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Supply chain transportation plans optimization  
Time-expanded graph enrichment heuristic

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Abstract. We address a problem of freight transportation in supply  
chains. To model flows over time in the system, we use time-expanded  
graphs. However, the time-expanded graphs’ size increases exponentially  
with the number of actors and the time dimension, which makes the  
industrial solvers inefficient to overcome real instances. To face this difficulty,  
we conceived an heuristic based from Boland’s and Hewitt’s Dynamic  
Discretization Discovery. We manipulates a partially time-expanded  
graph, comprised of a small subset of nodes and arcs, and enriches it incrementally.  
We produce a sparse graph with the essential elements and solve the associated problem,  
with much less constraints and variables.

Keywords: supply chain, time-expanded graph, heuristic

1 Introduction

This paper describes a resolution algorithm for the computation of supply chains’  
transportation and storage plans. We consider tri-echelon supply chain with  
suppliers, hubs and clients. Unfortunately, realistic instances in terms of network  
and time horizon quickly yield to problems too large to be sorted in a reasonable  
amount of time with an industrial solver. Boland and Hewitt [1] addresses to a  
comparable freight transportation problem over time, the Continuous Service  
Network Design Problem (CSNDP), of which the static version was reviewed by  
Crainic [2]. They conceived an ingenious method based on time-expanded graph  
enrichment to deal with the important data’s scale. The Dynamic Discretization  
Discovery (DDD) first generates an initial time-expanded graph constituted with  
a small subset of the nodes and arcs. Successively, the CSNDP is solved and the  
graph is enhanced until the reach of the optimal solution. Our works were drawn  
from this logic and led us to the following resolution heuristic.

2 Problem description

The supply chain can be represented with a time-expanded graph  
\(D_T = N_T, H_T \cup A_T\)  
derived from the ”static” network  
\(D = (N, A)\). The set of nodes  
\(N_T\) is obtained  
duplicating the physical locations (suppliers ∈ U, hubs ∈ V, customers ∈ W)
of $N$ through the time horizon. The set of arcs is decomposed into the holding arcs $H_T$ - connecting two occurrences of the same physical location - and the transportation arcs $A_T$. Each arc $((i, t), (j, t'))$ has a travel time $t' - t$, a permit-of-flow cost $c_{ij} \in \mathbb{R}^{++}$, a fixed cost $f_{ij} \in \mathbb{R}^{++}$, and a capacity $u_{ij} \in \mathbb{N}^*$. Let $K$ denote a set of commodities, each customer has a positive demand of commodity $k$ at time $t$: $d_{wk}^t$. So for each commodity we know the related sink $w$, but no predefined origin - any supplier can ship any commodity. We define SCNDP($D_T$) to be our Supply Chain Network Design Problem with integer variables $y_{ij}^{tt'}$ the resources required to route freight on arc $((i, t), (j, t'))$, and continuous flow variables $x_{ktt'}$. The following is a generic valid integer linear programming formulation of this problem:

$$\begin{align*}
\text{min} & \quad \sum_{A_T} f_{ij} y_{ij}^{tt'} + \sum_{K} \sum_{A_T} c_{ij} x_{ktt'}^{ij} + \sum_{K} \sum_{H_T} c_{ii} x_{kii}^{ij} \\
\text{s.t.} & \quad \sum_{A_T \cup H_T} x_{ktt'}^{ij} - \sum_{A_T \cup H_T} x_{ktt'}^{jl} \begin{cases} = 0 & \forall (j, t) \in V_T \\ \geq d_{wk}^t & \forall (j, t) \in W_T \forall k \in K \end{cases} \\
& \quad \sum_{K} x_{ktt'}^{ij} \leq u_{ij} y_{ij}^{tt'} \quad \forall ((i, t), (j, t')) \in A_T \\
& \quad x_{ktt'}^{ij} \geq 0, \quad y_{ij}^{tt'} \geq 0, \quad \forall ((i, t), (j, t')) \in A_T \cup H_T, \forall k \in K
\end{align*}$$

We seek to minimize the total expenses, i.e. the transportation costs and holding costs. Constraint 1 is an adapted Kirchhoff constraint, and Constraint 2 ensures that sufficient resource capacity is available for the commodities.

3 Method

Boland and Hewitt DDD is an exact method that solves the CSNDP with free holding costs for the commodities. It is based on the iterative refining of a partially time-expanded graph, for which certain arcs under-estimate real travel times, and therefore allow extra unfeasible consolidations opportunities. However, in our problem storing commodities has a cost. We use the DDD to find the optimal flow in a transportation point of view, and combine it with a storing cost injection procedure, to enrich the partially-time expanded graph. The final solution is an upper bound we compared with the results obtained with Gurobi on the full graph. The comparison reveals our method efficiency, increasing with the instances size.

References