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<th>DURACIÓN</th>
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INFORME FINAL
PROYECTO FONDECYT REGULAR

OBJETIVOS

Cumplimiento de los Objetivos Planteados en la etapa final, o pendientes de cumplir. Recuerde que en esta sección debe referirse a objetivos desarrollados, NO listar actividades desarrolladas.

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<td>1</td>
<td>Develop robust models and efficient solution methods for the deployment of security patrols on a network.</td>
<td>TOTAL</td>
<td>We have developed robust models for network design with equilibrium constraint, and continue to explore different possible variants on these models. Specifically our work has focused on variants of decomposition methods for the equilibrium flow and have not yet adapted them to the network design problem.</td>
</tr>
<tr>
<td>2</td>
<td>Develop robust models and efficient solution methods for network design with equilibrium flow.</td>
<td>PARCIAL</td>
<td>We have developed robust models for network design with equilibrium constraint, and continue to explore different possible variants on these models. Specifically our work has focused on variants of decomposition methods for the equilibrium flow and have not yet adapted them to the network design problem.</td>
</tr>
<tr>
<td>3</td>
<td>Create accurate measures of the sensitivity of a problem and its computational difficulty.</td>
<td>TOTAL</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Create decomposition method to solve large scale bilevel programs that make use of these sensitivity measures.</td>
<td>PARCIAL</td>
<td>We have developed decomposition methods to solve large scale bilevel programs but that do not exploit the feasibility margin yet. The decomposition methods include a number of decision points, such as which variables to generate next which can benefit from such information. During this last year we have developed a better understanding of the relationship between the feasibility margin sensitivity measure and showed that it can better bound changes to optimization problems than other measures such as the condition number. The next step is to implement it as a guiding rule for decomposition methods.</td>
</tr>
</tbody>
</table>

Otro(s) aspecto(s) que Ud. considere importante(s) en la evaluación del cumplimiento de objetivos planteados en la propuesta original o en las modificaciones autorizadas por los Consejos.

The two goals that have not been completely satisfied turned out to be harder than expected. We believe that our work under this project contribute important building blocks in addressing both goals.
For each specific goal, describe or summarize the results obtained. Relate each one to work already published and/or manuscripts submitted. In the Annex section include additional information deemed pertinent and relevant to the evaluation process.

**The maximum length for this section is 5 pages. (Arial or Verdana, font size 10).**

<Begin to write here>

**Fondect 1090630, year 2011**

**1. Development of robust optimization models for security patrol application**

We have developed optimization models with uncertainty for security patrol planning. These models have been extended from what has been done previously for airport police at LAX and now include patrolling transatlantic flights between the United States and Europe. These models include uncertainty in the adversary being considered in particular what their reward matrix is. A recent extension of this model we are investigating is how to patrol a network where attacker’s actions are paths through the network.

For this security application in which the number of possible patrolling assignments is massive, we have developed branch and price methods capable of solving the Stackelberg game that represents the interaction between security and adversaries. In particular the method exploits the problem structure both in the type of possible actions by the defender and in the structure of the reward matrix. The limit in the possible actions by the defender allows to find possible patrolling schedules by solving a network flow problem over a structured network. For instance, if we constraint all paths between origin and destination to have 5 arcs, solving the column generation problems can be done very efficiently. The structure in the reward matrix allows for heuristics that guide the branching process and provide good bounds on the optimal solution. Combined these two techniques give a very efficient branch and price method to solve the Security patrolling problem.

This work has been part of three published articles: one is a journal publication on the model development and practical deployment and two conference proceedings on the decomposition solution method and algorithms for models of uncertainty in the security game.


The extension to patrolling a network where attacker’s actions are possible paths on this network is also an example of a massive game, where the number of attacker actions is large. In this game, the defender decides to protect/patrol nodes in the network with a certain probability with the adversary then deciding which path to take on the network. This game can represent patrolling a city center, where police station themselves at different corners and criminals are moving through this network looking for opportunities to commit crime. Police may not necessarily catch the criminal, but their presence in the path of the criminal can have a dissuasive effect of the criminal activity. Given payoffs similar to the previous game, which only depend on the presence or not of a defender on the path of the adversary, and additive reward along the path, we have built a column generation approach to solving this problem which scales nicely. During this last year we discovered that this decomposition approach might provide only a local optimal solution due to the discontinuous nature of the defender rewards in the non-zero sum case. We developed a technique to restart the solution method exploring non visited regions of the solution space. This makes the proposed algorithm an exact method, however to the best of our knowledge the possible number of restarts can be large.
We have evaluated these patrolling strategies on different city networks and on games built to address crime in the center of Santiago and have found that it provides efficient solutions.

This work is part of the Master’s Thesis in Operations Research at University of Chile of the student Tomas Spencer, which will be defended in about one month. Subsequent to the thesis we expect to complete a publication with this work.

During this last year I began a collaboration with professor Dorit Hochbaum that focuses on a different form of decomposing the network security patrolling problem. In an application for nuclear threat detection vehicles equipped with radiation sensors will patrol a road network to sample radiation. Detection of a threat is achieved by contrasting the sampled radiation to a background radiation map that has been constructed. The proposed approach is to decompose the route construction with the probability of coverage problem. This creates a probability of coverage Stackelberg problem that is of manageable size and leaves us with the problem of selecting routes in a manner that would accurately represent the required probability of coverage. This problem can be translated into a k rural Chinese postman problem on a mixed direction network. Our work will consist of two parts: 1st to develop efficient algorithms to solve this k rural Chinese postman problem and 2nd to incorporate uncertainty into the implementation of these optimal solutions to avoid predictability of the security policy.

2. Development of robust optimization models for network design with equilibrium flow.

We have investigated and developed a robust model of network design with travel time and demand uncertainty. For tractability reasons the model considers continuous capacity decision variables on the arcs on the design decision. The flow then uses this existing capacity by infinitely many users that decide continuous fractions of flow on each path to complete the demanded flow on each od-pair. A column generation algorithm can be used to compute such a flow, given arc capacities. The master problem of this column generation method, however, remains a non-linear non-convex problem.

In collaboration with Professor Nicolas Stier-Moses of Columbia University we are in the process of exploring alternative formulations to this model. The challenge of the current approach is that the non-convexity of the master problem limits the size and scope of the type of problems that can be solved to optimality with this approach. An observation we are exploring is the fact that both capacity and tolls on an arc have a similar effect of increasing congestion, however a toll can be added in a linear fashion, whereas capacity typically appears in a non-linear non-convex fashion in BPR congestion functions. We are aiming to develop a new more tractable robust network planning model with equilibrium flow by shifting to tolls as design variables. We could recover optimal capacity decisions from optimal toll decisions through a non-linear transformation.

Another line of research, which falls in this line of work, involves the optimal design of a metro system under the presence of equilibrium decisions of users between using the constant travel time metro line being decided and an alternative road network with congestion. This work is being developed as the Master’s Thesis in Operations Research of Francisco Muñoz and in collaboration with Professor Antonio Mesa from Universidad de Sevilla. The network design problem is a hard integer problem that considers integer variables to determine if a station is built or not, if a line is built or not, and if a certain OD flow uses a certain metro line or not. We have decided on a piecewise approximation of the non-linear congestion function to build a linear mixed integer problem that could be solved with existing approaches. We are in the process of evaluating the scalability of this model and deciding how to implement efficient solution procedures. I am also supervising an additional Master’s Thesis in Operations Research of Alvaro Echeverria related to this line of work. This master’s thesis is focused on efficient methods of deploying emergency vehicles in a congested network setting, taking account the uncertain traffic conditions. In particular the problem of repositioning fire trucks during an emergency is requiring decomposition algorithms for an efficient solution.

With Professor Maged Dessouky we have explored methods to include market mechanisms in the offer of ridesharing alternatives to travelers in a transportation network. This type of model would lead to a different type of network equilibrium, in which some users might opt to
rideshare, possibly incurring a cost, but causing no congestion. We have produced one survey paper on current industry practice and theoretical models used in ridesharing. We have developed a network equilibrium models that decides the route assignment to each OD pair and also the number of people that opt to rideshare. We have developed a Frank-Wolfe algorithm to solve this problem and are in the process of evaluating the model on academic representations of real transportation networks.

Overall this line of work has already produced one submitted article, and should wind up producing one Master’s thesis and an additional publication.


3. Research on computing sensitivity analysis measures to identify robust problems and good decomposition points.

On this line of work I have pursued two different research ideas that contribute to the overall goal of having sensitivity measures that will help identify robust problems and good decomposition points for large scale problems. A good decomposition point creates a subproblem that will be solved repeatedly with similar data. Therefore, it is not only important to identify robust problems (that will not be too sensitive to data changes) but also to be able to quickly resolve a closely related problem to a previously solved problem. Therefore we have:

1. Developed a method to compute a robustness measure, defined by Ben-Tal and Nemirovski, the “feasibility margin”. This measure is correlated to Renegar’s condition number of a problem, however it specifically takes into account the problem and the uncertainty structure, whereas the condition number assumes any data coefficient could be perturbed. This measure should provide therefore better bounds on the change in the objective function of the problem due to changes in the data. We are in the process of numerically evaluating this measure versus Renegar’s condition number on the Netlib suite. These results should shed some insights into the value of this measure as a predictor in practice. This line of work is part of the Master’s Thesis in Operations Research of Rodrigo Lopez.

2. Developed warm start heuristics for interior point methods that are based on the sensitivity of the problem to data perturbations. That is, given a specific change of a solved problem (change to right hand side or objective) we propose a method to backtrack on previous solutions and penalize the change to speed up the solution to the modified problem. This method is inspired in a theoretical approach in which the total number of Newton steps would be bounded by Renegar's condition number, which is a measure of the sensitivity of the problem. This method is also being tested in reoptimizing linear programs from the Netlib suite based on changes to the right hand side due to branch and bound branching steps. This work is being carried out in collaboration with research professor Richard Waltz of the University of Southern California.

We have completed one master’s thesis on point 1., which will be defended this coming month and overall this line of work should produce two journal publications.

4. New/complimentary work on decomposition methods

During this last year I have also worked with the support of this grant on complementary research directions which fall in the general area of developing decomposition methods for optimization problems. In particular I have finished an earlier work on decomposition methods for robust vehicle routing in the case that there is service time uncertainty, which has led to a submitted article. In addition I began the supervision of two new Master’s Thesis on Operations Research (students Cristosthal Salas and Adolfo Rocco). These new lines of work are related to the topic of this project as the optimal solutions of the problems considered (logistics for a production company and timetabling in the retail industry) require the use of efficient decomposition methods for their solution. The hope is that we can use the sensitivity analysis
measures studied in point 3 to guide the decomposition solution methods that will be implemented.

This area of work has already led to one publication should conclude with two additional Master’s Thesis.

OTHER ACHIEVEMENTS OF THE PROJECT:
- Research visit(s) to other institution(s).
- Outreach activities related to the project’s main topic.
- Any other contribution, not addressed elsewhere, that you consider important.

The maximum length for this section is 1 page. (Arial or Verdana, font size 10).

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1. During this academic year I visited the University of Southern California twice, in September 2011 and March 2012. With the remaining funds I plan another visit during May to close up some ongoing publications. These visits have enabled me to continue my collaborations with: 1. the group lead by professor Milind Tambe and 2. with professor Maged Dessouky.
2. We presented our progress on models and algorithms for ridesharing at the INFORMS annual meeting in Charlotte NC, in November 2011.
3. Rodrigo Lopez has concluded his Master’s thesis on the topic of computing the feasibility margin of optimization problems. He is being scheduled for his defense next month.
4. Rodrigo Lopez presented his Thesis work at the IX Congreso del Instituto Chileno de Investigación Operativa (OPTIMA) in Pucón, October 2011.
5. Tomas Spencer has concluded his work on the project of a column generation approach for a Stackelberg security game protecting a network for his Master’s Thesis. He is in the process of writing the document.
6. The work on transit network design with equilibrium flow between the transit network and alternative flow is being carried out as the Master’s in Operations Research thesis topic of Francisco Muñoz.
7. Cristobal Salas has begun work on his Master’s Thesis on decomposition methods for logistics problems that arise in a real-world industry.
8. Adolfo Rocco has begun work on his Master’s Thesis. The topic is decomposition methods for timetabling at a retail company.
9. Alvaro Echeverria is working on his Master’s Thesis that focuses on methods to deploy emergency vehicles in congested conditions.
10. We began a collaboration with Dorit Hochbaum, during her visit to our department at the University of Chile of a new decomposition method to solve the problem of patrolling over networks with intelligent adversaries.
COOPERACIÓN INTERNACIONAL

Nº Proyecto: 1090630
Nombre Colaborador (a) Extranjero (a): DORIT HOCHBAUM
Afiliación Institucional Actual: UNIVERSITY OF CALIFORNIA, BERKELEY
Fechas de estadía Desde: 09/01/2012 Hasta: 13/01/2012

Describa las actividades realizadas y resultados obtenidos. Destaque su contribución al logro de los objetivos del proyecto. Si es pertinente, indique las publicaciones conjuntas generadas, haciendo referencia a lo informado en la etapa Productos. Agregue en la etapa anexos la información necesaria.

During this last year I begun a collaboration with professor Dorit Hochbaum that focuses on a different form of decomposing the network security patrolling problem. In an application for nuclear threat detection vehicles equipped with radiation sensors will patrol a road network to sample radiation. Detection of a threat is achieved by contrasting the sampled radiation to a background radiation map that has been constructed. The proposed approach is to decompose the route construction with the probability of coverage problem. This creates a probability of coverage Stackelberg problem that is of manageable size and leaves us with the problem of selecting routes in a manner that would accurately represent the required probability of coverage. This problem can be translated into a k rural Chinese postman problem on a mixed direction network. Our work will consist of two parts: 1st to develop efficient algorithms to solve this k rural Chinese postman problem and 2nd to incorporate uncertainty into the implementation of these optimal solutions to avoid predictability of the security policy.

During her visit, professor Hochbaum gave a seminar presentation at the Industrial Engineering Department, University of Chile

Nº Proyecto: 1090630
Nombre Colaborador (a) Extranjero (a): MAGED M DESSOUKY
Afiliación Institucional Actual: UNIVERSITY OF SOUTHERN CALIFORNIA
Fechas de estadía Desde: 24/05/2011 Hasta: 29/05/2011

Describa las actividades realizadas y resultados obtenidos. Destaque su contribución al logro de los objetivos del proyecto. Si es pertinente, indique las publicaciones conjuntas generadas, haciendo referencia a lo informado en la etapa Productos. Agregue en la etapa anexos la información necesaria.

With Professor Maged Dessouky we have explored methods to include market mechanisms in the offer of ridesharing alternatives to travelers in a transportation network. This type of model would lead to a different type of network equilibrium, in which some users might opt to rideshare, possibly incurring a cost, but causing no congestion. We have produced one survey paper on current industry practice and theoretical models used in ridesharing, which has been submitted for publication. We have developed a network equilibrium models that decides the route assignment to each OD pair and also the number of people that opt to rideshare. We have developed a Frank-Wolfe algorithm to solve this problem and are in the process of evaluating the model on academic representations of real transportation networks.

This is the second visit by professor Dessouky to the country. In both visits he also gave a seminar to the industrial engineering department at University of Chile.

Nº Proyecto: 1090630
Nombre Colaborador (a) Extranjero (a): RICHARD A. WALTZ
Afiliación Institucional Actual: UNIVERSITY OF SOUTHERN CALIFORNIA
Fechas de estadía Desde: 30/03/2009 Hasta: 03/04/2009

Describa las actividades realizadas y resultados obtenidos. Destaque su contribución al logro de los objetivos del proyecto. Si es pertinente, indique las publicaciones conjuntas generadas, haciendo referencia a lo informado en la etapa Productos. Agregue en la
etapa anexos la información necesaria.

Richard Waltz paso una semana trabajando en temas de partida rapida de algoritmos de punto interior que serian fundamentales en metodos de solucion de descomposicion, en los que se resuelven problemas similares repetidas veces. Este trabajo es parte de una publicacion en preparacion que estamos haciendo en conjunto.

Richard ademas dio un seminario en el Departamento de Ingenieria Industrial para el grupo AGCO (Algorithms, Games, Complexity and Optimization) de investigadores que se esta formando. El tema del seminario fue su trabajo sobre algoritmos basados en active set methods para resolver problemas convexos.

PRODUCTOS

ARTÍCULOS
Para trabajos en Prensa/ Aceptados/Enviados adjunte copia de carta de aceptación o de recepción.

Nº : 1
Autor (a)(es/as) : Jain, M.; E. Kardes; Kiekintveld C.; Ordonez, F.; Tambe, M.
Nombre Completo de la Revista : Proceedings of the Twenty-Fourth AAAI Conference on Artificial Intelligence (AAAI-10)
Título (Idioma original) : Security games with arbitrary schedules: A branch and price approach
Indexación : Otras Revistas
ISSN :
Año : 2010
Vol. :
Nº :
Páginas : 1-8
Estado de la publicación a la fecha : Publicada
Otras Fuentes de financiamiento, si las hay :

Envía documento en papel : no
Archivo(s) Asociado(s) al artículo :
aaa10-final.pdf

Nº : 2
Autor (a)(es/as) : Furuhata, M.; Ordonez, F; Dessouky, M.M.; Koenig, S.;
Nombre Completo de la Revista : EURO Journal on Transportation and Logistics
Título (Idioma original) : Dynamic Ridesharing Practice and Future Directions
Indexación : ISI
ISSN :
Año :
Vol. :
Nº :
Páginas :
Estado de la publicación a la fecha : Enviada
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| confirmationSubmissionEJTL.pdf

| Nº: | 3 |
| Autor (a)(es/as): | Souyris, S.; Cortes, C.E.; Ordonez, F.; Weintraub, A. |
| Nombre Completo de la Revista: | Optimization Letters |
| Título (Idioma original): | A Robust Optimization Approach to Dispatching Technicians under Stochastic Service Times |
| Indexación: | ISI |
| ISSN: | |
| Año: | 2011 |
| Vol.: | |
| Nº: | |
| Páginas: | |
| Estado de la publicación a la fecha: | Enviada |

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| Envía documento en papel: | no |
| Archivo(s) Asociado(s) al artículo: | OPTL-S-11-00541.pdf

| Nº: | 4 |
| Autor (a)(es/as): | Yin, Z.; Jain, M.; Tambe, M.; Ordonez, F. |
| Nombre Completo de la Revista: | Proceedings of the AAAI-2011 conference |
| Título (Idioma original): | Risk-Averse Strategies for Security Games with Execution and Observational Uncertainty |
| Indexación: | Otras Revistas |
| ISSN: | |
| Año: | 2011 |
| Vol.: | |
| Nº: | |
| Páginas: | 1-6 |
| Estado de la publicación a la fecha: | Publicada |

### Otras Fuentes de financiamiento, si las hay:
**OTRAS PUBLICACIONES / PRODUCTOS**

Sin información ingresada.

**CONGRESOS**

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TESIS/MEMORIAS

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Nombre y Apellidos del(de la) Tutor(a) :
Título Grado :
Institución :
País :
Ciudad :
Estado de Tesis :
Fecha Inicio :
Fecha Término :
Envía documento en papel :
Archivo Asociado :

1
Modelo para la Localización de Nuevas Compañías para el Cuerpo de Bomberos de Santiago
Alvaro Echeverria Solis
Fernando Ordóñez
Magister
Universidad de Chile
CHILE
Santiago
En Ejecución
01/03/2011

resumentesisAlvaroEcheverria.pdf

2
Diseño y Evaluación en la Práctica de un Modelo de Ruteo de Vehículos con Ventanas de Tiempo
Cristobal Salas Carrasco
Fernando Ordóñez
Magister
Universidad de Chile
CHILE
Santiago
En Ejecución
01/08/2011

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ANEXOS

A continuación se detallan los anexos físicos/papel que no se incluyen en el informe en formato PDF.