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A KNAPSACK OPTIMISATION MODEL TO DETERMINE THE REQUIRED ITEMS FOR AN ANNUAL DINNER

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Abstract: Many companies recognise the achievements and contributions of their employees throughout the year through annual dinners. Commonly, companies will allocate a certain amount of money to organise an annual dinner. However, planning such an event is not easy as the organising team needs to plan the event carefully according to the specified budget. This paper demonstrates how a binary knapsack problem approach is applied to help an insurance company select the required items for its annual dinner within the allocated budget. Two models were developed and solved using the LINGO 12.0 software. The first model was developed to determine the activities that will be selected based on the restriction of the total budget. The second model was developed to maximise staff preference on the selected items within the specified budget. The results of both models were compared and discussed. The item selection technique used in this study is for organisations with a limited budget.

Keywords: Knapsack problem, binary integer programming, optimization, items selection.

Introduction

In recognising the achievements of a company's milestones and staff contributions, many companies embrace the tradition of annual dinners. The organisation of such an event may provide the ideal context for collective recognition, improving staff motivation and working mood, as well as promoting the achievement of a company to its business market. For these very reasons, every organisation aims to have a unique annual dinner, gala dinner or anniversary celebration. Expenses association with an annual dinner has become part of a company's budget. Using the specified budget, the organising team needs to carefully plan the annual dinner. Planning such an event is not an easy task as it involves many items and activities.

In this paper, we demonstrate how a binary knapsack problem approach is applied to help a planning team from an insurance company select the required items for its annual dinner. A knapsack problem is a scenario where given a set of items with specific weight and assigned values, the value of the knapsack is maximised while remaining within the weight constraint (Fluschnik *et al.,* 2019). The knapsack problem can be found in many real-world scenarios, like resource allocation and selection problems (Gambrah, 2013; Kwarteng, 2017). Therefore, in the same way, this approach can be applied to determine the required items for the insurance company's annual dinner.

In the following sections of the paper, we have provided literature on the knapsack problem and its applications, followed by the formulation of the knapsack model. Next, the analysis and some brief discussion on the obtained results are presented. Finally the conclusion discusses the achievement of the study, as well as some suggestions for possible future work.

Materials and Methods

The Knapsack Problem

During a management meeting of the insurance company, representative from each department suggested several main items needed for the annual dinner. Each of the items has its own preference value given by the staff prior to the meeting. The team was allocated RM 30,000 for the selection of appropriate items from the suggested list. Its decision however, is constrained to the costs associated with each of the items. Based on literature reviews, the problem faced by the insurance company fits the characteristics of a knapsack problem.

A knapsack problem can be solved by a few methods, such as optimisation, heuristics and metaheuristics (Bednarczuk *et al.,* 2018; Ahmad Saidi *et al.,* 2021). The selection of the method usually depends on the size and complexity of the problem. The optimisation approach is an exact approach that guarantees the best solution by satisfying all the constraints. Heuristics and metaheuristics, on the other hand, are approximate approaches that are necessary to construct a control structure that is no longer guaranteed to find the best solution, but will always find a better solution. Hence, optimisation is suitable for a small-scale problem with less complexity. Many researchers had used the optimisation approach to solve the knapsack problem (Yang *et al.,* 2019; Martello & Monaci, 2020). For more complex problems, there are several important examples of real-life applications of the knapsack problem found in literature, such as resource allocation (Earnshaw & Dennett, 2003), advertising budget (Ichikawa *et al.,* 2009), operating room time (Blake & Donald, 2002) and project selection (Haddadh *et al.,* 2016).

For this study, we used the optimisation approach to solve the problem since it involves only 20 decision variables. To select the best items for the annual dinner, two integer programming (IP) models were developed and solved using LINGO version 12.0. The LINGO software, under the copyright of LINDO System Inc., is used in this study based on its straightforward intuitive manner using summations and subscripted variables, which allow users to express a mathematical model similar to a manual model formulation with pencil and paper.

The first model is developed to determine which activities will be selected based on the restriction of the total budget. The second model, meanwhile, was developed to maximise staff preference on the selected items within the specified budget. The preference value is determined based on scale of 1 to 10, whereby 10 is very important and 1 the least important. Decisions need to be made on 20 items, each with cost and preference values as displayed in Table 1. The knapsack capacity of this problem is the allocated budget, which is RM30,000.

Table 1: The list of suggested items

No.	Items (Variable)	Cost (RM)	Preference (scale 1-10)
1	Ballroom rental	5000	10
2	Furniture (tables and chairs)	1000	10
3	Food and beverages	11000	10
4	Recorders/cameras rents	1500	3
5	Overhead projector/cart/screen rents	2400	4
6	Sound system	2600	7
7	Band/emcee fees	3000	2
8	Special lighting	1500	5
9	Event/stage/table/chair décor	2000	8
10	Receptacles/dumpsters/trash service	1500	3
11	Security facilities	800	1

12	Posters/Invitation	200	2
13	Desserts	1500	2
14	Games things/Prizes	850	6
15	Grand photo booth	800	1
16	Parking rental	1000	8
17	Ballroom time extension	1000	1
18	Souvenir	800	6
19	Lucky draw/Gifts	2900	7
20	Performance	4000	5

The Integer Programming Models and the Results

In general, the knapsack problem in this study can be formulated as an IP model as in Equation (1):

$$Maximise \quad \sum_{i=1}^{n} V_i x_i$$

Subject to:

$$\sum_{i=1}^{n} C_i x_i \leq t$$

$$\forall i \in (1, \dots, n), x_i \in (0,1) \tag{1}$$

where xi = the number of i-items that are selected for the knapsack problem using $xi = 0$ or 1 (i = 1,2, … , 20). xi are binary decision variables, which equals to one (1) if the item is packed in the knapsack and zero (0) otherwise.

Ci = cost of each type of item i, for i = 1,2, … , n.

Vi = value associated with each item, in terms of number of items, the preference, for i = 1,2,…,n.

and

t = the total capacity allowable for the knapsack $i.e$ the allocated budget

Model A

We began by developing the first model (Model A) to determine the maximum number of items that would be selected from Table 1 based on the specified total budget. The objective function can be written as follows:

$$Max\ Z = x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7 + x_8 + x_9 + x_{10} + x_{11} + x_{12} + x_{13} + x_{14} + x_{15} + x_{16} + x_{17} + x_{18} + x_{19} + x_{20}$$

The objective function is subject to two constraints:

i) the maximum specified budget of RM30,000

5000x1 + 1000x2 + 11000x3 + 1500x4 + 2400x5 + 2600x6+ 3000x7+ 1500x8+ 2000x9 + 1500x10 + 800x11 + 200x12 + 1500x13 + 850x14 + 800x15 + 1000x16+ 1000x17 + 800x18 + 2900x19 + 4000x20 <= 30000

ii) the constraint of selecting the main components of the event is also included, which are the ballroom rental ($x1$), tables and chairs ($x2$), and food and beverages ($x3$);

$$x_1 + x_2 + x_3 = 3$$

The optimal solution for Model A is given in Table 2. The results show that 14 out of 20 items were selected. The total budget required is RM28, 450 and the total preference of the staff is only 68 out of the 101 preferences of all items. Six items that were not selected under this solution, which are x5, x6, x7, x9, x19 and x20.

Table 2: Results for Model A

No.	Decision variables	Items	Preference (scale 1-10)	Cost (RM)
1	X1	Ballroom rental	10	5000
2	X2	Furniture (tables and chairs)	10	1000
3	X3	Food and beverages	10	11000
4	X4	Recorders/cameras rents	3	1500
5	X8	Special lighting	5	1500
6	X10	Receptacles/dumpsters/trash service	3	1500
7	X11	Security facilities	1	800
8	X12	Posters/Invitation	2	200
9	X13	Desserts	2	1500
10	X14	Games things/Prizes	6	850
11	X15	Grand photo booth	1	800
12	X16	Parking rental	8	1000
13	X17	Ballroom time extension	1	1000
14	X18	Souvenir	6	800
		TOTAL	**68**	**RM28, 450**

Model B

As Model A focuses on maximising the number of selected items, Model B, on the other hand, aims to maximise the total preference weight given by the staff. In Model B, we modified the objective function of Model A, but the constraints remain unchanged. The objective function can be written as follows:

$$Max\ Z = 10x_1 + 10x_2 + 10x_3 + 3x_4 + 4x_5 + 7x_6 + 2x_7 + 5x_8 + 8x_9 + 3x_{10} + x_{11} + 2x_{12} + 2x_{13} + 6x_{14} + x_{15} + 8x_{16} + x_{17} + 6x_{18} + 7x_{19} + 5x_{20}$$

The optimal solution for Model B is given in Table 3. The results show that 12 out of 20 items were selected. The total budget required is RM29, 650 and the total preference of the staff is 80 out of the 101 total preferences of all items. Eight items that were not selected under this solution are $x4$, $x5$, $x7$, $x10$, $x11$, $x13$, $x17$ and $x20$.

Table 3: Results for Model B

No.	Decision variables	Items	Preference (scale 1-10)	Cost (RM)
1	X1	Ballroom rental	10	5000
2	X2	Furniture (tables and chairs)	10	1000
3	X3	Food and Beverages	10	11000
4	X6	Sound system	7	2600
5	X8	Special lighting	5	1500
6	X9	Event/stage/table/chair décor	8	2000
7	X12	Posters/Invitation	2	200
8	X14	Games things/Prizes	6	850
9	X15	Grand Photo booth	1	800
10	X16	Parking Rental	8	1000
11	X18	Souvenir	6	800
12	X19	Lucky Draw/Gifts	7	2900
		TOTAL	**80**	**RM29, 650**

Discussion

Table 4 displays the comparison between the developed models. The practical approach to solve this knapsack problem is by using Model B as it considers all the main items for the annual dinner, like the ballroom rental, tables and chairs, and food and beverages, while maximising the staff preference on the selected items. The percentage of preference for Model B is higher than Model A, which fulfill 79.21% of the total preference. In term of budget utilisation, Model B also recorded a higher value than Model A, which achieves 98.83% of the total budget at the cost of RM29, 650. However, as the cost for the main items are high, the number of selected items in Model B is less than Model A, which is only 12 items.

Table 4: Comparison of the two models

Components	Model A	Model B
Total cost (RM)	28, 450	29, 650
Budget utilisation (%)	94.83	98.83
No. of items selected	14	12
Preference fulfilment (%)	67.33	79.21

Conclusion

This study seeks to find the suitable items for the annual dinner of an insurance company based on the allocated budget. The problem was solved using the knapsack problem approach. The results show that the optimal solution given by Model B provides a better solution by maximising staff preference while ensuring the cost stays within the allocated budget. For future studies, the proposed IP model can also be used with some modifications to study different perspective of other type of item selection problems. In future, the knapsack model may also be embedded in a decision support system to help the management team make quick decisions for items selection.

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