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The implementation of simple additive weighting (SAW) method in decision making process for paint & coating

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Abstract. New product development is a changing goal that becomes increasingly complex as a result of a variety of known and unknown circumstances. Different attributes need to be considered in selecting the best product formulation such as cost, safety, health, environment, performance and many others. A solid decision at the early stage of process design are all essential aspects in building a great product. Therefore, multi-criteria decision making is an important aspect during product development process. In this work, Simple Additive Weighting (SAW) has been used for the decision-making process to identify the best paint alternatives considering three attributes: safety, health and performance. The rank from the most favorable alternative to the less favorable alternative are 2K Formulation, Gloss 1K Formulation, Matte 1K Formulation with the score 0.73, 0.69 and 0.46 respectively. A comparison between the SAW results obtained in this work with simple index-based methodology shows that the results are in agreement with each other and both methodologies are suitable to be used at the early stage of process development as the methodologies are simple. Further investigation shows that the SAW result gives more flexibility in prioritizing the attributes compared to the simple index-based methodology based on predetermined weight value.

Introduction

The development and application of chemical products in a daily life are important for the technology revolution and economic progress around the world. However, chemical components in various designed items that have been launched to the market may expose consumers to a range of safety and health issues. Several cases have been recorded in the past for example lawsuits from consumers claimed the contamination of asbestos in baby powder causes on the development of ovarian cancer [1], the death from mesothelioma due the exposure asbestos-containing talc that was used in paint manufacturing [2] and melamine contamination in milk powder leading to fatalities [3]. As a result, it's vital to use a systematic procedure to develop the products that meet acceptable safety and health standards. Different criteria need to be considered in selecting the best product formulation such as cost, safety & health, and performance of the product. A solid product strategy that takes into account positioning possibilities, feasibility, and a flexible development methodology are all essential aspects in building a great product. To resolve the issue, multi-criteria decision making (MCDM) also referred to as multiple criteria decision analysis (MCDA) can be used. MCDM is a technique that involves the analysis of various available choices for the decision-making process. Among the common MCDM tools are Simple Additive Weighting (SAW), Weighted Product Method (WPM), Analytic Hierarchy Process (AHP), Analytic Network

Process (ANP), Technique for Order Preference by Similarity to Ideal Solutions (TOPSIS), and others. The comparisons between the methodologies are presented in Table 1 [4], [5] indicates the advantages and disadvantages for each methodologies. Various MCDM techniques have been applied for decision making process in chemical process industry. In the work by Sarder, T. & Khan, M.R. AHP and TOPSIS methodology has been implemented to identify the right chemical supplier considering six attributes: quality of chemicals, price, timely shipment, social responsibility, safety management facility and risk management [6]. Other applications of MCDM via Analytic Network Process (ANP) has been demonstrated by the work by Othman, M.R. to select sustainable biodiesel production considering economy, environment, societal and technical aspects [7]. In more recent work, AHP model that combines a deep residual network with multiway principal component analysis (MPIDRN-AHP) for Tennessee Eastman Process (TEP) operation evaluation [8].

In paint and coating industries, the selection of paint is determined by various factors such as desired properties, work requirements and limitations, safety and environmental restrictions, compatibilities, and costs [9]. The identification of the best paint alternatives will be challenging due to the conflicting attributes of the paint. A clear example demonstrated by the case of selection water-based and solvent-based paint. Water based paint offers a good option for health environment attributes as the paint have lower volatiles organic compound (VOCs) compared to the solvent-based paint. However, in terms of drying time, solvent based paint would be better as the paint is less susceptible to environmental conditions such as temperature and humidity during the curing process [10]. While there are a lot of discussions on the conflicting attributes of the paint, there is no standard framework for the decision-making process to select the best paint alternatives. Therefore, in this study, SAW will be used for the decision-making process to identify the best paint alternatives considering three attributes: safety, health and performance. A comparison between the SAW results with simple index-based methodology will be conducted in order to understand the advantages and disadvantages of SAW for decision making process.

Development of Simple Additive Weighting (SAW) Framework for Paint Selection

In this work, the multi-criteria decision-making process for chemical products using SAW will be presented. The process will be demonstrated using the alternatives of polyurethane coatings for wood flooring by [11]. The process steps are as follows:

Identification of Chemical Product Alternatives and the Attributes

The first step involving the identification of chemical product alternatives together with attributes of the alternatives. In this work, three alternatives of polyurethane coatings; 2K Formulation, Matte 1K Formulation and Gloss 1K Formulation are shown in Table 2. The attributes: safety, health and performance considered in this work together with the parameters are summarized in Table 3.

Table 1: Comparison of MCDM techniques [4], [5]

Technique	Type of normalization	Suitability	Inputs	Outputs	Preference function	Approach	Ranking scale	Best alternative
SAW	Normalized score	Choice problems, ranking problems	Option Weights and score	Complete ranking with scores	Addition of preference value for each alternative	Quantitative	Positive values	Max value
WPM	Normalized score	Choice problems, ranking problems	Option Weights and score	Complete ranking with scores	Multiplication of criterion ratio	Quantitative	Positive values	Max value
AHP	Vector normalisation	Choice problems,	Pairwise comparison	Complete ranking	Priorities of decision problem using	Qualitative	0 to 1	Max value

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	(sum)	ranking problems, sorting problems (AHPsort)	on ratio scale (1–9)	with scores	hierarchy with a goal, decision criteria, and alternatives			
TOPSIS	Vector normalisation (square root of sum (L2 normalization	Choice problems, ranking problems	Ideal and anti-ideal option weights	Complete ranking with closeness score to ideal and distance to anti-ideal	Distance metric (Euclidean distance, Manhattan distance, Tchebycheff distance)	Qualitative and/or quantitative	0 to 1	Max value

Table 2: Alternatives of polyurethane coatings [11]

	2K Formulation	**Matte 1K Formulation**	**Gloss 1K Formulation**
Polyisocyanate	BAYHYDUR XP 2655	-	-
Dispersion	BAYHYDROL A 2651	BAYHYDROL UH 2874	BAYHYDROL UH 2874
Hardener solution	80% in PGDA	-	-
Matting agent	No	Yes	No
Mixing	Manual	Manual	Manual
VOC Content (g/L)	53	129	125
Bio-based content in paint (%)	45	51	46

Table 3: Attributes and parameters for MCDM

Safety parameters	Explosiveness (vol %), flammability (flash point), toxicity (TLV in ppm), chemical reactivity (NFPA rating)
Health parameters	Eye hazard, inhalation, ingestion, dermal
Performance parameters	Dry time, cure time, hardness, chemical resistance (water, ethanol, coffee, red wine, etc.), weathering artificial and natural tests of deterioration on external walls

Data Collection and Scoring Process

According to the parameters identified in Table 3, the data for each alternative will be collected. In this work, the safety and health data has been collected from the using Material Safety Data Sheet (MSDS) for BAYHYDUR XP 2655, BAYHYDROL A 2651 and BAYHYDROL UH 2874 while the data collected for performance originated from [11]. The scoring process for safety and health attributes was performed using index-based method, Product Safety and Health Index (PSHI) [10]. The scoring process for performance attribute was conducted using index-based method developed by M.Zainuddin [12]. In both indices, higher value indicates unfavorable situations compared to lower value. The sum of scores of each attribute will be used as the input for the next step.

Multicriteria Decision Making using SAW

The basic concept of the SAW method is to find the weighted sum of performance ratings on each alternative on all attributes. The first step in SAW method is normalizing the decision matrix (X) to a scale comparable to all existing alternative ratings.[13]. The formula for normalization for alternative i and attributes j given in Eq. 1 and Eq. 2:

$$R_{ij} = x_{ij} / \text{Max } x_{ij} \quad (1)$$

$$R_{ij} = \text{Min } x_{ij} / x_{ij} \quad (2)$$

With R_{ij} is the normalized performance rating of alternative i and W_j is the specified weight of attribute j, the preference value for each alternative (V_i) is given in Eq. 3. A larger value of V_i indicates that A_i's alternatives are preferred.

$$V_i = \sum W_j r_{ij} \quad (3)$$

Results & Discussion

The safety, health and performance assessment has been conducted using the methodology outlined in the previous section. The paint data for safety, health and performance together with the scores shown in Table 4 to Table 6. In general, higher score in the results indicated unfavorable situation i.e. poor performance, high potential of safety hazard and high potential of health hazard compared to the lower score. The comparison of the attributes for alternatives shown in Figure 1. Based on the results obtained, there are a conflict where if the safety and health aspects is the priorities of the decision, 2K Formulation is the best choice with the score 1 and 5 respectively. However, if the performance is the priorities of the decision, the Gloss 1K Formulation is the best choice while Gloss 1K Formulation is the worst choice.

Table 4: Safety Parameters Data and Scoring

Alternative	**2K Formulation**		**Matte 1K Formulation**		**Gloss 1K Formulation**	
Solvent Mixture	BAYHYDROL A 2651		BAYHYDROL UH 2874		BAYHYDROL UH 2874	
Properties and Score	Properties	Score	Properties	Score	Properties	Score
Explosiveness (vol%)	N/A	N/A	N/A	N/A	N/A	N/A
Flammability (Flash Point in C)	>96	1	>92	2	>92	2
Toxicity (TLV in ppm)	N/A	N/A	N/A	N/A	N/A	N/A
Chemical Reactivity (NFPA rating)	0	0	0	0	0	0
Total Score		**1**		**2**		**2**

Table 5: Health Parameters Data and Scoring

Alternative	2K Formulation		Matte 1K Formulation		Gloss 1K Formulation	
Solvent Mixture	BAYHYDROL A 2651		BAYHYDROL UH 2874		BAYHYDROL UH 2874	
Properties and Score	Properties	Score	Properties	Score	Properties	Score
Eye Hazard Statement	No Effect	0	H318 H319	2	H318 H319	2
Inhalation Volatility (Boiling Point in C)	96	1	92	1	92	1
Ingestion Hazard Statement	H302	1	H301	2	H301	2
Dermal Hazard Statement	H311	3	H310 H314	4	H310 H314	4
Total Score		**5**		**9**		**9**

Table 6: Performance Parameters Data and Scoring

Alternative	2K Formulation		Matte 1K Formulation		Gloss 1K Formulation	
Solvent Mixture	BAYHYDROL A 2651		BAYHYDROL UH 2874		BAYHYDROL UH 2874	
Dry Time Score	45	2	45	2	40	1
Cure Time Score	8 hrs, 12 min	3	2 hrs, 10 min	0	2hrs	0
Hardness Score	100	0	70	1	80	0
Chemical Resistance Score						
• Water	5	0	5	0	5	0
• Ethanol	5	0	4	1	5	0
• Coffee	5	0	5	0	5	0
• Red Wine	5	0	5	0	5	0
Total Score		**5**		**4**		**1**

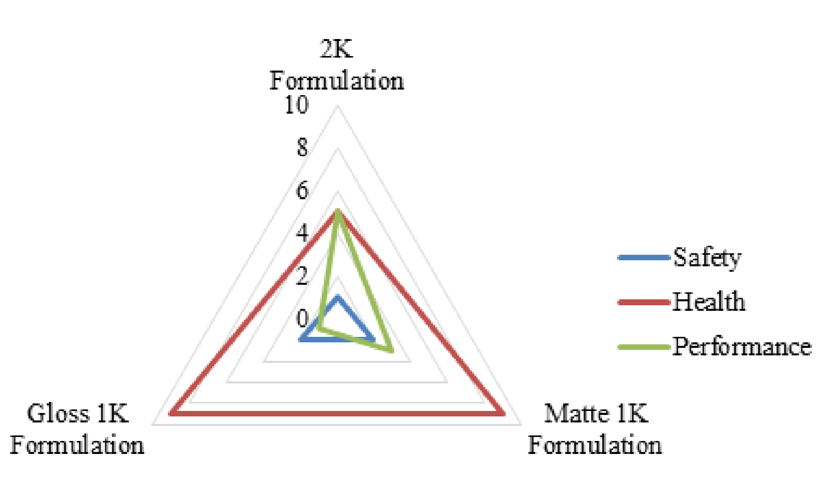

Figure 1: Paint Alternatives Evaluation Chart

To resolve the conflict, SAW was computed, and the results are presented in Table 7. A larger value of Vi indicates that the alternative is preferred. Based on SAW results, considering three attributes with equal weightage, the best choice is 2K Formulation followed by Gloss 1K Formulation and Matte 1K Formulation. The validation process has been done using a simple index-based method using sum of the score obtained in Table 4 to Table 6. Based on the score value, similar rank with SAW was obtained. However, in SAW methodology, more flexibility given to the assessor as the priorities can be assigned using pre-determine weight values. Higher weight value indicates more priority given to selected attribute. This flexibility has been demonstrated as the results presented in Table 8. The results show that, when more priorities given to performance attributes with weight value = 0.5, the best choice is Gloss 1K Formulation followed by 2K Formulation and Matte 1K Formulation.

Table 7 : Multicriteria Decision Making Results for Paint Alternatives

Alternative	**Weight**	**2K Formulation**	**Matte 1K Formulation**	**Gloss 1K Formulation**
Safety	0.33	1.00	0.50	0.50
Health	0.33	1.00	0.56	0.56
Performance	0.33	0.20	0.33	1.00
Final Value of Alternative (Vi)		**0.73**	**0.46**	**0.69**
Ranking		**1**	**3**	**2**
Simple Index Based Method		**11**	**14**	**12**
Ranking		**1**	**3**	**2**

Table 8 : Demonstration of Weight Impact in SAW for Paint Alternatives

Alternative	Weight	2K Formulation	Matte 1K Formulation	Gloss 1K Formulation
Safety	0.25	1.00	0.50	0.50
Health	0.25	1.00	0.56	0.56
Performance	0.50	0.20	0.33	1.00
Final Value of Alternative (Vi)		**0.60**	**0.43**	**0.76**
Ranking		**2**	**3**	**1**

Conclusion

In conclusion, in this work, the capability of SAW methodology to assist multicriteria decision making process for paint alternatives at the early stage of product development has been demonstrated. The rank obtained from the most favorable alternative to the less favorable alternative are 2K Formulation, Gloss 1K Formulation, Matte 1K Formulation with the score 0.73, 0.69 and 0.46 respectively. The validation process has been conducted and the results obtained using SAW is in agreement with the simple index-based methodology. Further investigation shows that the SAW result gives more flexibility compared to the simple index-based method in prioritizing the attributes based on predetermined weight value.

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