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USING ORTHOGONAL ARRAY IN DESIGNING EFFECTIVE QUESTIONNAIRE FOR IMPROVING INVENTORY ACCURACY AT ELECTRICITY WAREHOUSE

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ABSTRACT

The process of classical data collection through a survey is time-consuming, expensive, and may not be feasible. In practice, it is always good to make sure that the survey design works with the diversity of factors and levels that affect the products or services. Since the data quality gathered depends solely on the quality of the survey constructed and the written questions, this paper presents one of the most effective tools in designing a stated-choice survey using orthogonal array design to gather the information that improves the inventory accuracy in electricity company's warehouses. The stated-choice survey provides an effective way to explore survey respondents' preferences and evaluate the interchanges that survey respondents make in considering several product and service combinations. This method will help inventory engineers and workers for data collection with more information and a minimum number of questions and efforts.

Keywords

Orthogonal array; stated-choice survey; Discrete choice experiments and analysis; inventory control; inventory accuracy.

1. Introduction

Discrete choice experiments and analysis (DCA) are widely used in marketing research, health economics, and other areas. They have been used to establish policy or survey questions, construct consumer preferences on a specific topic, and assess current situations. Besides, they are instrumental when exploring and understanding people's preferences when data are not available of alternative products and services. In choice experiments, respondents are offered a set of different choices to be selected from a set of possible options.

In logistic, there are several criteria evaluated and considered simultaneously before purchasing a material, or a service. Verma et al. (1996) stated that purchasing decision about a material or service might consider several parameters such as service or product quality, speed of delivery, special incentives for buying, and price. Managers want to know how consumers integrate, value and exchange different product and service features. The DCA approach provides a robust and systematic way of recognizing the relative weights and change in attributes caused by decision makers' preferences. DCA approach is based on well tested, and relatively comprehensive random-utility theory (RUT) leading to a wide-range of traceable and testable models of selection behavior. In fact, RUT delivers a theoretical link among surveys, experiments, and the other forms of stated choices and the actions detected in real-life settings. Categorical outcomes are obtained from discrete choices because they select one alternative from each set of alternatives. Similarly, mathematical models demonstrating customer choice of product and services can be linked to budgets, labor scheduling, service offerings and several other factors called operating decisions. The statistical models can be employed from discrete-choices of buying processes and incorporated in decision-support systems (DSSs) to build a model for unique approaches. Dolnicar (2013) offered certain schemes for measurement in the social sciences to draw clear conclusions about various measurement challenges. Developing good survey questions is crucially important and precisely depend on defining what is being measured. For most measurements, experts argue for the requests of a good definition of the goals, however unable to provide helpful guidelines as how to build the definition that conforms with the criteria stated. Theoretical meaning of factors is usually discussed, for instance Bagozzi (2011) stated the ambiguity, vagueness, of factors. Dolnicar (2013) argues that good definition of criteria had better not be vague, imprecise, ambiguous, or unclear. The criteria must be obviously understood by the respondents who should agree on their meaning. When service marks are considered, if net definition is not allowed, will increase the uncertainty of decision-making in providing information. This is considered as the uncertain information, for reducing the effects of uncertain information, the intuitionistic fuzzy sets can be presented by considering the membership degrees (Mi et al., 2019) to reduce the ambiguity and vagueness. Yager (2017) presented the intuitionistic fuzzy sets to overcome the dilemma and develops the degree of flexibility in representing the information preferred. Vetschera (2017) stated that in decision-making problems determining the weights of criteria is the primary concern. In this context, analytic hierarchy process (AHP) is an appropriate method (William & Xin, 2018) for weight-determination like fuzzy AHP, fuzzy TOPSIS and fuzzy VIKOR approaches. The economic globalization brought economic integration of the world, the growth of services continue that becomes fast and steadily, is a global strategy of comprehensive industries (Meimand et al., 2017). For instance, VIKOR and TOPSIS approaches are practical methods to solve decision making problems, specifically in the condition where the assessment of options over buying criteria are conflicting. The fuzzy extensions of TOPSIS, VIKOR and AHP play an important role in the intuitionistic and hesitant fuzzy information, and linguistic information with hesitation (Liao et al., 2015) for solving the decision-making problem.

On the other hand, the qualitative research approaches can be carried out for the intent of apprising the enhancement of questionnaires for the inventory management solely. Nowadays, many surveys are conducted online with the questionnaires time taking 15 min on average to complete it. Surveys taking longer than 15 min might need less randomness or include systematic errors related with fatigue or boredom (Hoerger, 2010; Brosnan et al., 2018). Fan and Yan (2010) investigated short surveys and found out that they are less expensive and have several advantages over long surveys, they may return higher completion rates. Brosnan et al., (2018) proposed a statistical method for the evaluation and analysis of surveys, which is built on principal components analysis (PCA) for the elimination of redundant information and items with the loss of minimum information and optimal information gain. Abdi and Williams (2010) also studied the PCA to solve problems for determining the principal components. Yet, traditional PCA is not able to recognize the differences of items redundant and to provide optimum information for survey items. PCA suggests potential for reducing survey superfluous items. Brosnan et al. (2018) stated that no item is superfluous if each major component exhibits significant variability. Specialized sampling techniques are employed to attain balance between costs and statistical accuracy. Kolenikov (2010) stated that data collection in large-scale statistical surveys involves data clustering, data stratification, multiple and unequal selection possibilities, and sampling with or without displacement. Survey-sample designers use stratification to increase efficiency, protect against poorly unbalanced samples, to optimize the overall survey cost. Sampling weights are used for guaranteeing the unbiased estimation which are adjusted so that the weighted totals of poststratification variables fit the population totals. Nevertheless, a precise accounting for a complex survey design is extremely cumbersome.

The statistical method aims to decrease survey size, to solve the managerial problems of acquiring optimal information with minimal cost involving data collection across multiple points in time to improve data quality, both longitudinal and repeat cross-sectional. The PCA is a standard method for reducing a set of survey items (Boyes et al., 2009). Cervellera, et al. (2007) presented multivariate adaptive regression splines in high-dimensional inventory forecasting of water reservoir problem using stochastic dynamic programming, and orthogonal array (OA) experimental designs. They also studied the implementation of artificial neural networks (ANNs) as an alternative approach and found out that ANNs performed better with the OA-Latin hypercube designs. Ambreen et al. (2019) studied to find out disparate stock administration systems of assembling organizations in Pakistan to investigate the inventory management procedures functionally in the country. The problems of stock administration determined in this study are poor production schedule, spillover, stockout circumstance, high lead time and mishandling of records, it was determined that these parameters have significant influence on the effectiveness of inventory management system. Otchere et al.m (2016) examined the existing inventory management practices of a chosen company in Ghana. The study used interview administered questionnaire to collect data from staff of the company for keeping the stock always available. The survey revealed that, the company faced with serious long lead time challenges in ordering parts leading to cancellation of purchase orders, so losing customers.

2. Orthogonal Design

There are several related meanings of orthogonal concept in statistical and mathematical sense. Statistically speaking, two factors are orthogonal if they are statistically independent, a factor does not significantly affect the other factor in an experimental design. Therefore, orthogonal array avoids factors from being too complicated or redundant. The orthogonal design includes each of the level combinations (factor pairs) an equal number of times. For illustration, consider three factors A, B, and C, each has two levels 1 and 2 as shown in Table 1. It can be seen that the AB pairing (1, 1); (2, 1); (1, 2); and (2, 2) and other two pairings, AC and BC, have only one occurrence or repeating, at each level combination.

Table 1. Orthogonal design

	Factor		
	A	B	C
Factor levels	1	1	2
	2	1	1
	1	2	1
	2	2	2

In contrast, the non-orthogonal design does not contain factor level pairing the same number of times. For example, Table 2. displays AB level combinations; (1, 1); (2, 1); (1, 2); and (2,2). However, the other two pairings AC and BC, have a duplicated and missed level combinations. For AC, (1, 2); (2, 1); (1, 2); (2, 1); and the (2,2) combination is missing. For BC, (1, 2); (1, 1); (2, 1); (2, 1); and the (2, 2) combination is missing and (1,2) is redundant.

Table 2. Non-orthogonal design

	Factor		
	A	B	C
Factor levels	1	1	2
	2	1	1
	1	2	1
	2	2	1

Therefore, the features provided by orthogonal design help the analyst in constructing effective experiments that can estimate each main effect and interaction independently. On the other hand, if the design is not orthogonal, either by plan or by accidental loss of data, the results and explanations may be misguided.

The name of the orthogonal array is well known to statisticians in designing optimal experiments that require complete or only a fraction (short duration) of all factorial combinations. An orthogonal array defines a balanced layout, that is the factor levels are weighted alike. Then each factor can be evaluated separately from all other factors, thus the influence of one factor does not impact the estimation of another factor.

Each column in an orthogonal array defines a specific factor that can have two or more levels. Each row represents a run that indicates the factor level combinations for the run.

An orthogonal array OA is denoted by (*N.f.l.t*). The parameters *N*, *f*, *l*, and *t* represent the number of runs (rows), the number of factors (columns), the number of levels, and strength of the design, respectively. For illustration, Table 3 shows an OA (8.7.2.2) which includes only 8 runs which represents a fraction of the full factorial design. On the other side, if a full factorial design were used, it would have $2^7 = 128$ runs, which consumes more costs, times, and efforts. It can be noticed that any 2 columns (factors) of the array of Table 3, for example the first (A) and the third (C), each of the factor level combinations 11, 12, 21, and 22 occurs exactly the same number of times (two in this case) and that represents the strength of the OA. In general, orthogonal array designs emphasis mostly on major effects. However, some of the arrays allow a few selected interactions to be studied. Orthogonal arrays are widely used in computer science, engineering, and business Gopalakrishnan and Stinson (2008) and Garcia-Diaz and Phillips (1995)

Table 3. Orthogonal Array (8.7.2.2)

	A	**B**	**C**	**D**	**E**	**F**	**G**
1	1	1	1	1	1	1	1
2	1	1	1	2	2	2	2
3	1	2	2	1	1	2	2
4	1	2	2	2	2	1	1
5	2	1	2	1	2	1	2
6	2	1	2	2	1	2	1
7	2	2	1	1	2	2	1
8	2	2	1	2	1	1	2

3. Methodology

The method starts by the analyst for creating a choice design that defines the main factors for constructing the questionnaire. Each factor contains different levels or alternatives that properly define various choices provided by the factors. A number of factors' alternatives construct the options. A group of possible options defines a choice set, and each set contains the choice of the questionaries. After, the options are constructed, the total number of questions per respondent is defined based on different designs of orthogonal arrays (A Library of Orthogonal Arrays" http://neilsloane.com/oadir/). For an illustration purpose, figure 1 depicts the overall conceptual approach applied in this study.

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forming survey questions (factor descriptions and levels) | selecting appropriate OA from OA's library | deploy the questioner

Figure 1. Overall conceptual approach

4. Application on stated choice

Any manufacturing or distribution company's success in today's interrelated fast global supply chain logistic environment is directly linked to the organization's degree of inventory accuracy. However, the effort and approach required to achieving inventory accuracy are often misunderstood and underestimated. Every year the inventory committee people in the Electricity Company count and record physical items in warehouses and comparing them with quantity in the system record; that is, the accuracy here is the percentage of matching between the physical quantities and the recorded quantities in the inventory's system, a traditional cycle counting procedures are scheduled with no accuracy concern. Moreover, no suggested tools for accuracy improvement are studied. The linked inventory systems become unreliable and uncertain, especially when that happens in a critical and vital sector like Electricity Company warehouses. The problems associated with the system unreliability affect the supply chains with many wrong purchasing orders created by the purchasing department for the causes of shortage materials. As a result, excess materials and high costs for the inventory will be.

One of various suggested solutions to the electricity company is to design a stated choice questionnaire for the purpose of exploring and analyzing a lot of information to improve the inventory accuracy from the groups of inventory engineers and workers with minimum number of questions. This application intends to study different alternatives influence improving inventory accuracy. There are eight factors of interest: layout of warehouse areas, material classification types, gate security, tracking material equipment, inventory system structure, material documentation method, material handling type, and storage design. Table 4 lists the factors and the associated levels to be considered in the study.

The proposed design for the survey is displayed by the option or group of relevant factors that are suggested to improve inventory accuracy.

As shown in Table 4, the orthogonal fractional factorial OA (16.8.2.3) was selected from the orthogonal array's library [1] that allows sixteen questions, as it can be observed from Table 5 below of the stated choice questionnaire, that each row of the design defines four options (A, B, C, D).

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Table 4. Orthogonal array OA (16,8,2,3)

	A	B	C	D	E	F	G	H
1	0	0	0	0	0	0	0	0
2	0	0	1	1	1	1	1	0
3	0	1	0	0	0	1	1	0
4	0	1	1	1	1	0	0	0
5	1	0	0	1	1	0	1	0
6	1	0	1	0	0	1	0	0
7	1	1	0	1	1	1	0	0
8	1	1	1	0	0	0	1	0
9	1	1	1	1	1	1	1	1
10	1	1	0	0	0	0	0	1
11	1	0	1	1	1	0	0	1
12	1	0	0	0	0	1	1	1
13	0	1	1	0	0	1	0	1
14	0	1	0	1	1	0	1	1
15	0	0	1	0	0	0	1	1
16	0	0	0	1	1	1	0	1

All questions asked to the same respondent are grouped as blocks. As presented in Table 5, the proposed stated choice design suggests two blocks, as appears in table 5 with a dashed line separated between them, with eight questions each. Consequently, two respondents will be required to complete the questionnaire. This can be completed, for example, by circling one of the letters A, B, C, D for each row shown on the last column of the questionnaire of Table 5. The letters must be selected only once by each respondent. For example, respondent number 1 may select C, A, D, and B for rows 1,2,5 and 8, respectively. Therefore, redundancy of options is not allowed.

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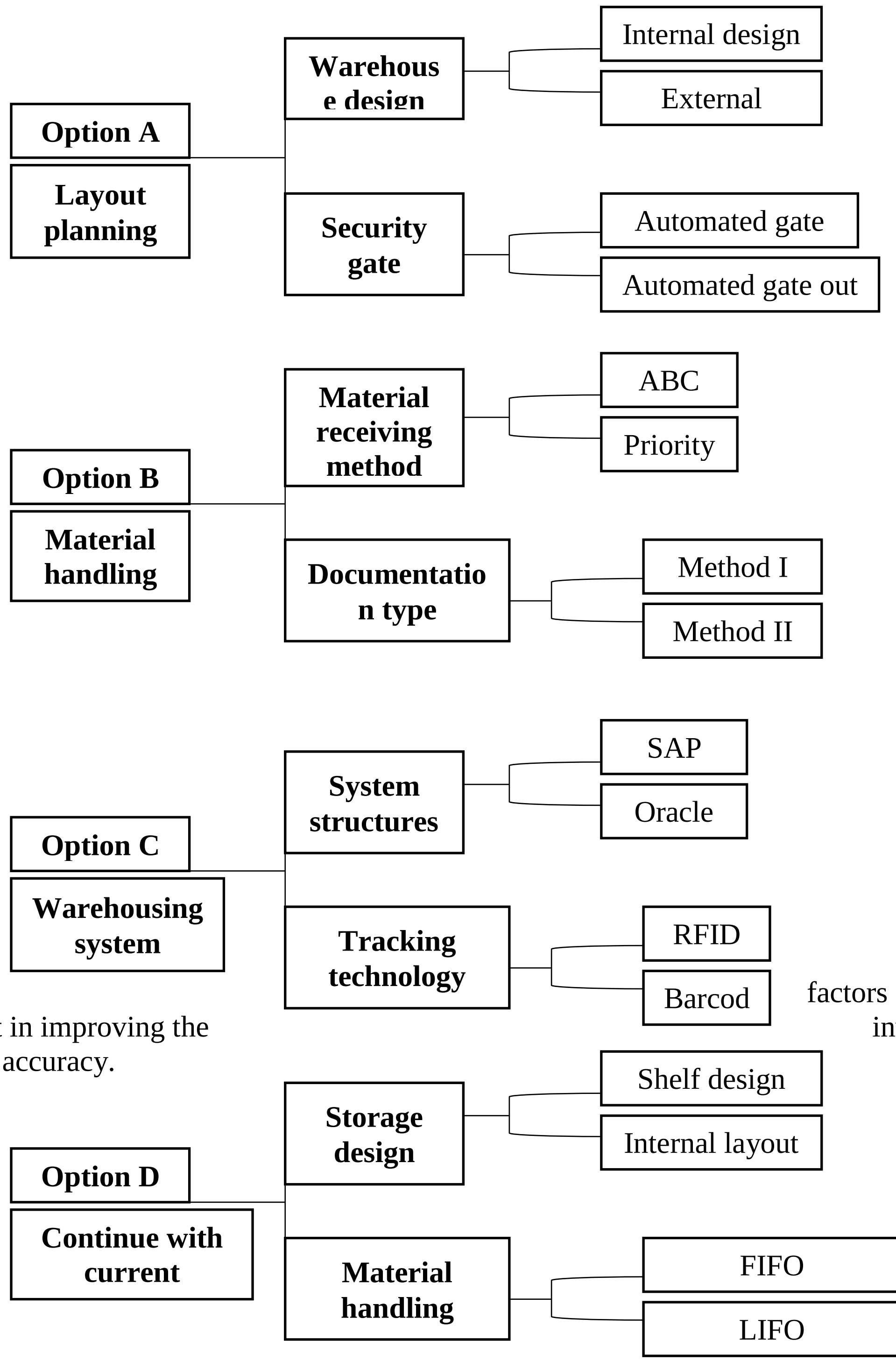

Figure 2. factors and levels that affect in improving the inventory accuracy.

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Table 5. Stated choice questionnaire for Improving Inventory Accuracy in Electricity Company Warehouses

Set	Option A		Option B		Option C		Option D		Circle only one option
	Warehouse Design	Security gate	Material receiving method	Documentation type	System structure	Tracking methodology	Storage design	Material handling	
1	Internal design	Automated gate in	ABC	Method I	SAP	RFID	Shelf Design	FIFO	A B C D
2	Internal design	Automated gate in	Priority	Method II	Oracle	Barcode	Internal layout	FIFO	A B C D
3	Internal design	Automated gate out	ABC	Method I	SAP	RFID	Internal layout	FIFO	A B C D
4	Internal design	Automated gate out	Priority	Method II	Oracle	Barcode	Shelf Design	FIFO	A B C D
5	External design	Automated gate in	ABC	Method II	Oracle	Barcode	Internal layout	FIFO	A B C D
6	External design	Automated gate in	Priority	Method I	SAP	RFID	Shelf Design	FIFO	A B C D
7	External design	Automated gate out	ABC	Method II	Oracle	Barcode	Shelf Design	FIFO	A B C D
8	External design	Automated gate out	Priority	Method I	SAP	RFID	Internal layout	FIFO	A B C D
9	External design	Automated gate out	Priority	Method II	Oracle	Barcode	Internal layout	LIFO	A B C D
10	External design	Automated gate out	ABC	Method I	SAP	RFID	Shelf Design	LIFO	A B C D
11	External design	Automated gate in	Priority	Method II	Oracle	Barcode	Shelf Design	LIFO	A B C D
12	External design	Automated gate in	ABC	Method I	SAP	RFID	Internal layout	LIFO	A B C D
13	Internal design	Automated gate out	Priority	Method I	SAP	RFID	Shelf Design	LIFO	A B C D
14	Internal design	Automated gate out	ABC	Method II	Oracle	Barcode	Internal layout	LIFO	A B C D
15	Internal design	Automated gate in	Priority	Method I	SAP	RFID	Internal layout	LIFO	A B C D
16	Internal design	Automated gate in	ABC	Method II	Oracle	Barcode	Shelf Design	LIFO	A B C D

4. Conclusions

This paper presents the process of conducting orthogonal arrays to construct a stated-choice factorial survey. Since the quality of the data gathering relies solely on the quality of questionnaire constructed and written questions, applying the stated choice survey is intended to effectively gather the information that helps improve the inventory accuracy in an electricity company warehouse. From a pool of several factors, eight factors with two levels are selected to improve the accuracy problem. Four options that combine relevant factors in sixteen sets of multiple choices are considered in the stated-choice factorial survey. The inventory's engineers and workers will be targeted for data collection with more information with a minimum number of questions and saving efforts, time, and costs of collecting the data. There are several issues needed to consider in designing a stated-choice factorial survey. For instance, how far factor levels can deviate from the current knowledge of the respondent and the order of presenting the questions.

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