XXIV

EWGLA

Edinburgh

EWGLA LOCATIONAL ANALYSIS

Proceedings of the XXIV EURO Working Group on Locational Analysis Meeting

23rd-25th May 2018

Wednesday, 23 May		Thursday, 24 May		Friday, 25 May	
8:30-9:30 9:30-10:00	Registration & Coffee Opening Session				
10:00-11:00	Plenary - A. Lodi	9:30-11:10	Parallel Session T1 T1a: Discrete Location II T1b: Planar Location II	9:30-11:10	Parallel Session F1a: Hub Location II F1b: Districting
11:00-11:30	Coffee	11:10-11:45	Coffee & Photo	11:10-11:40	Coffee
11:30-12:45	Parallel Session W1 W1a: Network Design I W1b: Applications I	11:45-12:45	Plenary - S. Wallace	11:40-12:55	Parallel Session F2a: Location-Routing II F2b: Competitive Location
12:45-14:20	Lunch	12:45-14:15	Lunch	12:55-14:15	Lunch
14:20-16:00	Parallel Session W2 W2a: Location-Routing I W2b: Planar Location I	14:15-15:30	Parallel Session T2 T2a: Network Design II T2b: Applications II	14:15-15:30	Parallel Session F3a: Airborne Location F3b: Discrete OMP
16:00-16:30	Coffee	15:30-16:00	Coffee	15:30-16:00	Coffee
16:30-17:45	Parallel Session W3 W3a: Hub Location I W3b: Discrete Location I	16:00-18:00	City Tour	16:00-17:00	EWGLA Session
19:00-21:00	Welcome Reception St. Cecilia's Hall	19:00-22:00	Optional Whisky Tasting & Dinner	19:00-23:00	Conference Dinner Contini Restaurant

PROCEEDINGS OF THE XXIV EURO WORKING GROUP ON LOCATIONAL ANALYSIS MEETING

Edited by

T. Byrne, M. Delorme, S. García Quiles, and J. Kalcsics

The University of Edinburgh

Contents

Welcome

Dear Locators,

We are delighted to welcome you to the XXIV EWGLA Meeting in Edinburgh - fàilte a Dùn Èideann, fàilte a Alba. Traditionally, the meetings of the EURO Working Group on Locational Analysis bring together researchers and practitioners working in the wide area of location science through the proposal of models and methods to solve theoretical and practical problems. Apart from the scientific value, EWGLA meetings have always been a very enjoyable and friendly come together of a small but cosy, enthusiastic and energetic group.

The success of past editions evidences a continuing interest of the research community in locational analysis. This meeting features 54 contributions (plus 2 more whose authors were not able to attend in the end) covering a broad range of topics, starting from classical topics like continuous and discrete location, over hub location and location-routing, to network design and various applications. The large number of presentations forced us to have parallel sessions during the three days of the conference. 79 participants from 16 different countries from America, Asia, and Europe will attend the meeting, representing a great opportunity to build new and enrich existing relationships, and to share experiences among locators from all over the world.

We would like to thank all those who contributed to the organization of this meeting, especially Dawn Wasley from ICMS, for the many things she did so that this conference was possible, to Jill Douglas and Karen Downie, from the School of Mathematics, for their help with the conference finances, and to all the colleagues of the scientific committee, for so kindly agreeing to review the submitted abstracts.

We are also very grateful to the different sponsors: EWGLA, The OR Society, The OR Group of Scotland, the Edinburgh Mathematical Society, and the School of Mathematics. Their generous financial support has been key,

among other things, to allow for the first time ever that all PhD students, 27 in total, were offered free registration. We would like also to thank the International Centre for Mathematical Sciences for offering their installations to host this meeting.

We wish you all a pleasant and fruitful stay in Edinburgh, a successful meeting and plenty of new ideas and collaborations.

Belén, Jörg, and Sergio.

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PROGRAM

Wednesday, 23 May

8:30 – 9:30 Registration

9:30 – 10:00 Opening Session

10:00 – 11:00 Plenary Talk

Chair: Jörg Kalcsics – Room: Newhaven Lecture Theatre - Level 4

11:00 – 11:30 Coffee Break

11:30 – 12:45 Network Design I

Chair: Rajan Batta – Room: Newhaven Lecture Theatre - Level 4

11:30 – 12:45 Applications I

Chair: Soheil Davari – Room: ICMS Seminar Room - Level 1

12:45 – 14:20 Lunch

14:20 – 16:00 Location - Routing I

Chair: Olivier Péton – Room: Newhaven Lecture Theatre - Level 4

14:20 – 16:00 Planar Location I

Chair: Atsuo Suzuki – Room: ICMS Seminar Room - Level 1

16:00 – 16:30 Coffee Break

16:30 – 17:45 Hub Location I

Chair: Elena Fernández – Room: Newhaven Lecture Theatre - Level 4

16:30 – 17:45 Discrete Location I

Chair: Ioannis Giannikos – Room: ICMS Seminar Room - Level 1

19:00 – 21:00 Welcome Reception (at St. Cecilia's Hall)

Thursday, 24 May

9:30 – 11:10 Discrete Location II

Chair: Iván Contreras – Room: Newhaven Lecture Theatre - Level 4

9:30 – 11:10 Planar Location II

Chair: Anita Schöbel – Room: ICMS Seminar Room - Level 1

11:10 – 11:45 Coffee Break and Group Photo

11:45 – 12:45 Plenary Talk

Chair: Sergio García Quiles – Room: Newhaven Lecture Theatre - Level 4

12:45 – 14:15 Lunch

14:15 – 15:30 Network Design II

Chair: Robert Aboolian – Room: Newhaven Lecture Theatre - Level 4

14:15 – 15:30 Applications II

Chair: Juan José Salazar González – Room: ICMS Seminar Room - Level 1

15:30 – 16:00 Coffee Break

16:00 – 18:00 City Tour

19:00 – 22:00 Optional Whisky Tasting and Dinner

Friday, 25 May

9:30 – 11:10 Hub Location II

Chair: Mercedes Landete – Room: Newhaven Lecture Theatre - Level 4

9:30 – 11:10 Districting

Chair: Carmela Piccolo – Room: ICMS Seminar Room - Level 1

11:10 – 11:40 Coffee Break

11:40 – 12:55 Location-Routing II

Chair: Pitu Mirchandani – Room: Newhaven Lecture Theatre - Level 4

11:40 – 12:55 Competitive Location

Chair: Lieselot Vanhaverbeke – Room: ICMS Seminar Room - Level 1

12:55 – 14:15 Lunch

14:15 – 15:30 Airborne Location

Chair: Bahar Kara – Room: Newhaven Lecture Theatre - Level 4

14:15 – 15:30 Discrete Ordered Median Problem

Chair: Justo Puerto – Room: ICMS Seminar Room - Level 1

15:30 – 16:00 Coffee Break

16:00 – 17:00 EWGLA Session

19:00 – 23:00 Conference Dinner

PLENARY TALKS

On Big Data, Optimization and Learning

Andrea Lodi

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In this talk I review a couple of applications on Big Data that I personally like and I try to explain my point of view as a Mathematical Optimizer – especially concerned with discrete (integer) decisions – on the subject. I advocate a tight integration of Machine Learning and Mathematical Optimization (among others) to deal with the challenges of decision-making in Data Science. For such an integration I try to answer three questions: 1) what can optimization do for machine learning? 2) what can machine learning do for optimization? 3) which new applications can be solved by the combination of machine learning and optimization?

Handling High-Dimensional Dependent Random Variables in Vehicle Routing

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Speeds in cities are obviously both stochastic and dependent in time and space. This has not been much studied in the vehicle routing literature, simply because it has not been clear how to handle the high-dimensional random vector of speeds. In this work we make a first attempt to handle correlations in time and space. We analyze problems with up to 25,000 correlated random variables, by heuristically generating scenario sets with controllable qualities. We obtain accuracies around 1% when evaluation the objective function for feasible solution to a VRP using only 15 scenarios. We discuss briefly how the approach possibly can be extended to some other problems.

ABSTRACTS

Responsive Make-to-Order Supply Chain Network Design

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Keywords: Facility Location, Supply Chain Network Design, Make-to-Order

Make-to-Order (MTO) and Assembly-to-Order (ATO) systems are successful strategies in managing supply chains that use mass customization and compete on product variety. The typical response time in Make-to-Stock (MTS) systems is much shorter than in MTO and ATO systems. Therefore a reduction of response time is a major issue in both MTO and ATO systems (Reichhart and Holweg 2007). In this paper we address the network design of a responsive supply chain consisting of MTO or ATO facilities facing stochastic demand from customers residing at the nodes of a network. Each facility has a finite processing capacity and thus the stochasticity of demand may lead to congestion delays at the facilities. We intend to determine the number, locations and capacities of the facilities as well as the flow of the products from facilities to customers so as to minimize the total network cost. We consider three problems. In the first problem, we minimize the total network cost while maintaining an acceptable response time with a given probability for delays. Although originally formulated as a non-linear integer program, we show that this problem can be reformulated to a Mixed Integer Program (MIP). In both the second and third problems, if the order is delivered after the targeted response time, the network will be charged a penalty for late delivery. In the second problem a penalty is charged on the number of units that are delivered later than the targeted response time. In the third problem the penalty charged depends also on the number of days that the delivery is late. Although the problems are highly non-linear, we managed to solve them in an efficient manner using the Tangent Line Approximation (TLA) technique, developed in Aboolian et al. (2007) to linearize the non-linearity in these models.

The closest work to our paper is Vidyarthi, Elhedhli and Jewkes (2009), who presented a model to determine the configuration of an MTO supply chain. In this paper the emphasis is on minimizing the customer response time, consisting of the production time and delivery time, through the acquisition of sufficient production capacity, the optimal allocation of workload to the manufacturing facilities, and the optimization selection of delivery modes. Without considering the delivery time, they modeled the congestion cost using a direct relationship with the average waiting time, which is not really practical and cannot guarantee a satisfactory service level. The second model developed by Vidyarthi, Elhedhli and Jewkes (2009) is to design a hybrid MTS-MTO supply chain network, in which the plants make generic products that are later assembled into the final product at the distribution centers. Though a two-echelon facility location model, it failed to consider the production time and inventory management of the semi-finished products in the MTS echelon. Vidyarthi, Bhardwaj and Sinha (2014) introduced a model similar to the MTO supply chain design model in Vidyarthi, Elhedhli and Jewkes (2009). But the decisions of demand allocation to facilities are allowed to vary from one time period to another in response to changing demand rates over time.

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Weber Location Problem with Probabilistic Customer Locations and Restricted Area

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Keywords: Weber problem, Restricted area, Probabilistic locations

This paper tackles a multi-facility Weber location problem which is characterized by probabilistic customer locations and the presence of a restricted area in a continuous plane. The restricted area is defined as an area where neither establishing and nor travelling is possible and is called as barriers. This planar location modeling framework determines the location of new facilities in the plane and allocates the customers with probabilistic locations to the facilities locations where a barrier exists. This mathematical model also specifies the amount of each commodity to send to each customer at minimum total traveled cost.Difficulties in modeling occur when barriers have random nature in size or position. In this paper, the barrier which has a random position and customer locations with probabilistic locations are incorporated in the multi-Weber location problem. In this research work, we particularly focused on the flood adaptive location of facilities in Paris. The barriers are the flood prone risk zone according to PPRI[1] which are classified in the river bank of the Seine.

1. Literature review

In related literature review, Canbolat and Wesolowsky (2010) first studied a single facility Weber location problem where a restricted area exists.

[1] Plan de prévention du risque d'inondation de Paris.

A probabilistic position has been considered for the restricted area and the rectilinear distance function has been used to formulate the model. They assumed that the customer locations are known a priori. Shiripour et al. (2012) extended the previous work to a multi-Weber location problem with a probabilistic line restriction area and formulated a mixed integer quadratic programming (MIQP) model. Amiri-Aref et al. (2013a) and Amiri-Aref et al. (2016) provided a methodology to reshape any polyhedral restricted area to rectangular-shape restricted area for a *minisum* and a *minimax*, respectively. Amiri-Aref et al. (2013b) and Javadian et al. (2014) studied this problem in a multi-period setting with a rectilinear distance function and formulated a mixed-integer nonlinear programming (MINLP) model for *minisum* and *minimax* objective functions, respectively.

All above-mentioned works have considered a restricted area in the Weber location problem assuming that the location of customers is given as input parameters. In the present work, we consider a probabilistic customer location when the restricted area exists. To the best of our knowledge, the papers presented in the related literature review have ingored this important factor in the modeling approach.

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Exact and Heuristic Approaches for Support Vector Machine with ℓ_1 Ramp Loss

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Keywords: Support Vector Machine, Ramp Loss, Mixed integer linear programming

Support Vector Machines (SVM) methods, see, e.g. [2], have proven to be one of the state-of-the-art methods for Supervised Classification. Given a set of objects Ω partitioned into two classes $\mathcal{Y}$ = {-1,1}, the aim of SVM is to locate a hyperplane on a high dimensional space $H(w,\gamma) = \{x : w \cdot x + \gamma = 0\}$ for classifying new objects.

We will focus our research in the model Support Vector Machine with Ramp Loss introduced by [1]. We will study the model considering the ℓ_1 norm because it is known that this is less sensible to outliers. The model (RL-ℓ_1) is formulated as a mixed integer linear program with conditional constraints:

$$
\begin{aligned}
\min \quad & \sum_{k=1}^{d}(w_k^+ + w_k^-) + C\left(\sum_{i=1}^{n}\epsilon_i + 2\sum_{i=1}^{n} z_i\right), & & \\
\text{s.t.:} \quad & \text{if } z_i = 0,\ \ y_i\left(\sum_{k=1}^{d}(w_k^+ - w_k^-)\cdot x_{ik} + \gamma\right) \geq 1 - \epsilon_i, & i = 1,\dots,n, & \quad (1)\\
& w_k^+ \geq 0, w_k^- \geq 0, & k = 1,\dots,d, & \\
& 0 \leq \epsilon_i \leq 2, & i = 1,\dots,n, & \\
& z_i \in \{0,1\}, & i = 1,\dots,n, &
\end{aligned}
$$

An equivalent formulation for this model can be obtained substituting the set of conditional constraints (1) with its linearized form, where M_i is an enough big constant:

$$y_i \left(\sum_{k=1}^{d} (w_k^+ - w_k^-) \cdot x_{ik} + \gamma \right) \geq 1 - \epsilon_i - M_i z_i \qquad (2)$$

The goal is to provide algorithms that obtain efficient exact and heuristic solution approaches. The exact approach is based on two strategies for obtaining tightened values of M_i. The first strategy required solving a sequence of LP and the second one uses the lagrangian relaxation to tighten the bounds.

On the other hand, the heuristic solution approach is an adaptation of the Adaptative Kernel Search proposed by [3]. The basic idea of this heuristic approach is to solve a sequence of restricted MILP derived from the original problem, obtaining a progressively better bound on the solution. The computational effort required to solve the first restricted MILP guides the construction of the subsequent MILPs.

Aknowledgements

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Arc Pricing in Hub Location Problems

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Keywords: Hub location problems, Pricing, Bilevel programming

This paper introduces the joint problem of locating hubs and determining transportation prices between the hubs. The customers send their commodities over the network with minimum cost. The transportation provider aims to maximize the revenue collected over the arcs between the hubs. The problem is modeled as a nonlinear bilevel programming formulation, which is in turn linearized, and strengthened through variable reductions as well as valid inequalities. Computational results of traditional branch-and-cut and Benders based branch-and-cut algortihms are presented. Managerial insights about the interaction between the location and pricing decisions are provided.

1. Introduction

We study a hub location problem that involves two levels of decision makers acting non-cooperatively. The upper level decision maker (leader) locates q hubs and provides transportation service between the hubs at a price to be determined. Each of the lower level decision makers (followers) aims to send its commodity from a source to a destination with minimum cost, either routing their commodities using the existing infrastructure or using the hub arc. More precisely, the hub arcs are used only if the transportation cost is cheaper by a factor γ than the cost of using the original infrastructure. The leader aims to maximise its revenue, finding the optimal location of the hubs and determining prices for all arcs connecting hubs.

Hub location problems have been studied extensively, with many variants based on the number of hubs to transport commodities, hub capacities, and objective function type (minisum or minimax). We refer the interested reader to the chapter [3] and to the papers [1, 2], for a comprehensive review. Joint hub location and pricing models, on the other hand, received less attention. Lüer-Villagra and Marianov [4] have studied a competitive hub location and pricing problem, where two hub networks compete to maximize their profits, with the existing hub network using mill pricing and the entrant using arc-based pricing. The most relevant study is [5], where the authors focus on the problem of deciding which arcs of a given network to invest on and subsequently apply pricing to.

In this paper, we present the formal definition of the problem, and a proof of $\mathcal{NP}$-Hardness. We provide a mixed integer nonlinear bilevel programming formulation for the problem, and its linearization. We strengthen this formulation with some variable reductions and valid inequalities. Finally, a computational study is addressed to check the potentials and limits of the formulation and a variant proposed for the problem.

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The Multi-Period Service Territory Design Problem

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Keywords: Multi-period service territory, Mixed integer linear programming, Location-allocation heuristic, Branch-and-price

Classical service territory design problems consist of partitioning a set of customers into territories in a way that some relevant planning criteria, such as compactness and balance, are satisfied [4]. In each territory, a service provider (e.g., a service technician) is responsible for visiting the customers in order to provide certain services (e.g., maintenance work) at their premises.

In this talk, we consider applications in which customers demand recurring service visits during a given planning horizon. This extends the classical problem to a multi-period setting. We refer to the extended problem as the *multi-period service territory design problem* (MPSTDP) [2]. In addition to the partitioning task of the classical problem, the MPSTDP contains also a scheduling task, which deals with the assignment of service visits to the days of the planning horizon subject to customer-specific visiting requirements.

The focus of this talk is on the scheduling task of the MPSTDP. We introduce the relevant planning criteria and present a mixed integer programming (MIP) formulation. Moreover, we propose two solution methods: The first one is an extension of the well-known location-allocation heuristic of Hess et al. [3] to a multi-period setting, which is based on the repeated solution of an integer programming model. The second one is an exact branch-and-price algorithm, which incorporates specialized acceleration techniques, in particular a fast pricing heuristic and techniques that reduce the symmetry inherent to the formulation [1].

We evaluate both methods on real-world problem instances. The results show that the location-allocation heuristic produces high-quality solutions. It clearly outperforms the previous solution method of our industry partner PTV Group, which has, in the meantime, been replaced by a method based on our location-allocation approach. The branch-and-price algorithm is able to solve problem instances with up to 55 customers and a planning horizon of four weeks to proven optimality in reasonable running times. Moreover, it yields significantly shorter running times compared to solving a compact MIP formulation with the general-purpose MIP solver Gurobi.

Acknowledgments
The authors thank their industry partner PTV Group for providing real-world test instances and their product PTV xCluster Server for benchmarking purposes.

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Location-Routing in Tourist Trip Planning

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Keywords: Location-routing, Trip planning, Profit maximization

Within location analysis, problems simultaneously addressing distribution decisions, typically drawing routes connecting several visiting points, have been called location-routing problems (LRP). Several variants and applications of these problems can be found in the literature, some of them already studied extensively [2, 1].

This work focuses on a specific LRP application which has not been addressed before, although suggested in [2]: tourist selection of hotel and places to visit in a given destination.

When planning trips, tourists' main decisions concern the place to stay (location), and choice of points of interest (POI) to visit and corresponding visiting schedule (routing). As the number of POI in any given destination is typically large, and often not all can be visited in the available time and/or budget, the goal is typically profit maximization (although this "profit" is sometimes not easily quantified and highly user-dependent).

In this work, to address this specific application, a new variant of the LRP is studied: a LRP considering a single location, profit maximization and time windows. This application shares some similarities with the orienteering problem with hotel selection (OPHS) (the reader is referred to [3] for a discussion about these similarities). The problem is firstly defined and then a MILP model is presented to solve it. Due to the difficulty in solving larger instances to optimality, the problem is then tackled using heuristic approaches. Finally, new instances are proposed and used to test the developed model and heuristics.

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A High-Dimensional Weber Problem with a Subspace as Feasibility Set

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Keywords: Continuous Location, Dimension Reduction, Approximation Algorithm

In the talk we present a variant of the *Weber problem* [1]: We are given facilities within a high dimensional real space but the solution to the problem is known to be contained in a lower-dimensional linear subspace. A reformulation to a lower-dimensional generalized Weber problem is given for which we discuss properties and present a generalized Weiszfeld-Algorithm to solve the problem.

1. Problem Formulation

Let $\mathcal{F} = \{F_1, \ldots, F_M\} \subset \mathbb{R}^N$ be the set of given facilities with weights w_i. The feasible set, however, is restricted to a given linear subspace V of dimension k, where we usually have $k << n$. Using a linear transformation we may assume w.l.o.g. that $V = \{x \in \mathbb{R}^N : x_i = 0 \;\; \forall i > k\}$. Then the problem can be formulated as

$$\begin{array}{lll} (P) & \min & \sum_{i=1}^{M} w_i \|x - F_i\|_2 & \\ & \text{s.t.} & x_i = 0 & \forall i = k+1, \ldots, N \\ & & x \in \mathbb{R}^N. & \end{array}$$

This problem occurs in an application and its optimal solution yields a lower bound on a location problem in a metric space consisting of trees (the so-called *phylogenetic tree space*) where one tries to calculate the "average tree". However, the following reformulation also suggests the usefulness of the problem itself because it turns out to be a generalization of the standard

Weber problem. Let $\mathcal{A} = \{A_1, \ldots, A_M\}$ where each A_i is the vector of the first k components of F_i and define $c_i := \sum_{j=k+1}^{N} F_{ij}^2$ to be the squared norm of the other $N-k$ components, then (P) is equivalent to

$$\begin{array}{lll} (P_{\text{red}}) & \min & \sum_{i=1}^{M} w_i \left(\|x - A_i\|_2^2 + c_i\right)^{\frac{1}{2}} \\ & \text{s.t.} & x \in \mathbb{R}^k. \end{array}$$

We receive the Weber problem in $\mathbb{R}^k$ whenever $c_i = 0 \; \forall i = 1, \ldots, M$ holds.

2. The Generalized Weiszfeld-Algorithm

Since our reformulated problem is a generalization of the Weber problem it is natural to try to generalize an existing solution method. We generalize the Weiszfeld-Algorithm [2] following the structure of [3], who has cleanly proven convergence theorems for Weiszfeld's algorithm. We carefully adapt all theoretical statements and proofs w.r.t. the terms $\|x - A_i\|_2$ to the $\left(\|x - A_i\|_2^2 + c_i\right)^{\frac{1}{2}}$ version to fit the altered objective function. As the main result we hence receive a very similar computationally fast iterative method, a gradient descent method with an implicitly calculated step size guaranteeing a decrease in the objective function in each step. When using optimality criteria for facilities beforehand, then the algorithm converges to the optimal solution for all starting points except for a denumerable set $P \subset \mathbb{R}^k \setminus \mathcal{A}$. We implemented and applied the algorithm to calculate bounds on the Weber problem in the phylogenetic tree space. This metric space is embeddable into a high-dimensional real space where certain regions of the metric space yield subspaces of the real space when embedded. Moreover, the Euclidean distance of two points after the embedding is not bigger than the distance in the metric space. So an optimal solution for the problem in the embedded subspace yields a lower bound for the problem constrained to the corresponding region in the metric space. The algorithm has a short computation time and we receive reasonable bounds on our problem.

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When Closest is not Always the Best: The Distributed p-Median Problem

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Keywords: p-Median, Ordered Weber, IP formulation, Finite dominating set

The classical p-median problem assumes that service to customers is always provided by the closest facility, while in practice, customers often interact for a variety of reasons with several of the facilities. In this talk we introduce the concept of a distribution rule for modeling such flows, and use it to formulate a new class of median problems which we call the "distributed" p-median problem. Different types of distribution rules are investigated leading to some interesting properties. For example, if the weights are increasing (i.e., assigned flows are greater to facilities that are further away) the problem can be solved in polynomial time as a 1-median problem. For decreasing weights we obtain generalizations of the standard models, which in turn lead to a broader interpretation of median points. Some small numerical examples illustrate the concept.

1. Introduction

The p-median problem locates p facilities to serve a set of customers. In classic location models it is assumed that the customers visit their closest facilities. But is this assumption always true?

In real-world, we believe that this is not the case. There may be a number of reasons for this. The customer may like to have some variety of choice even when facilities are assumed to be homogeneous. Thus, the customer may wander some times to his/her second closest or third closest facility (shopping mall, store, ...). The customer may also do this for social reasons, such as meeting friends. A distribution rule other than the 'closest' facility rule may capture customer preferences more realistically.

Here, we present an entirely new version of the p-median problem where the flow (or demand) of each customer is divided and routed to all p facilities. The distribution rule is specified by a vector $\lambda = (\lambda_1, \ldots, \lambda_p)$ (with $\sum_{i=1}^{p} \lambda_i = 1$) which distributes demand to facilities in the following way:

- λ_1 percent of the customers go to their closest facility,
- λ_2 percent of the customers prefer their second-closest facility,
- $\ldots$, and
- λ_p percent of the customers take the furthest facility.

Thus, the classical p-median problem in which each customer visits its closest facility becomes a special case with $\lambda = (1, 0, \ldots, 0)$.

By examining different distribution rules, the decision maker will have a number of different median-type solutions to choose from, instead of just one. This may lead to a better decision based on other considerations such as robustness or redundancy.

2. Main Results

We introduce the problem formally and show how it can be modeled as (nonlinear) integer program. For increasing distribution rules, i.e., the farther away a facility is the higher is the percentage of customers who wish to visit it, we can prove the following result.

Theorem 1. *An optimal solution to the distributed p-median problem with increasing distribution rule places all p facilities at an optimal solution of the 1-median problem.*

Decreasing distribution rules are more common in applications, but also more complicated. We present advanced integer programming formulations. We show that in an optimal solution each of the p facilities is a median point to some (appropriately defined) 1-median problem. We can use this result to derive the following finite dominating set.

Corollary 2. *For the continuous distributed p-median problem with a decreasing distribution rule and a block norm as distance measure there exists an optimal solution $\{X_1, \ldots, X_p\}$ such that each of the new facilities X_i, $i = 1, \ldots, p$ lies on a vertex of the grid spanned by the fundamental directions through the demand points.*

Districting Models to Redefine Strategies for Postal Mail Delivery Service

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Keywords: Postal sector, Delivery service, Districting models

In the last decades, the postal sector was characterized by profound changes due to different factors. First of all, technological development and digitalisation had a strong impact on customers' habits, thus leading to two macroscopic phenomena, that put in crisis the traditional business models: the *e-substitution*, i.e. the replacement of traditional mails by electronic forms of communication, that led to a strong reduction of mail volumes, and the *e-commerce*, that contributed to the growth of the Courier Express Parcel segment. Moreover, the evolution of the European regulatory framework led to a gradual liberalization of the market and to an increased competitiveness. These factors are pushing to a general rethinking of business models and to an innovative reorganization of logistic systems.

In this context, we started a collaboration with the main Italian Postal Provider (Poste Italiane), aimed at addressing some problems concerning the reorganization of mail collection and delivery services. In this work, we propose models to redefine strategies for postal mail delivery service.

Along the entire supply network, large hubs, named Postal Mechanization Centres (PMCs), are responsible of sorting mails "arriving from" and "departing towards" points within large competence areas. Thus, incoming mails are here accepted, consolidated and prepared to be distributed to different destinations. Typically, they are first sent to intermediate facilities, named Distribution Centres (DCs), that are in charge of organizing delivery service in smaller competence areas. Such areas are in turn subdivided in *delivery districts*, each assigned to single postmen.

Poste Italiane defined the current delivery districts on the basis of an algorithm, that guarantees that the total workload assigned to each postman does not exceed the workshift length. Considering that there exist different typologies of mails (*priority* and *ordinary*) with different delivery deadlines (one and two days), Poste Italiane is evaluating some novel strategies, based on the delivery of ordinary mails on alternate days, with the aim of improving the overall efficiency of the service.
In order to address the problem, we refer to the class of districting models, that are particularly suitable in the service-oriented applications to define competence areas for service provision. In the case under analysis, we consider the reference area of a generic DC as *study region*, the census tracts as *territorial units*, and the expected daily volumes to be delivered, for the ordinary and priority mails, as attributes to be associated to each unit.
In the first model, we consider two categories of postmen (P and O), devoted to deliver priority and ordinary mails, respectively. According to such assumption, each postman P is assigned to a single area, to be visited on a daily basis; while each postman O is assigned to a couple of districts, to be visited on alternate days. For example, in a week, the postman O will visit the first area on Tuesday and Thursday, and the second on Monday, Wednesday and Friday, and viceversa.
In the second model, similarly to the previous case, we consider two categories of postmen. Each postman in the first class is assigned to a couple of districts and delivers, on alternate days, both ordinary and priority mails within each of them. But, as priority mails need to be delivered everywhere every day, a second category of postmen (named *plus postmen*) is necessary to guarantee the service.
In this work, we formulated some models to represent the alternative strategies for the *postal mail delivery problem on alternate days*. The proposed models were tested on the case of the city of Bologna (Italy) and produced solutions were analysed to provide decision support in the redesign process.

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Capacitated Directed Cycle Hub Location Problem Under Congestion

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Keywords: Hub location problem, Hub-and-spoke networks, Network design and optimisation, Tabu search

Hubs are centres for collection, sorting, transshipment and distribution of cargo, passengers, and/or information. Transshipment hub ports play a crucial role in liner shipping and as such hub-and-spoke (HS) is the dominant network configuration in global container trade lanes. In a maritime HS network, cargoes collected from origin ports by feeder ships are transshipped to larger mainline ships at hub ports and distributed to destination ports again via transshipment to feeders at destination hubs.

The design of a HS network is the most strategic decision in the process of a shipping line's service development. Moreover, it determines options for other strategic and tactical level decisions to a great extent. Therefore, decisions concerned with the configuration of a liner HS network such as locations of transshipment hubs, feeder port allocations, and mainline routes require an elaborate approach that considers predominant phenomena of the industry such as port congestion and double cargo handling.

This research is concerned with the development of a hub location model for liner shipping in order to design and optimise liner HS networks. It also enables analysis of the impact of various factors on the network. In a network composed of ports that have mutual demands, the problem is to find the optimal number and locations of hub ports, determine allocations of non-hub feeder ports to these hubs, and routing of cargo flows in the resulting HS network so as to minimise the total cost of transportation. The total cost comprises five components: cargo collection and distribution defined for each origin-destination pair, inter-hub cargo flow, extra cargo handling at hubs (loading/unloading from feeders to/from mainliners), fixed hub cost, and hub port congestion. The problem is defined as a capacitated directed cycle hub location problem under congestion. The capacity limitations at hubs are set as the maximum cargo flow (both incoming and emanating) each hub port can handle. Each feeder port can be allocated to a single hub port only. Direct transport between feeders is not allowed.

The corresponding model is formulated as a mixed integer nonlinear programming model and it has three key differences from the classical hub location models. First, the arcs that connect hub ports form a directed cycle. Second, a major disadvantage of HS, i.e. congestion at hubs, is incorporated into the model by modelling each hub as an M/M/1 queueing system. Third, the cost of cargo handling is calculated by taking double handling at hub ports into account.

A Tabu search algorithm is proposed to solve the problem. Due to the complexity of the problem a hierarchical approach is taken among hubs location, allocation of ports to hubs, and hub-level routing decisions. Tabu search is used to improve hub locations and node allocations only. A hub-level route is iteratively constructed by applying local search on the current solution at each iteration of the algorithm. Separate Tabu lists are used for the following moves:

- Open hub: A new hub is located at a node.
- Close hub: One of the open hubs is closed.
- Change hub: A hub from the current set of hubs is closed and a new hub is opened at one of the non-hub nodes
- Shift allocation: The allocation of a non-hub node is changed from one hub to another.

Long-term memory keeps record of hub locations at nodes. To diversify the search, hubs that are most frequently located are closed and new hubs are opened at the least frequently employed nodes. The results are tested using four data sets and analysed using five important concepts: economies of scale, ports' hinterland traffic, sensitivity to changes of terminal handling charges, geographical centrality of hub ports, and effects of inter-hub flows on the hub-level route. Finally, possible directions for future research are provided.

Location Problems with Continuous Demand on a Polygon with Holes: Characterising Structural Properties of Geodesic Voronoi Diagrams

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Keywords: Planar facility location, Continuous demand, Barriers, Voronoi diagrams, Computational geometry, Non-linear optimisation

The problem of finding optimal locations for a set of service facilities is of strategic importance and has generated a large body of research literature. In most models customer demand is assumed to be discrete and aggregated to a relatively small number of points. However, in many urban applications the number of potential customers can be in the millions and representing every customer residence as a separate demand point is usually infeasible. Therefore it may be more accurate to represent customer demand as continuously distributed over some region. Recently, in Averbakh et al. (2015) [1], a new exact algorithm has been proposed for several conditional planar facility location problems with constant demand distribution.

Moreover, the region of demand and the region over which a facility can be feasibly located are often assumed to be convex polygons. However, this supposition is not a realistic one for real world applications. While a non-convex demand region can be modelled as its convex hull with zero demand where appropriate, a non-convex feasibility region requires more work. Yet more problems occur when we introduce areas that cannot be traversed (for example, holes) since then we can no longer use rectilinear distance and must instead use geodesic rectilinear distances.

We assume that the facilities can be located anywhere on the plane that is traversable and customers obtain service from the closest open facility. While the discussion below applies to a variety of location problems that can be defined in this setting, for concreteness we consider the market share problem where the locations of $p-1$ facilities are fixed, and we seek to find the optimal location for an additional facility with the objective of maximising the total demand attracted by that facility. Once the locations of all p facilities are specified, the demand space is partitioned into regions called "Voronoi cells"; the resulting partition is known as the "Voronoi diagram".

However, due to the presence of holes we no longer have the classic Voronoi diagram, but instead the geodesic equivalent diagram. As well as defining the boundaries within this altered diagram, an additional difficulty is that it is generally impossible to represent the objective function in closed form. In fact, the representation of the objective function depends on the *structure* of the Voronoi diagram, i.e., the position and the geometry of the cell boundaries. Unfortunately, this structure can change drastically with the location of the "free" facility, making the underlying optimisation problems quite difficult. The optimisation problem is greatly simplified if the location of the new facility is restricted to a sub-region where the resulting geodesic Voronoi diagram is "structurally identical" for every point in the region. Given such regions, we can derive a parametric representation of the objective function which is valid for any location in the region. This in turn allows us to optimise the location of the new facility over this region using classical non-linear programming techniques. This suggests a general solution approach for this class of models: first, partition the demand space into regions where Voronoi diagrams are structurally identical, then find the optimal location(s) within each sub-region, of which the best one is the optimal solution to the problem.

In this talk we extend the structural properties of classic Voronoi diagrams to geodesic rectilinear distances and show how to use them to identify the desired sub-regions. In addition, we discuss how to determine efficiently the parametric representation of the objective function over each region and how to solve the resulting non-linear optimisation problem.

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Two-Level Capacitated Facility Location with Concave Costs

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Keywords: Multi-level discrete location, Concave costs, Lagrangean relaxation

Multi-level facility location problems (MLFLPs) lie at the heart of network design planning in transportation and telecommunications systems. Given a set of customers and set of potential facilities partitioned into k levels, MLFLPs consider the selection of a set of facilities to open at each level so that each customer is assigned to a sequence of opened facilities, at least one from each level, while optimizing an objective function. Applications of these problems arise naturally in supply chain management where the interactions between manufacturing facilities, distribution centers, warehouses, and retail stores play a major role. We refer to [2] for a comprehensive review on MLFLPs.

In this talk we study a class of MLFLPs denoted as *two-level capacitated facility location problems with concave costs* (2CFLP-C), in which production, warehousing and distribution costs are considered to be concave functions of the quantities produced, stored and distributed. These concave functions provide flexibility to the model, i.e. can be used to represent various situations such as economies of scale in production and transportation costs as well as environmental costs associated with greenhouse emissions (see for instance, [3, 1]). The problem is defined as follows. Let I be the set of customers and V_1 and V_2 be the set of sites among which production facilities and warehouses need to be opened. Let d_i denote the demand of customer $i \in I$ and f_{1k} and f_{2j} be the fixed setup cost for opening facilities $k \in V_1$ and $j \in V_2$, respectively. Let b_{1k} and b_{2j} denote the maximum capacity of facilities $k \in V_1$ and $j \in V_2$, respectively. We define as $c_{ij}(x)$ to be the transportation cost of routing x_{ij} units from warehouse j to customer i and $c_{jk}(y)$ to be the transportation cost of routing $\sum_{i\in I} y_{ijk}$ units from plant k to warehouse j. We also define $p_k(u)$ as the operational and production costs required to produce u_k units at plant k and $w_j(v)$ as the cost of operating a warehouse at location j of sufficient size to handle v_k units. The 2CFLP-C consists of selecting a set of facilities to open at each level and of routing customer's demand with the objective to minimize the sum of the above mentioned costs. The problem can be formulated as follows:

$$\begin{aligned}
\text{minimize} \quad & \sum_{k\in V_1}\left(f_{1k}z_{1k} + p_k\left(u\right) + \sum_{j\in V_2} c_{jk}\left(y\right)\right) \\
& + \sum_{j\in V_2}\left(f_{2j}z_{2j} + w_j\left(v\right) + \sum_{i\in I} c_{ij}\left(x\right)\right) \\
\text{subject to} \quad & \sum_{j\in V_1} x_{ij} = d_i \quad i\in I && (1)\\
& \sum_{k\in V_2} y_{ijk} = x_{ij} \quad i\in I, j\in V_2 && (2)\\
& \sum_{i\in I} x_{ij} = u_j \le b_{1j}z_{1j} \quad j\in V_2 && (3)\\
& \sum_{i\in I}\sum_{j\in V_2} y_{ijk} = v_k \le b_{2k}z_{2k} \quad k\in V_1 && (4)\\
& x_{ij}, z_{ijk} \ge 0 \quad i\in I, k\in V_1, j\in V_2 && (5)\\
& z_{rj}\in\{0,1\} \quad r=1,2, j\in V_1\cup V_2, && (6)
\end{aligned}$$

where z_{rj} are the (binary) location variables and x_{ij} and y_{ijk} are the (continuous) variables that determine the units of product routed on each link.

We present and computationally compare several Lagrangean relaxations and linear integer relaxations used to obtain lower and upper bounds on the optimal solution of this problem.

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Robust Distribution Network Design Under Interdiction

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Keywords: Network Design, Interdiction, Bilevel Programming, Benders Decomposition

Certain infrastructures are critical to the functioning of a nation's economy and societal well being. The United States' Department of Homeland Security identifies sixteen infrastructure sectors as critical to the national security, economy, and public health. Three out of these sixteen critical infrastructure sectors, namely transportation systems, communications, and energy employ multi-echelon distribution network with intermediate facilities as a dominant network structure. While a distribution network with intermediate facilities (e.g. distribution center) is attractive due to its cost effectiveness and operational advantages, it is prone to severe disruptions in the event of a failure of any of its facilities. For example, a study suggests that it is possible to disrupt the entire United States' air network by interdicting just 2% of all its airports. Therefore, it is important to design these networks that are robust with respect to accidental failures like facility breakdowns, disruptions due to natural disasters, or to failures made maliciously by enemy entities. This necessitates the identification of critical facilities in networks so that resources may be allocated towards their protection.

Facility interdiction problems identify critical facilities in a network that when interdicted causes the maximum disruptions or loss of demand.
Church et al. [1] proposed the r-interdiction median problem (r-IMP) and r-interdiction covering problem (r-ICP). The r-IMP identifies the set of r facilities to remove from the existing ones to maximize the overall demand

weighted transportation cost of serving customers from remaining facilities, whereas r-ICP identifies the set of r facilities that when removed minimizes the total demand that can be covered within a specific distance or time. For other related works, see Church et al. [2], and Liberatore [3] and references therein. Facility interdiction in multi-echelon distribution networks has received scarce attention in the literature, despite its many applications [4].

In this talk, we present a robust distribution network design problem under the risk of interdiction (RDNDI) of intermediate facilities. The problem studied here has been modeled as a three-stage problem. In the first stage, the network designer/ operator (referred to as the "designer") constructs a two-echelon distribution network in which each facility has a fixed setup/location cost, a maximum capacity, and a per-unit inbound flow cost (from supplier to facility) as well as outbound flow cost (from facility to retailers). Before the attacker acts, the designer allocates an initial set of flows on the network, which yields some measure of flow cost. In the second stage, the attacker inflicts damage to the network by destroying the facility (completely) so as to maximize the minimum possible post-interdiction flow cost. Finally, in the third stage, the designer minimizes post-interdiction cost by solving a routing problem on the remaining network. The problem is different from those in previous network design literature in that our objective function includes a weighted combination of flow costs before and after enemy interdiction plus the fixed setup cost of opening facilities. The problem is formulated as an tri-level mixed integer linear programing (MILP) model and reduced to bi-level MILP. We present several variants of Benders decomposition algorithm to obtain the optimal solution.

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Location-Location Routing Problem: An Interesting Application

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Keywords: Location Routing Problem, Refugee camp location, Humanitarian logistics

In the classical Location Routing Problem the customers are at fixed and known locations. However; for some public applications such as refugee camps the locations of these camps are also decision variables for the municipalities. In this paper we define the Location-Location Routing Problem (L-LRP) in which the location of the demand nodes will also be determined in addition to the locations of depots and the routes of the services. We provide linear integer mathematical models. The models and application to the refugee camps in the southern part of Turkey will be discussed during the presentation.

1. Definition and Motivation for L-LRP

In the classical Location Routing Problem(LRP) the customers are at fixed and known locations. Given the known customer locations, in LRP models, decisions are taken for distribution center locations and corresponding vehicle routes. Many extensions and applications of LRP are reviewed in the literature[1, 2]. In these studies the demand points are assumed to be of known locations. However; for some public applications the locations of customers can also be decision variables coming from a discrete set. In this study we consider such an application where the locations of demand nodes will be determined while considering the distribution center location(s) and corresponding vehicle routes. To the best of the authors' knowledge this variant of the Location Routing Problem has not been defined in the location literature before. We refer this problem as Location-Location Routing Problem (L-LRP).

In refugee camps certain public services are required to protect health, safety, dignity, etc. of the refugees[3, 4]. Thus, municipalities should plan regular public service visits to the refugee camps to provide these services. In the refugee camp location problem municipalities decide the locations of hosting institutions and routes of service providers originated from these institutions. Actually, in addition; municipalities also decide the locations of these refugee camps. Thus refugee camp location problem is a direct application of the L-LRP. Developed models and solution methodologies proposed are also valid for multi commodity version. Also, additional problem dynamics can be considered for the problem.

For the L-LRP linear mixed integer mathematical formulations are proposed. The applications could be such that the required services could be of many diferent natures, i.e. multi commodity version of the problem is also valid. For example for refugee camps healthcare, education and public services are given to the refugees.

For computational analysis, the real data is obtained from the Southern part of Turkey where 2.9 million Syrian refugees live[5]. Models, solution methodologies and results will be discussed during the presentation.

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The Hierarchical Multi-Period Location of Facilities for the Elderly

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Keywords: Facility location, Multi-period, Ageing, Heuristic, Demographics

1. Abstract

For the first time in Britain, there are more people of a pensionable age than children under sixteen (CIOB, n.d.). The ageing phenomenon is not limited to the UK and is more of a global crisis. For instance, according to the UN's medium population projections, the number of people aged over 65 could rise from just over 600 million today to close to 2.5 billion by 2100 (Franklin, 2015). This change in the demographics of the world will have significant implications on a society such as the increased burden on the healthcare sector and slower GDP growth rates. The term old age is multidimensional and can be attributed to chronological, psychological, social or biological age of people. In this paper, we consider people above 65 as elderly citizens who are in need of support.

Senior centres are facilities for elderly adults who live independently that provide services such as lunchtime congregate meals, socialization, entertainment, and referrals to other service agencies (Johnson et al., 2005). There is some evidence in the literature around the correlation of proximity to facilities and the frequency of facility visits such as elders visits to exercise facilities (Sallis et al., 1990) and referral to healthcare services (Varkevisser et al., 2012). Modelling facilities with a distance-sensitive demand is not new to the literature. Actually, it dates back to early 60s when Huff (1963) presented a model in which the behaviour of clients in selecting facilities to refer was modelled as an increasing function of the attractiveness

of facilities and a decreasing function of the distance to travel. Real-world case studies confirm this assumption of distance-sensitivity to a great extent. For instance, Currie and Reagan (2003) found that each additional mile to the closest hospital corresponds to a 3% decrease in the probability that a child has a medical check-ups.

In this paper, we consider the multi-period facility location problem for senior centres considering budget constraints, capacity limitations and the effect of immigration for an ageing population such as United Kingdom. We assume that the attractiveness of facilities to elders is a function of qualitative factors such as the service types and quantitative factors such as distance to travel. We will address the inconsistent version of the problem in which facilities can be opened at a given period and shut down in another. The objective of the problem is to identify the set of facilities to operate in each region in each period, the service levels to offer and the allocation of budget in each period to location and operation of facilities. A mixed integer mathematical model will be presented, an efficient heuristic will be proposed and managerial insights will be provided.

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Bilevel Programming Models for Multi-Product Location Problems

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Keywords: Stackelberg game, Multi-product location, Bilevel programming

1. Abstract

A retail firm has several malls with a known location. A particular product, e.g., food processor, comes in p types, which differ by shapes, brands and features. The set of all p products is P. Each mall j has a limited capacity c_j of products in P to be sold at that location, so the firm has to choose what products to sold at what mall. Furthermore, the firm can apply discrete levels of discount on the products, e.g., 5% and 10% over the price π_k of product k. The objective of the firm is to find what products to sell at which mall, with what level of discount, so that its profit is maximized.
Consumers are located in points of the region. Each consumer or group of consumers i has a different set $P_i \subseteq P$ of acceptable products, and will purchase one of these, or none if it is not convenient for her. Consumers

maximize their utility, defined as

$$u_{ijkl} = r_{ik} - \alpha_{jkl} \cdot \pi_{jk} - 2d_{ij} \tag{1}$$

where r_{ik} is the maximum expenditure that customer i is willing to make to acquire product k; α_{jkl} is (100 - discount level l in percent) of the product k in mall j; π_{jk} is the price of the product k in the mall j and d_{ij} is the distance between consumer i's origin and mall j. Whenever this utility is negative for product k at all malls, the consumer does not purchase the product.

The agents (firm and consumers) play a Stackelberg game, in which the firm is the leader and the customers the follower. Once the firm decides the products to sell at each mall and the possible discounts, consumers purchase (or not) one of their acceptable products wherever their utility is maximized. We model the problem using first a bilevel formulation, and we further replace the follower problem by the primal constraints and optimality restrictions, to obtain a compact formulation. We also present a strong and a weak formulation.

Computational experience is offered, using known instances from the literature [1].

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Solving Discrete Ordered Median Problems with Induced Order: Preliminary Results

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Keywords: Ordered median problem, Induced ordered, Discrete location

The Discrete Ordered Median Problem with Induced Order (DOMP+IO) is a multi-level version of the classical DOMP, which has been widely studied. In this work, a DOMP+IO with two types of facilites (levels) is considered and some preliminary results are provided.

1. Introduction

Despite the multitude of location problems and extensions that have been developed, in some occasions it is possible to unify basic location problems that appear to be drastically different. A prominent development is the Discrete Ordered Median Problem (DOMP) [3], which is well known for its ability to generalize the p-median and p-center problems as well as define new problems based on the order of the demands in terms of their closest service distance or lowest cost. DOMP was introduced to provide a way to model many of the popular discrete location models, based upon ordering demand in terms of service by their respective closest facility. This ordered demand allows to represent intermediate hybrid problems between median and center problems.

However, many real world applications are concerned with finding more than one type of facilities, considering multiple levels of facilities and determining a hierarchical facility location problem. For instance, in health care systems, a common location problem usually consists in locating equipped clinics and hospitals (medical stations) [4]. In education systems, primary schools and high schools are usually considered to be located [5]. Applications in emergency medical service systems consider distinct medical centers, which constitute the different levels of providing emergency assistance [6]. Most problems in computer/telecommunication networks consists in locating concentrators, routers and terminals [1].

In this work, a multi-level version of DOMP is addressed. Concretely, in this case two kinds of facilities are considered, since most recent papers are dedicated to two-level problems [2]. Therefore, the goal of the proposed DOMP with induced order (DOMP+IO) is to locate all the facilities in such a way that a client should not be far from a secondary facility if he/she is far from (near to) a primary facility. For instance, hospitals can be considered as primary facilities and heliports as secondary facilities in an emergency medical service system. Consequently, the generalization of DOMP is carried out by introducing an induced order on the secondary facilities.

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A Two-Stage Heuristic Algorithm for the Green Location-Routing Problem

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Keywords: Green LRP, CO_2 emissions, Heuristic algorithm, Real life application

The Green Location-Routing Problem (GLRP) is an extension of the Location-Routing Problem in which fuel consumption and CO_2 emissions are considered. The GLRP decides location of depots, routing of vehicles, speed and load of vehicles on each link of the routes. Time windows and vehicle capacities are respected.

1. A solution approach to solve GLRP

As a solution approach, we propose a two-stage solution algorithm based on an iterated local search procedure. Basically, the proposed algorithm initially generates a feasible solution and then by using a local search procedure it tries to improve the solution. After that, to escape from a local optimum solution, it perturbs this improved solution to search the entire feasibility space. This local search and perturbation procedures repeats until a certain number of iterations is reached.

While generating initial feasible solutions for the GLRP, we first consider the decisions on locations of depots. For this purpose, we use a p-median based algorithm, where we decide the location of depots by selecting p depot candidates that have the lowest average distances to the customers.

Then, we assign each customer to the nearest depot in terms of distance. Then, to construct the routes, we use the Clarke & Wright Savings Algorithm [1], which also respects vehicle capacity and customer time window constraints. For the local search procedure, the well-known two-opt algorithm [2] is used. In the proposed algorithm, all possible two-opt moves are applied for all tours and the local search procedure is applied until there is no improvement in the solution. For the perturbation procedure, we apply the double-bridge (4-opt) move, in which the tour is divided into four parts and the second and fourth parts are interchanged.

2. A real life application

We also present a real life application to show the importance of the fuel consumption and emission cost while deciding the location of the depots and the routes of the vehicles. For this study, we consider a fast-moving consumer goods (FMCG) company that distributes cold drinks to schools and universities located in the west side of Istanbul, Turkey. Initially, we detect the type of schools in this region and we find 179 schools in total consisting of 119 elementary schools, 55 high schools and five university campuses with their actual coordinates. While deciding the candidate depot location, we search the location of the depots that are used for the distribution purposes for an FMCG company located in the west side of Istanbul. We find 16 candidate depot locations with their actual coordinates.

The distance between each candidate depot location and customer is calculated by the help of Google Maps via a visual basic code. Each type of school has different working hours and thus time windows are generated accordingly. It is assumed that the delivery trucks can leave the depot(s) at 06:00 am at earliest. Also, demand values are randomly generated for each type of school based on the number of students that will probably consume that type of drink. The service time for each school is assumed to be directly proportional to the demand of that school.

We apply the proposed algorithm to solve this real life application. Results will be discussed.

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A Multi-Objective Constraint Programming Approach for Route and Garage Allocation of Electric Buses

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Keywords: Electric Bus, Charging Station, Constraint Programming

Maintaining a sustainable public transportation system is one of the key tasks for metropolitan city administrations. In order to provide such systems, cities have to implement recent advances in fuel technology for both reducing operating costs and emission levels incurred by the vehicles. Electrification of urban transit fleets by adding full or hybrid electric vehicles with different types of battery systems is one of the effective solution approaches. Careful planning is needed to utilise these vehicles effectively - including the route allocation for electric buses, and the optimal placement of the necessary charging stations. This study aims to identify the optimum bus route allocation and charging station placement, through a case study in the city of Izmir in Turkey.

İzmir, the third largest city of Turkey, is operating a multimodal transit network comprising bus, metro, ferry and tram systems. Around 62% of all the daily boardings (1.7 million) are served by the public bus transportation system, with a fleet of around 1500 buses. In an effort to reach the goals mentioned above, the city administration procured 20 full electric buses and had put them into service since April 2017. They operate these buses in 20 different routes that belong to five different managerial districts of the public bus authority. Moreover, the buses are charged at five different garages of those districts, from where they begin their daily services.

The main reason for selecting totally distinct routes for each bus is for maximising the public exposure to this new bus type, and testing the performance of the vehicles and their battery systems for future investments. Currently, the buses are charged to 100% once daily through their overnight parking periods, and their trip schedules are planned loosely to avoid the risk of power failures due to insufficient charging. Therefore, it is observed that the bus operator cannot fully attest the capabilities and limits of these new vehicles with respect to representativeness, regarding actual passenger load, traffic congestion, and different route topologies. Moreover, the mid charging station units mounted at major route terminals are idle for long periods of time. Thus, a more thorough approach is required to fulfill both the economic goals for justifying the high levels of initial investments, and the social expectations of the administration.

In this study, we develop a multi-objective constraint programming (CP) formulation which performs the bus route allocation simultaneously with charging station placement. We use the constraint programming toolkit developed at the University of St Andrews which include Conjure and Savile Row. In combination, these tools allow us to state a CP model at a very high-level of abstraction and without making ad-hoc modelling decisions. Instead, the high-level model we develop is automatically converted to a low-level model in an efficient way before it is solved using a standard constraint solver. We used Minion as the solver in our experiments.

We identify two objectives corresponding to the two requirements of the public bus authority in our model: cost minimisation and exposure maximisation; the former being an operational goal and the latter for gathering public support for the electric buses which will, in turn, boost support for future investments. We use very detailed micro-data made available to us by the CANBUS system of the public bus authority. The data includes timestamped information about passenger numbers, geographical location, and the state of the battery for each electric bus. We calculate the optimal Pareto frontier and present a number of strategic schedule options with different amounts of cost and exposure. We also evaluate the current schedule with respect to these optimal schedules and demonstrate the possible gains.

On Carriers Collaboration in Hub Location

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Keywords: Hub Location, Carriers Collaboration, Mixed Integer Programming

In this work we study hub location problems based on different classes of collaboration agreements among multiple carriers, analyzing the associated economic and operational impact. We propose mixed integer programming formulations modeling different carriers collaboration schemes, comparing their performances to analyze the potential savings that may be enabled. Numerical results obtained through a set of computational experiments are summarized and analyzed, gathering some managerial insights.

1. Problem description and assumptions

Hub location is nowadays one of the most studied areas within locational analysis, because of its wide range of practical applications, and due to the high economic impact of the decisions encompassed in these problems. It often arises in practice that multiple carriers, while operating within the same underlying network, either share their customers, even when the service demand is heterogeneous, or compete for capturing customers when the same type of service is offered. This motivated the study of models where carriers aim at maximizing the demand captured within a given coverage radius [3, 7], aim at maximizing the net profit [1, 2], or compete with other carriers to maximize their market share [8, 4].

Different business conditions may push carriers to consider a collaborative approach, in view of the huge savings and environmental improvements that may occur. Different types of carrier collaboration models have been studied in the last years in fields related to transportation and logistics, like node and arc routing (see, for instance, [6, 5]). We are not aware however of any work on this topic in the area of hub location, even if examples of collaborative approaches abound, for instance, in airlines alliances.
In this work we assume that multiple carriers operate on a shared network and are required to make optimal decisions on the location of their respective hubs and the routing of their demands through the network. We introduce several collaboration models reflecting different classes of agreements between carriers: first, the case of a complete network without any set-up costs on the hub nodes and on the inter-hub edges is considered, then, more general models are studied, including the case of uncomplete networks. Carriers collaboration models are compared by analyzing in each case the potential savings obtained with respect to a purely competitive model. Mixed integer programming formulations are proposed and computationally tested. Numerical results from such a computational experience are presented and summarized for deriving managerial insights.

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Optimization of a Drone-Aided Delivery Network

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Keywords: Drone, Delivery, Location Routing Problem, Synchronization

Integrating drones into delivery networks has advantages such as reduced delivery times, costs and access to hardly reachable points. However, due to the limited abilities of drones, it is not possible to deploy solely drones in delivery networks. Thus, drones should be collaborated with the traditional delivery vehicles and this collaboration requires synchronization between drones and delivery vehicles. In this study we propose a mixed integer mathematical model minimizing the total delivery time to visit all demand points in a network in which a drone and a truck works in synchronization. The model and results obtained will be discussed at the presentation.

1. Introduction and Problem Description

In the past, drones were used mainly for military and surveillance purposes. With the technological developments in recent years, drones are easy to access and have started to gain more attention in different areas ranging from last-mile delivery in logistics operations to humanitarian aid distribution. Deploying drones in a delivery network has many advantages. To exemplify, drones can fly over congested roads without any delay, reach to areas having challenging geographical conditions or inadequate infrastructure. Additionally, they consume less energy compared to traditional vehicles. Although drones have such advantages, they also have some characteristics restricting them to be used on the delivery networks alone such as limited battery life, flight range, payload volume, and endurance [1]. Thus, to benefit from the advantages of drones, they can be used along with the traditional vehicles in the delivery network.

One way of utilizing drones and integrating them into a delivery network is to make them collaborate with the traditional trucks. In such collaboration, a truck and a drone move in tandem until a demand point, at that point drone leaves the truck and visits its assigned demand point, simultaneously truck continues to follow its route. Then, the drone and truck rendezvous at one of the following demand points which requires synchronization between the drone and truck and they continue to move together until the next sortie of the drone. This problem is defined as The Flying Sidekick TSP (FSTSP) by Murray and Chu [2] and a similar one is called TSP with Drone (TSP-D) by Agatz et al. [3]. The problem aims to find the route of the truck and movements of the drone while ensuring the synchronization and minimizing the latest time at which either the truck or the drone return to the depot. Murray and Chu [2] propose two mixed integer linear programming formulation and heuristics for two variants of the problem and Agatz et al.[3] model this problem as an integer programming formulation and propose several heuristics.

In this study, different from the previous mathematical models, we consider the location of a single depot from where the truck and drone depart as variable and also we place another drone which moves in between depot and demand points. We propose a mixed integer linear mathematical formulation aiming to determine the location of the depot, routes of the delivery truck and movements of the drones while ensuring synchronization between vehicles working in collaboration and minimizing the time of the last delivery. Model, solution methodologies and results will be discussed during the presentation.

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A Novel Bilevel Location Model*

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Keywords: Bilevel location, Semi-obnoxious facilities, Critical infrastructures, Benders' decomposition

Motivated by recent realworld applications in the protection of critical infrastructures against intentional attacks and in the location of semiobnoxious facilities, in the last decade, the use of bilevel programming has become an attractive topic in the field of locational analysis.

In this paper, we propose a novel bilevel location model in which, on the one hand, there is a leader that chooses among a number of fixed potential locations which ones to establish. Next, on the second hand, there is one or several followers that, once the leader location facilities have been set, chooses their location points, in a continuous framework. We assume that setting the leader's location points has some fixed cost per facility, and there is a budget constraint that can not be exceeded. The leader's goal is to maximize some proxy to the weighted distance to the follower's location points. Next, the follower(s) aim is to fix their location points as close as possible to the leader ones, minimizing a cost proportional to the distance to the location points set by the leader.

This problem structure can be found in different actual location applications. For example, it fits in the location of semi-obnoxious facilities. Semi-obnoxious facilities are those defined as useful for some users but unwelcome for some others because they may produce environmental concerns. This implies that, in general, population centers want these facilities away, but due to some interests there are some people in those centers that would

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like to have them nearby [1, 3, 4]. Classical examples of this kind of facilities are chemical and power plants, airports or waste dumps. In the cases in which the demand points are set first, and the semiobnoxious facilities later, the situation fits to our model. Another application that fits to our model goes into the protection of critical infrastructures against terrorist attacks or precious goods in some points against thefts [2, 5]. In order to protect infrastructures or to hide valuable goods, a first decision has to be made on where to place these elements and, after that decision is made, the terrorists or thieves choose their locations to try to reach the target at a minimum risk.

We develop the above bilevel location model for one or several followers and for any polyhedral distance. We propose different mixed integer linear programming formulations and prove the NP-hardness of the problem. Next, we compare the computational performance of the different formulations. Moreover, we develop different Benders decomposition algorithms for the problem. Finally, we report some preliminary computational results comparing the formulations and the Benders decomposition on a set of instances.

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What Plant Location, Line Graphs and Haplotyping Have in Common*

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Keywords: Discrete location, Plant location, Multiple assignment, Line graph

One of the most classic location problems consists in, giving a set of plant locations and a set of clients, deciding how many plants to open so that the total opening cost and the cost of serving the clients are minimum [1]. In the simplest version of the problem each client must be served by exactly one plant (single assignment). However, different assumptions can be made that produce new interesting models. We study the plant location problem with double assignment under some assumptions regarding compatibility of clients. We analyse different integer programming formulations for this variant. The new assumptions are translated into strong constraints that can lead to unfeasible models. We focus on the feasibility problem, i.e., we study the case of null costs and unlimited number of plants. We find that the resulting problem is strongly related with the problem of finding whether a graph is the line graph of some other graph and explore the implications of this fact. As a direct consequence, a connection between haplotype phasing and plant location problems comes to light [2]. In haplotype phasing, given a set of genotypes (individuals of a population), a minimum set of haplotypes that explains it is to be find (progenitors).

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New Valid Inequalities for a Class of p-Hub Location Problems

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Keywords: P-hub, Non-stop services, Set packing, Branch-and-cut

p-hub location problems in transportation networks are $\mathcal{NP}$-hard combinatorial optimization problems with many industrial applications. In the r-allocation variant [7], which consists of selecting p hubs, allocating each node to at most r of them and deciding the best reutes for sending the traffics between nodes, three optimization subproblems are involved: a service facility location problem, an assignment problem, and a transportation problem.

In this work we focus on finding new valid inequalities for this variant. Some of them have been adapted from inequalities proposed for related problems ([1], [2], [3], [4], [5]) such as the boolean quadratic problem, the uncapacitated single-allocation hub location problem, and the multiple-allocation hub location problem, while other inequalities are new contributions.

The intersection of many of them defines a *set packing* polyhedron [6], which has an associated *conflict graph* that we have studied in order to generate new valid inequalities for the problem, especially those of the *clique* and *odd-hole* classes.

In addition, we have derived some properties and conditions that emerge from features held by the optimal solutions to the problem. Such conditions, although they do not necessarily result in valid inequalities/equalities for the feasibility set, they can be ensured to be valid for the optimal solutions.

Computational results will be provided showing that the new inequalities help in strengthen the linear relaxation of the original formulation.

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Exact and Matheuristic Approaches to Locate Switches in a Spanning Tree

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Keywords: Cut vertex, Matheuristic, Switch

In this work we analyze the problem of locating switches on graphs. This location problem is a generalization of the Minimum Branch Vertices Spanning Tree Problem and the Minimum Degree Sum Spanning Tree Problem. We propose an exact method based on the decomposition of the graph into blocks. An integer programming model is solved for each block. We also propose a matheuristic method based on exactly solving a reduced graph obtained by removing some edges.

1. The problem

A switch allows to address incoming flow to several destinations. To locate a switch implies several connection costs: the allocation cost of users to switches and the installation switch cost. Therefore, the aim is to minimize the total cost.

2. The exact solution

Once the blocks of the graph are obtained, the exact solution is based on a decomposition algorithm which deals with each block separately and uses an improved formulation. For certain blocks it may be necessary to re-optimize. The exact algorithm finally obtains the global solution from the solutions of each block.

3. The matheuristic

Specially designed for graphs without relevant articulations, we propose an algorithm which obtains a reduced graph by removing some edges. The aim of this algorithm is to convert some nodes into articulation vertices. After that, we exactly solve this reduced graph by using the exact decomposition method previously proposed.

4. Computational experience

We have developed an exhaustive computational experience. A brief summary of the average results obtained is the following:

	v* exact	v* decomp.	time exact	time decomp.
Exact instances	1648.5	1648.5	229.8	12.0
Matheuristic instances	8661.9	8862.9	863.6	67.5

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Exact Approach to Solve the Capacitated Vehicle Routing Problem with Stochastic Demands and Restocking Policy*

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Keywords: Vehicle Routing, Stochastic Demand, Exact approach

This paper considers a vehicle routing problem where the customer demands are stochastic variables. Due to uncertainty, along a route the vehicle may be unable to load all planned customers' demand. The vehicle has to return to the depot, unload and then resume its trip. In order to avoid unplanned return trips to the depot, one may decide to make some preventive return: even if it is not full, the vehicle returns to the depot, unload and resume its trip at the next customer. These preventive returns avoid visiting the same customer twice at the expense of possibly making an unneeded return. In this paper, we propose an exact procedure for designing routes to minimize the total expected cost of the routes. It consists of a branch-and-cut algorithm based on the L-shaped method for stochastic programs with binary first-stage variables. Also, a sophisticated procedure has been designed to detect lower bounding cuts violated by a fractional solution. The paper proposes the first algorithm in the literature to find optimal solutions to the problem. The procedure is based on decomposing a fractional solution into chains and unstructured sets, and on lower bounds for each of these parts. Computational results show that the overall algorithm is able to find optimal solutions for some benchmark instances with

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up to 100 customers. This work is based on a manuscript by the authors that has being recently accepted to be published by *Transportation Science*.

A Single Allocation p-Hub Location Problem with General Cost Structure*

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Keywords: Hub location, Network design, Cost structure

Hubs are special facilities used in networks to sort, classify and consolidate flows between multiple origins and destinations, mostly to take advantage of some kind of economy.

Recently, the cost structures considered in Hub location models (HLMs) have been under review. The efforts in the literature can be classified in piecewise-linear, threshold-based and mixed cost structures.

We formulate and solve a single allocation p-hub location model, considering a general piecewise-linear cost function for every arc in the hub-and-spoke network. We use CPLEX to solve small instances (25 nodes), and a genetic algorithm for larger instances.

1. Introduction

Hub location is a very active are within Location Analysis [1]. The resulting hub location models have been used in postal, courier, parcel, air passen-

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ger and public transportation since the seminal works from O'Kelly and Campbell [5, 2]. The latest literature review is provided by [3].

Fundamental hub location models of the literature assumed that the interhub flows are discounted by a fixed factor. Most of the literature make the same assumption [1]. Efforts to improve the cost representation include piecewise-linear costs, mixed cost structures, and threshold-based discount, both for network design and hub location.

Our contribution is to formulate and solve efficiently a single allocation p-hub location model with general piecewise-linear cost functions. We also implement a genetic algorithm for large instances.

2. The problem

Let $G(N, A)$ be a graph, where the cost of using an arc $(i, j) \in A$ is modeled as a piecewise-linear function with T intervals. It the total flow in the arc is within $[U_{t-1}, U_t]$, both fixed cost F^t_{ij} and variable cost v^t_{ij} are charged. Figure 2 shows two examples: a. pseudo-convex piecewise-linear costs (congestion costs), and b. pseudo-concave piecewise-linear costs (economies of scale).

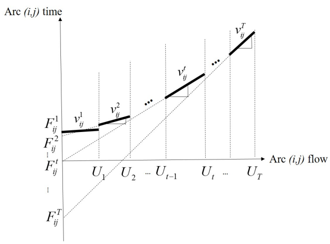

Figure 1. Pseudo-convex piecewise-linear costs.

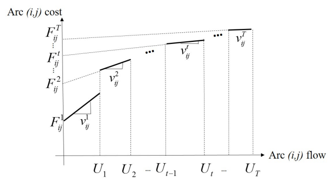

Figure 2. Pseudo-concave piecewise-linear costs.

Let Z_{ik} be 1 if node $i \in N$ is allocated to hub in $k \in N$, 0 otherwise; f^t_{ij} the flow through interhub arc (i, j) within the t-th flow interval; and I^t_{ij} be 1, if the flow through interhub arc (i, j) is within the t-th flow interval, 0 otherwise.

The resulting model is,

$$\min \sum_{(i,j)} \sum_{t=1}^{T} \left(F^t_{ij} I^t_{ij} + v^t_{ij} f^t_{ij} \right) + \sum_{(i,k)} \tilde{C_{ik}} Z_{ik} \tag{1}$$

$$U_{t-1} I^t_{ij} \leq f^t_{ij} \leq U_{t-1} I^t_{ij}, \; \forall (i,j), \; t \tag{2}$$

$$\sum_{t=1}^{T} I_{ij}^{t} \leq 1, \; \forall \, (i,j) \tag{3}$$

Objective function (1) minimizes the total costs. Note that as our problem considers single-allocation, collection and distributions costs can be precalculated for every node-hub allocation decision. Constraints (2) relate the decision variables with the flow intervals. Constraints (3) force to select at most one flow interval for every inter-hub arc. Additional constraints are formulated to design an appropriate single hub-and-spoke network, compute the flow in every arc of it, and bound the decision variables.

3. Solution approach

The model proposed can be solved in reasonable times (about 8 hours CPU time) for small instances of our problem (25 nodes).

For larger instances, we develop a genetic algorithm, based on [4]. The algorithm explore the solution space of the hub location and node-hub allocation variables.

Note that if the location and allocation decision are known, the remaining problem is to compute the interhub flows based in the cost structure. It is done by calling CPLEX 12.7 to solve the resulting small network design problem (for the p interhub subnetwork).

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Using Online Transaction Data for Offline Store Decisions: a Modified Huff-model for Determining a New Store Location

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Keywords: Huff model, Retail, Application

1. Modified Huff Model

This study proposes a modified Huff model that utilises online data to determine the probability of online patronage across a geographic area and how this can be further utilised to select locations for siting a new offline store for the retailer. The traditional Huff model approach results in distance decay relationship between store attraction and distance to the offline store. However, we use the notion of a growth function in relation to distance to calibrate the model in order to account for the phenomenon whereby as the distance between the customer and the offline store of the retailer increases, the online channel becomes more attractive to the customers; hence probability of patronising the online channel increases. We aim to use publicly available data as input in addition to transaction data from the retailer to predict the probability of patronising the online channel and determine a new location to open a new offline store. The probability of online channel patronage ($P_{ij(online)}$) is calculated as follows:

$$P_{ij(online)} = \frac{A_{ij(online)} D_{ij}^{\beta}}{\sum_{i \in I, j \in J} A_{ij(online)} D_{ij}^{\beta}} \qquad (1)$$

The variable $A_{ij(online)}$ represents attraction between online customers in the ith grid-cell and the jth store. It has dependency on the following variables: store size (S_j) represented in cubic-metres (m^3); expected number of customers (N_i) in the ith location estimated to have made an online purchase; the density of households ($1km^2$) (H_i) with children from the aged of 0-3 years; online store channel (O_j) defined as a binary measure (1 = yes and 0 = no); overall coverage of levels of internet connectivity (I_i); and finally, preference minority index (PM_i).

$$A_{ij(online)} = A_{ij(online)}(S, N, H, O, I, PM) = S_j N_i H_i O_j I_i PM_i \qquad (2)$$

The variable D_{ij} represents the distance (km) between online customers from the ith location to the jth store.

2. Results

Results show that the modified online Huff model yielded comparable results to the actual data in terms of patronage probability and potential location for siting a new offline store outlet, thereby ensuring model robustness.

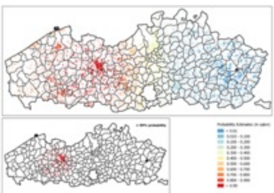

Figure 1. A map of Flanders showing that the highest probabilities of online patronage are in Ghent and neighbouring postcodes in East Flanders; probabilities $> 90\%$, depicted in red.

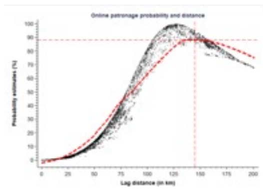

Figure 2. The spatial distribution of and probability predictions of online patronage using the modified online Huff model.

Both the expected and actual model outputs reveal the same locations as the optimum site for potential new store locations. Further, this enables the application of the model for various purposes especially in scenarios where there is limited data.

Bicriteria Multi-Facility Location Problems*

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Keywords: Bicriteria, Planar location, Median-objective, Gauges, Intractability

Motivated by improving commercial and safety aspects of public events, we are considering the classical bicriteria multi-facility location problem in the plane with median objective and block norms as distance functions. We will show in this presentation that for any fixed number of new facilities, the number of extreme nondominated points in the objective space is polynomial in the input data. However, for the general case, we provide a problem instance that has sub-exponentially many extreme nondominated points.

1. Motivation and Problem Formulation

Planar location problems with median objective are a widely used class of location problems to optimize profit or transportation times. Given are $M \in \mathbb{N}_{>0}$ demand points, denoted by $a_1, \dots, a_M \in \mathbb{R}^2$, and the number of new facilities $K \in \mathbb{N}_{>0}$ that have to be located in the plane. The median objective minimizes the weighted sum of distances between each pair of facilities and demand points. We will consider the bicriteria version of this problem, that is

$$\min_{X \in \mathbb{R}^{2K}} \quad (\Phi_1(X), \Phi_2(X)),$$

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where the two objectives are defined by

$$\Phi_p(X) = \sum_{k=1}^{K}\sum_{l=1}^{K} \tilde{w}_{kl}^{p}\tilde{\gamma}_{kl}(x_k - x_l) + \sum_{k=1}^{K}\sum_{m=1}^{M} w_{km}^{p}\gamma_{km}(x_k - a_m), \quad (p = 1, 2).$$

For each objective, there is a weight $w_{km}^{p} \geq 0$ between each demand point and new facility, as well as a weight $\tilde{w}_{kl}^{p} \geq 0$ between each pair of new facilities. As distance function we will consider block norms $\gamma(x) = \min\{\lambda \geq 0 \mid x \in \lambda B\}$, where B is a convex polygon, point-symmetric with respect to the origin that is also contained in the interior.

2. Complexity of the Problem and Solution Approach

It is well known for the single facility case that the set of efficient solutions is a chain of geometric objects (see for example [1]), defined by the demand points and the block norms, and has polynomial size. We will extend this approach to multiple facilities by considering the optimality conditions derived in [2] and give a geometric description of all efficient solutions. Additionally, by using the weighted sum method (see [3]), it is shown that for a fixed K, the set of nondominated points is polynomial in the input data, but for an arbitrary K a problem instance is provided that has a sub-exponential number of extreme nondominated points.

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Conservative Approach to Location Allocation Problem for Dimensional Facilities*

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Keywords: Facility location, Bilevel programming, Discretization

The model. The problem considered in this work is to locate some dimensional facilities in a general planar demand region. The facilities are shaped like polygons and the customers are distributed in the demand region according to a demand density that is an absolutely continuous probability measure. The location of the polygons must satisfy that all the polygons are contained in the demand region and that the interiors of the polygons do not intersect (we allow the polygons to intersect in their borders).

For a feasible location of the facilities, a partition of the demand region that determines the allocation of the customers to the facilities has to be done minimizing the access cost of the customers to the facilities and the distribution cost in the resulting subregions. See e.g. [1] for similar partitions in a different context.

The distribution cost depends on the utility obtained from each point in the demand region with respect to the polygonal facility which serves it. In the spirit of a *conservative social planner*, we consider that the utility obtained from a generic point in the demand region with respect to a polygon is given as the maximum distance between the point and the polygon, being the distance considered a distance induced by a norm.

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The social planner proposes the best location of the facilities in such a way that the summation of some additional costs over all the facilities must be the cheapest possible, knowing that the partition of the customers is done as it is explained above. These additional costs are the installation cost of each facility, a cost due to the congestion/waiting time to be satisfied by each facility and a cost induced by the lost demand.

We consider that the installation cost of each facility is not a fixed cost. Indeed, we assume that there exists a base installation cost density, which is given by an absolutely continuous measure over the demand region. Then, for a location of the facilities, the installation cost of a facility is computed over the base installation cost density occupied by the facility. Thus, the installation cost of each facility depends on where the facility is located.

The congestion cost is computed once the partition of the customers in the demand region is done. The higher the demand density that a facility satisfies, the higher the congestion cost associated to the facility.

In addition, we assume that demand in a certain subregion of the demand region is incompatible with the installation of a polygonal facility on that subregion. Therefore, the installation of the facilities in the demand region produces a loss of demand (whose amount depends on where the facilities are located) that has to be penalized.

These assumptions impose to our problem an hierarchical structure of bilevel problem (in particular, this structure is due to the congestion cost, which is induced by the partition of the customers determined by the location of the polygonal facilities). We refer to this bilevel problem by BL. Different particular applications, which are pesented in our work, fit within this general problem.

Main results. Under certain assumptions, we transform the bilevel problem BL in a discrete bilevel problem DBL that approximates it. The discrete problem DBL can be modeled as a mixed-integer linear programming problem, which gives us a tool to solve it. Besides an exact mixed-integer linear programming formulation, we proposes a GRASP algorithm to get good/reasonable solutions for larger size instances. This GRASP algorithm consists of different modules among which the most relevant is a wavefront algorithm that is able to obtain random feasible solution for the problem DBL.

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Multipurpose Shopping and Retail Store Location*

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Keywords: Location, Multipurpose Multi-stop shopping, Agglomeration

Non-competitive location models usually consider that consumers make a trip to a store, purchase a product and go back to their point of origin . However, in a large proportion of cases, consumers use the same trip to buy two (or more) items. To the best of our knowledge, models designed for the non-competitive location of retail facilities, have never considered the effects of this frequently-used behavioral pattern. This presentation offers a first attempt of including multipurpose shopping in a non-competitive location model, as well as a model for collaborative location for firms selling non-mutual substitute products.

We have simplified the problem to the maximum, aiming at measuring whether consideration of multipurpose shopping does change optimal locations. We solve the problems of two firms locating multiple stores in a region, in three cases: i) both firms locate without taking multipurpose shopping into account; ii) the follower locates having multipurpose shopping in mind; and iii) both firms locate cooperatively. In all models considered here, the products are not mutual substitutes and the consumers

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have a limit on the cost they are willing to incur for the purchase of each product.

We propose an integer programming formulation and an efficient heuristic that provides solutions and bounds. Computational experience is presented.

1. Multipurpose Shopping and Store Location

One of the multiple application of location analysis is finding optimal locations for retail stores. Reference [1] presents a recent survey of applications. A feature that differentiates retail stores from other facilities is the fact that consumers decide which store to patronize, as opposed to most public facilities, in which a central planner assigns users to facilities, or the case of a distribution company, that decides what warehouse will serve what customer. Practically all retail facility-location models deal with a single product and assume that customers are served by exactly one facility. This assumption implies that cost-minimizing or rational consumers will make one-stop trips, starting from an origin, stopping at the store to make the purchase, and returning to the origin. The exceptions are [2], [3], [4], in which there are two products, but these are essential. While these assumptions may apply in some circumstances, they do not in the context of retail facilities. In this context, multipurpose trips are the norm rather than the exception. Customers' trips could either stop at one place, as a supermarket or a mall, where all the desired products are available in one stop, or stop at more than one place, purchasing a different product in each stop.

Multipurpose trips allow consumers to obtain more than one product at a cost that is usually lower than the cost of purchasing the products separately. Consider two stores, say A and B, selling different products and located at points a and b, and a customer located at a point c. For the sake of simplicity, assume that distance matrices are symmetrical and that the triangular inequality holds. Purchasing the products separately means that the customer has to travel a distance 2(ca + cb). On the other hand, purchasing both products in the same trip requires traveling a distance (ca + ab + cb). As the reader can easily check, this is a shorter distance. When added over all consumers, a minimum distance is achieved when both stores A and B locate at the same point, i.e., agglomeration. If the products are not essential, customers are not willing to travel too far to obtain them, and by locating their stores closer to each other, the firms can increase the size of their markets. In other words, the firms benefit from this behavior, and so do the customers.

We model a situation in which two profit-maximizing firms A and B locate multiple stores each, offering different products. Consumers have a known reservation price for each product (i.e., the cost they are willing to incur to obtain the product), which in turn, upper bounds the distance they are willing to travel to purchase each product. Consumers make single-purpose trips to purchase A or B, or a two-purpose trip during which they purchase both products, or they may choose not to purchase anything, depending on the utility they obtain from each alternative action. We compare the situations in which the firms do not consider multipurpose shopping (the current standard); in which the second entrant does locate considering this behavior; and in which both firms locate collaboratively so to obtain the maximum profit for both.

Note that the difference between our problem and the models for essential products is that, in our case, there is a game in which the players are the two firms and the consumers, while in the case of essential products, consumers are not free players, as they will purchase both products no matter where the stores are located.

We propose an integer-programming model that solves the three variants of the problem. As the joint location problem takes a very long time to be solved using the exact model, we devise an efficient heuristic method that not only provides excellent solutions, but also finds upper bounds. Computational experience is also shown

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Quasimonotone Discrete Ordered Median Problem

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Keywords: Location, Combinatorial Optimization, Ordered Median Problem

The Discrete Ordered Median Problem, DOMP, is a modeling tool, that provides flexible representations of a large variety of location problems. Among others, it is possible to model most of the classical discrete location problems considered in the literature.

The DOMP consists in minimizing a globalizing function that represents the scalar product of a given ordered weighted vector λ and the vector of ordered costs of the assignments of the solution.

When λ satisfies the monotonicity condition, i.e. its coefficients are non-decreasing, we can apply specific formulations which have a better performance. Based on these latter implementations for the Monotone Ordered Median Problem, we present in this work some novel formulations for the DOMP. In particular, we remark some formulations which model the problem using only continuous variables except for the location variables.

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A General Model for Discrete Covering Location Problems*

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Keywords: Location, Covering, Discrete optimization, Lagrangian relaxation

This work introduces a general discrete covering location model, denoted by GMSCLP (General Multi-period Stochastic Covering Location Problem), that takes into account uncertainty and time-dependency aspects. Given a set of potential locations for facilities and a set of demand points, the objective is to decide which facilities must be operating in each time period to minimize the total expected cost satisfying some coverage constraints.

A mixed integer linear programming formulation is proposed for the problem. Furthermore, it can be observed that this model generalizes most of the covering related problems appearing in the literature. Besides, a Lagrangian relaxation based heuristic is developed for obtaining good feasible solutions for large instances. Finally, different measures to report the relevance of considering a multi-period stochastic setting are studied.

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1. Introduction to the problem

In general, there are two main types of covering problems depending on the objective of the problem: the set covering location problem (SCP) and the maximal covering location problem (MCLP). The objective of the former problem is to minimize the cost of installed facilities restricting that all demand points must be covered, see [4]. The latter consists of maximizing the covered demand limiting the number of operating facilities, see [1]. These two models and many others related with covering are unified in a model proposed in [2]. In this paper, we propose a model, GMSCLP, that extends this general model including multi-period and stochastic features.

The GMSCLP considers a finite planning horizon partitioned in a set of time periods. When a facility is installed or closed in a certain time period, a cost must be paid. Besides, the model includes costs for every time period where the facility is operating.

The model assumes also uncertainty in the coverage of each demand point. Moreover, a profit related with the number of facilities covering a demand point above its minimum threshold, and a penalty associated with the coverage shortage are modelled. These profits/penalties are also uncertain. This uncertainty is modelled by a finite set of scenarios with some previously known probabilities.

Given the previous framework, GMSCLP model aims to decide which facilities must be operating in each time period minimizing the total expected cost and satisfying some coverage constraints. A Lagrangian relaxation based heuristic which provides lower bounds and good feasible solutions is also developed. Besides, this work evaluates the relevance of using stochastic and time-dependency features using two measures: the expected value of perfect information and the value of multi-period solution, see [3].

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A Lagrangian Relaxation Method for Solving the p-Median Radius Formulation

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Keywords: p-Median, Radius formulation, Lagrangian relaxation

The p-median problem is one of the most important problems in discrete location. It was originally defined by Hakimi in 1964 ([3]) as a network problem and later formulated as an integer linear programming problem by ReVelle in 1970 ([4]). The most recent exact method to solve the p-median problem is a radius formulation where the problem is formulated as a set covering problem (see [1]). The algorithm proposed there starts with a partial formulation and develops a row generation technique to add more inequalities as needed. This strategy is embedded in a branch-and-bound algorithm and it is able to solve very large instances with several thousands of nodes. However, it does not work so well for problems with small values of p.

The p-median problem with Radius Formulation is expressed in the following way:

$$
\begin{aligned}
\min_{y,z} \quad & \sum_{i=1}^{n} \sum_{k=2}^{G_i} (D_{i,k} - D_{i,k-1}) z_{ik} & & \\
\text{s.t.} \quad & \sum_{i=1}^{n} y_i = p, & & \\
& z_{ik} + \sum_{\{j/c_{ij} < D_{ik}\}} y_j \geq 1, & & 1 \leq i \leq n, 2 \leq k \leq G_i, \\
& y_i \in \{0,1\}, & & 1 \leq i \leq n, \\
& z_{ik} \geq 0, & & 1 \leq i \leq n, 2 \leq k \leq G_i.
\end{aligned}
\tag{1}
$$

In this formulation, D_{ik} is the k-th largest distance at which a facility can be located from node i and there are G_i different values for node i. Decision variables y_i take value 1 if a facility is opened at node i and 0 otherwise. The radius variables z_{ik} take value 1 if node i is allocated to a facility at distance at least D_{ik} and 0 otherwise.

In this work we have developed a heuristic method based of Lagrangian relaxation and branch-and-bound to obtain good solutions. The radius constraint (1) is relaxed to form the Lagrangian dual problem and subgradient optimization was used to solve it. If the full set of radius constraints is relaxed, the dual problem can be solved quickly, however the bounds generated are weak. In order to get stronger bounds, we explore relaxing only a subset of the radius constraints. We look into how this affect the solution time and bounds for large instances with all types of values for p.

The Lagrangian dual problem obtained is as follows:

$$\begin{aligned}
\max_{\lambda} \min_{y,z} \quad \mathcal{L} = {} & \sum_{i=1}^{n} D_{i,2} + \sum_{i=1}^{n}\sum_{k=t}^{G_i} \lambda_{ik} + \sum_{i=1}^{n}\sum_{k=3}^{t-1} (D_{i,k} - D_{i,k-1}) z_{i,k} \\
& + \sum_{i=1}^{n}\sum_{k=t}^{G_i} (D_{ik} - D_{i,k-1} - \lambda_{ik}) z_{ik} - \sum_{i=1}^{n}\left[\sum_{k=t}^{G_i} \sum_{\{j/c_{ij}<D_{ik}\}} \lambda_{ik}\, y_j + D_{i,2}\, y_i\right]
\end{aligned}$$

$$\begin{aligned}
\text{s.t.} \quad & \sum_{i=1}^{n} y_i = p, & \\
& z_{ik} + \sum_{\{j/c_{ij}<D_{ik}\}} y_j \geq 1, & 1 \leq i \leq n, 3 \leq k \leq t-1, \\
& y_i \in \{0,1\}, & 1 \leq i \leq n, \\
& z_{ik} \in \{0,1\}, & 1 \leq i \leq n, 3 \leq k \leq G_i, \\
& \lambda_{ik} \geq 0, & 1 \leq i \leq n, t \leq k \leq G_i.
\end{aligned}$$

Values λ_i are the Lagrangian multipliers and t can take any value from 4 to G_i (size of the vector i of distances, removing possible multiplicities).

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A Sampling Matheuristic for the Location Inventory Routing Problem

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Keywords: Location Inventory Routing Problem, Sampling, Set partitioning, Matheuristic

The Location Inventory Routing Problem (LIRP) consists in simultaneously locating facilities in a logistics network, routing goods from a supply point to a set a demand points and managing inventories in the network.

We consider a network composed of a production plant, several distribution centers (DCs) to be located and a larger set of demand points. As shown in Figure 1, the distribution is organized in two echelons: the production plant delivers DCs by means of direct trips, then demand points are delivered by means of routes operated by a fleet of homogeneous vehicles.

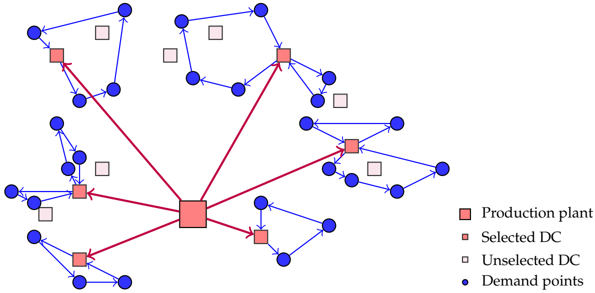

Figure 1. The network considered

The LIRP is modeled with a route based MILP formulation [1]. The binary decision variables concern location of DCs, allocation of demand points to DCs and the definition of routes. The continuous variables concern inventory decisions and product flows. The objective function is to minimize the total cost composed of fixed costs at DCs, holding costs and transportation costs. Demand points and DCs have limited storage capacity, while the production capacity at the production plant is not binding. The demand is assumed deterministic.

As a combination of several NP-hard problems, the LIRP is also NP-hard. Real-size instances are not tractable due to the potentially large number of routes, candidate facilities and time periods. However, in practical applications, the design of routes is restricted by several business constraints, so that the number of binary variables is large but not exponential.

This feature motivates the use of the proposed matheuristic sampling algorithm, inspired by the multi-space sampling heuristic by Mendoza and Villegas [2].

Concretely, the set of routes of an instance is first randomly shuffled and partitioned into independent subsets. Each subset leads to independent instances that are solved with IBM Ilog Cplex. The solutions to each subproblem found by Cplex are stored into pool of solutions acting as a memory [3]. This pool is used to build an new instance containing a subset of routes. The process is repeated until the new instance is considered tractable. It is then solved with Cplex.

We present several variant of the sampling matheuristic and evaluate them on a set of generated instances.

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Cooperative Covering Location Problems: Exact and Heuristic Approaches

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Keywords: Cooperative coverage, Heuristics

The basic idea of all covering problems is that customers who are within a certain predefined "service standard" of a facility, are considered adequately served, while those who are not within those limits are considered not being served at all. However this version of the coverage model is simplistic in the sense that it does not take into account the quality of the coverage offered or the possibility of cooperation among facilities.

In this paper we discuss covering location problems where demand points receive some sort of service by a set of facilities. In contrast to conventional covering models, the quality of service at any demand point is determined by the interaction of the facilities that may cover it. This interaction may involve cooperation among the facilities, as presented by Berman et al. (2011) or Averbakh et al. (2014) or disruptive interference as introduced by Marianov and Eiselt (2012).

We examine several reformulations of the basic models that may incorporate the quality of services provided by each facility and the ability to meet demand after multi-site cooperation. We present a number of models reflecting different variations of the problem and discuss their computational performance on some well data sets from the literature.

We then present some heuristic approaches that provide good solutions on large data sets where exact approaches fail to determine the optimal solution in reasonable computation time. These approaches are based on simple rules for obtaining a good initial solution to the problem and interchange heuristics for transforming the solution until some termination criterion is met.

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Routing and Detouring Consideration in Location of Refueling Points on a Network

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Keywords: Electric Vehicles, Continuous Location, Finite Dominating Set

Due to environmental and geopolitical reasons, many countries are embracing electric vehicles (EVs) as an alternative to gasoline powered automobiles. Other alternative-fuel vehicles (AFVs) powered by compressed gas, hydrogen or biodiesel have also been tested for replacing gasoline powered vehicles. However, since the associated refueling infrastructure of AFVs is sparse and is gradually being built, the distance between refueling points (RPs) becomes a crucial attribute for attracting drivers to use such vehicles. Optimally locating RPs will both increase demand and help in developing the refueling infrastructure, e.g., [1] [2].

This paper introduces a new set of location problems related to locating RPs on real lines, trees and general networks. First, the problem of feasibility is studied. A set of RPs is said to be feasible if all Origin-Destination (O-D) flows can be served. Given there are feasible locations, the optimal location problem then becomes "where should these RPs to be located such that a given fuel-related objective is minimized", for example, the objective of minimizing the maximum distance between RPs minimizes the range anxiety for drivers. Scenarios include single one-way O-D pair, multiple one-way O-D pairs, round trips, etc.

In our research, minimization of the number of RPs used to refuel all O-D flows is considered as the first objective, since building such refuel-

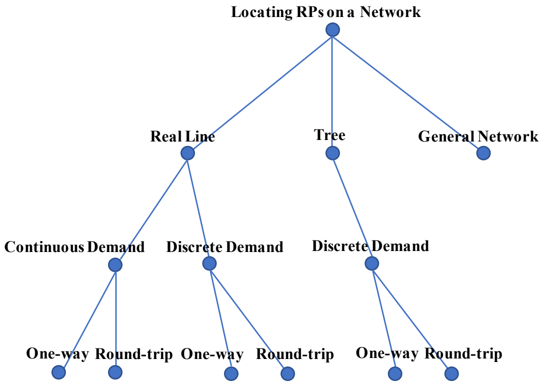

Figure 1. Hierarchy of Locating RPs on a Network.

ing infrastructure is costly. The objective of the problem is to locate a fixed number of stations (where candidate sites could be anywhere on the continuous network) to minimize weighted sum of the distance traveled by the vehicles.

This paper is divided into two parts. The first part deals with the simplest case — locating RPs on a real line. In the second part, we deal with location problems on a comb tree. We start with finding the minimum required number of RPs, and then present the proof of the existence of a finite dominating set. We then formulate the problem as a shortest path problem on an acyclic network and solve it optimally. The line problem can be also formulated as a mixed integer quadratic mathematical program, where the location variables are continuous on the line, the assignment of RPs to trips are 0-1 binary variables.The problem can be solved by MATLAB by using OPTI toolbox.

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Bi-Objective Model for Optimal Number and Size of Finite Size Facilities

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Keywords: Continuous location, Accessibility, Interference, Tradeoff

1. Introduction

Finite size facilities such as parks, stadiums, and cemeteries can be regarded as barriers because traveling within the facilities is prohibited [1–3]. The interference to traffic flow should be considered when planning finite size facilities. In this paper, we present a bi-objective model for determining the number and size of finite size facilities. The objectives are to minimize both the average closest distance to facilities and the probability that a random line intersects facilities. The former represents the accessibility of customers, whereas the latter represents the interference to travelers.

2. Bi-objective problem

Facilities are represented as circles with radius b. Suppose that n facilities are randomly distributed in a circular city with radius a, as shown in Fig. 1a. Let $E(R)$ be the average closest distance from a randomly selected location in the city to the nearest facility and P be the probability that a random line intersecting the city also intersects at least one facility.

Consider a bi-objective problem that minimizes both $E(R)$ and P. $E(R)$ and P are shown in Fig. 1b, where $a = 1, n = 1, \ldots, 10$, and the total area of facilities is $S = \pi/10$. As the number of facilities increases and facilities become smaller, $E(R)$ decreases but P increases. Thus, there exists a tradeoff between the accessibility of customers and the interference to travelers. If the accessibility of customers is the only concern, many small facilities are the best. If the interference to travelers is taken into account, fewer larger facilities would be better.

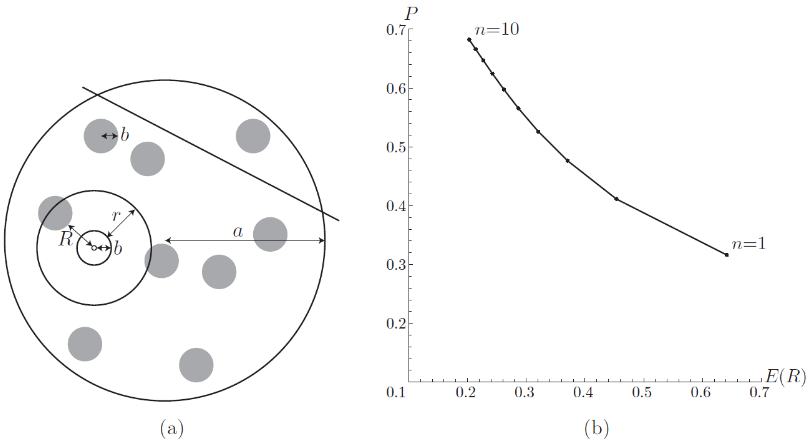

Figure 1. (a) Circular facilities in a circular city; (b) Average closest distance and probability of intersecting facilities.

3. Conclusions

This paper has developed a bi-objective model for determining the number and size of finite size facilities. The model focuses on the tradeoff between the accessibility and interference, and the tradeoff curve provides planners with alternatives for the number and size of facilities.

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Gini Index Minimization and Equitable Obnoxious Facility Location

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Keywords: Equitable location, Equity, Gini index, Obnoxious facility

When making location decisions related to public service facilities the distribution of distances among the service recipients (clients) and equity or fairness in treatment of the population is an important issue. In order to take into account both the equity some inequality measures are minimized. Quantification of the equity in a scalar inequality measure is well appealing to system designers and not complicating too much the decision model. Unfortunately, for typical inequality measures, the mean-equity approach may lead to inferior conclusions with respect to distances optimization (minimization or maximization for obnoxious facilities). The class of preference models complying with the optimization of distances as well as with an equal consideration of the clients is mathematically formalized with the concept of equitable dominance [6, 7]. Solution concepts equitably consistent do not contradict the minimization of distances or the inequality minimization. Therefore, the achievement of equitable consistency by the mean-equity models has a paramount importance.

The Gini coefficient [3] is a commonly used measure of inequity in income and wealth distribution. When applied to location models, equity is measured by the relative mean absolute difference of distances [5]. In order to achieve equity, we aim to locate facilities such that distances to the facility are equitable. In order to achieve this goal, the best location for new facilities is defined as the one that minimizes the Gini coefficient of the distances. It was empirically found in real-life applications [2] that this objective is achieved when the locations of the facilities are far from customers. Although it depends on the feasible set structure and there is no guarantee to achieve good equitable location for obnoxious facilities [1].

In this paper we consider the distances with a shift τ (or equivalently minimum target distance and measured deviations) $\tilde{y}_i = y_i - \tau$ and the corresponding Gini coefficient minimization

$$\min \ D(\tilde{\mathbf{y}})/\mu(\tilde{\mathbf{y}}) = \min \ D(\mathbf{y})/(\mu(\mathbf{y}) - \tau) \quad \text{for } \ \mu(\mathbf{y}) > \tau \tag{1}$$

where $\mu(\mathbf{y})$ denotes the mean distance while $D(\mathbf{y})$ is the mean absolute difference $D(\mathbf{y}) = \frac{1}{2m^2} \sum_{i \in I} \sum_{j \in I} |y_i - y_j| = \mu(\mathbf{y}) - \frac{1}{m^2} \sum_{i \in I} \sum_{j \in I} \min\{y_i, y_j\}$ We show that the Gini coefficient minimization (1) is consistent both with inequity minimization and with distances maximization provided that $\tau \geq \mu(\mathbf{y}) - D(\mathbf{y}) = \frac{1}{m^2} \sum_{i \in I} \sum_{j \in I} \min\{y_i, y_j\}$ at the optimum. Thus with minor clear restrictions on target selection τ the Gini coefficient minimization (1) guarantees equitable location of obnoxious facilities, The same properties remains valid for the weighted location problems. Moreover, similar results can be shown for the Schutz index (relative mean absolute deviation measure) and some other relative inequality measures. The interval of appropriate target values depends on the location problem structure (feasible set). Although it can be find or adjusted during the optimization process without necessity of a special feasible set analysis. Certainly, when replacing distances with some corresponding proximity measures (decreasing functions of distance) one may apply these results to location of desired facilities.

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A Feeder-Trunk Courier Network Design Problem Maximizing Traffic Capture and Minimizing Cost *

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Keywords: Network Design, Courier System, Flow Capture

1. Introduction

We propose a network design problem for a feeder-trunk private courier system. In this system, a minimum cost trunk (main path) is located between an origin (O) and a destination node (D) (both predetermined). The trunk or main path is composed by links. Links are connected to each other by either costless, non-active nodes, or by transfer nodes that are, at the same time, depots where parcels can get in or out of the courier system. Transfer nodes have a known cost. Links have a cost per distance. Costless stations can be built outside of the main path, that are connected through less expensive links to transfer stations on the path.

Customers are located at nodes in the region. Each station has a coverage or capture radius, representing the maximum distance the clients are

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willing to walk to reach a station. Thus, the flow (parcels) between a client's node pair is captured by the network if both nodes in the pair are within the capture distance of a station, be it on the path or not. Figure 1 shows a solution to the problem for a small instance. The path contains the nodes O-2-3-18-19-26-D. The transfer nodes are nodes O, D, 3 and 19; while the nodes 2, 18 and 26 are non-active nodes. Nodes 5, 9 and 28 are stations, connected to transfer nodes on the path. In Figure 1, the grey circles indicate the coverage provided by either transfer nodes or stations. For example, node 28 captures nodes 27-28-29, while node 1 is captured by the transfer station at the origin. Thus, the flow between nodes 1-29 is captured by the courier system. Related studies are presented in [1], [2], [3], [4].

We propose an integer programming model that minimizes the path construction cost, the transfer station location cost and the cost of the links not on the path. In addition, the model maximizes the flow capture. Both objectives are in conflict: if the cost is minimized, the flow capture tends to decrease; if the flow capture is maximized, the cost tends to increase.

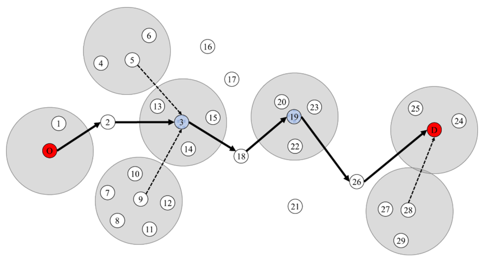

Figure 1. Solution scheme in a 31-node instance

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VND for the Capacitated Dispersion Problem

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Keywords: Diversity maximization, Dispersion, VNS, Metaheuristics

In this work, we investigate the adaptation of greedy randomized adaptive search procedures (GRASP) [1] and the variable neighborhood search methodology (VNS) [2] to efficiently solve the Capacitated Dispersion Problem. Dispersion and diversity problems arise in the placement of undesirable facilities, workforce management and social media, among others. Maximizing diversity deals with selecting a subset of elements from a given set in such a way that the distance among the selected elements is maximized.

Here, we target a realistic variant with capacity constraints for which a heuristic with a performance guarantee was proposed in [3]. In particular, we propose a hybridization of GRASP and a variant of VNS implemented within the Strategic Oscillation framework. To evaluate the performance of our heuristic proposal, we perform extensive experimentation to first set the key search parameters of its different elements, and then compare the final method with the existing one. In addition to this, we propose a mathematical model to obtain global optimal solutions for small size instances and compare our solutions with the well-known LocalSolver[1] software.

Computational results will be provided to show that our new hybrid proposal is able to obtain high quality solutions in short computing times, outperforming the state-of-the-art methods.

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Benders' Decomposition for Multi-Period Sales Districting Problem

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Keywords: Mixed integer linear programming, Sales districting problem, Multi-period, Benders' Decomposition

In the sales districting problem, we are given a set of customers and a set of sales representatives in some area. The customers are given as points distributed across the area and the sales representatives have to provide a service at the customers' locations to satisfy their requirements. The task is to allocate each customer to one sales representative. This partitions the set of customers into subsets, called districts. Each district is expected to have approximately equal workload and travelling time for each sales representative to promote fairness among them and the overall travelling distance should be minimal for economic reasons. However, the real travelling distance is often hard to calculate due to many complicating factors, e.g. time windows or unexpected situations like traffic jams, resulting in a loss of service. Therefore, one of the alternative ways is to approximate the travelling distance by considering geographical compactness instead.

We now extend this problem to be more realistic by considering that each customer requires recurring services with different visiting frequencies like every week or two weeks during the planning horizon. This problem is called *Multi-Period Sales Districting Problem*. In addition to determining the sales districts, we also want to get the weekly visiting schedule for the sales representative such that the weekly travelling distances are minimal and the workload and travelling time are balanced each week. Although the problem is very practical, it has been studied just recently.

In this talk, we focus on the scheduling problem for one sales representative in a specific district, which is already an NP-hard problem. We start by presenting a mixed integer linear programming formulation for the problem. Afterwards, we develop and implement a Benders' Decomposition to solve the problem, exploiting the structure of the formulation. We also implement some modifications to enhance the performance of the algorithm.

Semidefinite Bounds and Continuous Convex Reformulations for the Discrete Ordered Median Problem

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Keywords: Discrete ordered median problem, Semidefinite and copositive relaxations

This paper presents an exact continuous, linear, conic formulation for the Discrete Ordered Median Problem (DOMP) and several tight lower bounds derived coming out of it. We prove that there exists a transformation of a quadratic formulation of DOMP, using the same space of variables, that allows us to cast DOMP as a continuous linear problem in the space of completely positive matrices. This is the first positive result that states equivalence between the family of continuous convex problems and some hard problems in L.A. The result is of theoretical interest because allows us to share the tools from continuous optimization to shed new light into the difficult combinatorial structure of the class of ordered median problems.

1. Contributions

The discrete ordered median problem (DOMP) represents a generalization of several well-known discrete location problems, such as p-median, p-center or $(k_1 + k_2)-$trimmed mean, among many others. The problem was introduced in [6] and later studied by [7], [2], and [8], [5] and [1] among many other papers. DOMP is an NP-hard problem as an extension of the p-median problem.

[6] first presented a quadratic integer programming formulation for the DOMP. However, no further attempt to deal directly with this formulation was ever considered. Furthermore, that approach was never exploited

in trying to find alternative reformulations or bounds; instead several linearizations in different spaces of variables have been proposed to solve DOMP some of them being rather promising, [5] and [4].

Motivated by the recent advances in conic optimization and the new tools that this branch of mathematical programming has provided for developing bounds and approximation algorithms for NP-hard problems, as for instance max-cut, QAP, and other hard combinatorial problems [3], we would like to revisit that earlier approach to DOMP with the aim of proposing an exact alternative reformulation as a continuous, linear conic problem. Our interest is mainly theoretical and tries to borrow tools from continuous optimization to be applied in some discrete problems in the field of L.A. To the best of our knowledge reformulations of that kind have never been studied before for DOMP nor even in the wider field of L.A.

The goal of this paper is to prove that the natural binary, quadratically constrained, quadratic formulation for DOMP admits a compact, exact reformulation as a continuous, linear problem over the cone of completely positive matrices. Recall that a symmetric matrix $M \in \mathbb{R}^{n\times n}$ is called completely positive if it can be written as $M = \sum_{i=1}^{k} x_i x_i^t$ for some finite $k \in \mathbb{N}$ and $x_i \in \mathbb{R}^n$ for all $i = 1, \dots, k$.

The paper is organized as follows. We begin by formally defining the ordered median problem and its elements. Then, we present a binary quadratic, quadratically constrained formulation of DOMP. We build on this formulation the main results in this paper: DOMP is equivalent to a continuous, linear conic problem. Moreover, we can derive several tight lower bounds based on that formulation. Obviously, there are no shortcuts and the problem remains NP-hard but it allows us to shed some lights onto the combinatorics of this difficult discrete location problem. Moreover, it permits to borrow also the tools from continuous optimization to the area of L.A. We finish the paper with some conclusions and pointers to future research.

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Hub-and-Spoke Network Design under the Risk of Interdiction

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Keywords: Hub-and-Spoke network, Location-interdiction, Tri-level program, Decomposition methods, Supervalid inequalities

Hub-and-Spoke network finds application in the operation of businesses in transportation, energy and communication sectors. It is used in these businesses to bring down the cost of operations and to reduce fixed costs. Flow from different source nodes is collected in the hubs, where they are sorted based on their destination. These collected flows might either go from this hub to another hub or to the destination node directly. If the incoming flows to the hub are from another hub, the flows are sorted again for distribution to the destination node unless they are destined for the hub. The cost saving of employing a hub-and-spoke network comes from the accumulation of flows transhipped between hubs which result in better utilization of the carrier, thereby achieving economies of scale. Another advantage is the setting up of fewer links in the case of hub-and-spoke network which result in lesser fixed and monitoring costs of the network.

Though the hub-and-spoke network might be attractive from a cost reduction perspective, it might not be an effective risk management option considering the recent geopolitical events. For instance, any interdictor (typically a terrorist organization) can choose to attack the hubs to disrupt the flows in the system. Destruction of a hub rather than a spoke is more damaging to the decision maker because, hubs carry collected flows from spoke nodes in addition to the flows originating at or destined to the hubs. One recent example is the attack on the Ataturk International airport in Turkey. The airport which serves as a hub for Turkish airlines, Onur air, and Atlas global, served 60 million passengers in 2015 and is the eleventh busiest airport in the world. The attack carried out by terrorists resulted in 45 civilian deaths and more than 230 injuries. Following the attack, the flights destined to the airport were diverted to other hubs in the vicinity. The Transportation Safety Administration (TSA) and the Federal Aviation Administration (FAA) of the United States' government grounded several flights to/from Turkey resulting in severe cargo and passenger traffic disruptions throughout the world. Incidents like this, motivates our research question: Is it possible to design a hub-and-spoke network such that it is more resilient to targeted attacks with minimal economic loss? We seek to address the question by studying a hub-and-spoke network design problem under the risk of interdiction. In the next section, we present the outline of the model and solution method for this problem. Finally, we conclude by discussing some of the results based on our computational experiments.

Mitigating Structural Complexity in Network Design

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Keywords: p-Median, Complexity, Network Design

Facility location problems are well known combinatorial problems where the objective is either to minimise the cost incurred to serve customers from a set of facilities, or to maximise the profit obtained from such facilities. In most of this models cost and/or profit are the main drivers determining (either exogenously or endogenously) the number of facilities to be located (see, for example [2]). Our aim in this work is to bring to the field of facility location the concept of supply chain complexity. In this framework, complexity is understood as the pervasive effect of the proliferation of products, channels and markets. This notion of structural complexity highlights the fact that not always more is better, and that the apparent benefits from opening a new facility, or expanding to a new market, may be corroded by hidden complexity costs.

In [1] we deployed elements from information theory for proposing a measure for supply chain complexity, to which we refer as structural complexity, which allows the evaluation of the impact managerial decision in the overall complexity of the supply chain and, therefore, on its profitability. Two main factors affect the structural complexity value of a network:

the number of facilities and their location or, more specifically, the demand allocation that results from the location decision. The objective of our study is to evaluate the complexity of a given network design, to identify whether changes in the location pattern may contribute to reduce, or balance, the complexity faced by the manager of individual facilities, and to analyse the interaction between different location decisions and the structural complexity of the resulting network.

With this aim we propose an extension to the p-Median problem that takes into account the resulting network's complexity: the K-MedianPlex Problem. Given the highly combinatorial nature of this new formulation and the non-convexity of the objective function, we develop a simplified version that includes a complexity target, $\overline{C}$, as a constraint in a p-Median optimisation problem (we refer to this as the $\{K, \overline{C}\}$-Median Bounded Problem). We finally designed an algorithm that solves the simplified problem by means of developing a branch of q-Median subproblems whenever the inclusion of a new facility breaks the complexity constraint in the standard p-Median problem. These formulations allow us not only to obtain location patterns that satisfy certain complexity requirements but, also, to assess the (p-Median) suboptimality of location schemes that consider structural complexity issues as part of the decision process.

The main objective is to create awareness about the need of considering structural complexity issues, rather than a pure cost/profit perspective, when deciding the location and size of a distribution network.

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Big Triangle Small Triangle Method for the Weber Problem with a Rectangular Obstacle

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Keywords: Big Triangle Small Triangle Method, Weber Problem, Obstacle

The big triangle small triangle method (BTST method) is a method to obtain the exact optimal solution of location problems with nonconvex objective function. In this paper, we apply the BTST method to the Weber Problem with attraction and repulsion (WAR) where a rectangle obstacle exists in the plane. We show the outline of the algorithm.

1. Introduction

The BTST method is proposed by Drezner and Suzuki [2]. The first problem we solved in [2] is the Weber problem with attraction and repulsion (WAR problem). WAR problem is the Weber problem where the weight of the demand points are either positive or negative.

In this paper, we apply the BTST method to the WAR problem with a rectangular obstacle (WARRO problem). The paths from the demand points to the facility should not pass through the rectangle, and the facility should not be placed in the rectangle. The Weber problem with obstacles has been studied by [1]. However, WAR problem with a rectangular obstacle has not been studied so far.

2. WARRO problem

The demand points are scattered in the plane except the inside of the rectangular obstacles. The customers on the demand points access to the facility without passing through the rectangles. It means that if customers can not access to the facility directly, they should travel through a point or edges of the rectangle to make a detour to avoid the rectangle. We define the distance from the demand point to the facility as the generalized distance.

Our objective is to obtain the exact solution of the problem so as to minimize the sum of the weighted generalized distance. Note that the weight should be either positive or negative.

3. Outline of the algorithm

The outline of the algorithm is as follows:

1. The triangulation phase (phase 1)
2. The scanning phase. Obtain UB (phase 2)
3. The branch-and-bound phase (phase 3) A lower bound LB of the objective function is evaluated for each triangle. All triangles with their lower bound LB greater then UB are discarded If the minimum of the LB is larger than $UB/(1+\epsilon)$, stop. The triangle which attains the UB include the solution, and the objective function value is UB.

In phase 1, we use the Delauney triangulation. In phase 2, UB can be obtained by evaluating the objective function value at the centroid of each triangle and findng the minimum of them. In phase 3, LB is obtained by the tangent plane method proposed by [2].

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Multilevel Optimization Framework for Generalized Districting Problems

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Keywords: Branch and Bound, Geographical Districting, Political Districting, Contiguity, Discrete Location

The Generalized Districting Problem (GDP) seeks to divide a geographical region into a finite set of *districts* such that the districts satisfy certain well-defined criteria and are optimal with respect to domain-specific objectives. GDPs have applications in political re-districting, commercial territory design, school districting and police district design, among others. The specific objective function depends on the application and some typical objectives are to maximize compactness, balance population, minimize the footprint of the district, minimize the diameter of the district among others. Despite such variations in considerations, contiguity in districts is a common requirement in most GDPs. Further, GDPs are NP-hard and thus solving them is computationally intractable for all but the smallest problem instances.

While an instance of GDP comprises of a set of geographical units that need to be partitioned, it is common for such units to be hierarchically nested based on their natural boundaries. For political re-districting in the United States, census blocks are nested into census tracts, which in turn are nested into counties. A highly granular level guarantees better *quality* solutions, but becomes computational complex owing to a larger solution space, and vice-versa with a coarser level. Hence, there is a need for algorithms that solves GDPs while balancing this inherent trade-off.

A multi-level algorithm is presented that traverses between the different granularities. The idea is to iteratively aggregate units using an aggregation scheme, solve the problem to optimality at the coarsest level and then disaggregate the solution with local search improvements. One aggregation scheme at each level is to utilize administrative hierarchies such as census blocks, tracts and counties. Another scheme is to solve a matching problem that takes into consideration the objectives by pairing units that will lead to compact districts satisfying population balance constraints.

The second part of the work focuses on an exact method for solving GDP at the coarsest level. Several exact methods have been proposed in OR/MS literature to solve GDPs, including MIPs with a general objective function. Flow-based constraints have been recently popular and is currently considered the state-of-the-art method for ensuring contiguity in MIPs. However, these constraints are large in number in a generalized setting where district *centers* are not specified. A simple implementation in a commercial solver results in significant computational time for mid-sized instances. Another popular method is a two-stage approach where the first stage enumerates all feasible (contiguous) districts and the second stage solves a set covering problem by column generation. As the problem size increases, the enumeration stage becomes computationally expensive, forcing one to rely on heuristics. This suggests the need for exact methods that enforce contiguity efficiently.

The presented method uses a Branch and Bound (B&B) based approach. The main idea is to solve a contiguity-relaxed problem and prune partial solutions in the B&B tree that *potentially* lead to non-contiguous solutions. Every branch in the B&B tree corresponds to the assignment of a unit to a district. This results in an incremental build-up of partial solutions whose structure is exploited using a dynamic algorithm that efficiently verifies potential contiguity at each node in the tree. This dynamic algorithm performs provably better than verifying potential contiguity using a graph search.

Based on computational studies on congressional redistricting in US, results show that districting objectives (compactness and population balance) are improved by the multi-level traversal when compared to solving the problem at a single level. Matching-based aggregation leads to solutions are more balanced (in population) and compact than when using administrative hierarchies. Further, the pruning-based contiguity enforcement method solves many times faster than existing methods to solve MIPs which use contiguity constraints. The presented framework is an efficient tool for solving general districting problems and is also adaptable to additional application-specific considerations.

Revenue Management in Hub Location Problems

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Keywords: Revenue management, Hub location, Uncertainty, Benders decomposition

We formulate a hub location problem including aspects from revenue management problems. To this end, we consider one of the basic and classical revenue management model known as capacity-control discount fares within the hub location problem and develop a deterministic formulation of this problem. We further extend this model considering uncertainty associated with demand and revenues and develop a stochastic minmax regret formulation. Two exact algorithms based on a Benders reformulation are proposed to solve large-size instances of the problem. To evaluate the efficiency and robustness of the proposed algorithms, we perform extensive computational experiments.

1. Introduction

A hub location problem is a network design problem consisting generally of two main decisions: the location of hubs and the allocation of demand nodes to these hubs [2, 4]. While in revenue management problems, one of the basic issues is to intelligently allocate the available limited capacities to demand from different market segments, with the objective of maximizing total revenues [3]. We observed that hub locations, allocations, and decisions on the routing of flow can be effected by revenue management considerations. Hence, in this study, we incorporate revenue management decisions in hub location problems.

2. Problem Definition

The hub location problem that we study in this paper determines the location of hubs, the allocation of demand nodes to hubs, and also the routes of the flows through the network in order to maximize profit. Demand is segmented into different classes that are to be satisfied through hubs with limited capacities. Hence, the decision on how much of total capacity should be allocated to the demand from different classes is also to be made.

There is a given set of demand nodes with different classes of demand to be satisfied in-between. Hubs are to be located from a set of potential hub nodes to serve the demand between the nodes. We consider a capacitated environment for hubs where the capacity is defined as the amount of traffic passing through a hub.

Revenue is obtained from satisfying the demand of each origin-destination (O-D) pair. Prices paid by various classes are set to be different and known. The problem is to determine which set of O-D pairs to serve and how to serve them to maximize profit. In this regard, it is assumed that some classes can be served partially due to capacity constraints or remain unserved if it is not profitable to serve them.

For the design of the access network, the firm wants to design its network in the most profitable way. To this end, we consider multiple allocation strategy where there is no limit on the maximum number of hubs that a node can be allocated to.

The objective is to maximize profit which is calculated as total revenue minus total cost. Total cost includes the transportation cost and the installation cost of hubs. The transportation cost on the hub network between each O-D pair is calculated by the cost of transportation from origin-to-hub (collection), between hubs (transfer), and from hub-to-destination (distribution). Due to bulk transportation there are economies of scale between hubs.

Considering revenue management concepts in this study, we assume that demand is not precisely known. Hence, the optimal decisions have to be anticipated under uncertainty. The uncertainty associated with demands is described by a known probability distribution. Accordingly, we propose mathematical models considering a stochastic demand. We consider discrete type of uncertainty where uncertainty is represented by a finite set of scenarios.

Note that precise information regarding revenues may not be known ahead of time. Hence, we take revenues into consideration as uncertain parameters as well. It may not make sense to assume that there exists a probability distribution for uncertain revenues. In the absence of a known probability distribution for revenue, we use a set of scenarios describing uncertainty associated with revenues. In this case, we use a minmax regret type of objective function to model the problem with uncertain revenues.

3. Solution Methods

Benders decomposition is a partitioning method applicable for the problems that have the possibility of being decomposed into two smaller problems as an integer master problem and a linear subproblem [1]. According to this criterion, Benders decomposition is well suited for hub location problems with multiple allocation structure where by fixing the integer variables for the location of hubs, the problem could be decomposed into linear subproblems.

We present two algorithms based on Benders decomposition to solve our problem. We use several strategies to enhance the algorithms particularly in solving the subproblems and to speed up the convergence. Our computational results show that the proposed algorithms are very efficient and able to solve large-size instances in very reasonable CPU times.

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Flow-Capturing Problem with Probabilistic Demand Coverage and its Applications

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Keywords: Flow-capturing problem, Integer programming, Probabilistic model

In this paper, we focus on demands for service that arise from flows traveling between origin-destination nodes of a transportation network. If a facility is located on the preplanned journey route, travelers may choose to obtain a service. Focusing on this aspect, Hodgson (1990) developed the flow-capturing problem (FCP), which seeks to locate m facilities among the nodes of the network in order to maximize the number of demands that have at least one facility along their preplanned travel path.

In the original FCP, a given flow is deterministically captured when at least one facility exists along the travel path. However, this assumption is not always appropriate in real-world applications as the following two scenarios show:

Scenario1: location of commercial stores Travelers do not always drop by a commercial store each time they encounter a facility.

Scenario2: location of security guards Violators are not always identified by a security guard they encounter along the travel route.

Focusing mainly on the first scenario, Matsuo et al. (2015) extended the original FCP by introducing the probability p that a given flow is captured. They proposed a problem of maximizing the expected number of flows that become actual users of a facility, and applied an integer programming formulation to an example network. In their problem, the expected number of captured volume for a given flow becomes larger as the number of facilities along that path increases, but it does not depend on the location of the facilities. In the second example, however, it is important to identify and remove violators from the network as early in their trips as possible, the structure that was first considered in the inspection location problem by Hodgson et al. (1996).

By focusing on the second scenario, this paper explores the problem of placing security guards on a road network and relax the assumption that a security guard can always find violators with probability one. We propose the problem to determine m sites in a network that minimizes the expected total distance traveled by violators. This problem can be considered as an extension of the inspection location problem by introducing the probability that a security guard can identify a violator encountered along the travel path of the violator.

The proposed model is formulated as an integer programming problem and it is applied to instances constructed from road and railway networks. We compare optimal solutions obtained by the inspection location problem with those obtained by the proposed problem. We consider various other scenarios in which the probabilistic demand coverage in FCP can be applied. Possible extensions of the proposed model are also discussed.

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A Comprehensive Modeling Framework for Hazmat Network Design, Hazmat Response Team Location, and Equity of Risk*

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Keywords: Hazmat emergency response team, Bi-level network design, Greedy heuristic algorithms, Robust solution

This paper considers a bi-level hazmat transportation network design problem in which hazmat shipments have to be transported over a road network between specified origin-destination points. The bi-level framework involves a regulatory authority and hazmat carriers. The control variables for the regulatory authority are locations of hazmat response teams and which additional links to include for hazmat travel. The regulatory authority (upper level) aims to minimize the maximum transport risk incurred by a transportation zone, which is related to risk equity. Our measure of risk incorporates the average response time to the hazmat incidents. Hazmat carriers (lower level) seek to minimize their travel cost. Using optimality conditions, we reformulate the non-linear bi-level model as a single-level mixed integer linear program, which is computationally tractable for

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medium size problems using a commercial solver. For large size problems, we propose a greedy heuristic approach, which we empirically demonstrate to find good solutions with reasonable computational effort. We also seek a robust solution to capture stochastic characteristics of the model. Experimental results are based on popular test networks from the Sioux Falls and Albany areas.

This work presents three main contributions that differentiate our paper from the current literature. First, we consider simultaneous decisions on designing a road network and locating HRTs to mitigate hazmat transport risk. Second, we define a risk measure that includes the average response time to the hazmat incidents. The regulator's objective function incorporates this definition of risk and allows us to capture the interactions between network design decisions and HRT location decisions. Regional jurisdiction of HRT guides us to consider risk equity over network zones, where each geographic zone is assigned to exactly one HRT. Third, we propose a robust solution to deal with the stochastic characteristics of hazmat accident probability and hazmat release consequences.

The presented non-linear bi-level model is reformulated into a single-level mixed integer linear problem. The single-level model is solved using CPLEX 12.6 for a small size network. The greedy heuristic approach is able to find very good (near optimal or sometimes optimal) solutions in a short time period for large size test problems. Experimental results show that joint decision of network design and deployment of emergency response team may result in better risk reduction. Increasing the total number of available HRTs for deployment and the total available budget for link addition has a remarkable impact on risk mitigation.We also conclude that the greedy algorithm is computationally efficient and delivered high quality solutions. Finally, a robust solution is obtained for 27 scenarios under consideration by applying the proposed heuristic approach for a large size test problem. In practice, other emergency response units may be dispatched to the incident site, such as, Emergency Medical Service, Fire, and Police. This suggests a future work dedicated to joint deployment of all emergency units. Furthermore, the average response time is highly dependent on traffic congestion and incident location, thus, a robust solution should be investigated considering uncertainty in determining the response time. Another research opportunity is to consider the problem of adding additional HRTs to a situation where a certain number of HRTs already exist.

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A Column-and-Constraint Generation Algorithm for Stochastic Maintenance Location Routing

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Keywords: Facility location, Stochastic programming, Rolling stock

We demonstrate a new column-and-constraint generation algorithm for two-stage stochastic programming problems on a stochastic maintenance location routing problem. Our column-and-constraint generation algorithm contains (partial) Benders decomposition and the deterministic equivalent as special cases and can be used to trade-off computational speed and memory requirements. Our algorithm outperforms (partial) Benders decomposition in computational time and solving the deterministic equivalent with a commercial MIP solver in memory requirements for a maintenance location routing problem. In addition, for instances with a large number of scenarios our algorithm outperforms the deterministic equivalent in both computational time and memory requirements.

Stochastic maintenance location routing

The stochastic maintenance location routing problem tries to find the optimal location of maintenance facilities for rolling stock in a railway network.

Like most facility location problems, we have a set of candidate facilities and their costs, and we have to decide which facilities to open. However, the transportation costs of our customers (train units) are more intricate than can be modeled by fixed allocation costs. The problem of routing these train units to the maintenance facilities is called the maintenance routing problem (MRP). The MRP cannot be separated from the facility location problem because the ease with which a facility can be reached depends intricately on the railway infrastructure and the line plan.

A line plan consists of a set of train lines, where each line is a path in the railway network that is operated with a certain frequency by one rolling stock type. The line and fleet plan within a railway network changes regularly to accommodate changing travel demands. As a consequence, any reasonable facility location plan must work well under a wide variety of line and fleet plan scenarios. This include changes in how lines run, up and down-scaling of service frequencies on any given line, the rolling stock types assigned to the lines, and the introduction of new rolling stock types.

To deal with the features we outline above we provided a two-stage stochastic programming model (SMLRP) where the annual cost of the facilities and the annual maintenance routing cost averaged over a set of line plan scenarios is minimized. The first-stage decision for the SMLRP is to open or close a facility, given a set of candidate facilities, annual facility depreciation costs, and a discrete set of line planning scenarios. In the second-stage the annual maintenance routing costs for a first-stage location decision are determined for each line plan scenario. The second-stage problem corresponds with the MRP.

Furthermore, we provide the deterministic equivalent and design a new efficient column-and-constraint generation algorithm that contains Benders decomposition [2], partial Benders decomposition [1], and the deterministic equivalent as special cases. Our algorithm can be used to trade-off computational speed and memory requirements and performs always at least equally good as the algorithms that it contains as special cases.

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Optimal Location Model for Determining Base Hospitals for Doctor-Helicopters*

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Keywords: Air Ambulance, Generalized Maximal Covering, Integer Programming

In many countries, helicopters are used for patient transportation in emergency medical services. For such systems to work effectively, it requires much cost. In this study, we introduce a mathematical optimization problem in order to obtain an optimal location of base hospitals for helicopter emergency systems.

1. Introduction

In this presentation, we discuss location of base hospitals for air ambulance. Air ambulance is a transportation service to transport patients to and from a medical institute and accident scenes by using airplane or helicopter. In many cases, helicopters are utilized because of their mobilities. Air ambulance using helicopters is also called Helicopter Emergency Medical Service (HEMS). It is expected to shorten transportation time to a hospital, and to start initial treatment by a doctor on site.

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In Japan, air ambulance service started in 2001. As of November 2017, 51 helicopters are deployed in Japan. However, it is claimed that deployment of 80 helicopters is desirable taking into account the terrain and/or medical service situation [1]. On the other hand, it is not easy to increase the number of helicopters due to the budget constraint. To deal with this problem, we propose a mathematical optimization problem that determines optimal helicopter deployment based on a coverage model.

2. Model

Various models dealing with air ambulance deployment problems have been proposed thus far (e.g., [1]). However, applications of optimization models to large-scale problem instances seem to be limited. Thus, we apply a variant of Maximum Covering Problem and apply it to large-scale population data in Japan. As candidates for base, we choose 566 hospitals that play an important role in emergency medical in their individual region. For demand points, we set 178,411 points based on national census in 2015. Each demand point corresponds to a square with side length about 1 km where one or more people live. We assume that if the distance between a demand point and its closest candidate hospital is less than 7 km, ground transportation has advantage over air transportation. Thus, such demand points are excluded from target demands when calculating an objective function. We also assume that air transportation has a strong effect if the distance between a base hospital and a demand point is less than 50 km, and it has a moderate effect for less than 75 km. From these reasons, the objective function is defined to be the total covered demands weighted by the corresponding strong/moderate coverage values.

Under the above settings, we obtain optimal deployments of 51 helicopters that is the same number as currently deployed. In the optimal solution, the value of objective function is 8% greater than that calculated from the current deployment. At the same time, it can decrease the uncovered population from 2.0 million to 0.8 million.

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Drone Positioning in Complex Urban Areas*

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Keywords: Bicriteria Camera Placement, Network Location, MILP, Heuristic

Although the placement of stationary cameras has been a well studied topic in the past decades, not much work has been done to optimise the usage of moving cameras. In this presentation we will focus on drones and propose a model where we simultaneously consider the minimisation of the number of drones and their energy consumption.

1. Introduction

One of the first authors introducing drones for video surveillance were Maza and Ollero [1] in 2007. The following research was mainly focused on computing optimal trajectories for one or multiple drones in order to cover a given area (coverage path planning for drones). Note that in these applications each point of the area should be revisited in small time intervals by the moving drones instead of observing the whole area simultaneously. A survey of such models is given by Chen et al. in [2]. Other applications where drones are used do not intend to monitor the whole region but rather single target points of special interest (cf. Zorbas et al. [3]). In our model, we additionally want to consider obstacles which influence the field of view (FOV) of the drones. We further want to minimise the number of drones and the total energy consumption. We propose a two stage heuristic approach to solve this problem.

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2. Problem Setup

We consider the drones to monitor from the bird's eye perspective, i.e. each single drone covers a circular area on the ground. The higher a drone rises, the larger is its FOV. At the same time, the energy consumption increases with a higher altitude, as former research states (cf. Zorbas et al. [3]). For reasons of image quality, a maximum flying hight should be given. Obstacles limit the visual range of the drones. We model the real world problem by a polygon $\mathcal{P}$ with h holes representing the obstacles blocking the FOV. Neither targets nor drones are allowed to be placed in these forbidden areas. The points in the set of targets $\mathcal{T}$ need continual surveillance by the drones. The problem is to find a solution minimising both the number of drones such that each target is observed by at least one drone and the total energy consumption. Fewer drones need to fly higher, which results in an increase of energy consumption.

3. Two Phase Solution Heuristic

3.1 Phase I - Solving a Network Location Problem

We model the problem as follows: In an undirected graph $G = (V, E)$ create for each target $t \in \mathcal{T}$ a node v_t in G. Whenever two targets $i, j \in \mathcal{T}$ are visible from each other and do not exceed the maximum radius R we connect the two corresponding nodes v_i and v_j by an edge using the euclidean distance as edge weight. In the first phase, we restrict the possible drone locations to the positions of the targets. That is, find a dominating set $D \subset V$ in the graph G, such that all nodes $u \in V \setminus D$ are adjacent to a node $v \in D$. For reasons of limited resources, a subset D should be chosen such that the cardinality of D is minimised and the sum of the radii of the nodes in D is minimal. The radius of a node $v \in D$ is defined as the distance to the farthermost node $u \in V \setminus D$ which is assigned to v. Note that for our purposes, it is necessary to assign all nodes $u \in V \setminus D$ to a certain node $v \in D$ to determine the radii of the drones.

The resulting problem can be written as a mixed integer linear program (MILP). Solving this problem with GUROBI leads to unacceptable solution times. Therefore, we suggest the following heuristic approach: first, place a drone at every node in G, i.e. $D = V$. Then, in every single iteration, we decrease the number of drones by one choosing the vertex promising the biggest success, as a greedy-algorithm would do. In contrast to a typical greedy, our procedure may revoke its earlier decisions if the following test is satisfied: If we go back $t > 0$ iterations, is there a node that covers t feasible nodes better than the greedy solution? By this network location approach, we get a feasible solution for the real world problem. Since we have restricted the positions of the drones to the positions of the targets, can do better in reality, of course. This is done in Phase II.

3.2 Phase II - Re-Optimising

From the optimal solutions of Phase I, we gained an assignment of the targets to the drones. So, instead of solving the original problem like a planar multi-facility location problem, we can now focus on solving several easier single location problems, one for each drone. For example, this can be done using a planar 1-Center problem.

4. Conclusion and Future Research

In computational tests, the proposed heuristic provides promising results in reasonable time. Up to now, drones do not move in this model. As a next step, the model should be adapted to the case of moving targets and drones.

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Distance in the Supply Chain Network Design: A Literature Review

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Keywords: Distance, Transport, Vehicle Routing, Supply Chain, Network Design

Transport is one of the most cost-intense processes in the supply chain structure. Up to 80% of the supply chain costs are related to the flows of goods between facilities [2]. Thus, it is profitable to consider future operational transport-related expenses while making strategic facility location decisions [1].

We propose a literature review of joint location and routing decision models. We find that most papers are focused mainly on the development of computational methods and only scant attention is given to the issue of modeling distances. Our particular interest is in analyzing how distances are used as input in the location and routing models. Eventually, we present some concepts from the field of geography to illustrate how an interdisciplinary approach could help to expand supply chain optimization models and reach better decisions. The results show that in order to build a good optimization tool, even sophisticated solvers are not enough as they need fitting data for the distances in order to provide reliable outcomes. We argue that more appropriate distance estimation would lead to better decisions.

The primary assumptions are rooted in the idea of enhancing transport cost estimation by introducing the notion of distance friction from geography to operation research. Although data about distances nowadays is easily available (e.g. Google Maps), for the purpose of strategic decisions, the method of estimating distances needs to be developed. The technology development in this matter is ambiguous. On the one hand increasing data availability certainly enhanced the opportunities in estimating distances, on the other hand, the quantity of data and complex methods enlarged the required modeling effort. Web mapping services provide precise inputs for the operational and tactical decision levels but are not relevant when making strategic decisions, e.g. facility location choices. Such exact estimation unnecessarily increases the data quantity and in consequence the computational effort. Moreover, the variability that might occur (e.g. due to traffic accidents, congestion, infrastructure development etc.) is hard to estimate at the strategic level. Nevertheless, the impact of such variability might be significant in the long run perspective. Therefore, it needs to be estimated in the future transport cost when making a facility location choice. Given all the research effort put into the development of new solution methods for supply chain problems, much added value could be obtained from better distance inputs. Further empirical research is ongoing in this direction.

This research is a part of PREsupply project, currently ongoing in Wallonia (Belgium) which purpose is to provide efficient and affordable optimization tools for small and medium size companies (SMEs). The expected results of this study will contribute to build an optimization tool for estimating travel time and cost for SME's.

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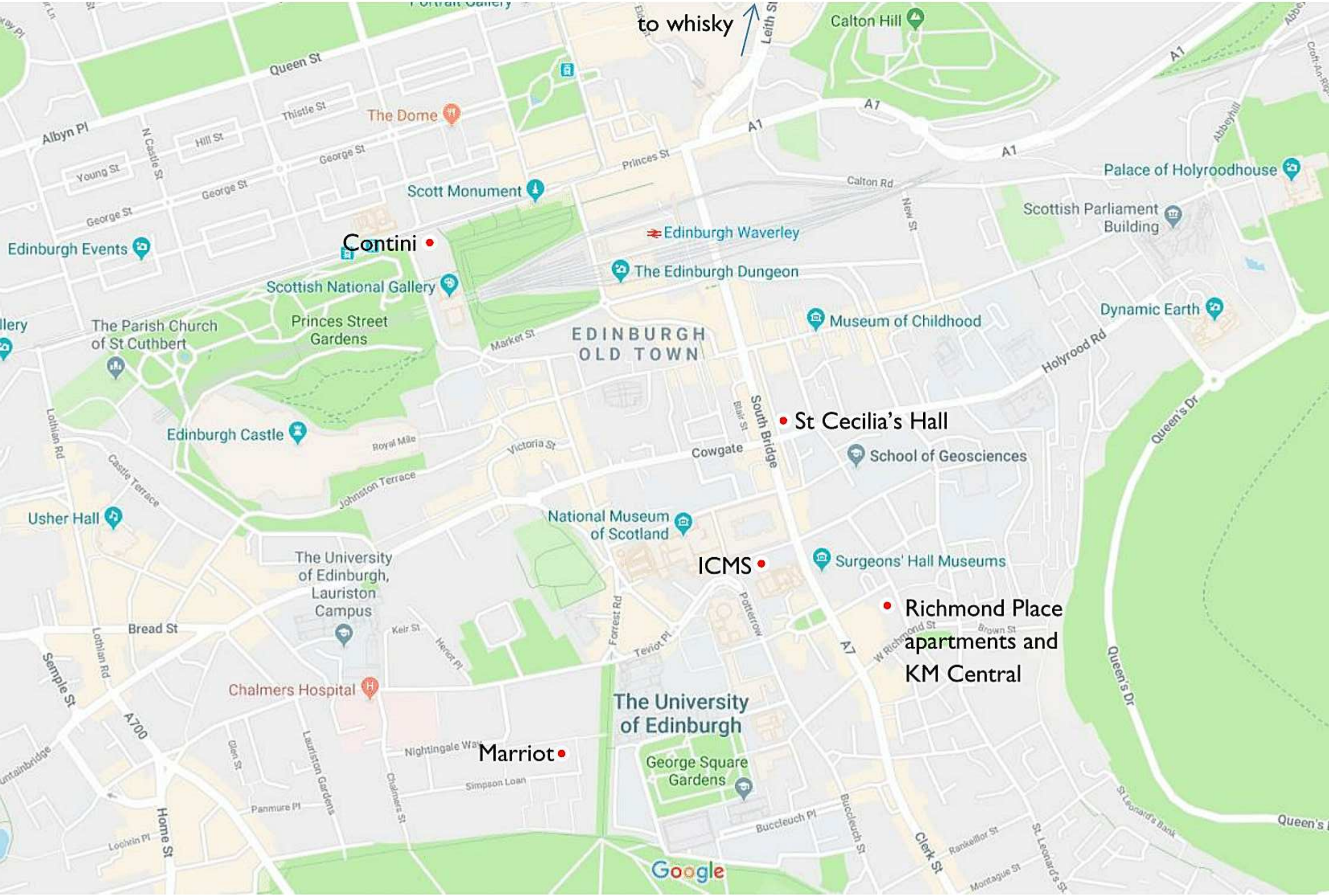
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St Cecilia's Hall
ICMS
Richmond Place apartments and KM Central
Marriot
Calton Hill
Palace of Holyroodhouse
Scottish Parliament Building
Dynamic Earth
Edinburgh Waverley
The Edinburgh Dungeon
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