TRANSPORTATION SCIENCE
Vol. 39, No. 4, November 2005, pp. 465–476
ISSN 0041-1655 | EISSN 1526-5447 | 05 | 3904 | 0465

DOI 10.1287/trsc.1050.0124

A Multiple Pairs Shortest Path Algorithm

I-Lin Wang
Department of Industrial and Information Management, National Cheng Kung University,
No. 1, University Road, Tainan, Taiwan 701, ilinwang@mail.ncku.edu.tw

Ellis L. Johnson, Joel S. Sokol
School of Industrial and Systems Engineering, Georgia Institute of Technology, Atlanta, Georgia 30332-0205
{ejohnson@isye.gatech.edu, jsokol@isye.gatech.edu}

The multiple pairs shortest path problem (MPSP) arises in many applications where the shortest paths and distances between only some specific pairs of origin-destination (OD) nodes in a network are desired. The traditional repeated single-source shortest path (SSSP) and all pairs shortest paths (APSP) algorithms often do unnecessary computation to solve the MPSP problem. We propose a new shortest path algorithm to save computational work when solving the MPSP problem. Our method is especially suitable for applications with fixed network topology but changeable arc lengths and desired OD pairs. Preliminary computational experiments demonstrate our algorithm's superiority on airline network problems over other APSP and SSSP algorithms.

Key words: shortest path; multiple pairs; algebraic method; LU decomposition; Carré's algorithm
History: Received: April 2004; revision received: May 2005; accepted: May 2005.

Introduction

The multiple pairs shortest path (MPSP) problem on a network is to compute the shortest paths for q specific origin destination (OD) pairs (s_i, t_i), $i = 1, \ldots, q$. This problem arises often in multicommodity networks (Barnhart et al. 1995) such as telecommunication and transportation networks. In this paper, we propose a new algorithm that saves computational work when compared to the methods currently used to solve MPSP problems. Our algorithm is especially effective when shortest paths between specific sets of OD pairs have to be repeatedly computed using different arc costs.

During the last four decades, many good shortest path algorithms have been developed. We can group shortest path algorithms into three classes: (1) those that employ combinatorial or network traversal techniques such as label-setting methods (Dijkstra 1959, Dantzig 1960, Dial 1965), label-correcting methods (Ford 1956, Moore 1957, Bellman 1958, Pape 1974), and their hybrids (Glover, Glover, and Klingman 1984); (2) those that employ linear programming (LP)-based techniques like the primal network simplex method (Goldfarb, Hao, and Kai 1990; Goldfarb and Jin 1999) and the dual ascent method (Bertsekas, Pallottino, and Scutellà 1995; Pallottino and Scutellà 1997); and (3) those that use algebraic or matrix techniques such as Floyd-Warshall (Floyd 1962, Warshall 1962) and Carré's (1969, 1971) algorithms. The first two groups of shortest path algorithms are mainly designed to solve the single-source (*or* sink) shortest path (SSSP) problem, which is the problem of computing a shortest path tree for a specific source (or sink) node. Algebraic shortest path algorithms, on the other hand, are more suitable for solving the all pairs shortest paths (APSP) problem, which is the problem of computing shortest paths for all the node pairs.

Currently, SSSP and APSP algorithms are used to solve MPSP problems. Obviously, the MPSP problem can be solved by simply applying an SSSP algorithm $\hat{q}$ times, where $\hat{q}$ is the size of a minimum node cover on an appropriately defined bipartite graph. Given the set N of nodes in the MPSP network, the bipartite graph includes two copies of each node: one representing that node's use as an origin and one representing its use as a destination. For each required shortest path, the bipartite graph includes an arc from the node representing the path's origin to the node representing its destination. The minimum node cover on this bipartite graph (i.e., the minimum set of nodes that includes at least one endpoint of each arc) corresponds to the minimum number of SSSP calls necessary to solve the MPSP problem. More specifically, any origin node i included in the node cover corresponds to using SSSP to find a tree of shortest paths out of i, and any destination node j included in the node cover corresponds to using SSSP to find a tree of shortest paths into j. Because this method requires many calls to SSSP, we call such methods *repeated SSSP algorithms*.

It is easy to see that repeated SSSP algorithms are more efficient for MPSP problems with small node covers (i.e., $\hat{q} \ll n$). However, for cases with larger node covers, both the APSP and SSSP methods may involve more computation than necessary. To cite an

JOURNAL OF INDUSTRIAL AND
MANAGEMENT OPTIMIZATION
Volume **2**, Number **3**, August **2006**

Website: http://AIMsciences.org

pp. **237–254**

MAXIMUM FLOW PROBLEM IN THE DISTRIBUTION NETWORK

R.L. Sheu

Department of Mathematics
National Cheng-Kung University, Tainan, Taiwan

M.J. Ting

Product Development Department
Shinkong Life Insurance Co., LTD., Taipei, Taiwan

I.L. Wang

Department of Industrial and Information Management
National Cheng-Kung University, Tainan, Taiwan

(Communicated by Shu-Cherng Fang)

Abstract. In this paper, we are concerned with the maximum flow problem in the distribution network, a new kind of network recently introduced by Fang and Qi. It differs from the traditional network by the presence of the D-node through which the commodities are to be distributed proportionally. Adding D-nodes complicates the network structure. Particularly, flows in the distribution network are frequently increased through multiple cycles. To this end, we develop a type of depth-first-search algorithm which counts and finds all unsaturated subgraphs. The unsaturated subgraphs, however, could be invalid either topologically or numerically. The validity are then judged by computing the flow increment with a method we call the *multi-labeling method*. Finally, we also provide a phase-one procedure for finding an initial flow.

1. **Introduction.** Consider the network $\mathcal{G} = (N, A, d, u)$ with $N = N_{PS} \cup N_O \cup N_S \cup N_T \cup N_D$ being the node set and A the arc set. The functions $d : A \rightarrow \mathcal{Q}_+$ and $u : A \rightarrow \mathcal{Q}_+$, which take non-negative rational values, represent respectively the minimum demand and the capacity on each arc. There are five types of nodes in the network $\mathcal{G}$: the S-node, the T-node, the O-node, the *Pseudo*-node, and the D-node. The S-nodes are source nodes. They can be thought to all come from a *Pseudo*-S-node. The T-nodes are termination (sink) nodes which can be combined into a single *Pseudo*-T-node. The O-nodes are the intermediate nodes other than the source and the sink nodes in the traditional network. The D-node is a very special feature. Each D-node has only one inward arc through which the goods must be proportioned to all its outward arcs at fixed ratios. It was first introduced by Fang and Qi in [5] to describe some manufacturing and/or distribution processes. Let the collection of each respective type be denoted by N_S, N_T, N_O, N_{PS}, and N_D.

2000 *Mathematics Subject Classification.* 90B10, 49M35.

Key words and phrases. Distribution network, maximum flow problem, labeling method, cycles.

This research work was partially supported by the National Center of Theoretic Sciences/ South of Taiwan.

Fast Heuristics for Designing Integrated E-Waste Reverse Logistics Networks

I-Lin Wang and Wen-Cheng Yang

***Abstract*—This paper investigates a mixed-integer linear programing model that solves an integrated facility location and configuration problem for recycling electronic waste (e-waste). Since different recycled e-waste consume different levels of recycling processes and resources, the capability of processing only one or more categories of recycled e-waste for each candidate facility is considered in addition to its location to maximize the total revenue. Computational experiments based on proposed heuristics are conducted using data collected from Taiwan's recycled e-waste market and show our proposed methods give a high-quality near-optimal solution in a promising time shorter than previous solution methods and CPLEX.**

***Index Terms*—Electronic waste, facility location, heuristics, mixed-integer linear programing, reverse logistics.**

I. Introduction

WITH the growing economy, the increasing amount of disposed goods can induce important environmental issues if they are not properly managed at product end of life. Reverse logistics, the activities to collect and process used products, has been extensively investigated recently to preserve as much of the residual value of used products in a way friendly to the environment. For example, the environmental regulations in Taiwan mandate the manufacturers and importers to take back their products. Manufacturers and importers contribute approximately $20 USD of disposition fees for each new electronic appliance and computer to a fund established by the Environmental Protection Administration (EPA) of Taiwan. The fund committee is responsible in evaluating the amount of disposition fees and certifying the take-back rate to establish an effective reverse logistics system.

Decisions made by the fund committee may have great affects on the entire reverse logistics system. In particular, changing the disposition fee for a specific category of recycled products may encourage (or discourage) reverse logistics companies to raise (or lower) its take-back rate. Besides specifying the subsidy for recycling specific products, a government may enact regulations to limit or encourage the locations or configurations for specific recycling facilities. To evaluate the performance of a reverse logistics system in its planning stage, a government or a company may first formulate their problem as a mathematical programing problem, solve it, and then perform sensitivity analysis. The design of a reverse logistics system is usually treated as a mixed integer linear programing problem (MIP) which seeks the maximum total revenue or minimum total cost obtained by optimal facility locations and transportation assignments for processing and shipping the recycled products or materials in accordance with the operational capacities and the regulations. The sensitivity analysis for MIP may be conducted by iteratively solving MIPs of the same problem structure but with slightly different settings of coefficients. Unfortunately, solving such a MIP in reasonable time is usually a hard task even using a state-of-the-art optimization software like CPLEX (see ILOG [4]).

Developing a solution method that computes the optimal or near-optimal solutions in shorter time is not only useful for conducting the sensitivity analysis, but also beneficial in solving network design problem under uncertainty. In particular, during the supply chain design phase, the uncertainty in demands and prices should be considered to achieve better management over the planned time horizon. The discounted cash flow analysis incorporated with the decision tree methodologies can be used for evaluating the network design decisions (see Chopra and Meindl [2]) under uncertainty, in which each node in the decision tree corresponds to an MIP. As one solves an MIP at each node in the decision tree and works backwards from future period based on the Bellman's principle, exponentially many MIPs have to be solved which could be a very time-consuming task. In practice, such a strategy analysis may not require all the MIPs to be solved to optimality; thus, fast heuristics to compute for solutions in shorter time will definitely decrease the computational efforts required for conducting the sensitivity analysis or designing the network under uncertainty.

Previous research in reverse logistics network design problem usually only considers universal facilities which can collect or process all kinds of recycled products. Such an assumption is, in fact, not realistic since the major players in recycling industries typically engage in niche markets based on their core competencies. Moreover, some governments (e.g., Taiwan) even make regulations to forbid certain categories of recycled products to be collected or processed by the same company or facility due to safety and environmental concerns, as well as maintaining the competitive market for the recycling industries. Therefore, a more reasonable assumption in designing a reverse logistics network should also consider different configurations of facilities for different categories of recycled products. Using different facility configurations to recycle different categories of

Manuscript received April 16, 2006; revised June 25, 2006. This work was supported in part by the NSC under Grant 93-2213-E-006-096.

I-L Wang is with the Department of Industrial and Information Management, National Cheng Kung University, Tainan 701, Taiwan, R.O.C. (e-mail: ilinwang@mail.ncku.edu.tw).

W-C Yang is with the Cell Manufacturing Support Section, Hannstar Display Corporation, Tainan County 741, Taiwan, R.O.C.

Color versions of one or more of the figures in this paper are available online at http://ieeexplore.ieee.org.

Digital Object Identifier 10.1109/TEPM.2007.899112

Asia-Pacific Journal of Operational Research
Vol. 25, No. 2 (2008) 135–150

ON SOLVING SHORTEST PATHS WITH A LEAST-SQUARES PRIMAL-DUAL ALGORITHM

I.-LIN WANG

Department of Industrial and Information Management
National Cheng Kung University, Tainan, Taiwan
ilinwang@mail.ncku.edu.tw

Received 15 August 2005
Accepted 17 July 2007

Recently a new least-squares primal-dual (LSPD) algorithm, that is impervious to degeneracy, has effectively been applied to solving linear programming problems by Barnes *et al.*, 2002. In this paper, we show an application of LSPD to shortest path problems with nonnegative arc length is equivalent to the Dijkstra's algorithm. We also compare the LSPD algorithm with the conventional primal-dual algorithm in solving shortest path problems and show their difference due to degeneracy in solving the 1-1 shortest path problems.

Keywords: Least-squares; primal-dual algorithm; shortest path; Dijkstra's algorithm.

1. Introduction

The *least-squares primal-dual algorithm* (LSPD) (Barnes *et al.*, 2002) is a primal-dual algorithm for solving LPs. Instead of minimizing the sum of the absolute infeasibility in the constraints when solving the restricted primal problem (RPP), as does the original primal-dual algorithm (PD), LSPD tries to minimize the sum of the squares of the infeasibility.

In particular, to solve an LP:

$$\begin{aligned} &\min cx \\ &\text{s.t.} \quad Hx = b,\ x \geq 0 \end{aligned}$$

with an initial feasible dual solution π, LSPD maintains complementary slackness conditions by seeking solutions to a quadratic RPP which is a *non-negative least-squares problem* (NNLS):

$$\begin{aligned} &\min \|b - Ex\|^2 \\ &\text{s.t.} \quad x \geq 0 \end{aligned} \tag{1.1}$$

where $E = \{H_{\cdot j} : \pi H_{\cdot j} = c_j\}$. Using the solution x^* to NNLS, LSPD identifies a dual improving direction $s^* = b - Ex^*$ and calculates the step size θ to obtain

JOURNAL OF INDUSTRIAL AND
MANAGEMENT OPTIMIZATION
Volume **5**, Number **4**, November **2009**

doi:10.3934/jimo.2009.5.929

pp. **929–950**

A NETWORK SIMPLEX ALGORITHM FOR SOLVING THE MINIMUM DISTRIBUTION COST PROBLEM

I-Lin Wang and Shiou-Jie Lin

Department of Industrial and Information Management
National Cheng Kung University
Tainan, 701, Taiwan

(Communicated by Shu-Cherng Fang)

Abstract. To model the distillation or decomposition of products in some manufacturing processes, a minimum distribution cost problem (MDCP) for a specialized manufacturing network flow model has been investigated. In an MDCP, a specialized node called a D-node is used to model a distillation process that connects with a single incoming arc and several outgoing arcs. The flow entering a D-node has to be distributed according to a pre-specified ratio associated with each of its outgoing arcs. This proportional relationship between arc flows associated with each D-node complicates the problem and makes the MDCP more difficult to solve than a conventional minimum cost network flow problem. A network simplex algorithm for an uncapacitated MDCP has been outlined in the literature. However, its detailed graphical procedures including the operations to obtain an initial basic feasible solution, to calculate or update the dual variables, and to pivot flows have never been reported. In this paper, we resolve these issues and propose a modified network simplex algorithm including detailed graphical operations in each elementary procedure. Our method not only deals with a capacitated MDCP, but also offers more theoretical insights into the mathematical properties of an MDCP.

1. Introduction.

The minimum cost flow problem is a specialized linear programming problem with network structure which seeks an optimal flow assignment over a network satisfying the constraints of node flow balance and arc flow bounds (see [1]). However, these constraints are too simplified to model some real cases such as, for example, the synthesis and distillation of products in some manufacturing processes. For this purpose, Fang and Qi [8] proposed a generalized network model called the *manufacturing network flow* (MNF). The MNF considers three specialized nodes: I-nodes, C-nodes, and D-nodes, to model the nodes of inventory, synthesis (combination), and distillation (decomposition), in addition to the conventional nodes: S-nodes, T-nodes, and O-nodes, which serve as sources, sinks, and transhipment nodes, respectively. Fang and Qi [8] also defined a *minimum distribution cost problem* (MDCP) for a specialized MNF model referred to as the distribution network which contains both D-nodes and conventional nodes. A D-node represents a distillation process and only connects with a single incoming arc

2000 *Mathematics Subject Classification.* Primary: 90B10, 05C85; Secondary: 05C21.

Key words and phrases. network optimization, manufacturing network, distribution network, minimum distribution cost flow problem, network simplex algorithm.

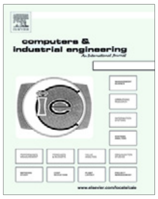
I-Lin Wang was partially supported by the National Science Council of Taiwan under Grant NSC95-2221-E-006-268.

Computers & Industrial Engineering 60 (2011) 593–601

Contents lists available at ScienceDirect

Computers & Industrial Engineering

journal homepage: www.elsevier.com/locate/caie



A network flow model for clustering segments and minimizing total maintenance and rehabilitation cost

I-Lin Wang [a,*], Yi-Chang James Tsai [b], Feng Li [b]

[a] Department of Industrial and Information Management, National Cheng Kung University, No. 1, University Rd., Tainan 701, Taiwan
[b] School of Civil and Environmental Engineering, Georgia Institute of Technology, 210 Technology Circle, Savannah, GA 31407, United States

ARTICLE INFO

Article history:
Received 1 June 2010
Received in revised form 20 December 2010
Accepted 3 January 2011
Available online 13 January 2011

Keywords:
Pavement optimization
Spatial clustering
Uncapacitated facility location problem
Shortest path
Integer programming

ABSTRACT

Because of shrinking budgets, transportation agencies are facing severe challenges in the preservation of deteriorating pavements. There is an urgent need to develop a methodology that minimizes maintenance and rehabilitation (M&R) cost. To minimize total network M&R cost of clustering pavement segments, we propose an integer programming model similar to an uncapacitated facility location problem (UFLP) that clusters pavement segments contiguously. Based on the properties of contiguous clustered pavement segments, we have transformed the clustering problem into an equivalent network flow problem in which each possible clustering corresponds to a path in the proposed acyclic network model. Our proposed shortest-path algorithm gives an optimal clustering of segments that can be calculated in a time polynomial to the number of segments. Computational experiments indicate our proposed network model and algorithm can efficiently deal with real-world spatial clustering problems.

1. Introduction

Transportation agencies, such as the Georgia Department of Transportation (GDOT) in the USA, are facing the challenge of preserving deteriorating pavements with a shrinking budget. GDOT is responsible for maintaining 18,000-mile interstate and state highway system by contracting out projects based on different pavement conditions that require different Maintenance and Rehabilitation (M&R) methods. M&R methods and treatment methods are used interchangeably in this paper.

Each pavement M&R project ("project") consists of a group of contiguous road segments; a segment is typically one mile or less and has had a pavement condition survey revealing the pavement distress type, severity, and extent. This survey is performed annually at the segment level using a 100-ft sample section that is used to represent the overall pavement condition. Ten distress types, rutting, load cracking, block cracking, reflection cracking, patches/potholes, ravelling, edge distress, bleeding/flushing, corrugations/pushing, and loss of section, are measured. Note that even if several types of distresses may appear in one segment, a single measure (see Álvarez, López-Rodríguez, Canito, Moral, & Camacho, 2007) on the distress condition for the entire segment will be used.

Based on the distress condition of a segment, a proper M&R method is determined, and contiguous segments are clustered into a pavement M&R project. Ideally, segments are clustered by the same pavement condition that requires the same M&R method. Unfortunately, adjacent pavement segments can deteriorate at different rates, exhibit different distresses, and, consequently, require different treatment methods. Currently, the best treatment method (e.g. the one with the highest treatment unit cost) will be applied to all segments in a pavement preservation project (i.e. a cluster). The challenge is to cluster segments needing the same treatment into cost effective pavement M&R projects. We call this a *segment clustering problem* (SCP). Finding the most cost-effective segment clustering helps transportation agencies preserve more roads with a limited budget.

Fig. 1a illustrates the example of an SCP in which eight segments having different treatment costs, numbered from 1 to 8 from left to right, are to be clustered. Fig. 1b shows segments 1 and 2, 3 to 6, and 7 and 8, are clustered into three projects; Fig. 1c illustrates an alternative SCP. Currently, the best treatment method (i.e. the most expensive) is applied to all segments in a cluster. For example, when segments 1 and 2 are clustered, the most expensive treatment (i.e. the treatment on segment 2) will be applied on both segments. This will result in a higher total M&R cost as shown in the shaded areas in Fig. 2b and c. The objective of SCP is, thus, to find the cluster combination that will minimize M&R cost.

Mathematically, a *k*-cluster combination divides the *m* segments into *k* clusters, obtained by placing $k-1$ separators over the $m-1$ internal segment boundaries. Thus, a *k*-cluster for *m* segments may have C_{k-1}^{m-1} possible combinations, and there can be $\sum_{k=1}^{m} C_{k-1}^{m-1} = 2^{m-1}$ cluster combinations for all possible values of *k*.

[*] Corresponding author. Tel.: +886 6 2757575x53123; fax: +886 6 2362162.
E-mail address: ilinwang@mail.ncku.edu.tw (I.-L. Wang).

0360-8352/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.cie.2011.01.001

Mathematical Biosciences 231 (2011) 120–125

Contents lists available at ScienceDirect

Mathematical Biosciences

journal homepage: www.elsevier.com/locate/mbs

Mathematical properties and bounds on haplotyping populations by pure parsimony

I-Lin Wang *, Chia-Yuan Chang

Department of Industrial and Information Management, National Cheng Kung University, No.1 University Rd., Tainan 701, Taiwan

ARTICLE INFO

Article history:
Received 8 September 2009
Received in revised form 20 August 2010
Accepted 18 February 2011
Available online 24 February 2011

Keywords:
Haplotype inference
Pure parsimony
Bioinformatics
Integer programming
Compatible graph

ABSTRACT

Although the haplotype data can be used to analyze the function of DNA, due to the significant efforts required in collecting the haplotype data, usually the genotype data is collected and then the population haplotype inference (PHI) problem is solved to infer haplotype data from genotype data for a population. This paper investigates the PHI problem based on the pure parsimony criterion (HIPP), which seeks the minimum number of distinct haplotypes to infer a given genotype data. We analyze the mathematical structure and properties for the HIPP problem, propose techniques to reduce the given genotype data into an equivalent one of much smaller size, and analyze the relations of genotype data using a compatible graph. Based on the mathematical properties in the compatible graph, we propose a maximal clique heuristic to obtain an upper bound, and a new polynomial-sized integer linear programming formulation to obtain a lower bound for the HIPP problem.

1. Introduction

The Post-Genomic Era focuses on functional genome analysis, including studying the knowledge about the genetic constitution of an individual chromosome called the haplotypes. Information from the haplotype data can be applied in various domains, such as linkage disequilibrium, inference of population evolutionary history, disease diagnosis, and customization of treatment for each individual [1]. However, since the time, labor, and expense involved in directly collecting the haplotype data require too much resources and efforts, the researchers usually collect the descriptions of one conflated pair of haplotypes called the genotype data, rather than the haplotype data [2] for further analysis. We are interested in solving the population haplotype inference (PHI) problem which infers the haplotype data for a population of diploid species from their genotype data. Since each genotype has to be resolved by a pair of haplotypes from a large number of possible haplotype pair candidates, the PHI problem is a difficult combinatorial problem.

Although there are many possible haplotype pairs for resolving a given genotype matrix, the real-world haplotype pairs are constituted by a very few amount of distinct haplotypes. For example, Drysdale et al. [3] identify 13 SNPs in the human β_2AR gene, which can be composed by many (e.g. with number up to $2^{13} = 8192$) possible haplotype combinations. However, among all the possible haplotype combinations, only 10 haplotypes are related to asthmatic cohort. Thus Gusfield [4] suggests a combinatorial optimization problem called the haplotype inference based on pure parsimony (HIPP) which seeks the minimum amount of distinct haplotypes to resolve a given genotype matrix.

Suppose we have m genotypes and each genotype contains n sites. These data can be expressed by an $m \times n$ genotype matrix G, where each row in the genotype matrix corresponds to a genotype data for one individual, each column stands for one SNP, and each element in G has value 0, 1, or 2. A site is called *homozygous wild type* if it has value 0, *homozygous mutant type* if it has value 1, and *heterozygous* if it has value 2. A site in a genotype is resolved if it has value 0 or 1, and ambiguous if it has value 2. A genotype is called resolved if there are two haplotypes such that for every site with value 0 or 1 in that genotype, the value of that site in the two haplotypes are either both with value 0 or both with value 1; for every site with value 2 in that genotype, one of the haplotype must have value 0 and the other haplotype must have value 1 in that site. The objective of an HIPP problem is to find a $2m \times n$ haplotype matrix, in which the ith row in the genotype matrix is resolved by the $(2i-1)$th and the $2i$th rows in the haplotype matrix, and the number of distinct haplotypes is minimized.

Take Fig. 1 for example. Given a genotype matrix $G = \{202, 021, 212\}$, there are 2, 1, and 2 possible haplotype pairs to resolve genotype 1, 2, and 3, respectively. Furthermore, there are 6, 5, 5, or 4 distinct haplotypes if we select (p_1, p_3, p_4), (p_1, p_3, p_5), (p_2, p_3, p_4) or (p_2, p_3, p_5) to resolve the genotype matrix, respectively. Using the pure parsimony criterion, (p_2, p_3, p_5) will be selected to resolve all the genotypes, since this combination induces the minimum number of distinct haplotypes.

* Corresponding author. Tel.: +886 6 2757575 53123; fax: +886 6 2362162.
E-mail address: ilinwang@mail.ncku.edu.tw (I-L. Wang).

0025-5564/$ - see front matter © 2011 Elsevier Inc. All rights reserved.
doi:10.1016/j.mbs.2011.02.008

Applied Mathematics and Computation 217 (2011) 9798–9809

Contents lists available at ScienceDirect

Applied Mathematics and Computation

journal homepage: www.elsevier.com/locate/amc

Haplotyping populations by pure parsimony based on compatible genotypes and greedy heuristics

I-Lin Wang *, Hui-E Yang

Department of Industrial and Information Management, National Cheng Kung University, No. 1, University Rd., Tainan 701, Taiwan

ARTICLE INFO

Keywords:
Haplotype inference
Integer programming
Bioinformatics
Compatibility graph
Heuristics

ABSTRACT

The population haplotype inference problem based on the pure parsimony criterion (HIPP) infers an $m \times n$ genotype matrix for a population by a $2m \times n$ haplotype matrix with the minimum number of distinct haplotypes. Previous integer programming based HIPP solution methods are time-consuming, and their practical effectiveness remains unevaluated. On the other hand, previous heuristic HIPP algorithms are efficient, but their theoretical effectiveness in terms of optimality gaps has not been evaluated, either. We propose two new heuristic HIPP algorithms (MGP and GHI) and conduct more complete computational experiments. In particular, MGP exploits the compatible relations among genotypes to solve a reduced integer linear programming problem so that a solution of good quality can be obtained very quickly; GHI exploits a weight mechanism to selects better candidate haplotypes in a greedy fashion. The computational results show that our proposed algorithms are efficient and effective, especially for solving cases with larger recombination rates.

1. Introduction

In the post-genomic era, the development of a full haplotype map has high priority since Helmuth [1] suggests that the knowledge about the genetic constitution of an individual chromosome called haplotypes can be applied in linkage disequilibrium, inference of population evolutionary history, disease diagnosis, and customization of treatment for each individual. The haplotype is a sequence of closely linked single nucleotide polymorphisms (SNPs) in one copy of a chromosome. There are two haplotypes in a pair of chromosomes in all diploid organisms. Since the collection of haplotypes data requires a huge amount of cost and time, the data for genotypes rather than haplotypes are collected. A genotype is the description of one conflated pair of haplotypes. The computational problem to construct the haplotypes from genotype data is called haplotyping. Two categories of haplotyping problems are investigated in literature: one category is concerned with haplotyping a single individual based on the data and methodology of shotgun sequence assembly [2–4], and the other category is concerned with haplotyping a population [5,6]. We study the latter category in this paper.

Clark [5] first brings up the population haplotype inference (PHI) problem to infer haplotypes from genotypes for a group of individuals. He also gives an inference rule, assuming the genotypes with zero or one ambiguous sites contain the frequently observed haplotypes in the population. After that, many PHI solution methods and problems are proposed, including the estimation-maximization (EM) algorithm by Excoffier and Slatkin [7], Long et al. [8], and Hawley and Kidd [9], Bayesian method by Stephens et al. [10], Niu et al. [11] and Stephens and Donnelly [12], maximum resolution (MR) problem by Gusfield [6], perfect phylogeny haplotype (PPH) problem by Gusfield [13], and PHI problem that satisfies the pure parsimony

* Corresponding author.
E-mail address: ilinwang@mail.ncku.edu.tw (I.-L. Wang).

doi:10.1016/j.amc.2011.04.073

J Intell Manuf (2012) 23:2271–2280
DOI 10.1007/s10845-011-0571-z

Scheduling two-stage hybrid flow shops with parallel batch, release time, and machine eligibility constraints

I.-Lin Wang · Taho Yang · Yu-Bang Chang

Received: 1 August 2010 / Accepted: 20 June 2011 / Published online: 22 July 2011

Abstract This paper investigates a difficult scheduling problem on a specialized two-stage hybrid flow shop with multiple processors that appears in semiconductor manufacturing industry, where the first and second stages process serial jobs and parallel batches, respectively. The objective is to seek job-machine, job-batch, and batch-machine assignments such that makespan is minimized, while considering parallel batch, release time, and machine eligibility constraints. We first propose a mixed integer programming (MIP) formulation for this problem, then gives a heuristic approach for solving larger problems. In order to handle real world large-scale scheduling problems, we propose an efficient dispatching rule called BFIFO that assigns jobs or batches to machines based on first-in-first-out principle, and then give several reoptimization techniques using MIP and local search heuristics involving interchange, translocation and transposition among assigned jobs. Computational experiments indicate our proposed re-optimization techniques are efficient. In particular, our approaches can produce good solutions for scheduling up to 160 jobs on 40 machines at both stages within 10 min.

Keywords Flow shop with multiple processors · Scheduling · Dispatching · Mixed integer programming · Heuristic algorithm · Makespan

I.-L. Wang (✉)
Department of Industrial and Information Management, National Cheng Kung University, No1. University Rd, Tainan 701, Taiwan
e-mail: ilinwang@mail.ncku.edu.tw

T. Yang · Y.-B. Chang
Institute of Manufacturing Information and Systems, National Cheng Kung University, No1. University Rd, Tainan 701, Taiwan

Introductions

Over the decades, semiconductor manufacturing has become the most capital and labor intensive industry in Taiwan. Besides investigating new manufacturing technologies to boost the productivity, the semiconductor manufacturers also make much effort in promoting their quality of services by improving the production quality and shortening the production time to maintain their competitive edge. Since the equipments for processing wafer is extremely expensive, how to maximize the productivity and utilization of equipments within shorter time become critical issues in semiconductor manufacturing industries. To this end, different techniques such as seeking the optimal lot sizes, Work-In-Process levels, shop floor control, and production scheduling have been widely investigated.

The process of wafer manufacturing is a FSMP (Flow shop with multiple processors) problem, in which the products must go through specific procedures, and pass through the processors in specific orders. Note that jobs could follow very different routing in the production systems due to the re-entrant characteristic of semiconductor manufacturing, which makes the flow-shop assumption restrictive in semiconductor manufacturing. Different products may go through the processors in the same order but are processed by different recipes. To speed up the manufacturing process, machines that can process batch jobs are widely used. In particular, a batch process may handle two or more jobs of the same recipes at the same time, but jobs of different recipes can not be put into the same batch. The batch job process has become a common practice in semiconductor manufacturing industry. Note that we assume zero setup time for changing recipes, since in some manufacturing process different recipe simply refers to different length of time for some chemical processing. Take the wet etching process for example; jobs

Flex Serv Manuf J (2013) 25:343–366
DOI 10.1007/s10696-012-9150-7

Scheduling unrelated parallel machines in semiconductor manufacturing by problem reduction and local search heuristics

I-Lin Wang · Yi-Chi Wang · Chih-Wei Chen

Published online: 25 May 2012

Abstract We investigate a difficult scheduling problem in a semiconductor manufacturing process that seeks to minimize the number of tardy jobs and makespan with sequence-dependent setup time, release time, due dates and tool constraints. We propose a mixed integer programming (MIP) formulation which treats tardy jobs as soft constraints so that our objective seeks the minimum weighted sum of makespan and heavily penalized tardy jobs. Although our polynomial-sized MIP formulation can correctly model this scheduling problem, it is so difficult that even a feasible solution can not be calculated efficiently for small-scale problems. We then propose a technique to estimate the upper bound for the number of jobs processed by a machine, and use it to effectively reduce the size of the MIP formulation. In order to handle real-world large-scale scheduling problems, we propose an efficient dispatching rule that assigns a job of the earliest due date to a machine with least recipe changeover (EDDLC) and try to re-optimize the solution by local search heuristics which involves interchange, translocation and transposition between assigned jobs. Our computational experiments indicate that EDDLC and our proposed reoptimization techniques are very efficient and effective. In particular, our method usually gives solutions very close to the exact optimum for smaller scheduling problems, and calculates good solutions for scheduling up to 200 jobs on 40 machines within 10 min.

I.-L. Wang · C.-W. Chen
Department of Industrial and Information Management, National Cheng Kung University,
No. 1 University Rd, Tainan 701, Taiwan
e-mail: ilinwang@mail.ncku.edu.tw

Y.-C. Wang (✉)
Department of Industrial Engineering and Systems Management, Feng Chia University,
No. 100, Wenhwa Rd., Taichung 40724, Taiwan
e-mail: wangyc@fcu.edu.tw

Operations Research
Vol. 61, No. 6, November–December 2013, pp. 1346–1359
ISSN 0030-364X (print) | ISSN 1526-5463 (online)

http://dx.doi.org/10.1287/opre.2013.1215

Models for Effective Deployment and Redistribution of Bicycles Within Public Bicycle-Sharing Systems

Jia Shu
Department of Management Science and Engineering, School of Economics and Management,
Southeast University, Nanjing, Jiangsu 210096, China, jshu@seu.edu.cn

Mabel C. Chou, Qizhang Liu, Chung-Piaw Teo
Department of Decision Sciences, NUS Business School, National University of Singapore, Singapore,
Republic of Singapore {bizchoum@nus.edu.sg, bizlqz@nus.edu.sg, bizteocp@nus.edu.sg}

I-Lin Wang
Department of Industrial and Information Management, National Cheng Kung University, Taiwan, China,
ilinwang@mail.ncku.edu.tw

We develop practical operations research models to support decision making in the design and management of public bicycle-sharing systems. We develop a network flow model with proportionality constraints to estimate the flow of bicycles within the network and the number of trips supported, given an initial allocation of bicycles at each station. We also examine the effectiveness of periodic redistribution of bicycles in the network to support greater flow, and the impact on the number of docks needed.

We conduct our numerical analysis using transit data from train operators in Singapore. Given that a substantial proportion of passengers in the train system commute a short distance—more than 16% of passengers alight within two stops from the origin—this forms a latent segment of demand for a bicycle-sharing program. We argue that for a bicycle-sharing system to be most effective for this customer segment, the system must deploy the right number of bicycles at the right places, because this affects the utilization rate of the bicycles and how bicycles circulate within the system. We also identify the appropriate operational environments in which periodic redistribution of bicycles will be most effective for improving system performance.

Subject classifications: bicycle sharing; proportional network flow; simulation.
Area of review: Transportation.
History: Received February 2011; revisions received March 2012, May 2013, August 2013; accepted August 2013. Published online in *Articles in Advance* November 7, 2013.

1. Introduction

With heightened concerns about global oil prices, carbon emissions, and traffic congestion, governments around the world are exploring ways to "nudge" urban residents to commute using public transport instead of private automobiles. Several cities have set up public bicycle-sharing systems to facilitate short trips within the city. A bicycle-sharing system (BSS) is "a self-service short term, one-way-capable, bike rental offer in public spaces, with network characteristics" (OBIS Project 2011, p. 10). A standard BSS consists of a network of bicycle stations where bicycles are docked and available for pick up. Licensed operators often use low price or even free access to bicycles (for limited time) to entice commuters to adopt this transport mode. As of April 2013, there were around 535 bicycle-sharing programs around the world, with an estimated fleet of 517,000 bicycles (http://en.wikipedia.org/wiki/Bicycle_sharing_system).

The advantages of using bicycle sharing include increased transit use, decreased personal vehicle trips, lower greenhouse gas emission, and improved public health. DeMaio (2009, p. 52) concluded that "as the price of fuel rises, traffic congestion worsens, populations grow, and a greater worldwide consciousness arises around climate change, it will be necessary for leaders around the world to find new modes of transport and better adapt existing modes to move people in more environmentally sound, efficient, and economically feasible ways. Bicycle sharing is evolving rapidly to fit the needs of the 21st century."

Several cities in China have already started public bicycle projects, with Hangzhou now running arguably the world's largest bicycle-sharing program, with 50,000 bicycles deployed across 2,000 stations. It has close to 1.2 million registered users. This dwarfs the more famous VELIB program in France, which has around 20,000 bicycles deployed across 1,451 stations. In Kaohsiung, Taiwan, the first BSS, called C-Bike, was initiated in late February 2009. It originally had 20 bicycle stations, all located near train stations, with 1,500 bicycles deployed. By May 2009, it had 30 more bicycle stations in scenic areas, business