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Graph-Based Modeling for Optimal Strategy in Online Buying

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Abstract. Discount is a type of online purchase promotion that is presented based on the total value of consumer purchases. In this paper, an online purchase optimization problem will be studied, where a buyer is interested in buying several items ($x \geq 2$) by considering the total value discounts from different retailers, so that result in significant cost savings. The comparison shopping websites can be an alternative for consumers to find and compare information on items they want to buy from many online retailers. An integer programming formulation is proposed to obtain a near-optimal model of the online purchase problem. Then this formulation was developed into a graph-based modeling which was presented to build an optimization model (OptiGraph). The OptiGraph model obtained consists of the OptiNode set (subgraph) SG_a, SG_b, SG_c (retailer a, b, and c which contains nodes m_1 and m_2 in each subgraph representing the item to be purchased) and the OptiEdge set which describes the relationship between nodes in the subgraph. All nodes and edges contain the constraint function properties of the integer programming formulation of the online purchase problem with discount.

Keywords: Online buying, shopping website, online purchase problem

INTRODUCTION

Buying multiple items from different online retailers causes shipping costs to increase, so online customers needto calculate the shipping costs charged by grouping the items they want to buy and will buy from a number ofonline retailers to minimize shipping costs. Supported by sales promotion tools, such as discounts, attract customers' attention in calculating the total cost to be paid with consideration of discounts and minimum shipping costs.

In a previous study, (Błażewicz et al., 2010) presented their research on the optimization problem of online shopping. The problem studied in this study is the problem of optimizing online shopping for multiple items in several online retailers, where the total cost of a customer to buy a certain set of items must be minimized from all available offers. Then (Błażewicz & Musiał, 2011) found the first algorithm for solving the online shopping optimization problem and showed the results of the calculations. Furthermore, (Blazewicz et al., 2014) redeveloped the online shopping optimization problem by involving a new parameter, namely discounts and showing the basic algorithm. Then (Musial et al., 2016) put forward their research to present several algorithms to solve online shopping optimization problems that consider shipping costs and discount prices based on world observations, which means the more money customers spend in shopping, the bigger discounts they get.

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The problem of optimizing online purchases from different retailers that offer a total discount value was also raisedby (Kameshwaran & Benyoucef, 2008) in their research. In this study a decision support tool was developed for a buyer who is interested in buying several items from different online retailers that offer a total value discount. The researcher proposes an integer programming formulation to get a near-optimal model for the problem. The proposed decision tool could be implemented by a shopping comparison site that provides pricing information for individual products.

In this study which refers to the research of (Kameshwaran & Benyoucef, 2008), our interest is in the scenario where a buyer is interested in buying several different items simultaneously. Our focus here is on the buyers who take advantage of the total value discounts offered by online retailers when purchasing multiple items. The total value discounts is the discount offered if the total value of the purchase exceeds a certain limit or is within a certain range. This business practice is a common sales promotion tool used by online retailers today. The discount is purely based on the total value of the purchase. Discounts can be in the form of cashback, rebates, gift vouchers, or gift points. For buyers interested in buying multiple items, taking into account the total value of discounts from different retailers will result in significant cost savings. Prices of a product from different retailers can be obtained from comparison shopping websites. With this information and the total value discounts offered from the retailer, the buyer must determine the optimal retailer's allocation of goods, i.e. from which retailer to buy goods. We model this problem asan optimization problem.

By using graph-based modeling, the optimal strategy for the optimization problem of online shopping will be modeled in determining which store should be chosen by buyers who want to buy several items from several retailers. This is intended so that the total final cost to be paid (taking into account the total value discounts) is minimal. The search for the required item can be searched by utilizing comparison shopping websites.

PRELIMINARIES

The online purchase optimization problem proposed by (Kameshwaran & Benyoucef, 2008) in their research, develops a decision support tool for a buyer who is interested in buying several items from different online retailers that offer a total discount value. In this study, we focus on the study of modeling the optimal strategy for online shopping problems using graph-based modeling. Graph-based modeling abstraction is presented to build an optimization model which is also known as OptiGraph (Jalving et al., 2020). The proposed OptiGraph abstraction consists of a set of OptiNode N (each node can be assigned a property in the form of an optimization model with local variables, constraint functions, objective functions, and data) and a set of OptiEdge E (where each edge can be assigned the property of the set of connecting constraints) which describes the relationship between the OptiNode (Khattak et al., 2019).

In this paper, an online purchase optimization problem will be studied, where a buyer is interested in buying several items $(x \geq 2)$ by considering the total value discounts from different retailers, so that result in significant cost savings. Discounts are applied if the total purchase at an online retailer exceeds a certain limit. Items can be searched by buyers using comparison shopping websites. The comparison-shopping websites provide price information for a product from different online retailers, as well as additional information, such as retailer credibility, shipping costs, sales tax, and so on. Based on this information, the buyer can choose the optimal retailer.

The following is an illustration of optimizing online purchases using comparison shopping websites:

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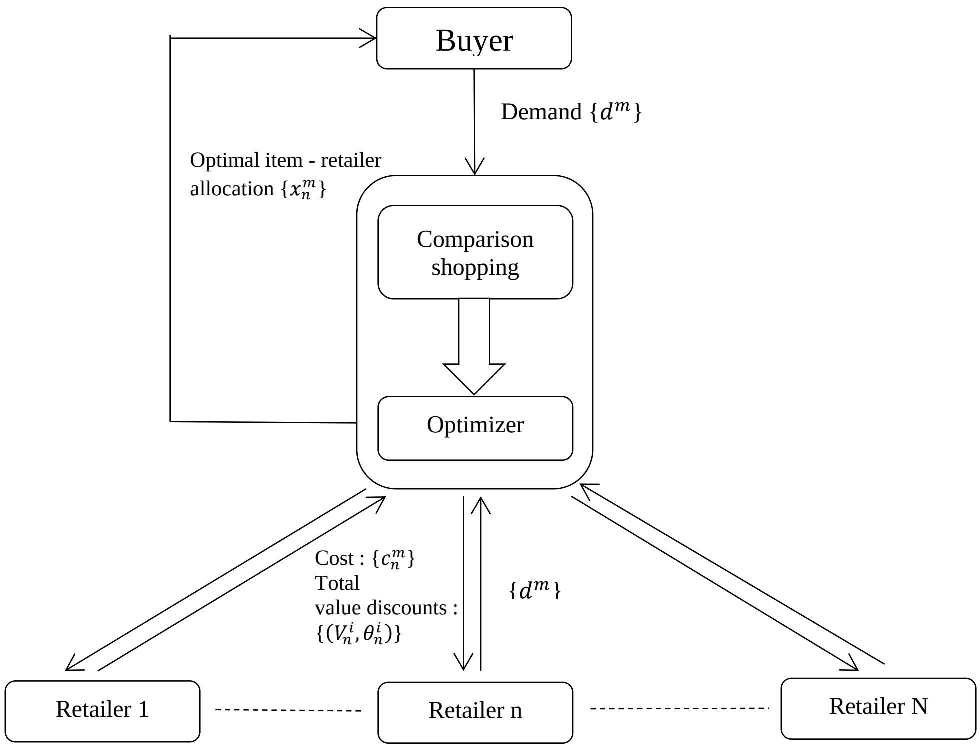

Figure 1. Illustration of optimizing online purchases by utilizing comparison shopping websites

Next, we will study graph-based modeling to be applied to the online purchase optimization model above by applying graph-based abstraction to build an optimization model which is also known as OptiGraph. The optimization model at each node can be expressed algebraically (as in a pre-built online purchase optimization modeling language) or as a graph. To illustrate this, we will consider an OptiGraph (subgraph), each with its own local node and edge. This set of OptiGraphs (subgraphs) is assembled to form a global OptiGraph (graph).

MAIN RESULT

The discussion of this research focuses on the scenario where a buyer is interested in buying $1, \dots, m, \dots, M$ items with demand $d^m \geq 1$, $d^m \in Z$ for each item m from $1, \dots, n, \dots, N$ different online retailers. Retailer n has inventory $s_n^m \geq 0$ for item m with unit price $c_n^m \geq 0$. It is assumed that retailer n provides $I_n \geq 1$ the type of total value discounts that is applied to the buyer if the total purchase exceeds a certain price limit. The discount offered by retailer n can be represented in the form:

$$\left\{(V_n^0, \theta_n^0), (V_n^1, \theta_n^1), \dots, \left(V_n^i, \theta_n^i\right), \dots, \left(V_n^{I_n}, \theta_n^{I_n}\right)\right\} \quad (3.1)$$

If the total value of purchases from retailer n is in the range $\left[V_n^i, V_n^{i+1}\right]$, then the discount value obtained is θ_n^i. By definition $\left[V_n^i, V_n^{i+1}\right]$, then $V_n^{i+1} > V_n^i$ such that $\theta_n^{i+1} \geq \theta_n^i$. Hence, for $i = 1, \dots, m = 0$ it can be assumed that $V_n^0 = \theta_n^0 = 0$.

Referring to the illustration in Figure 2.1, a buyer searches for information on the items he wants to buy $\{d^m\}$ through a shopping comparison site, so that information about items will be obtained starting from the price of item m at retailer n which is assumed to be $\{c_n^m\}$, inventory of m items at retailer n

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which is assumed to be $\{s_n^m\}$, and the total value discounts function $\{(V_n^i, \theta_n^i)\}$ from N different online retailers. Then all this information is passed to an optimization step which determines the online retailer's allocation of the optimal selection of items $\{x_n^m\}$, where $\{x_n^m\}$ represents the number of m items to be purchased from retailer n.

In forming an integer programming formulation to allocate optimization, then x_n^m is defined as an integer decision variable that indicates the number of items m to be purchased from retailer n. In addition, to form a limit on the total discount value, the binary variable $\{y_n^i\}$ is used. If $y_n^i = 1$ then θ_n^i discount is available for purchase of item $i = 1, \dots, m$ from retailer n because purchases are in the range $[V_n^i, V_n^{i+1}]$ and $y_n^i = 0$, otherwise. Therefore, the objective function for minimizing the total purchase cost taking into account the discount is given as follows:

$$\min \sum_n \sum_m c_n^m x_n^m - \sum_n \sum_i \theta_n^i y_n^i \quad (3.2a)$$

s.t.:

$$\sum_n x_n^m = d^m \quad \forall m \quad (3.2b)$$
$$x_n^m \le s_n^m \quad \forall n, m \quad (3.2c)$$
$$\sum_i y_n^i = 1 \quad \forall n \quad (3.2d)$$
$$\sum_m c_n^m x_n^m \ge \sum_i V_n^i y_n^i \quad \forall n \quad (3.2e)$$
$$x_n^m \ge 0, x_n^m \in Z \quad \forall n, m \quad (3.2f)$$
$$y_n^i \in \{0,1\} \quad \forall n, i \quad (3.2g)$$

For all of the above, $m \in [1, \dots, M]$, $n \in [1, \dots, N]$, and $i \in [1, \dots, I_n]$. $\sum_n \sum_m c_n^m x_n^m$ in equation (3.2a) represents the total cost of purchasing all items m from all retailers n and $\sum_n \sum_i \theta_n^i y_n^i$ represents the sum of all the total value discounts obtained. The constraint form in (3.2b) shows that the buyer's demand for item m is the number of items to be purchased after selecting each item through a comparison shopping websites. The constraint in (3.2c) is an inventory constraint. The items m to be purchased must be in accordance with the inventory of these items at the retailer n. The constraint in (3.2d) ensures that only one total discount value is selected for each retailer. The constraint in (3.2e) states that the total purchase price of an item is consistent with the discount offered, meaning that to get a discount, the prices of all items purchased at retailer n must be greater than or at least equal to the total range of purchase prices set by the retailer.

Without the total value of the discount, the optimization problem in online purchases is relatively simple. Several algorithms can provide optimal allocation in selecting the retailer with the minimum cost for each item, depending on the retailer's inventory capacity. Thus, the variable $\{x_n^m\}$ can be assumed to be linear for the constraints (3.2b) and (3.2c) because there will always be an integer optimal solution. However, given the discount constraint (3.2e) and the nature of the objective function (3.2a), the variable $\{x_n^m\}$ must be specified as an integer variable.

M request items can be from different categories such as books, accessories, electronics, and so on. However, retailer N does not have to sell all items M. Because there are some retailers who only sell certain items. Therefore, the formulation of minimizing the total purchase cost above can be easily used for this category of retailers, namely by modifying inventory $s_n^m = 0$ for item m that is not sold by a retailer n.

Furthermore, the integer programming formulation of the optimal online purchase model by considering the above discount can be modeled into graph-based modeling. The OptiGraph model was built by applying an online purchase optimization model with discount considerations as an optimization model that includes variables, constraints, and objective functions. This OptiGraph abstraction consists of a set of OptiNode N (each node is assigned a property of a variable, constraint, or objective function) and a set of OptiEdge E (each edge is assigned a property of a set of connecting constraints) which will describe the relationship between the OptiNodes.

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To illustrate the graph-based modeling (OptiGraph) of the optimal model of online purchases by considering discounts, we try to apply an example from the research of (Kameshwaran & Benyoucef, 2008), where it is assumed that a buyer is interested in buying two types of textbooks. Through comparison shopping websites, the textbooks are compared to obtain price information, shipping costs, available discounts, retailer credibility, and sales tax from different retailers. From that information, we took a sample of three of the lowest-cost retailers to build the OptiGraph model.

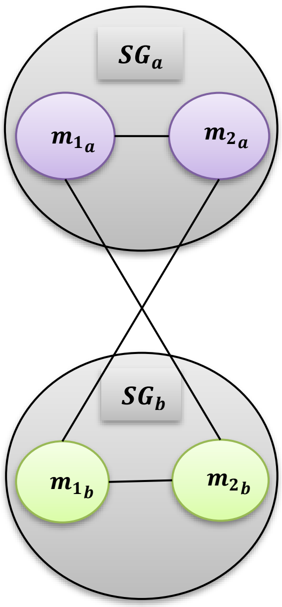

Figure 2. Subgraph partition between retailer a and b

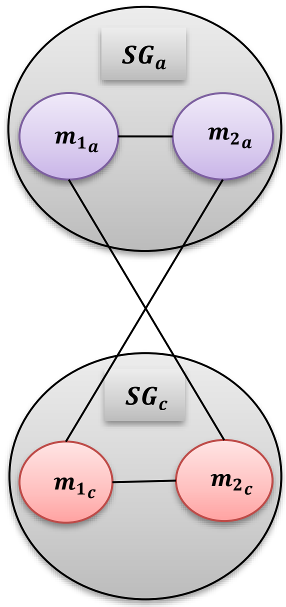

Figure 3. Subgraph partition between retailer a and c

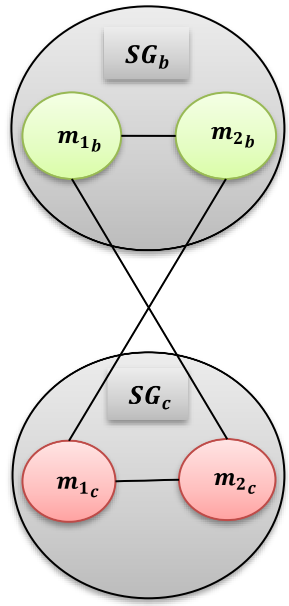

Figure 4. Subgraph partition between retailer b and c

The three images above show the partitions which are the parts (subgraphs) to form a global graph G. The subgraphs SG_a, SG_b, SG_c above represent retailers a, b, and c which contain two nodes in each subgraph that represent the item to be purchased, namely m_1 and m_2. The items m_1 and m_2 in the subgraph SG_a are the same items as the items in the subgraphs SG_b and SG_c. Every node m_1 in each subgraph is connected exactly once to each of the other node m_2. This aims to see the costs that will be incurred for each pair of items m_1 and m_2 that want to buy taking into account the total value discounts. So that in the end we will get the pair of items m_1 and m_2 which has the lowest cost. To declare that, an integer programming formulation will be applied from the optimal model of online purchases by considering discounts, in the form of the partition above.

To describe graph-based modeling as a whole, an OptiGraph will be formed which is a combination of the three graph forms above which are given the optimal model properties for online purchases by considering discounts, for each node and edge.

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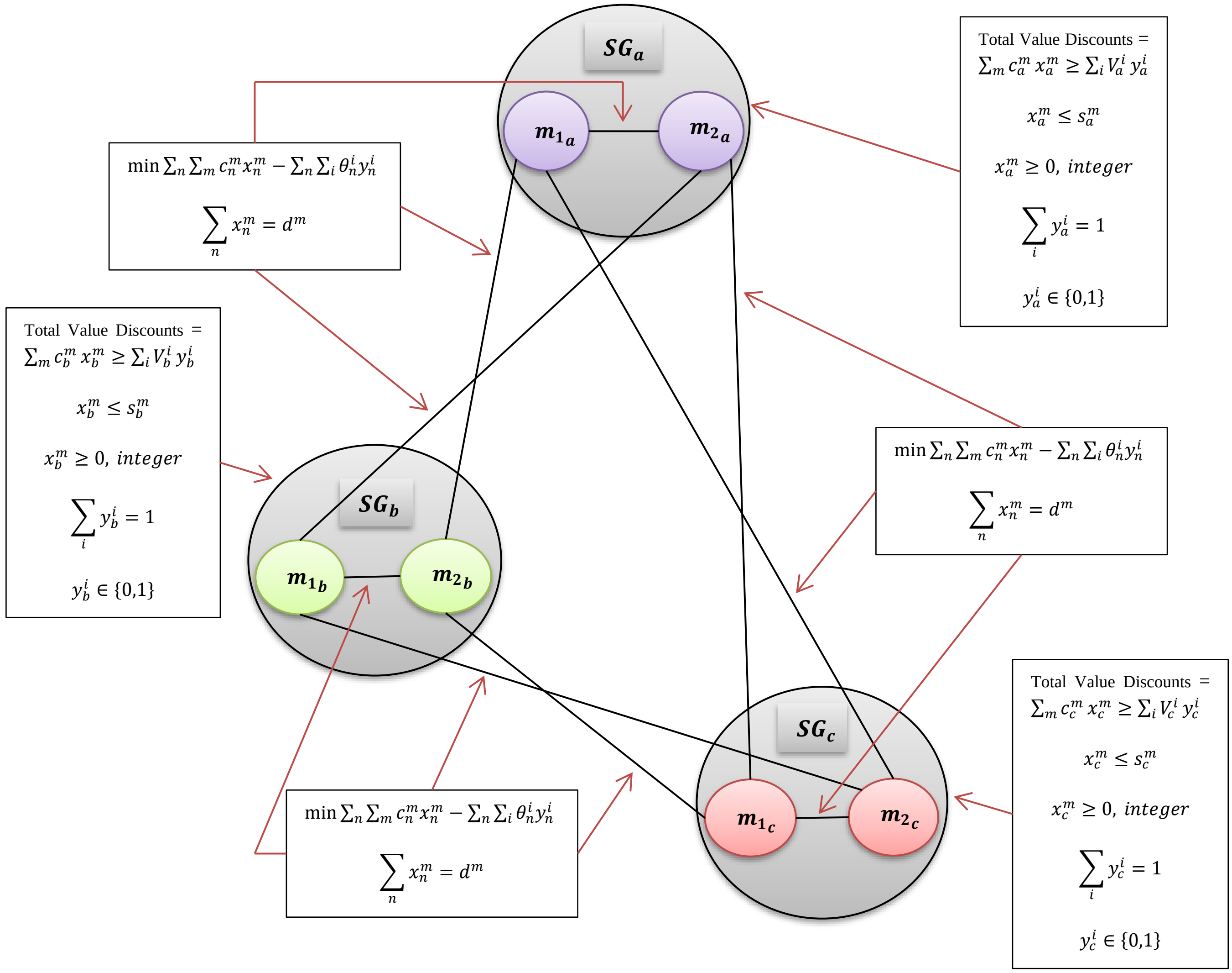

Figure 5. OptiGraph online purchase optimization model by considering discounts

The graph above is a graph-based modeling that is presented to build an optimization model which is also known as OptiGraph. The OptiGraph abstraction above consists of subgraphs SG_a, SG_b, and SG_c which represent retailers. This figure is a form of graph-based modeling to minimize the cost of purchasing items m_1 and m_2 from retailers a, b and c. In each subgraph there are nodes that represent items m_1 and m_2 that want to buy and edges that describe the relationship between nodes. Node m_1 is connected by an edge with node m_2 of each retailer with the objective function property $\min \sum_n \sum_m c_n^m x_n^m - \sum_n \sum_i \theta_n^i y_n^i$ for minimize costs. This is done to find pairs of items m_1 and m_2 that have the minimum cost with consideration of shipping discounts from retailers a, b and c. All subgraphs SG_a, SG_b, and SG_c are assigned the constraint function property $\sum_m c_n^m x_n^m \geq \sum_i V_n^i y_n^i$ which indicates that there is a total value discounts with a range of purchase costs.

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CONCLUSION

Based on the explanation that has been described previously, it can be concluded that the optimization problem in online purchases for a buyer who wants to buy several items from different retailers by considering the total value discounts can be modeled into an integer programming formulation. A decision support tool, namely a comparison shopping websites, can be used to obtain and compare price information for the item you wish to purchase from all available retailers. An integer programming formulation is proposed to obtain a near-optimal model of the online buying problem. This formulation can then be developed into a graph-based modeling which is presented to build an optimization model which is also known as OptiGraph. The OptiGraph model consists of subgraphs SG_a, SG_b, and SG_c which represent retailers and nodes which represent items m_1 and m_2 that want to buy. Node m_1 is connected by an edge with node m_2 of each retailer with the objective function property $f()$ $\min \sum_n \sum_m c_n^m x_n^m - \sum_n \sum_i \theta_n^i y_n^i$ for look for the pair of items m_1 and m_2 that has the minimum cost with consideration of shipping discounts from retailers a, b and c. The subgraphs SG_a, SG_b, and SG_c are assigned the constraint function property $\sum_m c_n^m x_n^m \geq \sum_i V_n^i y_n^i$ which indicates that there is a total discount value with a range of purchase costs.

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