Print ISSN: 1738-3110 / Online ISSN 2093-7717
http://dx.doi.org/10.15722/jds.15.7.201707.35

Complexity and Algorithms for Optimal Bundle Search Problem with Pairwise Discount*

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Received: May 30, 2017. Revised: June 15, 2017. Accepted: July 15, 2017.

Abstract

Purpose – A product bundling is a marketing approach where multiple products or components are packaged together into one bundle solution. This paper aims to introduce an optimal bundle search problem (hereinafter called “OBSP”) which may be embedded with online recommendation system to provide an optimized service considering pairwise discount and delivery cost.

Research design, data, and methodology – Online retailers have their own discount policy and it is time consuming for online shoppers to find an optimal bundle. Unlike an online system recommending one item for each search, the OBSP considers multiple items for each search. We propose a mathematical formulation with numerical example for the OBSP and analyzed the complexity of the problem.

Results – We provide two results from the complexity analysis. In general case, the OBSP belongs to strongly NP-Hard which means the difficulty of the problem while the special case of OBSP can be solved within polynomial time by transforming the OBSP into the minimum weighted perfect matching problem.

Conclusions – In this paper, we propose the OBSP to provide a customized service considering bundling price and delivery cost. The results of research will be embedded with an online recommendation system to help customers for easy and smart online shopping.

Keywords: Internet Shopping Optimization Problem, Bundle Search Problem, Perfect Matching Problem, Online Shopping Recommendation.

JEL Classifications: C44, C61, C65.

1. Introduction

The motivations and intentions for online shopping are widely different across the culture and SNS (Social Network Service) may be a powerful method for online recommendation (Singh, 2014; Kim et al., 2014). A product bundling strategy is a marketing approach where multiple products or components are packaged together into one bundled solution (Yang & Lai, 2006). It is known that Amazon was one of the firsts to utilize bundle sales online and has seen huge success because of it. For example, a digital camera is bundled with accessories like an SD card, light and a camera case. Typically, product bundles are appealing for online retailer for several reasons. First, bundling can effectively increase sales amount by selling more without additional transaction costs. Second, bundling makes it harder for customers to compare price compositely and return to the site where the absolute price is lowest. Third, bundling can encourage cross-selling if the product bundles include items from new categories.

* A preliminary version of paper has been published at summer conference of ICBE 2017.
This work was supported by the Ministry of Education of the Republic of Korea and the National Research Foundation of Korea (NRF-2016S1A5A2A01023036). This work was also supported by the research grant of the Kongju National University Fund in 2017.

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Stremersch and Tellis (2002) classified bundling problems into two categories. Firstly, they defined product bundling as the integrated sale of two or more separate products or services at any price (Stremersch & Tellis, 2002). Secondly, they defined price bundling as the sale of two or more separate products in a package at a discount without any integration of the products (Stremersch & Tellis, 2002). They also suggested three bundling strategies: pure, mixed, or unbundling. Pure bundling occurs when a consumer can only purchase the entire bundle or nothing while mixed bundling occurs when consumers are offered a choice between purchasing the entire bundle or one of the separate parts of the bundle (Stremersch & Tellis, 2002).

As the price competition in the online market becomes more intense, the prices for the same products vary widely and online retailers have their own discount policies. Discount of online retailers may happen based on the total purchasing price or between pairwise items. Total purchasing price discount means that if the total price of products bought from same retailer is greater that some threshold, there are discounts proportional to the total price of purchasing. Pairwise discount means that there are benefits of saving money between product pairs if you buy them from same retailer. Pairwise discount is one of the marketing approach to encourage cross-selling strategy.

Suppose that you are going to buy multiple items in the online market, there are two ways for online shopping. One is to select a lowest product individually while the other is to select all products simultaneously with a comparison. If a customer has many items to buy, finding an optimal combination of retailers with a minimum price is a boring and time consuming work. Online shoppers are increasingly purchasing multiple items in a single order due to the convenience of shopping, shipping costs and various recommendation systems.

Recently, the comparison shopping agents (CSA) or shopbots have emerged as important business intermediaries that provide decision support to both the shoppers and the merchants (Pathank, 2010). Searching and recommending an optimal bundles satisfying customer shopping lists becomes very important. However, current recommending systems are limited only for a individual single product and it is difficult to find a recommending system supporting multiple shopping products or bundles. Unlike He and Ioerger (2004) who studied bundle search problem with total purchasing price discount, our research aims to suggest an optimal bundle search problem with pairwise discount and propose an efficient algorithms by utilizing the structure of problem.

The rest of paper is organized as follows. Literature reviews for the problem are provided in section 2. In section 3, we provide a mathematical formulation for the problem with numerical example. In section 4, we provide two results from the complexity analysis. Concluding remarks and implications of the research are provided in section 5.

2. Literature Reviews

2.1. General bundling problem

Starting with Stigler (1963), there has been several streams of research on bundling problem in the economics and management science and many authors studied the benefits from the relationships between reservation prices and product prices (McCardle et al., 2007). Ernst and Kouvelis (1999) studied the inventory decision of a company with mixed bundling strategy. Stremersch and Tellis (2002) provided a comprehensive survey of the literature in bundling problem. Jedidi et al. (2003) developed an optimal product-line pricing policy considering heterogeneity in the joint distribution of reservation process. Yang and Lai (2006) compared the performance of various bundling strategies on online shopping environments. McCardle et al. (2007) developed mathematical models for two product classes (basic and fashion) to calculate the optimal bundle prices, order quantities, and profits under bundling. Blazewicz et al. (2009) introduced an internet shopping optimization problem which tries to minimize the sum of item price and delivery cost and analyzed the complexity of problem. Beladev et al. (2016) introduced a novel model of bundle recommendations that integrate collaborative filtering techniques, demand functions, and price modeling. Kim (2016) studied the differences and interaction effects between Korean and Thai consumers on the perceived financial risk depending on the types of product and bundle price discount.

2.2. Bundle search problem

Chang et al. (2003) studied bundle search problem for optimal travel package and proposed a heuristic algorithm for generating top-K bundles from pairwise relationship graphs. He and Ioerger (2004) studied bundle search problem with total purchasing price discount and proposed a heuristic algorithm by combining price itself and discount ratio. Garfinkle et al. (2006) studied to design bundle search and recommend system considering the bundle pricing and discount promotions. They illustrated a disadvantage of using ‘one item for each search’ to purchase a bundle and proposed an mathematical model based on the set covering problem. They developed a greedy heuristic algorithm and showed the performance of heuristic by computational experiment. Chang and Lee (2010) proposed mathematical models for various shopping optimization based on suppliers’ pricing context such as delivery cost, discount coupon, credit card discount, mileage coupon.

2.3. Online recommendation system (ORS)

Researchers have found there are significant price variations even for identical items and the variations among

<Table 1> Summary of literature review

Category	Researcher	Results
General bundling problem	Stigler (1963)	introduced the profitability of bundling
	Ernst & Kouvelis (1999)	studied the inventory decision of a company with mixed bundling strategy
	Stremersch & Tellis (2002)	provided comprehensive survey of the bundling problem
	Jedidi et al. (2003)	studied optimal product-line pricing policy
	Yang & Lai (2006)	compared the performance of various bundling strategies
	McCardle et al. (2007)	developed models for two product classes to calculate the optimal bundle prices, order quantities, and profits
	Blazewicz et al. (2009)	studied optimization problem in online shopping minimizing item price and delivery cost
	Kim (2016)	studied the effects on the perceived financial risk depending on the types of product and bundle price discount
	Beladev et al. (2016)	introduced bundle recommendations with collaborative filtering, demand functions, and price modeling
Bundle search problem	Chang et al. (2003)	bundle search problem for optimal travel package
	He & Ioerger (2004)	bundle search problem with total purchasing price discount
	Garfinkle et al. (2006)	bundle search and recommend system considering the bundle pricing and discount promotions
	Chang & Lee (2010)	mathematical models for various shopping optimization based on suppliers' pricing context
Online recommendation system	Jeong (2003)	proposed case-based bundle recommendation agents with object modeling technique
	Pathank (2010)	analyzed popular CSAs to check whether they provide complete and accurate price dispersion information
	Pu et al. (2012)	surveyed the user experience research in recommending systems and derived a set of usability design guidelines
	Beladev et al. (2016)	proposed that online recommender systems will enhance e-commerce sales by recommending relevant products to their customers

many vendors have made it difficult for a customer to find the best price for his shopping lists. In response, a number of comparison-shopping search engines, widely known as "shopbots", have become popular such as 'Simon.com', 'Froogle.com', and 'PriceGrabber.com' (Garfinkel et al., 2006). Jeong (2003) proposed case-based bundle recommendation agents with object modeling technique for a set of sea food in korea. The web-based comparison shopping agents (CSAs) or shopbots have emerged as important business intermediaries that provide decision support to both the shoppers and the retailers (Pathank, 2010). Pathank (2010) analyzed popular CSAs to check whether they provide complete and accurate information of price dispersion. Pu et al. (2012) surveyed the user experience research in recommending systems and derived a set of usability design guidelines. Beladev et al. (2016) proposed that ORS will enhance e-commerce sales by recommending relevant products to their customers. Summary of literature reviews is displayed at <Table 1> below.

However, most current shopbots are developed towards one-product-at-a-time search. Therefore, customers who want to find the best price for multiple products have to repeat a search for each item and then combine the search results as a whole. Only a few shopbots allow customers to bundle search for multiple items as a whole by showing the total purchasing price of items from a single retailer or from multiple retailers. However, none of these shopbots can incorporate the variety of bundling and pricing alternatives that are frequently offered by online retailers (MohanKumar & Saravanan, 2013).

3. Mathematical Formulation

In this section, we give a formal definition of the OBSP addressed in this paper. To explain our problem, we give a simple numerical example. Suppose that there are 3 items (item-1, item-2, item-3) to buy and 3 retailers (shop-1, shop-2 and shop-3) are candidates for shopping. Each retailer has a different price and discount policy for same product or product pair. As you can see in <Table 2> below, individual price of item is different such that the price of item-1 is 20 at shop-1 and 19 at shop-3 and the price of item-2 is 30 at shop-1 and 28 at shop-3. Furthermore, discount policy is different at each retailer such that pairwise discount between item-1 and item-2 is 5 at shop-1 while there is no pairwise discount between item-1 and item-2 at shop-3. Therefore, buying item-1 and item-2 at shop-1 is more economical than shop-3 even though the shop-3 suggests a least price for item-1 and item-2 respectively.

<Table 2> Price of a bundle at each retailer

bundle	contents	shop-1	shop-2	shop-3
1	item-1	20	20	19
2	item-2	30	29	28
3	item-3	20	19	19
4	item-1&2	45	46	47
5	item-2&3	45	46	47

	$x_{1,1}$	$x_{1,2}$	$x_{1,3}$	$x_{1,4}$	$x_{1,5}$	$x_{2,1}$	$x_{2,2}$	$x_{2,3}$	$x_{2,4}$	$x_{2,5}$	$x_{3,1}$	$x_{3,2}$	$x_{3,3}$	$x_{3,4}$	$x_{3,5}$	y_1	y_2	y_3		
min	20	30	20	45	45	20	29	19	46	46	19	28	19	47	47	50	50	50		
s.t.	1			1		1			1		1			1					$\geq$	1
		1		1	1		1		1	1		1		1	1				$\geq$	1
			1		1			1		1			1		1				$\geq$	1
	1	1	1	1	1											$-K$			$\leq$	0
						1	1	1	1	1							$-K$		$\leq$	0
											1	1	1	1	1			$-K$	$\leq$	0

<Figure 1> Formulation for the numerical example in <Table 2>

Our problem can be formally stated as follows. Let $M=\{1,2,...,m\}$ and $N=\{1,2,...,n$ be the sets of retailers and items, respectively. Let $B=\mathrm{B}_1,\mathrm{B}_2,...,\mathrm{B}_\mathrm{b}$ be the set of the bundles. Note that $B_k,\ k=1,2,...,b$, is the set of some items in N. Let $p_i(B_k)$ be the price required when bundle B_k is purchased from retailer i for $i=1,2,...,m$ and $k=1,2,...,b$. For consistency of notation, let $p_i(\varnothing)=0$, $i=1,2,...,m$. Let d_i be a delivery cost at retailer i and w_j be the number of item j which should be purchased. Note that the total number of item j purchased from all retailers should be equal to w_j. Let $X=(X_1,X_2,...,X_m)$ be the schedule with $X_i=(B_1(x_{i,1});B_2(x_{i,2});\cdots;B_b(x_{i,b}))$ meaning that the number of B_k purchased from retailer i is $x_{i,k}$ for $i=1,2,...,m$ and $k=1,2,\ldots,b$. Let y_i be a binary decision variable, where $y_i=0$ if $X_i=\varnothing$ and $y_i=1$, otherwise. Then, our problem can be mathematically formulated as follows.

$$Min\ \ z(X)=\sum_{i=1}^{m}\left(\sum_{k=1}^{b}x_{i,k}p_i(B_k)+d_iy_i\right) \qquad (1)$$

$$s.t.\ \sum_{i=1}^{m}\sum_{k=1}^{b}\sum_{j\in B_k}x_{i,k}\geq w_j \text{ for } j=1,2,...,n \qquad (2)$$

$$y_i\geq\sum_{k=1}^{b}x_{i,k}/K \qquad (3)$$

$$x_{i,k}\ :\ \text{integer for } i=1,2,...,m \text{ and } k=1,2,...,b, \qquad (4)$$

where K is a sufficiently large value. Let our problem be referred to as Problem P.

Consider the instance in <Table 2> such that

- $m=3,\ n=3$ and $b=5$;
- $w_j=1,\ j=1,2,3$ and $d_i=50,\ i=1,2,3.$

Note that according to the notation above,

- $B_1=1,\ B_2=2,\ B_3=3,\ B_4=1,2,\ B_5=2,3;$
- $p_1(B_1)=20,\ p_1(B_2)=30,\ p_1(B_3)=20,$ $p_1(B_4)=45,\ p_1(B_5)=45;$
- $p_2(B_1)=20,\ p_2(B_2)=29,\ p_2(B_3)=19,$ $p_2(B_4)=46,\ p_2(B_5)=46;$
- $p_3(B_1)=19,\ p_3(B_2)=28,\ p_3(B_3)=19,$ $p_3(B_4)=47,\ p_3(B_5)=47.$

Then, that instance can be formulated as follows. Note that for simplicity, the formulation can be described as the simplex tableau.

4. Results of Problem P

In this section, we show that the complexity of Problem P is strongly NP-hard, and present a special case when there exists a optimal algorithm in polynomial time bound. In general, to tackle a combinatorial optimization problem like Problem P, the first step is to verify its computational complexity since system developers in the field have a high interest about the difficulties to find an optimal algorithms. If Problem P is NP-hard, then it is very prohibitively time consuming to try to obtain the exact optimal solution (Garey & Johnson, 1979). In that case, it is usual to investigate the special case that can be solved in polynomial time, or develop an approximation algorithm. In this paper, we adopt the first approach.

To prove the strong NP-hardness, we use the exact cover by 3-sets problem (X3C), which is known to be NP-complete in the strong sense (Garey & Johnson, 1979). The X3C can be stated as follows: Given a set $Q = 1,2,...,3q$ and a collection $C = C_1, C_2, ..., C_l$ where $C_i \subseteq Q$ and $|C_i| = 3$, $i = 1,2,...,l$, does C contain an exact cover for Q, that is, a subcollection $C' \subseteq C$ such that every element of Q occurs in exactly one member of C'?

Theorem 1 : Problem P is strongly NP-hard even if $d_i = 0,\ i = 1,2,..,m.$

Proof : Given an instance of the X3C, we construct an instance of Problem P as follows. There are the sets of retailers $M = 1,2,...,l$ and items $N = 1,2,...,3q$ such that for $i = 1,2,...,l,$

- Retailer i has three items corresponding to the three elements in C_i;
- Retailer i sell them only by the bundle consisting of three items, which implies that $p_i(B_k) = \infty$, if $B_k \neq C_i$;
- $p_i(B_k) = 3$ if $B_k = C_i$;
- The number of each item to be purchased is one, that is, $w_j = 1,\ j = 1,2,...,3q.$

This reduction can be done in polynomial time. It is observed that the problem of obtaining a schedule X for the reduced Problem P with $z(X) \leq 3q$ is equivalent to the X3C. The proof is complete.

Theorem 2 : Problem P is strongly NP-hard even if all items are free, that is, $p_i(j) = 0,\ j = 1,2,...,n.$

Proof : Given an instance of the X3C, we construct an instance of Problem P as follows. There are sets of retailers $M = 1,2,...,l$ and items $N = 1,2,...,3q$ such that for $i = 1,2,...,l,$

- Retailer i sells only the three items corresponding to the three elements in C_i;
- $d_i = 1.$

This reduction can be done in polynomial time. It is observed that the problem of obtaining a schedule X for the reduced Problem P with $z(X) \leq q$ is equivalent to the X3C. The proof is complete.

Theorem 3 : Problem P is polynomially solvable if the

- The number of each item to be purchased is one, that is, $w_j = 1,\ j = 1,2,...,n$;
- The number of items consisting of the bundle is at most two, that is, $|B_k| \leq 2$, $k = 1,2,...,b$;
- The delivery cost of each retailer i is free, that is, $d_i = 0,\ i = 1,2,..,m.$

Proof : We prove the polynomiality of Problem P by reducing it to the minimum weighted perfect matching (MWPM) problem, which can be stated as follows: Given $G = (V, E)$ and edge cost $c_{i,j}$ for $(i,j) \in E$, find the set of edges $M \subseteq E$ such that

- The edges in M covers all nodes (Note that this set of edges is referred to as perfect matching);
- The total cost of the edges in M is minimum among all perfect matching.

If $|N|$ is even, then Problem P can be reduced to the MWPM problem by letting

- $V = N$ and $E = (j_1, j_2) \mid j_1,\ j_2 \in N$;
- $c_{j_1, j_2} = \min p_i(j_1, j_2) \mid i = 1,2,...,m.$

Otherwise, it can be reduced to the MWPM problem by letting

- $V = N \cup 0$ and $E = (j_1, j_2) \mid j_1,\ j_2 \in N \cup 0;$
- $c_{j_1, j_2} = \min p_i(j_1, j_2 \setminus 0) \mid i = 1,2,...,m.$

Since the MWPM problem is known to be solved in polynomial time (Garey & Johnson, 1979), the proof is complete.

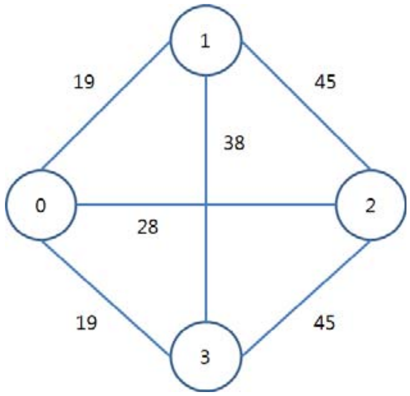
Consider a instance in <Table 2> such that

- $m = 3,\ n = 3$ and $b = 5$;
- $w_j = 1,\ j = 1,2,...,n$ and $d_i = 0,\ i = 1,2,...,m.$

Since this instance satisfies the properties in Theorem 3, it can be reduced to the MWPM problem. Note that according to the reduction scheme in Theorem 3,

- $N = 0,1,2,3$ and $E = (0,1),(0,2),(0,3),(1,2),(1,3),(2,3);$
- $c_{0,1} = \min p_1(1), p_2(1), p_3(1) = 19$;
- $c_{0,2} = \min p_1(2), p_2(2), p_3(2) = 28$;
- $c_{0,3} = \min p_1(3), p_2(3), p_3(3) = 19$;
- $c_{1,2} = \min p_1(1,2), p_2(1,2), p_3(1,2) = 45$;
- $c_{1,3} = \min p_1(1,3), p_2(1,3), p_3(1,3) = 38$;
- $c_{2,3} = \min p_1(2,3), p_2(2,3), p_3(2,3) = 45$.

Note that there exists no bundle consisting of items 1 and 3. In this case, for each i, the value of $p_i(1,3)$ can be calculate as $p_i(1,3) = p_i(1) + p_i(3)$. Thus, we can construct a corresponding graph for the reduced MWPM problem as follows:



<Figure 2> The corresponding graph for the reduced MWPM problem

Note that the optimal solution for this MWPM problem is $0,1,2,3$, which implies that an optimal recommendation for Problem P is to purchase item 1 at shop-3 and purchase item 2 and 3 at shop-1 as a bundle.

5. Discussion and Implications

Bundling is known to be an effective marketing strategy especially in online shopping. With tremendous bundling options suggested by online retailers, customers want to optimize purchasing plan with a little search cost. Therefore, optimal bundling recommendation system has been interested and will be appeared in the near future.

This paper introduces a new optimization problem which tries to recommend optimal purchasing plan for a customer with multiple shopping lists. Considering a limitation that existing online shopping system recommends one-product-at-a-time search, our research model has an originality since our model recommends all-product-at-one-time search. Furthermore our recommendation models contribute to reduce a searching cost of customers and increase a sale of retailers by providing an easy and intelligent online shopping environment.

It is usual to analyze the complexity of a new optimization problem since system developers in the field have a high interest about the difficulties to find an optimal algorithms.

We provide two results from the complexity analysis in this paper. First, our problem belongs to strongly NP-Hard in general case, which implies system developers in the field that it is prohibitively time consuming to try to obtain the exact optimal solution. Second, in special case that there exists at most two items for a bundle and there is no difference with delivery cost, we suggest an optimal algorithm by transforming our problem into minimum weighted perfect matching problem.

This research has several limitations. Our research model is based on the assumption that informations about items to purchase are standardized globally or domestically and price informations are available in real time. Even though we suggest an optimal algorithm in some special case of problem, we do not suggest efficient heuristic methods in general case. Finally, we do not suggest an experimental results with field data.

Further research to collect informations about items exactly and in real time is required and developing an efficient heuristic for the problem in general case is also required.

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