Applying Fuzzy Multi-Criteria Decision Making for the Selection of Competitive Factors in Robotics Based on System Development Life Cycle

Orasa Sirasakamol* Punnita Taecharoen* Narin Jiwitan** Kitti Puritat*** and Kannikar Intawong****

Received: August 27, 2023
Revised: January 22, 2024
Accepted: March 7, 2024

* Corresponding Author: Punnita Taecharoen, E-mail: punnita@rmutl.ac.th

DOI: 10.14416/j.it/2024.v2.001

Abstract

Robots are a technology that plays an important role in many industries today. Competition in the robot market is high, so choosing the right competitive factors for robots is important. This study uses a Fuzzy Analytic Hierarchy Process (F-AHP) method to select appropriate competitive factors for the robot. It considers competitive factors in robots and system development life cycles (SDLC). The research results found that important competitive factors for robots include: All 5 experts focus on (C1) interaction factors giving robots flexibility and adaptability to changing environmental conditions while (SC1–5) image processing gives robots the ability to sense and respond to the environment while competing effectively. Combining these two factors improves competitive performance and allows the robot to maximize its time in changing situations. Among the alternative scenarios compared with factors at levels 1 and 2, option A1 (Robotic 1) performed the best in terms of achieving optimal time, as indicated by its calculated weight (Ni) = 0.508 and All 5 students determined the weight values according to Table 1, focusing on factors (C2) Posture factors affect a robot's performance in competition. Maintaining the correct posture helps the robot be agile and efficient in carrying out its tasks and factors (SC2-6) in level 2 Climbing steep slopes gives robots the ability to burn off energy and maintain stability in difficult conditions. Efficient operation in steep conditions is an important competitive factor. Among the alternative scenarios compared with factors at level 1 and level 2, option A1 (Robotic 1) performed the best in terms of achieving optimal time, as indicated by its calculated weight (Ni) = 0.573. This study shows that the F-AHP is an effective tool for selecting appropriate competitive factors for robots.

Keywords: Robots, Competitive factors, AHP, Fuzzy, SDLC.

1. Introduction

In the realm of robotic competitions, the context extends beyond the physical arena where robots compete. It encompasses the broader objectives of fostering technological advancement, encouraging collaboration among participants and inspiring the next generation of engineers and innovators. These competitions provide a stage for participants to showcase their robots' agility adaptability, and efficiency in addressing specific tasks or challenges [1]. The educational landscape must recognize that robots are not merely mechanical entities but sophisticated systems equipped with artificial intelligence sensors and actuators. They are designed not only to perform tasks efficiently but also to adapt to dynamic and unforeseen challenges. Whether in the classroom research lab or industry setting, comprehending the context of robotics allows educators and students alike to harness the full potential of these technological marvels.

* Department Electrical, Faculty of Engineering, Rajamangala University of Technology Lanna.
** Department of Business Information Systems, Faculty of Business Administration and Liberal Arts, Rajamangala University of Technology Lanna.
*** Department of Library and Information Science, Faculty of Humanities, Chiang Mai University.
**** School of Public Health, Faculty of Public Health, Chiang Mai University.

This article aims to study the specific factors of robots used in competitions in the following aspects: Interaction Mobility Navigation Manipulation and Intelligence to determine the most significant factors for competition consideration, the selection process involves analyzing the quantities with the highest importance. The selection process of prototype factors uses the F-AHP technique to analyze the hierarchy of matrix equations.

2. Theories and Related Research

Decision-making involves the utilization of criteria or various tools to assist in the process of making choices in order to minimize the chances of errors or enhance the accuracy of decisions. Probability and conditional reasoning play a significant role in decision-making. This is because individuals' rationale in pursuing their objectives often necessitates selecting the best possible outcomes or rewards.

2.1 System Development Life Cycle (SDLC)

Software Development Life Cycle (SDLC) is a process that emphasizes software development through various stages. Generally, SDLC comprises the following steps:

1) Requirement Analysis: This step involves analyzing and gathering all the necessary requirements for the software including understanding the problem and user needs.

2) Design: Taking the requirements obtained from the previous step the team plans and designs the structure or architecture of the software.

3) Implementation: The team begins to create the software model based on the designed plan.

4) Testing: The developed model is tested to ensure it functions correctly and any errors are identified and fixed.

5) Deployment and Maintenance: The model that has been tested is deployed for real-world use and the team is responsible for maintaining and updating the software to keep it current and responsive to user needs

SDLC is a process that helps the team with a framework for developing a model and enables efficient tracking and control of the progress of development [2].

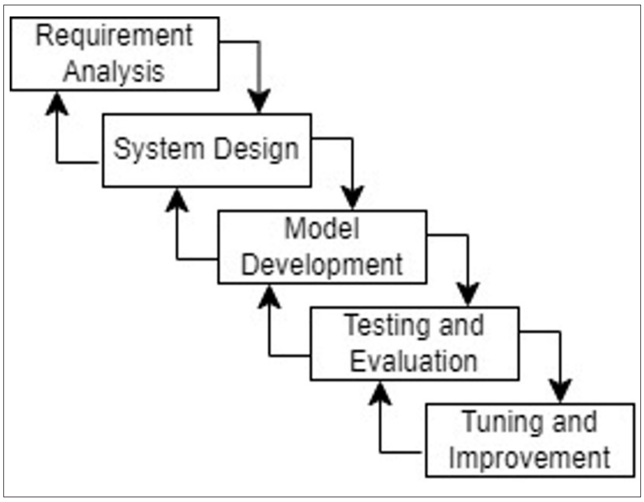

Figure 1. *System Development Life Cycle (SDLC).*

All of these process steps are methods that can be used to enhance decision-making efficiency regarding the selection of competition factors in robotics. This is an important aspect of research related to robotics.

2.2 Multi Criteria Decision Making (MCDM)

Multi Criteria Decision Making (MCDM) is a popular method used for decision-making analysis to select alternatives that best align with or are most suitable according to multiple criteria. The significant characteristic of MCDM is the involvement of stakeholders in the decision-making process and the weighting of all options for accurate results.

AHP (Analytic Hierarchy Process) and F-AHP (Fuzzy Analytic Hierarchy Process) and Fuzzy Logic are widely used in various sectors such as education industry and engineering to solve decision-making problems. Multi-criteria decision-making is an approach that aids in selecting the most appropriate criteria for predefined alternatives [3].

The traditional approach of MCDM is insufficient to handle linguistic uncertainties [4]. Therefore, it is recommended to use Fuzzy-based MCDM to deal with ambiguity in the decision-making process. Additionally, the Fuzzy approach leads to more plausible outcomes.

2.3 Fuzzy Analytic Hierarchy Process (F-AHP)

The Fuzzy Analytic Hierarchy Process (F-AHP) is a decision-making analysis method used for selecting or prioritizing alternatives in complex decision-making scenarios. It involves transforming real numbers into fuzzy numbers and structuring the decision-making process into a hierarchical framework using matrix equations [5]. The F-AHP process consists of five steps:

1) Convert real numbers into fuzzy numbers.

2) Populate the matrix with fuzzy numbers to pairwise compare alternatives.

3) Calculate the weights for each criterion using the theory of the Analytic Hierarchy Process.

4) Calculate the weights for each alternative by combining steps 1 to 3.

5) Convert or defuzzify the fuzzy numbers to real numbers and determine the values of the alternatives by multiplying criterion weights with alternative weights.

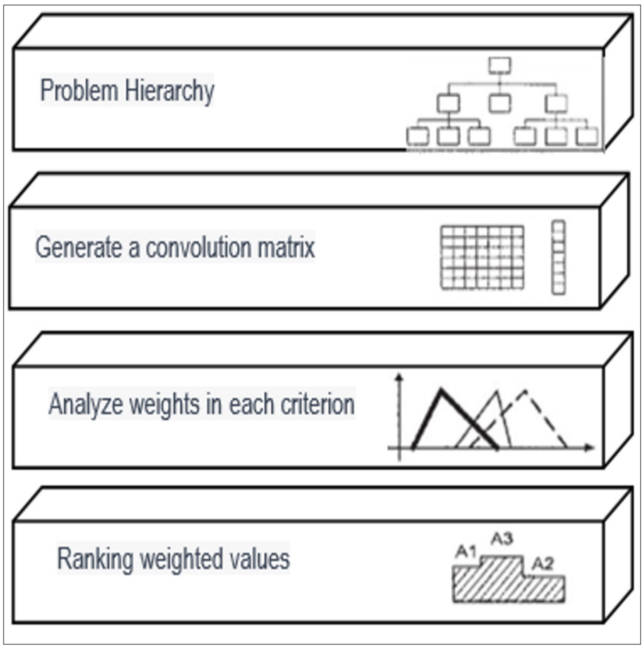

Figure 2. *Hierarchical Cluster Analysis Process.*

2.4 Fuzzy Set and Fuzzy Number

Fuzzy Set and Fuzzy Number: Zadeh (1965) [6] introduced the Fuzzy Set Theory to manage uncertainty arising from imprecision and vagueness. Mathematical operations and programming can be applied to the domain of Fuzzy Set which is a class of objects with a continuous degree of membership. Such sets are characterized by a membership function that assigns a membership level ranging from 0 to 1 to each object (Kahraman et al., 2019) [7]. The tilde symbol (~) is placed over a symbol if it denotes a Fuzzy set. Fuzzy numbers represented as triangular fuzzy membership functions are denoted as l, m, and u, signifying the minimum value, the value with the highest trend, and the maximum possible value respectively. This explains the concept of Fuzzy membership function of triangular fuzzy numbers as depicted in Figure 3.

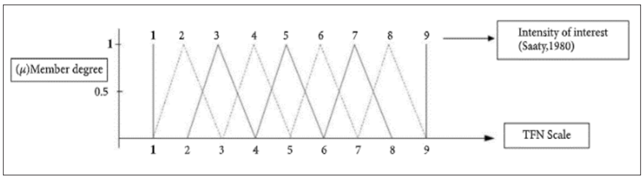

Figure 3. *Membership Function of Triangulars.*

$$u\tilde{A}(\mathrm{X}) = \tilde{M} = (l, m, u) \quad (1)$$

E. Ertugrul Karsak [8] conducted a study on the problem of robot selection using a multi-criteria decision-making approach based on Choquet Integral. The main characteristic of Choquet Integral is its ability to aggregate interactions between various features for decision analysis. This problem is often overlooked in previous studies on robot selection. The proposed decision framework utilizes data extracted beforehand from experts in analyzing a reference set of robot alternatives using the same selection criteria as the current assessment. It employs Choquet Integral to determine the most suitable robot.

Athale and Chakraborty (2016) [9] conducted a study comparing the effectiveness of using Multi-Criteria Decision Making (MCDM) to rank industrial robot selection problems. They concluded that for the specified robot selection problem it is advisable to place greater importance on selecting appropriate criteria.

Changwon Kim and Yeesock Kim (2020) [10] introduced a multi-robot navigation strategy using a multi-objective decision-making algorithm namely Fuzzy Analytic Hierarchy

Process (F-AHP). The objective was to analyze and select the most suitable positions as sub-goals from various points on the mobile robot's detection boundary. This analysis was carried out considering the following three objectives: distance to the target destination collision safety and robot orientation adjustment to face the target. Alternative solutions were evaluated by determining the relative importance weights of the objectives as the F-AHP algorithm alone was insufficient for multi-robot navigation. Game theory with participation was incorporated to enhance the algorithm's efficiency. The proposed multi-robot navigation algorithm was tested on up to 12 mobile robots in various simulated scenarios with changing factors.

Bipradas Bairagi and Balaram Dey (2016) [11] utilized the Fuzzy Analytic Hierarchy Process (F-AHP) method to evaluate and select robots for automated foundry operations. In this approach AHP is integrated with fuzzy techniques to define the characteristics of the purchase order based on similarity. In each case (F-AHP) is used to assess the covering weights of the selection criteria under consideration to evaluate and select robots. The real-life problem of selecting robots for practical foundry operations was referred to in order to demonstrate and verify the suitability and potential of the utilized method. An analysis and comparison of the research results showed that the F-AHP-based approach serves as a valuable and efficient representation suitable for selecting the best robots in various environmental conditions.

3. Research Methodology

The study employed the F-AHP model to investigate the decision-making process for selecting factors related to competitive robots. The analytical hierarchy process depended on the system development process. The analysis of results was carried out based on the following principles of operation.

3.1 Research Framework

The research process follows a structured framework consisting of sequential steps.

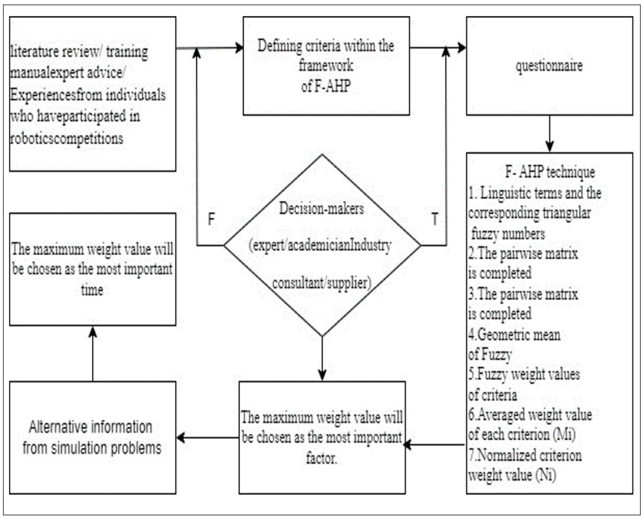

Figure 4. *Research Framework.*

3.1.1 Study of information related to robot factors to effectively utilize information for the evaluation and preparation of robotics competitions both domestically and internationally. The primary goal of these competitions is to provide the education sector with insights into the contextual characteristics and behavior of participating robots. Additionally, the competitions aim to foster the development and application of skills and knowledge to enhance the educational experience. A comprehensive consideration of all factors is essential to achieving these objectives.

1) Five experts were selected for this research based on the following criteria.

1.1 Possesses a deep understanding of robot design and operation in competition settings for a minimum of 5 years.

1.2 Demonstrates experience in related fields or competitions, including mechanical, automation, programming and robotics aspects. For instance, involvement in guiding students to compete at the World Skills level with a minimum of 10 instances.

1.3 Holds academic expertise in robotics and related technology with a background of 5 years or more in a professional setting.

1.4 Proficient in decision analysis using F-AHP demonstrating versatility with various decision-making theories such as AHP, F-AHP, ANP, PROMETHEE, TOPSIS. Capable of applying decision making theories in multiple formats.

2) Five students are interested in participating in the competition and studying in the Robotics and Automation program.

Table 1. *Data of Factors Related to Robotics Competition [12, 13].*

Criteria	Sub-Criterial
1) Interacting factors (C1)	Remembering faces (SC1-1) Posture (SC1-2) Robot vision (SC1-3) Image system (SC1-4) Process image (SC1-5) Voice recognition (SC1-6) Interacting with users (SC1-7) Speech recognition (SC1-8)
2) Posture factors (C2)	Getting up (SC2-1) Walking (SC2-2) Standing (SC2-3) Running (SC2-4) Jumping (SC2-5) Climbing steep slopes (SC2-6) Navigating obstacles (SC2-7) Using wings for flying (SC2-8) Using fins for swimming (SC2-9)
3) Accuracy factors (C3)	Characteristic (SC3-1) Range (SC3-2) Sensor (SC3-3) Disturbances (SC3-4)
4) Object movement factors (C4)	Picking up (SC4-1) Extending arms and legs (SC4-2) Bending arms and legs (SC4-3)
5) Intelligence (C5)	Brain simulation (SC5-1) Perception simulation (SC5-2) Logical method (SC5-3) Calculation method (SC5-4) Statistical method (SC5-5) integration method (SC5-6)
6) Drive system configuration factors (C6)	Wheel-based mobility (SC6-1) Belt-driven mobility (SC6-2) Leg-based mobility (SC6-3) Flight-based mobility (SC6-4) Aquatic mobility (SC6-5)

3.1.2 The most crucial aspect of robotics competitions is the ability to effectively address the challenges presented in each round. Inappropriate choices during competition can result in wasted time for each round. Each round of the robotics competition introduces different problem statements, requiring participants to be familiar with the identity and components of their robots. Therefore, experts or those with prior competition experience carefully consider the primary and secondary factors influencing the robot's performance in each round. They assess which factors contribute most to bringing the robot closer to the target quickly as dictated by the specific problem statement.

The top level 0, signifies the ultimate goal of this research which is to enable robots to reach the target level in the shortest possible time. While at level 1, the factor for selecting factors from [14] on page 43 necessitates participants to thoroughly study this information. It comprises 6 factors ranked in order of importance to be utilized in decision-making for robotics competition. These criteria are C1) Interactivity C2) Mobility C3) Accuracy C4) Object Handling C5) Intelligence and C6) Drive System Design (only one factor is exemplified for analysis in the paper). At level 2, enhances the primary factors and provides additional explanation and confidence-building aspects for decision-making. This is subdivided into 27 factors as depicted in Table 1.

Analysis at level 2 will not be presented on paper as the analytical approach is similar to that at level 1 and the paper may not provide sufficient space. Finally at level 3, alternative factors have simulated various competition scenarios [15] to decide on the optimal factors for consideration. This aids in achieving the fastest competition times in the next round.

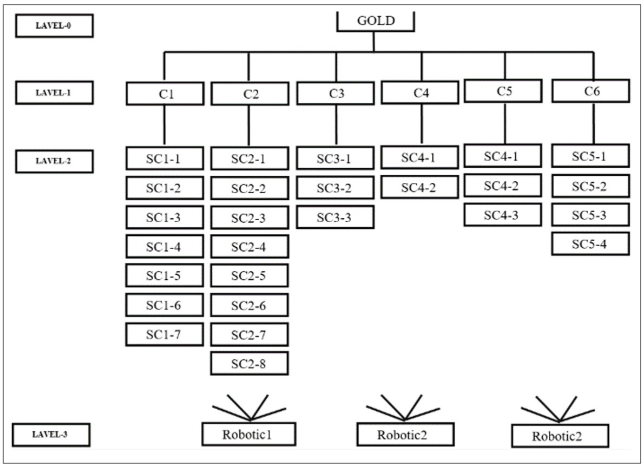

Figure 5. *Problem Decomposition into Layers of F-AHP Model for Factors of Competitive Robotics.*

In analyzing the researcher has analyzed the main factors and alternatives to show the comparisons in F-AHP analysis the researcher has shown the steps and methods of analysis only for the 5 experts. Therefore, all the data of every factor and expert is kept in Microsoft Excel.

3.2 Linguistic Variables and Corresponding Fuzzy Triangles.

After receiving all criteria and options the researcher therefore a questionnaire according to the criteria.

Step 1 involves decision-makers using linguistic terms to compare criteria or alternatives. This is done by converting the values from qualitative assessments into numerical form through linguistic variables. The average score of assessors is determined based on the principles of the triangular membership function which ranges from 1 to 9 [16], [17].

The real number values (l, m, u) constituting the triangular number are "l", the smallest probable value, "m", the most probable number, and "u", the largest probable value. The membership function of a triangular Fuzzy number is defined as follows.

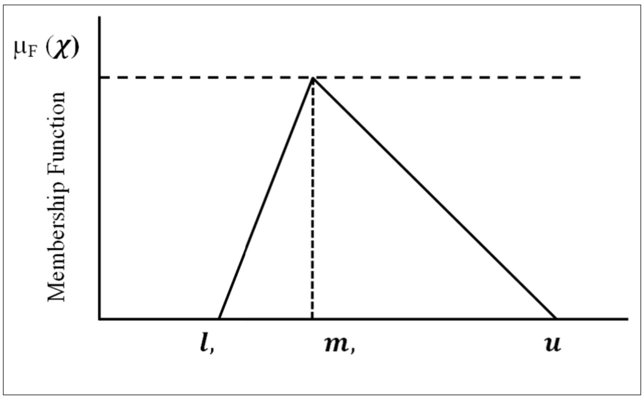

Figure 6. *Membership function of a triangular number*

$$\mu\tilde{A}(\chi) = \widetilde{M} = (\boldsymbol{l}, \boldsymbol{m}, \boldsymbol{u})$$

Set up the Triangular Fuzzy Numbers (TFN's). Each expert makes a pair-wise comparison of the decision criteria and gives them relative scores. In this method the Fuzzy conversion scale is as in Table 2 this scale has been employed in Fuzzy prioritization approach [18].

Table 2. *Linguistic terminology 1-9 and Corresponding Numerical Scale through Fuzzy Triangles.*

F-AHP Scales	Linguistic Trust	Triangular Fuzzy Nun's (l, m, u) Scales	Reciprocal TEN's (1/u, 1/m, 1/l) Scales
$\tilde{1}$	Equal Important (Eq. Imp.)	(1,1,1)	(1,1,1)
$\tilde{3}$	Weak Important (W. Imp.)	(2,3,4)	(1/4,1/3,1/2)
$\tilde{5}$	Fairly Important (F. Imp.)	(4,5,6)	(1/6,1/5,1/4)
$\tilde{7}$	Strong Important (S. Imp.)	(6,7,8)	(1/8,1/7,1/6)
$\tilde{9}$	Absolute Important (A. Imp.)	(9,9,9)	(1/9,1/9,1/9)
$\tilde{2}$	The intermittent values between two adjacent scales	(1,2,3)	(1/3,1/2,1/1)
$\tilde{4}$		(3,4,5)	(1/5,1/4,1/3)
$\tilde{6}$		(5,6,7)	(1/7,1/6,1/5)
$\tilde{8}$		(7,8,9)	(1/9,1/8,1/7)

3.2.1 Linguistic Terms in Data Creation and Analysis to create pairwise comparison matrices for the factors as outlined in Table 2 can be identified as follows:

1) If experts assign equal importance to criterion C1 as C1, itself the value becomes "Eq. Imp" The resulting pairwise comparison is 1, 1, 1.

2) If experts assign equal importance to criterion C1 as C2, the value becomes "W. Imp" The resulting pairwise comparison is 2, 3, 4.

3) If experts assign less importance to criterion C1 compared to C3, the value becomes 1/W. Imp The resulting pairwise comparison is 1/4, 1/3, 1/2.

4) If experts assign less importance to criterion C1 compared to C4, the value becomes 1/W. Imp The resulting pairwise comparison is 1/4, 1/3, 1/2.

5) If experts assign less importance to criterion C1 compared to C5, the value becomes "W. Imp" The resulting pairwise comparison is 1/4, 1/3, 1/2.

6) If criterion C1 has the same importance as C6 criterion, the value becomes " A. Imp" " The resulting pairwise comparison is 1/9, 1/9, 1/9.

Table 3. *Pairwise Comparison Matrix using Buckley's (1985) method with Geometric Mean used for weight calculation.*

Matrix analogy display						
CRI	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**
C1	Eq. Imp	1/F.Imp	1/F.Imp	1/F.Imp	1/ W.Imp	Eq. Imp
C2	F. Imp	Eq. Imp	1/F.Imp	1/ W.Imp	Eq. Imp	1/ W.Imp
C3	F. Imp	F. Imp	Eq. Imp	W. Imp	1/ W.Imp	W. Imp
C4	F. Imp	W. Imp	1/ W.Imp	Eq. Imp	1/ W.Imp	W. Imp
C5	W. Imp	Eq. Imp	1/ W.Imp	W. Imp	Eq. Imp	1/ W.Imp
C6	Eq. Imp	W.Imp	1/ W.Imp	1/ W.Imp	1/ W.Imp	Eq. Imp

$$\tilde{A}(l,m,u)^{-1}\left(\frac{1}{u},\frac{1}{m},\frac{1}{l}\right) \qquad (2)$$

This process of generating pairwise comparison matrices is applied to all criteria and levels. The results from the comparison process are then used for further analysis.

$$\tilde{a}_{ij} = \frac{\sum_{k=1}^{k} \tilde{d}_{ij}^{k}}{k} \qquad (3)$$

If decision makers are more than one each decision maker's preference will be averaged and the average will be calculated according to equation 3.

Table 4. *For consistent linguistic translation using a pairwise comparison matrix.*

Pairwise Comparison Matrix						
CRI	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**
C1	(1,1,1)	(1/6,1/5, 1/4)	(1/6,1/5, 1/4)	(1/6,1/5, 1/4)	(1/4,1/3, 1/2)	(1,1,1)
C2	(4,5,6)	(1,1,1)	(1/6,1/5, 1/4)	(1/4,1/3, 1/2)	(1,1,1)	(1/4,1/3, 1/2)
C3	(4,5,6)	(4,5,6)	(1,1,1)	(2,3,4)	(1/4,1/3, 1/2)	(2,3,4)
C4	(4,5,6)	(2,3,4)	(1/4,1/3, 1/2)	(1,1,1)	(1/4,1/3, 1/2)	(2,3,4)
C5	(2,3,4)	(1,1,1)	(1/4,1/3, 1/2)	(2,3,4)	(1,1,1)	(1/4,1/3, 1/2)
C6	(1,1,1)	(2,3,4)	(1/4,1/3, 1/2)	(1/4,1/3, 1/2)	(1/4,1/3, 1/2)	(1,1,1)

3.2.2 Step 2: Due to the averaging configuration the pairwise comparison support matrix will be updated based on the transformations indicated in Table 4.

3.2.3 Step 3 involves substituting the values of the transformed pairwise comparison triangle analyses which have been converted into an absolute form from the matrix table. The geometric mean value of the comprehensive set of pairwise comparison values for the "interrelation aspect" criterion ($\tilde{R}_i$)will be calculated using the following formula.

$$\tilde{R}_i = \left(\prod_{j=1}^{n} \tilde{d}_{ij}\right)^{\frac{1}{n}} \qquad (4)$$

3.2.4 Step 4 involves calculating the covering cluster weights for each criterion which can be obtained from Equation 5. Compute the vector sum of each entity then find the exponentiation (-1) of the vector sum representing the numbers within the covering cluster triangle.

Table 5. *Geometric Mean of Fuzzy Logic.*

CRI	$\tilde{R}_i$		
C1	0.324	0.372	0.445
C2	0.589	0.693	0.849
C3	1.587	2.054	2.570
C4	1.000	1.308	1.698
C5	0.794	1.000	1.260
C6	0.561	0.693	0.891

Total = =(D62*G62*J62*M62*P62*S62) ^ (1/6)

Reverse P (-1) =D85^ (-1)

$$Increasing(INCR) = REVERSEP(-1) \quad (5)$$

To find the fuzzy weight of the criteria $\tilde{w}_i$ multiply each $\tilde{R}_i$ with this reverse vector.

$$\tilde{W}_i = \tilde{r}_i \otimes (\tilde{r}_i \oplus \tilde{r}_2 \oplus .... \oplus \tilde{r}_n)^{-1} \quad (6)$$

$$\tilde{W}_i = [(0.756 \times 0.094);(0.855 \times 0.117);(1.017 \times 0.150)]$$

$$\tilde{W}_i = [0.071;0.097;0.138]$$

Therefore, the relative fuzzy weights of each criterion are presented in Table 6.

Table 6. *Relative Fuzzy Weights of Each Criterion.*

CRI	$\tilde{W}_i$		
C1	0.042	0.061	0.092
C2	0.077	0.113	0.175
C3	0.206	0.335	0.529
C4	0.130	0.213	0.350
C5	0.103	0.163	0.260
C6	0.073	0.113	0.184

3.2.5 Step 6: The values obtained from the relative fuzzy weights of each criterion are still ambiguous triangular numbers. Therefore, the ambiguity must be resolved by the centripetal method using the equation introduced by Chou and Chang [19] using equation 7.

$$\tilde{M}_i = \frac{lw_i + mw_i + uw_i}{3} \quad (7)$$

$\tilde{M}_i$ is an unambiguous number but needs to be normalized by following Equation 8.

$$N_i = \frac{M_i}{\sum_{i=1}^{n} M_i} \quad (8)$$

Table 7. *Average Weight Criteria ($\tilde{M}_i$) and Normal Weight Criteria ($\tilde{N}_i$).*

CRI	$\tilde{M}_i$	$\tilde{N}_i$
C1	0.065	0.060
C2	0.121	0.113
C3	0.357	0.333
C4	0.231	0.163
C5	0.175	0.163
C6	0.123	0.115
Total	1.081	

3.3 Alternative Criteria

This article explores three possible scenarios, with Robot 1 [20] representing a contender designed for sheep herding competitions. In rural areas sheep farming is a prevalent practice serving both agricultural and tourism purposes. One crucial aspect that sheep farm owners must address is safeguarding their flocks from stray dogs that may infiltrate the farm and pose a threat to the sheep. Such incidents can result in substantial losses. The upcoming competition challenges participants to employ creativity and innovation in devising the robot's movement to efficiently manage the situation. Assuming the robot's role is to herd the sheep it must guide the sheep (represented by white ping pong balls) into the sheepfold while driving away the simulated wild dogs (represented by orange ping pong balls) from the sheepfold

Robot 2 [20] represents a participant in the basketball robot game. Basketball is a widely played international sport where two teams compete to score points by shooting the ball into the opposing team's basket. The team with the highest score at the end of the game is declared the winner. In the case of the basketball robot competition, it simulates the human basketball game. Each team has one robot with exceptional abilities in capturing and shooting the basketball. The competition is divided into two halves, each lasting 3 minutes. The team with the highest score at the end of the game emerges as the winner of the competition.

Robot 3 [20] serves as a representative in the search and rescue competition. The robot is tasked with assisting disaster-stricken individuals at designated locations by deploying life-sustaining bags. The transfer of life-sustaining bags requires the robot to load them once and place them in predetermined positions. The robot must navigate within the white area or the safe zone while avoiding entry into hazardous zones or areas marked with black lines. Upon successful completion of the mission the robot is required to return to the starting point. To assess various aspects of the competing robot it is crucial to prepare scenarios and challenges. These challenges serve as models that help evaluate the capabilities of the robot [21].

3.3.1 Linguistic Terms in Data Creation and Analysis

Table 8. *Transforming the Languages Referenced by Pairwise Comparison Matrices into Numerical Terms.*

Alts	A1	A2	A3
A1	(1,1,1)	(2,3,4)	(2,3,4)
A2	(4,5,6)	(1,1,1)	(1,1,1)
A3	(9,9,9)	(1,1,1)	(1,1,1)

3.3.2 The geometric means of the fuzzy comparison ($\tilde{W}_i$) and the alternative relative fuzzy weights for each criterion ($\tilde{R}_i$) are mentioned in Table 9.

Table 9. *Aalternative relative fuzzy weights ($\tilde{R}_i$).*

Alts	$\tilde{R}_i$			$\tilde{W}_i$		
A1	1.587	1.710	1.817	0.460	0.520	0.580
A2	0.550	0.585	0.630	0.160	0.178	0.201
A3	1.000	1.000	1.000	0.290	0.304	0.319
total	3.138	3.295	3.447			
Reverst	0.319	0.304	0.290			
Increase	0.290	0.304	0.319			

Table 10. *Average Weight Criteria ($\tilde{M}_i$) and Normal Weight Criteria ($\tilde{N}_i$).*

Alts	$\tilde{M}_i$	$\tilde{N}_i$
A1	0.520	0.518
A2	0.179	0.179
A3	0.304	0.303

3.3.3 Weight of Alternative Criteria

Table 11. *Displaying the Weight of Each Choice for Each Criterion.*

Criteria	Weight	A1	A2	A3
C1	0.06	0.597	0.202	0.059
C2	0.113	0.307	0.255	0.147
C3	0.333	0.113	0.327	0.235
C4	0.215	0.597	0.202	0.147
C5	0.163	0.425	0.425	0.296
C6	0.115	0.518	0.179	0.101
Total		0.373	0.300	0.313

4. Evaluation Results

Following the conclusion of the Level 3 decision analysis the criteria for analysis were applied to both experts and all students. This article provides an example from Expert 5 only. This selective focus is due to the extensive nature of explaining the entire process to everyone in the document. The final results for all participants will be consolidated and presented in the summary in 4.1 and 4.2

4.1 All 5 experts focus on (C1) interaction factors giving robots flexibility and adaptability to changing environmental conditions while (SC1–5) image processing gives robots the ability to sense and respond to the environment while competing effectively. Combining these two factors improves competitive performance and allows the robot to maximize its time in changing situations [21]. Among the alternative scenarios compared with factors at level 1 and 2, option A1 (Robotic 1) performed the best in terms of achieving optimal time, as indicated by its calculated weight (Ni) = 0.508, as shown in Table 12.

Table 12. *Summarizing evaluations by decision-makers based on experts 5.*

Scores of Alternatives to related Criteria					
	Weights (Ni)	Level2	A1	A2	A3
C1	0.336	SC1-1 (0.116)	0.014	0.014	0.007
		SC1-2 (0.125)	0.012	0.007	0.009
		SC1-3 (0 .111)	0.01	0.005	0.007
		SC1-4 (0 .119)	0.011	0.004	0.005
		SC1-5 (0 .136)	0.017	0.100	0.015
		SC1-6 (0 .117)	0.011	0.011	0.011
		SC1-7 (0 .121)	0.011	0.007	0.009
		SC1-8 (0 .125)	0.012	0.007	0.003
C2	0.298	SC2-1 (0.132)	0.007	0.007	0.007
		SC2-2 (0.114)	0.006	0.004	0.005
		SC2-3 (0.092)	0.005	0.004	0.002
		SC2-4 (0.100)	0.006	0.004	0.005
		SC2-5 (0.099)	0.006	0.003	0.003
		SC2-6 (0.118)	0.007	0.002	0.002
		SC2-7 (0.104)	0.006	0.003	0.004
		SC2-8 (0.128)	0.007	0.002	0.002
		SC2-9 (0.112)	0.006	0.00.	0.002
C3	0.275	SC3-1 (0.119)	0.014	0.014	0.014
		SC3-2 (0.111)	0.013	0.008	0.01
		SC3-3 (0.136)	0.015	0.015	0.015
		SC3-4 (0.242)	0.013	0.01	0.006
C4	0.245	SC4-1 (0.133)	0.022	0.018	0.028
		SC4-2 (0.128)	0.019	0.012	0.03
		SC4-3 (0.109)	0.017	0.021	0.026
C5	0.296	SC5-1 (0.136)	0.015	0.015	0.03
		SC5-2 (0.128)	0.012	0.016	0.02
		SC5-3 (0.124)	0.012	0.018	0.026
C6	0.221	SC6-1 (0.123)	0.008	0.011	0.013
		SC6-2 (0.135)	0.007	0.008	0.011
		SC6-3 (0.133)	0.012	0.012	0.012
		SC6-4 (0.104)	0.008	0.01	0.012
		SC6-5 (0.105)	0.012	0.012	0.012

Level1							
Alts	C1	C2	C3	C4	C5	C6	Total
A1	0302	0.307	0.212	0.322	0.452	0.200	0.508
A2	0.065	0.032	0.047	0.058	0.039	0.047	0.507
A3	0.059	0.032	0.045	0.051	0.049	0.053	0.485

4.2 All 5 students determined the weight values according to Table 1, focusing on factors (C2) Posture factors affect a robot's performance in competition. Maintaining the correct posture helps the robot be agile and efficient in carrying out its tasks and factors (SC2-6) in level 2 Climbing steep slopes gives robots the ability to burn off energy and maintain stability in difficult conditions. Efficient operation in steep conditions is an important competitive factor. Among the alternative scenarios compared with factors at level 1 and level 2, option A1 (Robotic 1) performed the best in terms of achieving optimal time, as indicated by its calculated weight (Ni) = 0.573, as shown in Table 13.

Table 13. *Summarizing evaluations by decision-makers based on students 5.*

Scores of Alternatives to related Criteria					
Level1	Weights (Ni)	Level2	A1	A2	A3
C1	0.299	SC1-1 (0. 133)	0.014	0.014	0.007
		SC1-2 (0. 105)	0.012	0.007	0.009
		SC1-3 (0. 125)	0.01	0.005	0.007
		SC1-4 (0. 133)	0.011	0.004	0.005
		SC1-5 (0. 127)	0.017	0.100	0.015
		SC1-6 (0. 119)	0.011	0.011	0.011
		SC1-7 (0. 129)	0.011	0.007	0.009
		SC1-8 (0. 128)	0.012	0.007	0.003
C2	0.335	SC2-1 (0.131)	0.007	0.007	0.007
		SC2-2 (0.113)	0.006	0.004	0.005
		SC2-3 (0.084)	0.005	0.004	0.002
		SC2-4 (0.091)	0.006	0.004	0.005
		SC2-5 (0.111)	0.006	0.003	0.003
		SC2-6 (0.145)	0.027	0.002	0.002
		SC2-7 (0.129)	0.006	0.003	0.004
		SC2-8 (0.106)	0.007	0.002	0.002
		SC2-9 (0.127)	0.006	0.003	0.002

Scores of Alternatives to related Criteria					
Level1	Weights (Ni)	Level2	A1	A2	A3
C3	0.235	SC3-1 (0.120)	0.014	0.014	0.014
		SC3-2 (0.129)	0.013	0.008	0.01
		SC3-3 (0.137)	0.015	0.015	0.015
		SC3-4 (0.134)	0.013	0.01	0.006
C4	0.289	SC4-1 (0.138)	0.03	0.024	0.019
		SC4-2 (0.133)	0.028	0.018	0.011
		SC4-3 (0.109)	0.026	0.017	0.021
C5	0.222	SC5-1 (0.118)	0.026	0.013	0.013
		SC5-2 (0.142)	0.017	0.01	0.013
		SC5-3 (0.144)	0.022	0.011	0.015
C6	0.256	SC6-1 (0.131)	0.011	0.007	0.009
		SC6-2 (0.142)	0.008	0.005	0.006
		SC6-3 (0.144)	0.009	0.009	0.009
		SC6-4 (0.103)	0.01	0.006	0.008
		SC6-5 (0.130)	0.011	0.011	0.011

Level1							
Alts	C1	C2	C3	C4	C5	C6	Total
A1	0.365	0.322	0.289	0.330	0.254	0.392	0.573
A2	0.210	0.257	0.330	0.354	0.336	0.245	0.466
A3	0.202	0.400	0.4323	0.220	0.256	0.303	0.468

5. Summary

This paper is to study the prototype factors of robots suitable for competition and use the Multi Criteria Decision Making (MCDM) method with the Fuzzy Analytic Hierarchic Process (F-AHP) model to select and evaluate the main 6 factors, 35 sub-factors, and 3 alternatives It also forms the basis for decision-making in robotics competitions and serves as a repository of information for individuals in academia and related commerce.

The researcher has studied related literature to collect basic information about robots and factors in robot competition and System Development Life Cycle (SDLC). From the literature study Collect factors related to robots used in competition by considering factors that affect the success of robots in competing in the market. and from general educational institutions participating in the competition. Then determine the weight of the factors based on the importance of each factor to the success of the robot.

The method used for the comparison was a face-to-face questionnaire using the question entry method. For example, which factor is more important than which factor by how much according to the level of consideration? Compare from table. Both sides enter scores to determine weights by developing a decision model.

Next is to analyze the results of the decision model to select appropriate competitive factors for the robot in the competition. Data analysis will get factors at level 1 and level 2. Then the weight of the data obtained will be analyzed against level 3, which is comparing factors with alternative problems to use in making the best time.

In addition, the researcher uses additional research methods such as collecting field data from real competitions to support the results of this research. Analysis and evaluation show that experts identify the interaction aspect as the best weight for the competitive robot factor while beginners identify the nature of the gesture. Both sides estimated the weight of Robotic 1 in the same way.

It also emphasizes the importance of accepting robots as complex systems equipped with artificial intelligence and the need to understand the context in which robots compete. Education and industry decision making in robotics involves using criteria and tools to reduce errors and increase decision accuracy, with probability and conditional reasoning playing a key role.

6. Discussion

6.1 Differences in academic experiences and knowledge can be assumed to lead to varying perspectives.

1. It is conceivable that experts may emphasize factors related to efficiency and effectiveness in competition, while students may focus on aspects influencing the design or development process.

2. Experts may possess a deep understanding of the rules and requirements of the competition whereas students may have a more limited comprehension.

6.2 The analysis with a shared viewpoint on the proposed solution for addressing the time management issues of the robot's factors at level 3 indicates a consensus. Both sides of the assessment agree that Robotic 1 is ranked as the top choice based on the highest weighted criteria. What the analysis with a shared viewpoint means is that both parties agree on the prioritization of Robotic 1 as the preferred solution.

6.3 The Fuzzy Analytic Hierarchy Process (F-AHP) method is used for ranking when comparing both sides. Serves to distribute weight, resulting in higher values during analysis. Therefore, using vague numerical values in the analysis will reduce the risk of decision making.

6.4 Therefore F-AHP employs the fuzzy set coverage theory for pairwise comparisons instead of crisp numerical values. This grants F-AHP the capability to make decisions under coverage considering the uncertainties of various factors. This process mimics human-like thinking enhancing decision-making efficiency.

7. References

[1] C. Marknual, *Research Intelligence, Robot industry and the development of the Thai manufacturing sector robotic-series1*. Available Online at https://www.krungsri.com/th/research/research-intelligence/ri-robotic-series1-landscape, accessed on 30 June 2023.

[2] D. Gupta, A. Ahlawat, and K. Sagar. "Usability Prediction & Ranking of SDLC Models Using Fuzzy Hierarchical Usability Model." *De Gruyter,* Vol. 7, No. 1, pp. 161-168, June, 2017.

[3] H. R. Weistroffer and Y. Li. "Multiple criteria decision analysis software." *Multiple Criteria Decision Analysis,* pp. 1301-1341, 2016.

[4] T. Tsoutsos, M. Drandaki, N. Frantzeskaki, E. Iosifidis and I. Kiosses. "Sustainable energy planning by using multi-criteria analysis application in the island of Crete." *Energy Policy, Elsevier,* Vol. 37, No. 5, pp. 1587-1600, May, 2009.

[5] G. Kabir and M.A.A. Hasin. "Multi-criteria inventory classification through integration of fuzzy analytic hierarchy process and artificial neural network." *International Journal of Industrial and Systems Engineering,* Vol. 14, No. 1, pp. 74-103, January, 2013.

[6] L.A. Zadeh. "Fuzzy Sets." *Information and Control,* Vol. 8, No. 3, pp. 199-249, 1965.

[7] C. Kahraman. *Knowledge-Based Systems.* Available Online at https://www.journals.elsevier.com/knowledge-based-systems/editorial-board/professor-cengiz-kahraman, accessed on 30 June 2023.

[8] E.E. Karsak. "Robot selection using an integrated approach based on quality function deployment and fuzzy regression." *International Journal of Production Research,* Vol. 46, No. 3, pp. 723-738, February, 2008.

[9] Ch. Sudip and P.S. Aithal. "A Smart IDE for Robotics Research." *International Journal of Management, Technology, and Social Sciences (IJMTS),* Vol. 7, No. 1, pp. 513- 519, June, 2022.

[10] C. Kim, Y. Kim, and H. Yi. "Fuzzy Analytic Hierarchy Process-Based Mobile Robot Path Planning." *Multidisciplinary Digital Publishing Institute,* Vol. 9, No. 2, February, 2020.

[11] B. Bairagi and B. Dey. "Selection of robotic systems in fuzzy multi criteria decision-making environment." *International Journal of Computational Systems Engineering,* Vol. 2, No. 1, pp. 32-42, 2016.

[12] A. Narkglom, *Robot industry in Thailand.* Available Online at chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://waa.inter.nstda.or.th/prs/pub/Robot-Whitepaper-Cover.pdf, accessed on 25 July 2023.

[13] P. Luenam. "Prioritized factors using fuzzy analytic hierarchy process: understanding concepts and its application." *Modern Management Journal,* Vol. 11, No. 1, pp. 1-12, January-June, 2015.

[14] P. Meesad, *LACC System and Artificial Neural Networks.* Available Online at http://202.44.34.134/teacher/FileDL/phayung36255362552.pdf, accessed on 25 October 2009.

[15] Development Bureau OBEC Building, *Simulated problems used in robot competitions.* Available Online at https://www.sillapa.net/rule61/robot-68.pdf, accessed on 30 June 2023.

[16] CODECRUCKS, *Linguistic variables and hedges in fuzzy logic.* Available Online at https://codecrucks.com/linguistic-variables-and-hedges-in-fuzzy-logic/, accessed on 30 July 2023.

[17] R.L.N. Murty, S.G. Kondamudi, M.V. Suryanarayana, and P. Giribabu. "Application of Buckley's fuzzy AHP to identify the most important factor affecting the unorganized micro-entrepreneurs borrowing decision." *International Journal of Management (IJM),* Vol. 11, No. 6, pp. 665-674, June, 2020.

[18] Y. Fu, M. Li, H. Luo, and G.Q. Huang. "Industrial robot selection using stochastic multicriteria acceptability analysis for group decision making." *Robotics and Autonomous Systems,* Vol. 122, December, 2019.

[19] S.Y. Chou and Y.H. Chang. "A decision support system for supplier selection based on a strategy-aligned fuzzy SMART approach." *Expert Systems with Applications,* Vol. 34, No. 4, pp. 2241-2253, May, 2008.

[20] T.T. Mac, C. Copot, D.T. Tran, and R.D. Keyser. "Heuristic approaches in robot path planning: A survey." *Robotics and Autonomous Systems,* Vol. 86, pp. 13-28, December, 2016.

[21] A.A. Ali, A.T. Rashid, M. Frasca, and L. Fortuna. "An algorithm for multi-robot collision-free navigation based on shortest distance." *Robotics and Autonomous Systems,* Vol. 75, pp. 119-128, 2016.