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A Mathematical Approach to Neuromarketing: A Weapon – Target Assignment Model

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Abstract
This study developed a nonlinear mathematical optimization model. The aim of the study is to look neuromarketing from a mathematical perspective. The model originates from the well-known weapon target assignment problem in military operations research. This study proposes that the model can be properly adapted to neuroscience and business applications. The objective of the model is maximizing the total expected satisfaction ratio of people by understanding the functioning of their brain activities under neuroscientific and budget constraints. The recipe is applied to neuromarketing by a hypothetical example which is solved by MS Excel's Solver.
Keywords: Neuromarketing; Neuroscience; Weapon target assignment problem; Nonlinear programming; Military Operations research
Jel Classification: C65 – D87

1. Introduction

Neuroscience applications have been used for business in recent years. Although they do not necessarily need to be associated with brain research, neuroscientific studies and findings about human decision-making gained increasing attention(Hubert,2010). This shows that neuroscience knowledge may be transferred to other disciplines.

Neuromarketing which is an interesting tool of marketing, uses neuroimaging vehicles to monitor the effect of advertisements on customers' brain activity. In addition, it is a neuroscientific method to understand and analyze the change in customers' emotions and behavior related to markets (Somani,2014). Neuromarketing can also be described as the use of modern brain science that measures the impact of marketing and advertising on consumers(Bosak,2013).

It is better for marketing researchers to have a clear understanding of the abstractions held in the customers' mind since these abstractions make customers ready to be persuaded with messages intensification when a certain level of it fits their goals. In addition, considering the role of emotions in decision making by using neuroscience developing more effective methods for triggering those emotions became possible (Vashishta and Balaji,2012). Actually

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neuroscience approaches can provide complementary information regarding choice processes and types of customers although they cannot replace the data and methods in current marketing practice(Venkatraman, Clithero, Fitzsimons, Huettel,2012).

An attempt to observe the brain activities of customers, medical diagnostic devices are used and that means this type of technology plays the role of mind readers for marketers(Hammou, Galib, Melloul,2013). Furthermore, different techniques can be used as tools for neuromarketing, such as Positron Emission Tomography (PET) (Lee, Broderick, Chamberlain, 2007), Magnetoencephalography (MEG), Functional Magnetic Resonance Imaging (fMRI), Electroencephalography (EEG) (Lee et. al., 2007; Solnais, Perez, Fernandez, Abela, 2013; Somani,2014; Hammou et. al.,2013). Advanced neuroimaging techniques make possible allow an increasingly precise identification of neural responses across specific brain regions(Solnais et. al., 2013). Galvanic Skin Response (GSR) (Lee et. al., 2007) and Transcranial Magnetic Stimulation (TMS) (Hammou et. al.,2013) are also other possible techniques used in neuromarketing. Neuromarketing helps their customers (business companies) mostly so as to form their marketing strategies. There can be found more details about real world applications of neuromarketing in business (see; Haq,2007; Brat,2010; Blakeslee,2004).

There are ethical worries about using neuroimaging in the application of neuroscience to marketing. Neuroethics is well-positioned to offer guidance for beneficent and non-harmful deployment of neuromarketing techniques. Thus, it is proactively dealing with ethical issues related to the manipulation of the human brain(Murphy, Illes, Reiner, 2008).

Studies about neuromarketing are relatively wide in the literature. Campero and Hernandez (2013) aimed to analyze the theoretical and methodological approaches to the study of neuromarketing for designing business strategies in their artical. Sebastian (2014a) investigated the literature regarding the neuromarketing tools, methods and specific techniques in his article. Bosak's research (2013) showed that neuromarketing instruments have influence on consumer's behavior. Khushaba et al. (2013) assessed the brain response to marketing stimuli using EEG and eye tracking. Some articles about neuroethics concerns (Rebecca and Belden, 2008; Sebastian, 2014b; Murphy et. al., 2008).

In this study, a mathematical model is proposed for neuromarketing, which is based on the weapon-target assignment model. The paper is organized in the following way: Firstly the weapon target assignment model is defined, secondly the model is developed, a numerical example solved by using MS Excel Solver and lastly the solutions were mentioned stated.

2. The Weapon – target assignment problem

The Weapon Target Assignment (WTA) problem can be defined as finding a proper assignment of weapons to targets with an objective(Lee, Lee, Su, 2002). This objective can be minimization of expected damage of own-force assets(Lee, Lee, Su, 2002), or considering the total expected damage value of targets to be maximized (Çetin and Esen, 2006; Esen, Çetin, Esen, 2008). Indeed, this model is communicable as a fundamental problem arising in defense related applications of operations research (Ahuja, Kumar, Jha, Orin, 2003).

Mathematical formulation of the Weapon Target Assignment problem is as follows (Çetin and Esen,2006):

T be targets and numbered $1,2, \dots, T$,

W be weapon types and numbered $1,2, \dots, W$,
U_j be value of target j,
p_{ij} be the probability of destroying target j by a single weapon of type i,
x_{ij} be the number of weapons of type i assigned to target j,
W_i be the number of weapons of type i,
T_j be the minimum number of weapons required for target j

$$\max \sum_{j=1}^{T} U_j \left(1 - \prod_{i=1}^{W} \left(1 - p_{ij}\right)^{x_{ij}}\right)$$

(1)

Subject to,

$$\sum_{j=1}^{T} x_{ij} \leq W_i$$

(2)

$$\sum_{j=1}^{W} x_{ij} \geq T_j \qquad (3)$$

$x_{ij} \geq 0$ and integer, $\forall i = 1,2,3, \dots, W$, $\forall j = 1,2,3, \dots, T$.

The WTA problem can be formulated as nonlinear integer programming model and it is known as NP-complete(Ni, Yu, Ma, Wu, 2011). Since there does not exist any exact methods for the WTA problem, which can solve even small size problem; heuristic methods can employ(Çetin and Esen, 2006; Esen et. al., 2008).

3. Developing the model

In this study, a mathematical programming model is proposed for neuromarketing. In order to develop this model, The Weapon – Target Assignment problem is used with making analogy in neuroscience. The model is as flowing.

The Weapon – Target Assignment is a military problem whose goal is to maximize the total expected damage value of targets(Tulunay,1991). In assumed that, analogously weapons can be determined as used material (These materials represented as "*stimulus tool*" in this study.) on the product or its packaging (Colors, pictures and etc.) and they influence some parts of brain in specific rates. The related parts of the brain are our targets which are shot by weapons like military targets. The objective of the model is maximizing the total expected satisfaction ratio of people with using knowledge of their brain activities. The rate of impact of weapons is denoted by x_{ij} , decision variables of mathematical programming model. The mathematical programming model is as follows.

Let $i = 1,2,3, \dots, W$ be the number of materials which influence the brain. (Analogously military weapons)

Let $j = 1,2,3, \dots, T$ be the number of the targeted parts of the brain. (Analogously military targets)

W_i be the rate of impact of the stimulus tool type i available,

T_j be the minimum rate of the required impact for the targeted part of the brain type j,

U_j be the relative stimulus tool weight,

x_{ij} be the rate of impact of the stimulus tool of type i assigned to the targeted part of the brain type j,

c_{ij} be the unit variable cost of an stimulus tool type i to the targeted part of the brain of type j,

B be the total advertising material budget on the product (such as special colors, special effects and so on),

p_{ij} be the probability of influencing the targeted part of the brain type j by a single stimulus tool type i,

β_i be the upper limit for percentage of total advertising material cost on the product type *i*,

The first step is determining the objective function. The objective is to maximize the total expected satisfaction ratio of people,

$$\max \sum_{j=1}^{T} U_j \left(1 - \prod_{i=1}^{W} \left(1 - p_{ij}\right)^{x_{ij}}\right) \tag{4}$$

The second step is determining the constraints. There is specific impact rate of the stimulus tool on the product, which influences the brain.

$$\sum_{j=1}^{T} x_{ij} \leq W_i \tag{5}$$

where $\forall i = 1,2,3, \dots, W$.

We assume that the stimulus tool influences a specific part of the brain. Model can satisfies the impact rate requirement of related part of the brain by adding following constraint,

$$\sum_{j=1}^{W} x_{ij} \geq T_j \tag{6}$$

where $\forall j = 1,2,3, \dots, T$.

The stimulus tool cost per target for each of material on the product can be model as,

$$\sum_{j=1}^{T} \frac{1}{T} c_{ij} x_{ij} \leq B\beta_i \tag{7}$$

So;

$$\sum_{i=1}^{W} \beta_i = 1 \tag{8}$$

Finally, non-negativity constraints complete the mathematical model,

$x_{ij} \geq 0$ and $x_{ij} \in [0,1]$, $\forall i = 1,2,3, \dots, W$, $\forall j = 1,2,3, \dots, T$.

The model is a nonlinear mathematical programming model. To solve it, some software can be employed for near optimal solutions such as MS Excel Solver and LINGO or heuristic approaches can be used for solve the problem and find near optimal solutions (Çetin and Esen, 2006).

4. Numerical example

A hypothetical example is as follows: Suppose that a company is planning to release a new product. Company wants to use neuroscience knowledge. It knows the importance of the some purchasing factors such as colors, design and environment conditions (Akcay, Dalgin, Bhatnagar, 2011; Hadjali, Salimi, Nazari, Ardestani, 2012; Nezhad and Kavehnezhad, 2013). The company has eight stimulus tools (as weapons *W*=8), namely; it uses five different colors, special design for their logo and product picture on packaging. It is planning to release with lower price than its rivals and write it where customers can easily see. The funny ad music is played in the store where the released product is selling. Assume that the brain lobes; frontal lobe whose responsible for motor functions, cognitive process, executive function, attention (Chayer and Freedman, 2001; Stuss and Levine, 2002; Catani, Acqua, Vergani, Malik, Hodge, Roy, Valabregue, Schotten, 2012); parietal lobe whose responsible for processing sensory information and perceptions, decision making, numerical cognition, integration speech comprehension and spatial awareness (Bisley and Goldberg, 2010); occipital lobe whose responsible for vision functions (Bender, Postel, Krieger, 1957; Grill-Spector,2015); temporal lobe whose responsible for processing sounds, understanding speech, memory, understand spoken concepts, emotional processing (Schmahmann, 2008; Squire, Stark, Clark, 2004; Binder, Frost, Hammeke, Bellgowan, Springer, Kaufman, Possing, 2000) may be considered as the brain targets (*T*=4) for decision making. From past neuroscience surveys, the company knows the percentages and unit costs of reaching the target brain lobes according to the stimulus tools. The probabilities (p_{ij}) are shown in Table 1. Also, the unit variable costs (in $10000), impact rates (the assumption of the weapons maximum effectiveness), brain lobe values (weights of targets), and the rate of impact required for each brain lobe is shown in Table 2. It is seen in Table 1 that some material has probability of 0 for reaching some targets. As shown in Table 2, occipital lobe is the most important lobe, frontal lobe is the least important lobe for the weapons. Because it is assumed that visuality and emotional process more important than other properties in this example. But these weights can be changed with respect to features of our weapons. The total advertising material budget on the product is $20.000 (*B*=$20.000). The company wants to restrict expenditure shares with $\beta_{1,2,3,4,5} = 0{,}06$; $\beta_6 = 0{,}40$; $\beta_7 = 0{,}20$; $\beta_8 = 0{,}10$, respectively. The problem is the maximizing the total expected satisfaction ratio of people in their brain under the budget and neuroscience constraints.

Table 1

The Probability Matrix

	Frontal lobe (T1)	Parietal lobe (T2)	Occipital lobe (T3)	Temporal lobe (T4)
Color1 (W1)	0,38	0,46	0,70	0,45
Color2 (W2)	0,45	0,41	0,65	0,49
Color3 (W3)	0,41	0,40	0,72	0,42
Color4 (W4)	0,35	0,42	0,68	0,50
Color5 (W5)	0,39	0,44	0,63	0,44
New design logo and picture (W6)	0,68	0,70	0,75	0,72
Lower price (W7)	0,80	0,75	0,05	0,02
Music (W8)	0,49	0,45	0,00	0,56

Table 2

The Unit Variable Cost Matrix

	Frontal lobe (T1)	Parietal lobe (T2)	Occipital lobe (T3)	Temporal lobe (T4)	Impact rates
Color1 (W1)	0,600	0,600	0,600	0,600	0,90
Color2 (W2)	0,700	0,700	0,700	0,700	0,90
Color3 (W3)	0,650	0,650	0,650	0,650	0,89
Color4 (W4)	0,660	0,660	0,660	0,660	0,85
Color5 (W5)	0,730	0,730	0,730	0,730	0,82
New design logo and picture (W6)	0,800	0,800	0,800	0,800	0,95
Lower price (W7)	0,900	0,900	0,900	0,900	0,99
Music (W8)	0,300	0,300	0,300	0,300	0,70
Rate of impact required	0,95	0,93	0,90	0,85	
Lobe weights	0,10	0,20	0,40	0,30	

The model is solved using MS Excel's Solver as a decision making tool. The computer CPU time is 1 second with Intel(R) Core(TM) i7-4770 CPU 3.40GHz and 8Gb RAM. The objective function near optimal value of the model is obtained as 0,83086123. According to near optimal value of objective function, people's satisfaction ratio nearly 83,08% under our constraints. The total cost is $10652,5. The total Color1, Color2, Color3, Color4, Color5 expenditure is $6000. The new design logo and picture expenditure is $1900. The lower price strategy causes $ 2227,5 cost. The ad music expenditure is $525. According to results cheapest stimulus tool is ad music, the most expensive stimulus tool is lower price strategy. The total cost of influencing the frontal lobe is $1855, whereas the parietal lobe is $2777, the occipital lobe is $3401, the temporal lobe is $2618. The stimulus tools (Weapons) almost optimal assignment for brain lobes as follows: $x_{13} = 0{,}80$; $x_{21} = 0{,}56$; $x_{24} = 0{,}12$; $x_{33} = 0{,}74$; $x_{43} = 0{,}61$; $x_{44} = 0{,}12$; $x_{52} = 0{,}66$; $x_{62} = 0{,}11$; $x_{64} = 0{,}84$; $x_{71} = 0{,}39$; $x_{72} = 0{,}60$; $x_{84} = 0{,}70$ and other 0. According to near optimal solution; Color1 effects the occipital lobe with 0,80 impact rate, Color2 effects the frontal lobe with 0,56 impact rate and the temporal lobe with 0,12 impact rate. Color3 effects the occipital lobe with 0,74 impact rate. Color4 effects the occipital lobe with 0,61 impact rate and the temporal lobe with 0,12 impact rate. Color5 effects the parietal lobe with 0,66 impact rate. New design logo and picture effects the parietal lobe with 0,11 impact rate and the temporal lobe 0,84 impact rate. Lower price strategy effects the frontal lobe with 0,39 impact rate and the parietal lobe with 0,60 impact rate. Ad music effects the temporal lobe with 0,70 impact rate. It is observed that there is no assignment for zero probabilities. The target brain lobes are effected by percentages 61,63%; 74,08%; 92,53%; 83,65%, respectively.

5. Conclusion

A nonlinear mathematical optimization model is developed in this study. The model is mainly known as the weapon target assignment problem in military operations research. Hence, it has applications in social sciences, such as media allocation (Çetin and Esen, 2006), and etc.

The aim of the model is to look neuroscience from a mathematical perspective by proposing the application of optimization model to neuromarketing with a hypothetical example. There are 32 decision variables and the model is solved with MS Excel Solver add-in. The weapons (called as stimulus tools) are assigned to targets (called as brain lobes) with different rates (probabilities). The objective function gives the near optimal (maximum) satisfaction ratio under budget and neuroscientific constraints.

The objective of the proposed model is maximizing the total expected satisfaction ratio of people by understanding the functioning of brain. In this way, the producer can improve his product according to the model results. The model may be employed for other sciences, such as psychology, neuroscience and so on. In the hypothetical example, we used eight illustrative stimulus tools. They can be updated according to experimental results in real world conditions. A scientist can focus on only a part of the brain as a target instead of our hypothetical targets and applies the model with his stimulus tools as weapons.

The results give opinion about how stimulus tools influence and satisfy customers. Customer satisfaction can be improved by using different materials by changing probabilities. Therefore, people can appreciate much more. In future studies, model can be improved by using fuzzy variables or approach into consideration with a multi-objective way. Also, other military operations research models can be adapted to neuroscience surveys.

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