus, the distribution of the customer flows is guided by the equilibrium: the demand rate at a facility depends on the waiting time incurred, which is by itself a function of the demand rate. The objective is to maximize the total profit of the facilities. Exact solution procedure is developed for the one facility case and aspects of the multi-facility case are discussed. Our paper bridges two streams of literature: special pricing models and facility location and congestion models. To the best of our knowledge, no location models that consider the combined effect of congestion and price on the firm's profit while taking into account equilibrium-based customer behavior have been published.

Single-Facility Model

Consider a network $G(N,L)$, with $|N| = n$ nodes, $|L| = l$ links, and shortest distance metric given by $d_{ij}$ for $i, j \in N$. A revenue-maximizing firm wishes to locate a single facility on the network, determine the capacity of the facility and choose the price to be charged for the service. Facility can be located anywhere in the set $N \cup L$. Customers from node $i \in N$ seeking to obtain service from a facility located at $x \in N \cup L$ have a "dis-utility function" depending on three factors: the travel distance $d_{ix}$, the price $p$ and the expected waiting time $w : \alpha d_{iz} + \beta p + \gamma w$ where $\alpha$, $\beta$ and $\gamma$ are customers' elasticity parameters with respect to travel distance, price and waiting time, respectively.

Demand process for a customer at node $i \in N$ using facility at $x \in N \cup L$ is assumed to be Poisson with mean $v_{ix} = \lambda_i \exp(-u_{iz})$, where $\lambda_i > 0$ represents the maximum potential demand. Note that the actual average demand $v_{ix}$ is assumed to have exponential decay governed by the dis-utility function $u_{ix}$. For simplicity, we assume the service process at the facility is a Poisson process with rate $\mu$. Therefore, the facility operates as a $M / M / 1$ queuing system.

Let $(x, p, \mu)$ be the location price and capacity decision of the firm, respectively. Then the expected demand at the facility is given by:

$$\lambda(x, p, \mu) = \sum_{i=1}^{N} \lambda_i \exp[-\alpha d_{ix} - \beta p - \gamma w(x, p, \mu)].$$

The expected waiting time from a $M / M / 1$ system satisfies

$$w(x, p, \mu) = \frac{1}{\mu - \lambda(x, p, \mu)}.$$

(1)

Let $C$ be the unit capacity cost. The single facility problem can be formulated as follows:

$$\max R(x, p, \mu) = p \cdot \lambda(x, p, \mu) - C \cdot \mu,$$

subject to (1). The following results can now be derived (please see Berman, Krass and Tong (2008) for details):

Theorem 1: *Given any price $p > 0$ and service rate $\mu > 0$, there exists an optimal facility location within the set of nodes N.*

Theorem 2: *Given any location $x \in N \cup L$, there exists a unique optimal price $p^*$ and capacity $\mu^*$ such that*

$$p^* = \frac{1}{\beta} + C \quad \mu^* = \frac{2\gamma L(x) + \beta\gamma C}{4L(x)^2},$$

*and the resulting equilibrium waiting time $w^*$ and arrival rate $\lambda^*$ under $p^*$ and $\mu^*$ at $x$ is*

$$w^* = \frac{2}{\gamma} L(x) \quad \lambda^* = \frac{\beta\gamma C}{4L(x)^2},$$

*where*

$$L(x) = -LambertW\left( -\frac{1}{2}\left( \frac{\beta\gamma C \exp(\beta p^*)}{\sum_{i=1}^{n} \lambda_i \exp(-\alpha d(i, x))} \right)^{\frac{1}{2}} \right).$$

Based on Theorems 1 and 2, the optimal solution can now be found in linear time by enumerating all nodes: for each node $j \in N j$, we compute the optimal price, capacity and the resulting waiting time by Theorem 2 (note that these are given in closed form), and select the nodes with the lowest value of the objective function.

Multi-Facility Model

Suppose now that we are trying to locate $m > 1$ facilities on the network. Two levels of decisions are involved. First the firm has to select the locations $x = (x_1,\dots, x_m)$, prices $p = (p_1,\dots, p_m)$ and capacities $\mu = (\mu_1,\dots,\mu_m)$. The customers then select the facility to patronize that maximizes their utility. Let $v_{ij}$ be the resulting customer flow from node $i$ to facility $j$ located at $x_j \in N \cup L$ and charging price $p_j > 0$. The problem can be formulated as follows:

$$\max R(x, p, \mu) = \sum_{j \in M} \left( p_j \sum_{i \in N} v_{ij}(x, p, \mu) - C \cdot \mu_j \right),$$

where

$$w_j = \frac{1}{\mu_j - \sum_{i \in N} v_{ij}}, \quad \forall j \in M$$

$$v_{ij} = \lambda_i \exp\left(-\alpha d_{ij} - \beta p_j - \gamma w_j\right), \quad \forall i \in N, \forall j \in M .$$

The resulting problem is much more difficult than the single-facility version due to the embedded customer choice sub-problem. The final flow depends on customers' decision rules. For example, customers could cooperate with the firm to obtain system optimal distribution of flow (e.g., if customer-to-facility assignments can be centrally enforced). Alternatively, customers could behave as non-cooperating players leading to a traffic equilibrium where nobody has any incentive to deviate unilaterally. Some preliminary results for these cases can be found in Berman, Krass and Tong (2008).

# The Stochastic p-Hub Center Problem with Service-Level Constraints

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## Abstract

Small package delivery companies offer services where packages are guaranteed to be delivered within a given time-frame. With variability in travel time, the configuration on the hub-and-spoke delivery network is vital in ensuring a high probability of meeting the service-level guarantee. We present the stochastic p-hub center problem with service-level constraints, which are modeled using chance constraints. We discuss results and propose a heuristic for solving the problem.

# The design of incomplete hub networks

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## Abstract

Hub facilities are used to consolidate and disseminate flow in many-to-many distribution systems. Hub location problem deals with finding the location of hub facilities and the allocation of the non-hub nodes (demand centers) to these located hub facilities. It is assumed that there is economy of scale generated within hub-to-hub transportations. This economy of scale is typically estimated by using a constant discount factor ($\alpha$) between the inter-hub connections.

In hub location problems, it is usually assumed in the literature that the hub network is complete, i.e. there is a direct hub link present between every pair of hub nodes. There are few studies in the literature relaxing this complete hub network assumption. However, in some instances, the service that is provided with a complete hub network can also be provided with an incomplete hub network.

In this study we focus on designing hub networks, which are not necessarily complete, for the single allocation hub location problems. No network structure other than connectivity is imposed on the induced hub network. First, the single allocation incomplete hub covering network design problem is defined and an efficient mathematical formulation with $O(n^3)$ binary variables is introduced. The performances of some valid inequalities are also explored for this model. The model strengthened with valid inequalities is tested on various instances of the CAB data set and on the Turkish network. With our model, we were able to solve all CAB instances within 1 hour of CPU time with the optimization solver CPLEX to optimality.

The single allocation incomplete $p$-hub center, $p$-hub median, and the hub location with fixed costs network design problems are also defined and $O(n^3)$ mathematical formulations for these problems together with some computational analyses on the CAB data set are presented.

# The tree-of-hubs location problem: A comparison of formulations

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## Abstract

The Tree-of-Hubs Location Problem is studied. This problem, which combines several aspects of some location, network design and routing problems, is inspired by those transportation systems in which (i) several locations send and receive a product, and (ii) the performance can be improved by using transshipment points (hubs) where the product is collected and distributed.

Traditionally, hub location models assume that the hubs are fully interconnected, that is to say, that there exists a link connecting any pair of hubs, which can be used by applying the corresponding discount factor. However, some hub location models have been proposed recently where two hubs are not necessarily connected by some link. In this work, we propose a single allocation model for locating a fixed number of hubs on a network. The particularity of our model is that we require the hubs to be connected by means of a (non- directed) tree. To the best of our knowledge, the location of a tree on a network has not been considered previously in the context of hub location. Potential applications of our model arise when the cost of the links between hubs is very high, and as a consequence full interconnection is prohibitive. Since all the flows in the network must be sent through the hubs, a path must exist between each pair of hubs, i.e., a connected graph must be built. But due to the high cost of the connections, connectivity must be achieved using the minimum number of links.

The problem we address involves location, design, and routing decisions. The location decisions refer to the location of the hubs on the nodes of the network. The design

decisions refer to the way the selected hubs are interconnected so as to define a tree and to the (single) allocation of the nodes to the selected hubs. The routing decisions refer to the way in which the flows between vertices of the network are routed through the tree of hubs. In the problem in question the location and the design decisions determine the routing decisions, since for each pair of nodes of the network there exists only one path connecting them in the tree of hubs. Hence, in addition to hub-location problems, our problem is also related to other types of problems studied in the literature where location, design or routing decisions are considered.

The problem is defined on a directed graph where it is assumed that for each pair of nodes there exists a known amount of flow that must be sent through the network. To this end p hubs must be located on the network and connected by means of a tree. Each node must be allocated to one single hub and all the flow from/to the node must leave/enter it through its allocated hub. Excepting the arcs that connect each node with its allocated hub, the only arcs that can be used for routing the flows must be links connecting hubs. There is a unit transportation cost associated with each arc. As usual, if hubs are located at both end-nodes of the arc, a discount factor is applied to the unit cost. We assume that the set-up cost for the hubs is the same at each potential location. Given that there is a fixed number p of hubs to be located, this cost is not taken into account, since it is constant and, thus, it does not affect the optimization of the system. We also assume that there is a set-up cost for establishing a link between hubs, which is the same for each arc of the network. Since the hubs are connected by means of a tree, there is also a fixed number p-1 of such links, so the overall link set-up cost is constant and, thus, it is not taken into account. Therefore, we aim to minimize the operation costs of the system, which depend on the amount of flow that circulates through each arc, and on the links to which the discount factor is applied.

We propose and analyze several alternative formulations for the problem. These formulations are compared in terms of the lower bound that they produce and of the computational effort required to solve them. Computational results will be presented.

# Single hub location of air cargo using the generalized Weber model

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## Abstract

Many airlines adapt the hub-and-spoke system where economies of scale exist in the transportation cost. Most of the air cargo airlines have single hub airports in the United States while most passenger airlines have a few hub airports. In this decade, transportation costs have been greatly influenced by the sudden rise in fuel prices. This paper analyzes how the change of transportation costs affects single hub airport locations of air cargo in the United States using the generalized Weber model.

The airline hub location problem was presented by O'Kelly[1], and recent literature mainly formulates the problem as a discrete facility location problem using mathematical programming models. We formulate a continuous single-facility location problem using nonlinear cost functions in which the marginal cost decreases as distance or demands increases.

The generalized Weber model finds the location of a facility which minimizes the weighted sum of transportation costs, which is a power function of the Euclidean distance to a set of demand points. Recently, many effective algorithms for the generalized Weber problem have been developed following the BTST method[2].

We confirm economies of scale in both distances and demands from the parameters estimated by the actual transportation cost of air cargo in 1999, 2002 and 2007. The elasticity of distances has decreased greatly while the elasticity of demands hardly changes in this period. The location of airport hubs will move to the east coast of the United States, which contains many large demand points, as the economies of scale in distance become larger.

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# Hub Location for Time Definite Transportation

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## Abstract

Hub location models have been used to analyze a wide variety of transportation systems, including airlines, motor carriers, railroads and maritime shipping. Much research has addressed, and extended, fundamental cost-oriented hub median models and service oriented hub center models. This presentation describes research on new hub location models that extend hub median and hub arc location models to include service level constraints. This is motivated by operations of time definite trucking firms that offer very reliable scheduled service between major cities. These firms provide higher service levels than general LTL motor carriers at lower costs than air freight carriers. The design of a hub network for time definite transportation depends on the tradeoff between the transportation cost savings from circuitous routings that facilitate consolidation and the lower service levels from the circuitous routes.

We present new hub location models that minimize transportation costs while ensuring service levels are met in terms of maximum origin-destination delivery times and distances. We provide optimal solutions for hub location models that locate fully interconnected hubs (as in hub median problems) and models that locate hub arcs to allow more flexibility in design. Results are compared for standard hub location data sets.

# A Discussion of Some Location Problems Global Warming Can Cause

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## Abstract

We identify and discuss qualitatively some location problems that may occur due to global warming. Increases in sea level may cause location problems, including relocation and shutdown problems, on an unprecedented scale. Climate changes may render some currently livable regions unlivable, and vice versa. The location modeling community should consider these problems.

# A Pipeline Network Design Model for Geologic Carbon Sequestration and Carbon Credit Pricing

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## Abstract

Several strategies exist for creating a carbon-neutral society, including increased energy efficiency and alternative fuels. However, carbon-based fuels are both abundant and cheap, and will remain a major fuel source (including hydrogen production) for the foreseeable future. For example, the USA alone has hundreds of years of known coal reserves, and if present oil prices are sustained, this coal can be profitably converted to oil and natural gas. Carbon capture and storage (CCS) is the process of capturing CO2 at its source (power plants, cement works etc.) and storing (or sequestering) it in geologic reservoirs such as abandoned oil fields. If coal power stations were to directly pass CCS costs onto consumers, it is estimated that electricity costs may only increase a few cents a kilowatt-hour. Due to continued expected CO2 emissions and its impact, it is likely that CCS will play a significant role. We present a linear programming model that optimizes the infrastructure supporting CCS. The model minimizes the cost of capturing, transporting, and sequestrating CO2 taking into account carbon credit pricing. Specifically, the model simultaneously determines:

- which CO2 sources (such as power stations) should be made carbon-capture ready
- which geologic reservoirs should be carbon-storage enabled
- optimal allocation of CO2 among available sources and sinks
- pipeline transportation routes
- pipeline capacities

The model can be set up to minimize the cost to sequester a target amount of CO2 or maximize the amount of CO2 that is profitable to sequester given carbon credit pricing. The model outputs can be then be used by decision makers to test carbon credit price levels, and optimally design pipeline networks and capacities and allocate CO2 among carbon sources and reservoirs.

# Comparison of Different Methods for the Optimal Location of Pumping Wells in an Aquifer

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## Abstract

Groundwater plays an important role in satisfying the increasing demand for water. The exploitation of aquifers requires the construction and operation of facilities, which location and size should take into account many different issues – in particular, setup and operation costs, and various environmental issues. The determination of the optimal solution to models representing real-world problems can be a difficult task since the model includes nonlinear functions and discrete variables. The literature shows different attempts to tackle this type of models, but sometimes at the expenses of oversimplifying the cost functions (either by ignoring fixed costs or by forcing them to be linear) or by considering the physical behavior of aquifers in a rather unrealistic way.

The model dealt with in this presentation is aimed at defining the number, location and pumping capacities for a set of new wells to be installed in an aquifer, while rigorously taking into account the behavior of the aquifer. The objective is to minimize the total setup and operation costs required to extract a given flow from the aquifer. The physical behavior of the aquifer is incorporated in the model through the response matrix approach. This approach allows the representation of the aquifer behavior in a very efficient and realistic way. In particular, it provides information on the relationship between pumped flows and consequent water drawdowns needed to establish the constraints representing environmental concerns.

Four different approaches are suggested and compared to solve the model. In the first approach, the MINLP model is converted into a NPL model by approximating the discontinuous fixed charge terms with a continuous function based in a “penalty polynomial coefficient”. The second approach follows the same philosophy but the approximation is accomplished through a “penalty exponential coefficient”. It is important to emphasize that the “penalty coefficient” approach is actually a smoothing function approach, and it does not have the meaning of the penalty function approach found in NLP methods. The third approach consists in using a simulated annealing heuristic based on an analogy with the annealing and subsequent cooling of metals. Simulated annealing has been found to be a robust iterative search method that avoids being trapped in local optima. The forth approach considers a MINLP commercial solver (DICOPT++ included in the GAMS software). The solving procedure is based on the

principle of decomposition and relaxation (a sequence of NLP sub-problems and relaxed versions of a MILP master program are solved).

The model was applied to a hypothetical problem defined for a real hydrologic setting, a part of the Setúbal aquifer system in the Palmela area (located south of the Tagus River, close to Lisbon). The results obtained for the four approaches show that NLP with penalty coefficients (linear or exponential) achieved poor solutions when compared with those produced by DICOPT++ and simulated annealing. The results for DICOPT++ and simulated annealing were quite similar. Simulated annealing was much more time consuming (ten times), but it must be pointed out that all the approaches except simulated annealing were very sensitive to the starting solution. Generally speaking, the NLP approaches and DICOPT++ needed a lot of work, and, at the end, the quality of the solution was not guaranteed. In contrast, once properly calibrated, the simulated annealing heuristic is ready for any implementation with good probability of finding a good solution. Indeed, after 50 runs using different seed numbers for the pseudo-random generator, simulated annealing showed its robustness by almost always achieving the same solution. Simulated annealing is much more time consuming, but the quality of its solutions is more reliable.

# What Foreclosed Homes Should a Municipality Purchase to Stabilize Vulnerable Neighborhoods?

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## Abstract

Over the past two years, increased rates of mortgage foreclosures in the U.S. have resulted in bankruptcies of over 100 mortgage lenders, losses to banks, hedge funds, pension systems and other investors in the range of $400 billion (Bajaj 2007). The housing market effects of the foreclosure crisis, and the wider credit crunch that has resulted, are severe. The number of troubled subprime mortgages increased nearly 20 percent between the fourth quarter of 2005 and the fourth quarter of 2006, and the excess of housing supply over demand is estimated to be around 800,000 units. Though only a minority of metropolitan areas recorded declines in median housing prices in 2006, the effects have been especially pronounced in economically troubled regions (Joint Center for Housing Research 2007).

In response, municipalities such as Boston, MA are increasing counseling services to homeowners at risk of foreclosure, securing foreclosed and abandoned properties, cleaning lots and making plans to purchase some of them at steep discounts (Drake 2008). Purchases of foreclosed and abandoned properties, when banks and mortgage companies are amenable to such transactions, represent a particularly attractive strategy because it has the potential to minimize blight, reduce unanticipated housing mobility, and to provide affordable homeownership opportunities to low- and moderate-income families. However, the cost of purchasing foreclosed properties far exceeds the resource available in most urban centers. Thus, not-for-profit managers must solve the following decision problem: What subset of a large number of foreclosed properties available for acquisition should be purchased to enable neighborhood stabilization and revitalization?

In this paper, we develop a coverage-based facility location model for housing acquisition (Marianov and Serra 2002) intended to jointly optimize objectives of social benefit and equity, while accounting for limited public funds. These objectives are

derived from 'sustainable housing principles' that recognize the social, environmental, economic and cultural dimensions of sustainable housing development (Turcotte 2006). The coverage component of the model is inspired by the notion of spatial spill-over effects (positive and negative) of foreclosed housing acquisition and redevelopment. Since the policy problem is fairly unstructured, engages multiple stakeholders, has a local focus and addresses needs of disadvantaged populations, we will apply principles of community-based operations research in model-building and analysis (Johnson and Smilowitz 2007). We apply our model to data from the economically struggling Massachusetts town of Lowell, which has faced sharp increases in foreclosures between 2006 and 2007 (richardhowe.com 2008). We use multiobjective analysis to identify alternative housing purchase strategies that may be associated with improvements in objective space over the status quo. Next steps include timing of housing purchases, and the uses to which redeveloped properties may be put, i.e. residential, commercial and mixed-use.

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# Voronoi Approaches to Location Problems Related to Wireless Sensor

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## Abstract

Because of the recent advances of the sensor technology, very small sensors equipped with CPU, GPS and other facilities have become practically in use. Many researchers of various fields have found that the wireless sensors related issue is a rich field of research seeds.

For location scientists, there are several pioneering works related to it. For example, Heinzelman et al [2] formulated the problem of selecting special sensors called cluster heads for networking the wireless sensors as the p-median problem. Patel et al. [3] introduced a variation of a maximal expected covering location model with considering the relocation costs of cluster heads. However, these studies are based on the discrete formulation of the problems.

Many problems in the continuous plane are still remained unconsidered. Because the sensors are scattered from the air to the sensing area such as battle fields, the problems in the continuous plane are sensitive for the practical usage of the sensors. For example, given a sensing area and the sensing range of each sensor, the problem to decide how many sensors should be scattered in the sensing field is still an open problem.

In this paper, we consider the following two problems in a continuous plane related to wireless sensor using the Voronoi diagram. We assume that the sensing range of each sensor should be a disk with the same radius, and the sensors are distributed randomly in a unit square.

The first problem is to find the number of sensors which is needed to cover the whole sensing area. For this problem, we need to calculate the area covered by many disks whose centers are randomly distributed in a unit square. It is not straightforward to calculate the area. Recently, Drenzer and Suzuki [1] found that the area is calculated using the standard Voronoi diagram. We calculate the area for sets of randomly

distributed disks for many times and find the average coverage ratio. By this method, we make a system to find the number of sensors needed to cover α% of the given sensing area in real time. Figure 1 shows a part of the preliminary results.

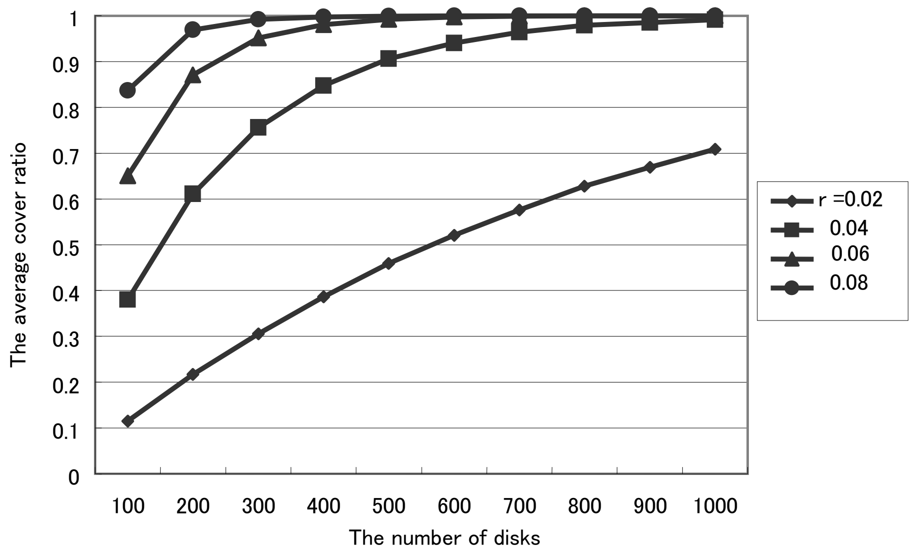


Fig. 1 Average cover ratio of disks for various radius *r* and number of disks

The second problem is to decide the minimum radius of the sensing range of the sensors to cover the whole sensing area when the sensors can move by a given small distance. Because the sensors have only a limited battery, it is appropriate to assume that the sensors can move only a small distance if they have mobility. The problem is a p-center problem when the position of the facilities is restricted. We formulate the problem as a nonlinear programming problem and propose a heuristic algorithm using the standard Voronoi diagram. The algorithm is a modification of that proposed by Suzuki and Drenzer [4] for the p-center problem. It is a descent method where we calculate the descent direction by numerical differentiation. We show the results at the presentation.

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# Stochastic Facility Location in the Process Industry

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## Abstract

In this paper we consider a multicommodity fixed-charge location problem with stochastic yields which is derived from a real-world application in the process industry. We introduce a non-linear mixed integer formulation, propose a Lagrangian approach to calculate lower bounds and Variable Neighborhood Search to provide feasible solutions. Computational tests show that we can obtain near optimal solutions for realistic instances with 10 facilities, 40 customers and 70 products.

We consider a location problem (SFLPI) in the process industry. The facilities considered in this problem produce paper, textile, food, rubber or intermediate- and petro-chemical products in semi-continuous chemical processes. The SFLPI has three characteristics which distinguish it from other location problems:

1. Facilities have to deal with yield uncertainty. Due to this uncertainty, it is not possible to fulfill customer demand exactly. Thus on the one hand overproduction causes holding costs while on the other hand shortages lead to high penalty costs.

2. Each facility is capable of processing different products. The switchover to a different product causes switchover times which reduce the available facility capacity. Besides the initial facility setup costs, additional inclusion costs for each product have to be considered.

3. There are economies-of-scale at high production quantities. This leads to a non-linear objective function.

The overall task is now to decide about the location and size of the facilities, the products to process in each facility and the assignment of quantities to customers. We provide different non-linear mixed integer formulations and relaxations. In order to calculate good upper bounds, we identify a portfolio of neighborhoods utilizing capacity changes, reassignments of products and production quantities between facilities and reassignments of customers between facilities. These neighborhoods are combined to a Variable Neighborhood Descend and to a Variable Neighborhood Search approach. To evaluate upper bound quality, we decompose the SFLPI in a Lagrangian manner into three sub-problems. All three problems can be solved easily by inspection. Combined with a sub-gradient approach to adjust the Lagrangian multipliers, this leads to very tight lower bounds.

We perform computational tests with realistic instances with up to 10 facilities, 40 customers and 70 products. Using discrete yield distributions, we utilize Jensen's inequality to reduce the number of scenarios for certain facilities which decreases the number of variables in the model significantly. For the largest test instances the gaps between upper and lower bounds are less than 4%.

# Stochastic Location-Assignment on an Interval with Sequential Arrivals

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## Abstract

A given number of servers are pre-positioned on an interval to serve demands that will arrive at random locations on the interval. The total number of demands to be served may not be known apriori, but will not exceed the number of servers. The demands arrive sequentially, and upon arrival, each is assigned to one of the servers, with that server unavailable for future demands. The remaining unassigned servers are not repositioned. The cost associated with each assigned server-demand pair is the distance between them. Both server-location and server-to-demand assignment decisions are made to minimize the expected sum of the costs for all assigned pairs. A necessary condition for optimality of servers-locations is derived, and the set of optimal servers-locations is characterized. For demands that are independent and uniformly distributed over the interval, the convexity of the location problem's objective function and the uniqueness of optimal server-locations are shown. Optimal server locations are found for problems with up to 10 servers and uniform demands, and some insights are derived based on these instances.

# Authors:

Aboolian, Robert – Session: Fri 10:30am-12:10pm; Abstract 38
Ahipasaoğlu, Damla S. – Session: Sat 1:30pm-3:10pm (1); Abstract 85
Albareda-Sambola, Maria – Sessions: Fri 1:30pm-3:10pm (1); Sat 8:30am-10:10am; Abstracts 51 & 75
Alumur, Sibel – Session: Tue: 10:30am-12:10pm; Abstract 134
Álvarez-Socarrás, Ada M. – Sessions: Fri 1:30pm-3:10pm (1); Abstract 46
Antunes, António - Sessions: Fri 3:30pm-5:10pm (1); Fri 3:30pm-5:10pm (2); Sat 1:30pm-3:10pm (2); Tue 1:30pm-3:10pm; Abstracts 60, 69, 89, & 141
Barbosa-Póvoa, Ana – Session: Thurs 1:30pm-3:10pm (1); Abstract 7
Bassamboo, Achal – Session: Fri 8:30am-10:10am; Abstract 37
Berman, Oded – Sessions: Fri 10:30am-12:10pm; Fri 3:30pm-5:10pm (1); Tue 8:30am-10:10am; Abstracts 38, 60, 130
Bhadury, Joy – Session: Fri 8:30am-10:10am; Abstract 36
Bielicki, Jeffrey – Session: Tue 1:30pm-3:10pm; Abstract 140
Bigotte, João – Sessions: Fri 3:30pm-5:10pm (1); Fri 3:30pm-5:10pm (2); Abstracts 60 & 69
Bischoff, Martin – Sessions: Fri 1:30pm-3:10pm (1); Fri 3:30pm-5:10pm (1); Abstracts 50, 66
Blanco, V. – Session: Thurs 3:30pm-5:10pm (1); Abstract 24
Blanquero, Rafael – Session: Thurs 1:30pm-3:10pm (2); Abstract 16
Bogataj, Marija – Session: Thurs 1:30pm-3:10pm (1); Abstract 11
Bozkaya, Burçin – Session: Mon 10:30am-12:10pm; Abstract 106
Brimberg, Jack – Session: Fri 1:30pm-3:10pm (2); Abstract 59
Bruno, Giuseppe – Session: Sat 8:30am-10:10am; Abstract 73
Caballero-Hernández, Saúl I. – Session: Fri 10:30am-12:10pm; Abstract 39
Campbell, James F. – Session: Tue 10:30am-12:10pm; Abstract 138
Canbolat, Mustafa S. – Session: Tue 3:30pm-5:10pm; Abstract 72
Cano-Belmán, Jaime – Session: Thurs 10:30am-12:10pm; Abstract 2
Captivo, Maria Eugénia – Sessions: Fri 3:30pm-5:10pm (2); Sat 8:30am-10:10am; Tue 8:30am-10:10am; Abstracts 67, 78 & 123
Caro, Felipe – Session: Tue 3:30pm-5:10pm; Abstract 147
Carrizosa, Emilio – Session: Thurs 1:30pm-3:10pm (2); Abstract 16
Cho, Nayoung – Session: Fri 3:30pm-5:10pm (1); Abstract 64
Chopra, Sunil – Session: Fri 8:30am-10:10am; Abstract 37
Church, Richard L. – Sessions: Fri 8:30am-10:10am; Sat 1:30pm-3:10pm (2); Mon 8:30am-10:10 am; Mon 10:30am-12:10pm; Mon 3:30pm-5:10pm; Abstracts 35, 89, 101, 105, 118 & 121
Clímaco , João – Sessions: Sat 8:30am-10:10am; Tue8:30am-10:10am; Abstracts 78 & 123
Contreras, Iván – Sessions: Mon 1:30pm-3:10pm; Tue 10:30am-12:10pm; Abstracts 121 & 135
Cordone, Roberto – Session: Mon 3:30pm-5:10pm; Abstract 120
Correia, Isabel – Session: Sat 1:30pm-3:10pm (1); Abstract 87