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A new approach in graph- based integrated production and distribution scheduling for perishable products

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Abstract- *This study is concerned with how the quality of perishable products can be improved by shortening the time interval between production and distribution. As special types of food such as dairy products decay fast, the integration of production and distribution scheduling (IPDS) is investigated. An integrated scheduling of both processes improves the performance and costs because the separated scheduling of these processes without considering mutual requirements leads to non-optimal solutions. An optimal solution to IPDS requires simultaneously solving of the production scheduling and vehicle routing problems. This article deals with a variation of IPDS that contains a short shelf-life product; hence, there is no inventory of the product in the process. Once an amount of products is produced, they must be transported with non-negligible transportation time directly to various customer locations. The objective is to determine the minimum cost of the makespan and number of vehicles required to complete the distribution of the products to satisfy the demand of a given set of customers over a wide geographic region. The overall problem consists of permutation flow shop scheduling with* m *machines,* n *jobs and vehicles with different speeds and transportation capacities which transport* n *jobs from the manufacturing company to* c *customers distributed in various zones by determining the vehicle routes and number of vehicles. After developing an Integer Linear Programming (ILP) model of the problem, because it is NP-hard, a new graph-based heuristic method is proposed to efficiently solve the problem.*

Keywords-*Production and distribution, Permutation flow shop scheduling, Vehicle routing problem, Integration, Graph-based scheduling*

1. INTRODUCTION

Production and distribution operations are two important operational functions in a supply chain. To achieve the optimal operational performance in a supply chain, it is important to integrate these two functions and schedule them jointly in a coordinated manner. However, most of the proposed integrated and synchronized approaches focus on the tactical decision level of supply chains (Schmid et al., 2013; Madronero et al., 2015). In recent years, integrated scheduling has generated a lot of interest among researchers. In contrast to classical scheduling, this type of scheduling problem involves not only the production part but also distribution. The objective of integrated scheduling is to optimize both parts simultaneously. The obtained procedure will become a detailed schedule that provides an efficient solution for operations management. In this paper, a class of integrated scheduling problems is considered that includes production and distribution.

In many applications involving make-to-order or time-sensitive (e.g., perishable) products, finished orders are often delivered to customers immediately or shortly after production to avoid any quality reduction. In such a supply chain, product quality is determined not only by the production processes but also through the coordination of the production and distribution decisions. In this situation, the delivery of products must be done within a strictly limited time after production. The non-inventory production and transportation problem is routine in many industries in which a time-sensitive product cannot be in storage due to its short shelf-life. The product must be delivered within a tightly limited time after its production, so the production and distribution operations must be highly integrated. When the production

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plant has a limited production rate and the transportation time is not instantaneous, any inefficiency in the integrated schedule may either cause the product to expire before it reaches the customers or cause the delivery to miss a customer's delivery deadline. Thus, the production and distribution operations must be closely linked and integrated because any inefficiency in the integrated schedule causes a decrease in the quality of the product, expiry before delivery, extra expenses and a lack of customer satisfaction. To ease this coordination, production sites are usually directly connected to customers by a fleet of vehicles (Farahani et al., 2012). Consequently, there is little or no finished product inventory in the supply chain, such that production and outbound distribution are very closely linked and must be scheduled jointly in order to achieve the desired on-time delivery performance at a minimum total cost. However, the analysis of practices in case studies shows that currently the production and distribution operations are done separately, which causes operational and customer dissatisfaction (Ullrich, 2013). So, this paper investigates integrated production and distribution decisions as a trade-off among customer satisfaction, the quality of the delivered products and total costs. Research on integrated scheduling models of production and distribution is relatively recent but is growing very rapidly.

This study was motivated by a practical scheduling problem encountered at a leading manufacturer of various products at which the departure time after production in flow shop scheduling is not fixed and needs to be determined in order to minimize costs and to satisfy customers.

The differences and contributions of this paper compared with the wider IPDS literature can be summarized as follows:

1) A new problem is defined. The integrated production-distribution scheduling (IPDS) problem is considered in which the first stage contains permutation flow shop scheduling and in the second stage the distribution problem involves designing vehicle routes for picking up finished goods and delivering them from manufacturer to customers.
2) A new integer linear programming model is developed which simultaneously considers both production and distribution scheduling in an integrated manner. This model is practical on large scales for real cases such as the dairy product industry.
3) A new graph-based heuristic method is proposed to efficiently solve the problem.

This paper studies the integrated production and distribution scheduling problem and extends features such as non-negligible transportation time and delivery consolidation. Comparison of this problem with previous works shows that the combination of the product's limited lifespan, machine scheduling decisions and the vehicle routing decisions, which can lead to the possibility of expiry before it reaches a customer, are the critical features that make it different. The problem is complicated by limited transportation capacity, the size of a customer's order and its location and the departure time, which are not fixed and must be determined. On the other hand, these complications also make the resulting integrated scheduling problem challenging and interesting. The particular variation that is considered involves a single production plant with multiple production machines in flow shop scheduling and a given set of customers at different locations over a geographic region, as shown in Fig. 1.

The aim of this research is top integrate the scheduling in a mathematical model which is developed to investigate the effect of integrated production scheduling and distribution decisions on the total costs. This is similar to various real-world environments such as the food, dairy products and chemical industries, which are highly perishable. Since this problem has an NP-hard structure [5], a new graph-based heuristic method is proposed to efficiently solve the problem.

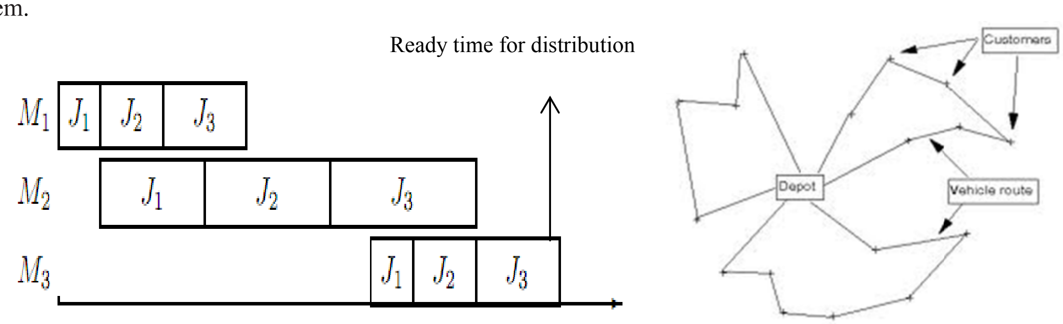

Fig. 1. Integration of flowshop scheduling and vehicle routing problem scheduling

The remainder of this paper is organized as follows. Section 2 presents results from previous works on integrated supply chain scheduling. In Section 3, the problem is described and the mathematical model of the problem is presented. In Section 4, a graph-based heuristic integrated scheduling in an illustrative example is described. Finally, Section 5 elaborates concluding remarks and some suggestions for future research.

II. LITERATURE REVIEW

In this section, the literature that explicitly involves both production and transportation activities on integrated supply chain scheduling is presented. Integrating production and outbound delivery scheduling is very critical and common in the supply chain of time-sensitive products (Chen, 2010; Chen et al., 2009). For example, Buer et al. (1999) focus on newspaper printing and distribution, mail processing and distribution are studeid by Wang et al. (2005), and industrial adhesive materials production and delivery are investigated by Devapriya et al. (2006). Therefore, finding how to effectively integrate the production and delivery stages at the operational level so as to decrease the operational costs and improve customer service becomes very important to the success of a company. However, most of the existing models on production-distribution scheduling problems only study strategic or tactical levels of decisions, and very few have addressed integrated decisions at the operational level. Chandra and Fisher (1994) emphasize the need to study these integrated scheduling issues at the operational level. They consider an integrated scheduling problem where a plant produces and stores products until they are delivered to the customers by a fleet of trucks. They provide two solutions. The first solution solves the production scheduling and vehicle routing problems separately, but the second one solves the problem in a coordinated manner. Their computational results show that the total operating cost decreases in the coordinated approach. Chen and Vairaktarakis (2005) and Pundoor and Chen (2005) also show that there is significant benefit in using the optimally integrated production-distribution schedule compared to a schedule generated by a separate and sequential scheduling approach in the context of the models considered in their research. They emphasize that integration is a superior approach to improve the total performance in decreasing costs, as is investigated in this paper.

Chen (2004, 2010) reviews papers that deal with integrated production scheduling and outbound distribution. He focuses on the two main area of direct delivery (one destination) and vehicle routing (multiple destinations). He also provides a survey of models and results in the area of integrated scheduling of production and distribution. He presents a unified model representation scheme, classifies existing models into several different classes, and for each class of the models gives an overview of the optimality properties, computational tractability, and solution algorithms for the various problems studied in the literature. In his researches, he noted that there is a gap in consideration of the due date and distribution by vehicle routing for practical situations. Lee and Chen (2001) study machine scheduling problems with explicit transportation considerations. They identify two types of transportation situations in their models. The first type involves transporting a semi-finished job from one machine to another for further processing. The second type involves transporting a finished job to the customer or warehouse. Both the transportation capacity and transportation times are taken explicitly into account in their model. They classify the computational complexity of various scheduling problems by either proving their NP-hardness or providing polynomial algorithms. Chang and Lee (2005) consider an extension of Lee and Chen's work, where each job is assumed to occupy a different amount of storage space in the vehicle during delivery. They show that the problems that jointly consider production and delivery with the consideration that each job may require a different amount of space during transport are intractable, and provide heuristics for some cases of the problem. Zhong et al. (2007) study a similar problem to the one studied by Chen (2004) with the objective of minimizing the makespan. In practical cases focusing on the type of transportation, Hajiaghaei-Keshteli & Aminnayeri (2014) present integrated production and rail transportation scheduling by emphasizing the application of rail distribution. Saidi-Mehrabad et al. (2015) present a new integrated model in scheduling and routing by automated guided vehicles that focus on new methods of transportation. In some research, the type of product is more important than the type of transportation in the practical models investigating integrated modelling. Chen et al. (2009) and Farahani et al. (2012) propose a production and distribution scheduling for perishable food products. Liu et al. (2014) present an integrated scheduling to improve the operation of production and delivery in ready-mixed concrete plants. Algorithms for solving these problems include approximation algorithms, intelligent algorithms and other solution approaches such as a graph-based approach. As mentioned, the type of product and transportation is important in the practical cases and industries that are emphasized in this paper. As shown in Table 1, it is obvious that most of the research focuses on direct delivery and single or parallel production in integrated production and distribution scheduling. There is a research gap in integrated routing and flow shop scheduling in the literature. On the other hand, because of being NP-hard, most of the solution approaches are metaheuristic and heuristic and there is a gap in graph-based solution approaches such as that studied in this paper. This is the motivation for focusing this research on graph-based integrated production and routing scheduling.

To the best of our knowledge, it seems that no research considers both permutation flow shop scheduling with the due date and tardy cost in the production stage and vehicle routing with consideration of the customer’s deadline Few researches consider the transportation fleet in their models. This study is extended by assuming that the first stage of the supply chain is composed of m machines as the flow shop environment in the production stage and v vehicles involved in designing vehicle routes for picking up and delivering finished goods in the second stage. It can be practical in real cases to serve a number of customers in various geographical zones. The additional contribution is focusing on the graph-based solution approach mentioned in this paper.

III. PROBLEM DESCRIPTION

A. Assumptions

As mentioned previously, the scheduling of products and vehicles in a two-stage supply chain is investigated here. The first stage contains permutation flow shop scheduling with m machines and n jobs, and the second stage is composed of a number of vehicles with similar transportation capacities that need to be determined and that transport n jobs from the manufacturing company to c customers distributed in various geographic zones. All vehicles are available upon completion of all jobs (i.e., C_{max}).

TABLE I. Overview of literature of integrated production and distribution scheduling

Existing literature	Machine configuration			Number of customers		distribution		Solution approach		
	Single	Parallel	Flowshop	Single	Multiple	Vehicle routing	Direct delivery	Heuristic	Mata heuristic	Graph based
Buer et al.(1999)[8]	✓				✓		✓	✓		
Chang and Lee(2004)[5]	✓			✓			✓	✓		
Wang et al.(2005)[9]	✓				✓		✓	✓		
Devapriya et al. (2006) [10]	✓			✓			✓	✓		
Chen and Vairaktarakis (2005)[12]		✓		✓			✓	✓		
Pundoor and Chen (2005)[13]	✓			✓			✓	✓		
Lee and Chen (2001)[15]	✓			✓			✓	✓		
Zhong et al. (2007)[16]		✓		✓			✓	✓		
Gesmar et al.(2008)[28]	✓				✓	✓			✓	
Averbakh and Xue(2010)[21]	✓				✓		✓	✓		
Zegordi et al.(2007)[22]	✓				✓		✓		✓	
Cheng et al.(2015)[23]	✓				✓		✓		✓	
Ullrich (2013)[4]		✓			✓	✓			✓	
HajaghaiKeshteli and Aminnayeri(2014)[17]	✓			✓			✓		✓	
Liu et al.(2014)[20]	✓			✓			✓		✓	✓
Contribution of this paper			✓		✓	✓		✓		✓

The problem is described as follows. There is a set of jobs (N={1,2,…,n}) to be processed by a set of machines (M={1,2,…,m}) at the production stage, which is permutation flow shop scheduling. All jobs have to be processed in an identical order on a given set of machines. The processing of each job is continuous once the processing begins. After processing, the finished jobs need to be delivered by the vehicles, which have a similar capacity Q, to a set of customers (C={1,2,…,c}). The aim is to find a set of tours for several vehicles from a depot (i.e. the manufacturer's site) to a number of customers with the objective of the minimum number of vehicles and makespan costs. They return to the depot without exceeding their capacity. Each customer is visited only once by a single vehicle.

At the beginning of the horizon, customers require a set of jobs and send the requirements to the manufacturer. At the subsequent delivery stage, a fleet of vehicles with non-predefined capacity delivers the finished jobs to the pre-specified customers. The capacity of the transporters is measured by a certain amount of volume. Each customer is visited only once by a single vehicle. Only one vehicle is allowed to visit each customer.

B. Mathematical model

A mathematical formulation of the proposed integrated production-distribution scheduling (IPDS) problem is presented in this section. The parameters are as follows:

n	number of jobs
m	number of machines
c	number of customers
i	job index, $i = 1, 2, \ldots, n$
p	job position index, $p = 1, 2, \ldots, n$
r	machine index, $r = 1, 2, \ldots, m$
j, l	customer index
k	vehicle index
T_{ri}	operation time of job i on machine r
dd_k	deadline for vehicle k to deliver to customers
d_{jl}	distance between customer j and customer l
e_{ij}	physical space of customer j `s demand i
v_k	speed of vehicle k
Q	capacity of vehicle for transporting job from manufacturing company to customers
cd	vehicle cost
cp	production cost in flowshop scheduling stage

Variables of model are as follows:

V	number of vehicles
B_{rj}	start time of job j on machine r
u_j	arbitrary non-negative real number (flow or number of customers visited) for sub-tour elimination at customer j
r_k	vehicle k ready time represents the latest completion time
c_{max}	maximum completion time of all jobs (makespan)
Z_{ij}	1 if job i is in position j is processed; otherwise, equals zero
x_{jl}^{k}	1 if customer l is served after customer j by vehicle k; otherwise, equals zero

Miller et al. (1960) propose a mathematical programming formulation to prevent sub-tours in the vehicle routing problem. Kyparisis and Koulamas (2006) propose a definition to consider the vehicle velocity and distance instead of time. All the above assumptions are used to develop the following model for the integrated production-distribution scheduling (IPDS) problem.

Min $cd.v + cp.r^k$

$$\sum_{p=1}^{n} Z_{ip} = 1 \qquad 1 \le i \le n \tag{1}$$

$$\sum_{i=1}^{n} Z_{ip} = 1 \qquad 1 \le p \le n \tag{2}$$

$$B_{1p} + \sum_{i=1}^{n} T_{1i} Z_{ip} = B_{1,p+1} \qquad 1 \le p \le n-1 \tag{3}$$

$$B_{11} = 0 \tag{4}$$

$$B_{r1} + \sum_{i=1}^{n} T_{ri} Z_{i1} = B_{r+1,1} \qquad 1 \le r \le m-1 \tag{5}$$

$$B_{rp} + \sum_{i=1}^{n} T_{ri} Z_{ip} \le B_{r+1,p} \qquad 1 \le r \le m-1 \quad 2 \le p \le n \tag{6}$$

$$B_{rp} + \sum_{i=1}^{n} T_{ri} Z_{ip} \le B_{r,p+1} \qquad 2 \le r \le m \quad 1 \le p \le n-1 \tag{7}$$

$$c_{\max} = B_{mn} + \sum_{i=1}^{n} T_{mi} Z_{in} \tag{8}$$

$$\sum_{k=1}^{v} \sum_{l=1}^{c} x_{jl}^{k} = 1 \qquad j = 1, 2, \ldots, c \tag{9}$$

$$\sum_{k=1}^{v} \sum_{j=1}^{c} x_{jl}^{k} = 1 \qquad l = 1, 2, \ldots, c \tag{10}$$

$$\sum_{l=0}^{c} x_{lh}^{k} - \sum_{j=0}^{c} x_{hj}^{k} = 0 \qquad h = 1, 2, \ldots, c \quad k = 1, 2, \ldots, v \tag{11}$$

$$\sum_{j=1}^{c} x_{0j}^{k} = 1 \qquad k = 1, 2, \ldots, v \tag{12}$$

$$u_j + 1 \le u_l + c(1 - x_{jl}^{k}) \qquad k = 1, 2, \ldots, v \quad l = 1, 2, \ldots, c \quad j = 1, 2, \ldots, c \tag{13}$$

$$\sum_{k=1}^{v} \sum_{j=1}^{c} x_{0j}^{k} = v \tag{14}$$

$$\sum_{k=1}^{v} \sum_{l=1}^{c} x_{l0}^{k} = v \tag{15}$$

$$\sum_{i=1}^{n} \sum_{j=0}^{c} \sum_{l=0}^{c} e_{ij} x_{lj}^{k} \le Q \qquad k = 1, 2, \ldots, v \tag{16}$$

$$r^k \ge c_{\max} \qquad k = 1, 2, \ldots, v \tag{17}$$

$$r^k + \sum_{l=1}^{c} \sum_{j=0}^{c} {d_{jl}} / {v_k} \, x_{jl}^{k} \le dd_k \qquad k = 1, 2, \ldots, v \tag{18}$$

The aim is to minimize the sum of vehicles cost and departure time, which depends on the makespan costs. Constraint set (1) and (2) represents the assignment that guarantees that every job is assigned to one position and every position to one job. Constraint set (3), (4) and (5) ensures the permutation flow shop scheduling property that there is no idle time on the first machine and the first job is processed on all machines without delay. Constraint set (6) guarantees that the start of each job on machine r+1 is no earlier than its finish time on machine *r*, which prevents the simultaneous processing of jobs on one machine. Constraint set (7) ensures that the job processes in position p+1 in the sequence do not start till the processing of the job in position p on that machine is completed. Constraint set (8) represents the makespan. Constraint set (9) and (10) are the common constraints for the vehicle routing problem that mean that every customer is serviced by just one vehicle. Constraint set (11) is the flow conservation constraint for each customer that when the vehicle has serviced a customer, it must depart the current customer to service the next one. Constraint set (12) ensures that every vehicle must provide a one-time service to customers. Constraint set (13) prevents a sub-tour that is disconnected from the depot. Constraint set (14) and (15) confines the number of vehicles to service the customers to v vehicles. Constraint set (16) guarantees that the maximum flow in any arc leaving the root is equal to Q and the maximum vehicle *k* capacity is confined to Q. The relation of the production and distribution stages is important in the IPDS problem. Constraint set (17) and (18) focuses on the integration of the production and distribution stages that emphasizes the ready time of vehicles upon completion of all jobs. Constraint set (17) determines the departure time of vehicles. Constraint set (18) satisfies the deadline according to the departure and delivery time.

Lemma 1. The integrated production-distribution scheduling (IPDS) problem is NP-hard.

Proof. Chang & Lee (2004) and Geisma & Laporte (2008) proved that a problem with only one geographical zone, one manufacturer and one vehicle is NP-hard. According to Pinedo (2012) and Gary and Johnson (1979), the flow shop scheduling problem with the C_{max} minimization objective is also NP-hard. As the IPDS problem is an extension of two NP-hard problems, i.e., flow shop scheduling and the vehicle routing problem, the integrated problem must be NP-hard in the strong sense.

NP is not equal to P problems, so there is no algorithm to find global optima in polynomial computational time. Therefore, metaheuristics or heuristics must be applied to solve large-scale problems within a reasonable computation time.

IV. HEURITIC ALGORITHM

Each of the integrated production and distribution scheduling problems is strongly NP-hard Ullrich(2013), Chang and Lee (2004). Therefore, a new graph-based heuristic method is proposed to efficiently solve the proposed problem addressed in this research.

A. Graph-based heuristic integrated scheduling in illustrative example

This section details the methodological approach for the integrated scheduling of production and transportation operations. The approach gives special attention to a common modelling procedure for production and transportation operations based on a graph. This includes permutation flow shop scheduling for customer demand by machines as the initial stage, and road distribution by vehicles, which is typically the final transportation mode between the plant and customers.

The graph G= (V,E) consists of a set of nodes *V* and a set of edges *E*, in which each edge represents a connection between a pair of nodes. In this approach, the nodes are located in the *x/y* plane, in which the *x*-axis represents time *t* and the *y*-axis represents the locations of production machines and delivery vehicles.

B. Flowshop scheduling in graph

As mentioned, integrated production and distribution scheduling is a problem integrating and coordinating flow shop scheduling and vehicle routing. In this article, permutation flow shop scheduling is the permutation of jobs on the sequence of machines in order to minimize the vehicle departure time (makespan) so as to minimize the departure cost. Let C_{i,j_k} be the completion of the *i*th operation of job j_k. Assume that the jobs run in the order $j_1,\ldots,j_n$ and go through the machines in order $M_1,\ldots,M_m$. As explained, Fig. 2 is the graph associated with the permutation j_1,j_2,j_3 (three jobs) on

M_1, M_2 (two machines). The critical path in this graph is the makespan associated with scheduling the jobs in the given order. The critical path to any node is the completion time of that operation.

In the graph, each node's completion time is its processing time, plus the maximum completion time of its predecessors (immediately above and immediately to the left). As in Fig. 3, the makespan is computed as 16.

C. Vehicle routing problem in graph

In the vehicle routing problem after completion time of the production stage, vehicles depart the plant to service the customers. In order to minimize the number of vehicles, the first step is to sort the customers according to the angle to horizon in increasing order, and customers selected are limited by the vehicle capacity. As the vehicles have fuel consumption, and wear and tear, this influences the total cost, while on the other hand minimizing the number of vehicles can minimize this. In this stage, the transportation routes for delivery of the customer orders are determined with respect to the vehicle capacity in order to minimize the total vehicle and production costs. Fig. 3 shows the locations of customers and Fig. 4 is an illustrative example of sorting the customer locations as the angles of customer a,…,k in order to select customers according to the increasing order of angles. In the end, three vehicles can satisfy all the customers' orders.

D. Integrated scheduling and routing problem based on graph

The problem focuses on the integration of production and distribution scheduling. In integrated scheduling, the time between the completion time of the production stage and delivery to customers is limited by a deadline so the products are distributed to customers according to the vehicles' capacity limits and the deadline constraint. The integration of production and distribution is satisfied and the completion of production is connected to routing and delivery to the customers. In this example, after the completion time that is computed in section B, the delivery to customers is started to satisfy the vehicles' capacity limits and the deadline time in order to minimize the completion time and the cost of the number of vehicles.

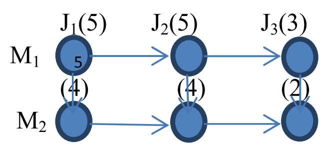

Fig.1. Flowshop scheduling graph

points	X	Y
a	6	0
b	11	1
c	9	1.33
d	10	4.5
e	8	7
f	7	6.5
g	5	6
h	5	4
i	2	6.5
j	4	4.5
k	3	4

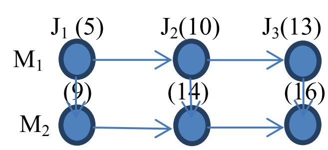

Fig. 2. Computing the critical path

E. Managerial implication

This paper discusses the practical implications of managerial decisions to integrate production and distribution scheduling. The focus of this study is to show the practical implication of the integrated model to consider simultaneous flow shop scheduling and vehicle routing decisions. The integrated scheduling problems studied in this paper are based on models for production and distribution that apply to a wide range of practical applications. The integrated approach prevents a decrease in product quality, expiry before delivery, extra expenses and lack of customer satisfaction. It is practical in many industries involving make-to-order or time-sensitive (e.g., perishable, dairy) products, where finished orders are often delivered to customers immediately or shortly after production to limit quality reduction.

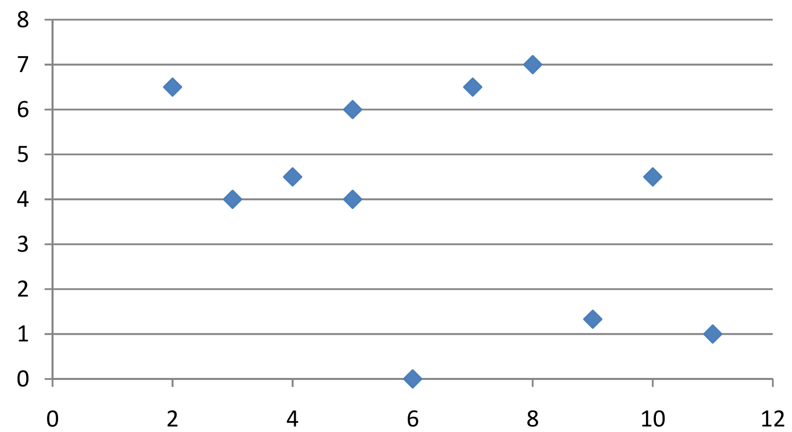

Fig. 3. Position of customers in the *x/y* plane

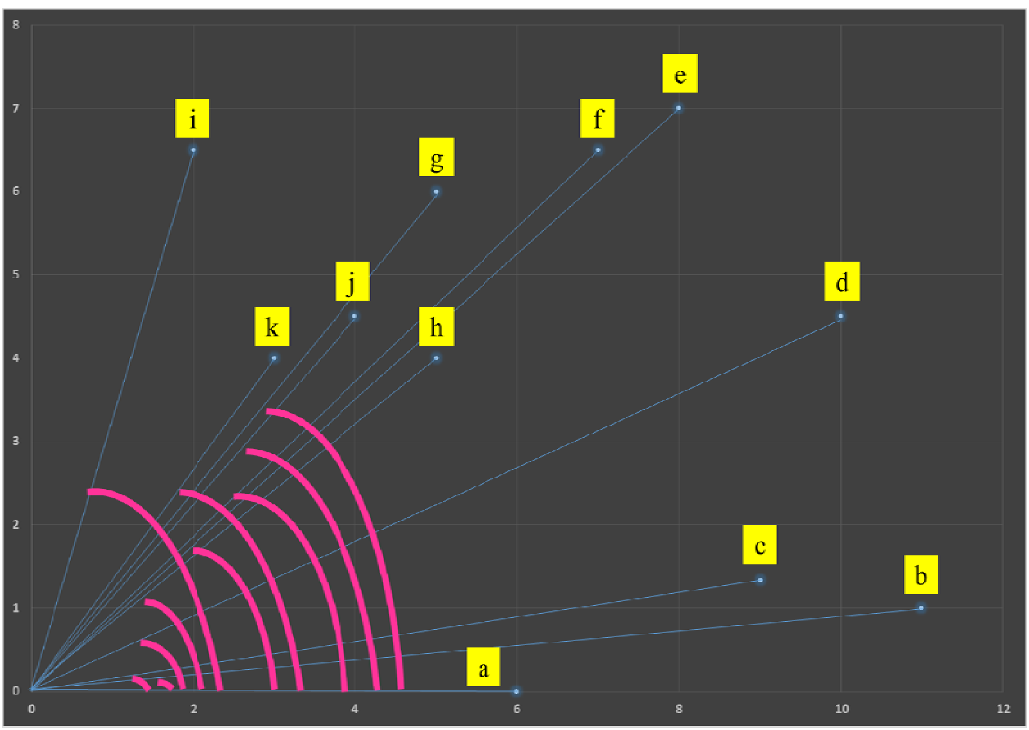

Fig. 4. Illustrative example of sorting customer position angle

TABLE II. Results of random instances with small sizes

Instance No.	Size				Graph base algorithm(ALG)		LINGO		PD
	Machine	Job	vehicle	Customer	Value	CPUT (s)	Value	CPUT (s)	
1	2	5	2	6	29493	22	29493	4	0
2	2	10	3	6	38736	19	38736	17	0
3	2	15	3	6	39937	20	39937	42	0
4	5	5	2	6	32967	19	33517	12	٠
5	5	15	2	6	42337	20	42234	60	0.002
6	2	5	3	7	30043	21	29993	38	0.001
7	2	10	3	7	32586	20	32586	27	0
8	2	15	3	7	32837	21	32837	51	0
9	5	5	2	7	29467	19	29467	15	0
10	5	15	2	7	38101	22	38184	52	0
11	2	5	3	8	29943	17	32443	23	٠
12	2	10	3	8	39886	17	39886	160	0
13	2	15	3	8	40154	21	40137	129	0.0004
14	5	5	2	8	34467	21	34467	107	0
15	5	15	2	8	43984	17	43834	136	0.003
16	2	5	3	9	30143	17	33843	116	٠
17	2	10	3	9	40236	19	40236	160	0
18	2	15	3	9	40637	20	40487	92	0.004
19	5	5	2	9	33417	19	33417	72	0
20	2	5	3	10	24983	19	24943	59	0.001
Average						19.5		68.8	0.0006

F. Validation of the graph-based algorithm

For comparison, the MILP model is solved with the mathematical software LINGO 13.0. The graph-based algorithms in this paper are coded in MATLAB 2013. They are implemented on the computer with Intel Core 2Duo 2.5 GHZ and 3GB RAM.

The test problems are generated randomly. *PD=100×max (0, ALGs-LINGOs)/LINGOs* is used to compare the graph-based algorithm and Lingo solutions. All the *PD* percentages and the total average of the problems shown in Table 1 are less than 0.06%. The average running time of the graph-based algorithm is less than the optimal approach.

V. CONCLUSION AND FUTURE RESEARCH

This paper tackles a practice-oriented integrated production and distribution scheduling. IPDS focuses on products with a short lifespan and includes flow shop scheduling decisions in a single plant, a fleet of limited-capacity trucks for delivering customers' orders with consideration of vehicle routing, and a number of customers with defined locations and demands. The goal is to design routes that serve all customers within each trip and to schedule production in order to minimize the vehicle and departure time costs while satisfying the vehicle capacity. In the perishable products industry, these costs are perhaps most prominent and are strongly influenced by the two interrelated stages of production and distribution. In this paper, a scheduling problem in a two-stage supply chain environment is proposed with the objective function of minimizing the sum of the vehicle and departure time costs. The production and distribution scheduling are integrated into a flow shop environment and vehicle routing. This model is still a good representation of real-world cases such as the dairy products industry. After presenting the IPDS problem as an integer linear programming model, since the problem is NP-hard in the strong sense, a heuristic graph-based algorithm is proposed.

Future research is needed to investigate an integrated scheduling problem where the machine configurations and distribution are more complex, such as in batch scheduling, two-stage vehicle routing or consideration of multiple plants that are distributed in various geographic regions. The integration of different levels of decision-making, tactical or strategic, helps to optimize the whole supply chain. Tightening the gap between theory and practical application would be highly worthwhile for more research.

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