

Exploring competitive sports technology development: using a MCDM model

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Abstract:

In this study, our primary focus is the exploration of essential technologies that play a pivotal role in enhancing the training of competitive sports. This involves not only understanding the individual technologies themselves but also delving into the intricate cause-and-effect relationships that bind them. By unraveling these connections, we can provide well-informed recommendations that drive the development of technological advancements in the realm of competitive sports. To achieve our research objectives, we propose an assessment framework for assessing competitive sports technology development with the Decision-Making Trial and Evaluation Laboratory, and design a questionnaire, which will be used in the interview with nine experts to learn of the affecting relationships between the developments. Our findings revealed most important developments being Internet of Things which serves as a linchpin connecting diverse technologies. Following closely is Artificial Intelligence (AI), which revolutionizes the landscape by automating tasks such as data analysis and strategic planning, formerly reliant on manual efforts. Additionally, the emergence of 5G wireless technology accelerates the transmission of crucial information, thereby expediting the exchange of insights and strategies in that order, which prove to be the three most important technologies in our assessment framework system and affect image recognition technology and wearable sensing devices. The conclusions are the applications like Internet of Things helping linking many technologies, the Artificial Intelligence technology replacing manual work of statistics of data and formulating skills and tactics, and the acceleration of past transmission of messages by means of 5G wireless technology, which are the technologies used to improve training methods for sport players to increase training effectiveness and improve sport performances.

Key Words: internet of things, multi-criteria decision making, decision science, sports training

Introduction

The performances in competitive sports represent the strength a nation shows. Whereas the spirit of modern competitive sports is to seek the higher, the farther and the stronger, competitive sports have another aspect that can fully showcase the soft strength and national health of a nation, while being able to promote international cooperation and national status as well as helping a nation in terms of international visibility (Sport Administrator, Ministry of Education, 2017). Hence, countries are the more fervent in supporting and discussing the development of sport policy and participation of academic research (Sekitani & Zhao, 2021; Leeds, 2019). Training of competitive sports is largely divided in three stages: training, game and adjustment.

Training stage refers to the early stage of training prior to the games; the game stage refers to the period of game; the adjustment stage means the period of adjustments to training after the games (Ratten, 2020). Technology is also applied to annual training programs for sport players and coaches. For example, the virtual reality technology is applied, combining wearable sensing devices, in pre-game training for sport players to help them take simulating training in various complex contexts of sports (Neumann et al., 2018; Arndt et al., 2018), and wearable sensing devices are used to collect physiological data of sport players as reference in sport training (Cummins et al., 2013; Valchinov & Pallikarakis, 2014).

Also applied are the image recognition technique and Artificial Intelligence to monitor the sport players in terms of motion skills to see if any posture is incorrect or needs adjustment during training and amid the game; these technologies can also monitor the sport players for any foul behaviors during the game, whereby to assist both the coaches and the referees as well as help decreasing sport injuries happening to the players (Claudino et al., 2019; Naglah et al., 2018). Wearable sensing devices can also be applied, combining the high speed of 5G wireless technology and high accuracy of Internet of Things throughout the training stage to measure the physiological data of sport players (Jones & Denison, 2016), where an additional employment of image recognition technology to analyze and adjustment of actions and tactics during game can serve as reference for organization of subsequent training and skills and tactics of games (Kasiri et al., 2017; Cummins et al., 2013).

In recent years, multi-criteria decision-making (MCDM) models have been widely employed in various research contexts to analyze complex issues or make decisions within different environments. MCDM involves evaluating and ranking different solutions based on multiple factors or criteria, often conflicting with each other. These criteria are influenced by interrelationships among factors, and numerical measurements are used to provide a favorable framework for addressing problems and identifying optimal solutions. This aids decision-makers in effectively resolving diverse problems and showcases strong soft computing capabilities.

One prominent approach within MCDM is the Decision Making and Trial Evaluation Laboratory (DEMATEL) method, which has been utilized by many researchers (Asadi et al., 2022). Compared to other methods, DEMATEL excels in uncovering mutual influences among factors from the perspective of decision-makers. It achieves this through the use of an Influential Network Relation Map (INRM), a structured visual representation, which helps decision-makers gain a clear understanding of primary influencing factors and factors influenced by others. This facilitates a better grasp of causal relationships (Gabus & Fontela, 1972).

This technique finds extensive application in evaluative issue analyses across various fields, including the investigation of influencing factors within the realm of sports. Chou et al. (2017) employed DEMATEL to identify key factors affecting the outsourcing of sports venues. They identified five major dimensions: policy feasibility, market feasibility, financial feasibility, architectural planning feasibility, and operational oversight feasibility.

The study concluded that policy feasibility and architectural planning feasibility are the primary influencing factors for the successful outsourcing of sports venues, offering valuable reference points for future governmental endeavors. In a study by Chen and Sun (2012) concerning the leisure sports choices of the elderly, seven assessment criteria were considered: physical condition, psychological state, entertainment, social aspects, environment, cost, and family. Using DEMATEL, the interdependencies among these factors were determined to enhance participation in leisure sports and identify crucial elements for boosting elderly engagement in appropriate leisure activities.

Psychological well-being and entertainment emerged as the most significant considerations for planning leisure sports, followed by physical health (Cabras et al., 2017). Applying DEMATEL, Cabras et al. (2017) investigated competitive strategic indicators in the video game console industry, categorizing them into four dimensions: revenue, opportunities, costs, and risks. The results indicated that costs held the highest impact weight, offering valuable insights for assessment and aiding video game console companies in enhancing strategic performance.

Past research indicated increasing scientific studies on the relationship between competitive sports technology development, yet there are still many aspects of the relationship to be explored and examined. Most past research discussed only about the technological applications of certain technologies in competitive sports, failing to understand in a comprehensive way the effect of technology on competitive sports. Therefore, it is important to explore how technologies of all varieties affect competitive sports.

From the above stated research background and motivation, the specific objectives of this study are as follows:

- (i) to understand what competitive sports technologies have been developed, and to propose an assessment framework for competitive sports technology development as well as in what ways the competitive sports technology development affect.
- (ii) to explore the assessment framework for competitive sports technology development to assess the effect of the technologies, whereby to analyze the weights and ranks of these technologies.
- (iii) to explore, by applying MCDM, the cause-effect relationship between the technologies being developed within the assessment framework for competitive sports technology development, to identify the technologies that affect most significantly, and to present recommendations to decision supporters in order to facilitate technology development in favor of competitive sports.

Material & methods

As technology advances, technologies have gradually been applied in both hard- and software equipment and training modes for sport players to assist in the performance of competitive sports players (Peng & Pan, 2021). What are competing in the arena of major competitive sports are not only the skills and strengths of players, it is also the sport science and technology of every nation that is tested. How to apply technology development in the training and games for competitive sports players to help increase their performance remains one of the problems of focus by the nations on competitive sports. This study thus establishes an expert decision taskforce to explore the technology development of competitive sports. The members of the decision taskforce comprised of nine experts from the government, academia, industry, and national team coaches, who possess specialized knowledge. These interviewed experts included official at local sports bureau and the persons from multiple institutions like university physical education department, electronic & information industry related to sport technology and national teams under the Sport Administration. They were elected because of profound knowledge, being reliable and rich work experience in their respective realms. The information on their personal backgrounds is as Table 1 shows.

Table 1 Summary of information on personal backgrounds of expert decision taskforce

Expert No.	Working for/Title	Education background (years of service)
1	Competitive sports dept. at university/Prof.	Ph.D. (26 years)
2	Physical education dept. at university/Prof.	Ph.D. (31 years)
3	Physical education dept. at university/Prof.	Master (27 years)
4	Electronic & information industry/engineer	Ph.D. (7 years)
5	ICT industry/engineer	Bachelor (13 years)
6	Electronic tech. industry/engineer	Master (10 years)
7	Sports Administration/national team coach	Ph.D. (23 years)
8	Local sports bureau/official	Ph.D. (10 years)
9	Sports Administration /national team coach	Ph.D. (15 years)

To establish the competitive sports technology development in Taiwan, we began by summarizing existed literature to lay out an initial assessment framework for competitive sports technology development in Taiwan, and then conducted seven meetings with the nine experts to discuss about and review whether the assessment framework needed modification. As such, the competitive sports technology development will be elaborated in the below stated literature. To establish the competitive sports technology development in Taiwan, we began by summarizing existed literature to lay out an initial assessment framework for competitive sports technology development in Taiwan, and then conducted seven meetings with the nine experts to discuss about and review whether the assessment framework needed modification. As such, the competitive sports technology development will be elaborated in the below stated literature.

Collection of physiological data of sport players using wearable sensing devices (C₁)

Wearable sensing devices and Global Positioning System have mostly been used as commonly seen coaching-assisting tools in professional sports in recent years (Aughey, 2011). GPS is capable of telling position, measuring speed accurately and recording time information at high precision. When it is embedded into wearable sensing devices to measure the body data of sport players in action, it is free from external effects and prone to arrive at highly accurate measurements. Currently sensors have been made into a variety of accessories, e.g., glasses, shoes, wrist straps, caps, sox, clothes, headset and smart phone (Xu & Guo, 2020), facilitating users to capture their own physiological data. When sport events develop worldwide, the applications of wearable sensing devices in sports become more frequent and broad; for instance, smart gloves worn by baseball players measure the pressure on their arms and elbows and the pitching range of pitchers (Lizzio et al., 2020). A smart wristband worn by swimming players measures their frequency and force of stroke as well as heart rate (Bächlin & Tröster, 2012).

Customizing sport equipment and ware for sport players employing 3D printing technology (C₂)

Presently the makers who respond to the sport markets' high demand for customized equipment attempt to apply the 3D printing technology to customize sport equipment and ware for sport players. The process ranges from developing, testing to production, enabling the players to update their personalized sport equipment and strengthen their physical quality. Many sport players suffer sport injuries. Given that about 20%-40% of the injuries happen to the knees of basketball and soccer players (Anirudh & Yeole, 2021), makers develop, by using the 3D printing technology, knee protectors that can protect the knees and reduce the happening of sport injuries.

Effectively perfecting sport players' training in different contexts using Virtual Reality to enhance their ability (C₃)

Virtual Reality as a training solution intrigues many because it not only realizes safe and repeated training but also can control the training environment completely (Wood et al., 2021). When used reasonably, Virtual Reality can enhance sport levels and training scenes, allowing sport players to increase the training efficacy and be immersed in various predefined virtual contexts. In Virtual Reality equipment, users can increase their experience with the equipment, as there are good interactions in virtual settings. Hence, Virtual Reality as new technology is found with immense prospect of development (Zhou, 2021). The power of Virtual Reality in sport training lies in its capability of simulating sport activities from the first-person and 3D perspective and creating presence specifically in respect of users' learning style in visual, audial and kinetic senses, while helping them develop the necessary perception and sporting skills.

Artificial Intelligence technology embedded in sport technology software equipment capable of accurately upgrading players' training quality (C₄)

The fast-advancing Artificial Intelligence technology has blended in our everyday life in recent years. Examples are the applications to face and image recognition, combination with medicine, mass transportation, and electronic products. With data, artificial intelligence can do analysis and make predictions, where it is used to assess sport players' performance in individual's or group competitive sports (Rajšp & Fister, 2020). Sport players use wearable devices, sensors and equipment that uses Internet of Things as well as intelligent data analytic methods and tools to increase training efficiency or reduce workload, while maintaining better training performance (Rajšp & Fister, 2020). These technologies not only are employed in sport player training but also begin to be applied in training at schools. When agilely employed in tennis training at senior high schools, they enrich the contents of training and increase both the training efficiency and training effectiveness of tennis

lessons, as they create good learning atmosphere and environment to upgrade training quality (Zhang & Tsai, 2021).

Internet of Things in combination with Internet accurately collecting and analyzing sport data of players (C₅)

The Internet of Things technology is capable of application to sports and health monitoring systems with high efficiency, high accuracy and at low cost, and being embedded in wearable sensing devices to monitor on training for sport players (Xiao et al., 2020), receive their physiological parameters for assessment of stabilities during sports (Jin et al., 2021); other usages include testing consumptions during sports to establish effective data (Yang & Ming, 2021), and lastly achieving expected training effectiveness. Two pieces of Internet of Things technology, namely, workout tracer and body sensors, have significant effect on the training efficiency of sport players (Li et al., 2020). For instance, Internet of Things can track the shooting performance of professional basketball players and do remote analysis, where with the statistics on the peak performance of each play in dribbling, scope of jumping basket and other motions (Du, 2021), it is possible to effectively plan on dedicated training programs based on analytic reports on the individuals to boost their power. Sensors worn by field & track sport players on the leg detect the force and strengths of legs stretching during the movement and calculate the steps accurately, based on which data the players then improve their strategies (Deng, 2021). As such, the Internet of Things technology helps sport players understand their own advantages and deficiencies to improve on their tactics in the game, as well as helps both the coaches and the players decide in better teaching options (Jiang, 2021).

Image recognition technology that analyzes sport players' motions allowing them better tactic applications (C₆)

Amid the Internet development, depth displaying visual recognition and search has been widely applied in many real life cases (Pan & Li, 2020). Today, video and image technology is slowly blending in everyday life and sport training (Li, 2021). Sport video analysis is an emerging trade, which analyzes sport games in terms of actions and tactics, and provides assessments of players' performance to coaches and sports related trades (Kasiri et al., 2017). The competitive sports environment needs statistics on sport players' performance to measure their actions during the game and to distinguish detailed actions of execution (Kasiri et al., 2017). In track & field training, the video image recognition technology is closely related to training, where on the one hand the video image technology is capable of promote track & field training to a great extent, and on the other, track & field teaching and training need the support by video image technology to record every moment's action (Li, 2021).

5G wireless technology being realized in living application and developing sport technology (C₇)

5th Generation Wireless System is characterized by high speed, low lag, and multi-links (Massaro & Kim, 2021); it creates a linked world with Internet of Things, supports Internet of Things applications and enhances the functions (Saddoud et al., 2020). Of the 5G wireless technology functions, some may be displaying for the first time with Internet to the audience in large-scale sport games. The technologies involved include trajectories and bounce distribution of ping pong ball, tracking of badminton shuttle, realization of rich contents of on social network by increasing live cast flow, real-time 3D cast with wide view and free angles, Artificial Intelligence is based sport data analysis during cast, technology-enhanced broadcast systems of sport games, etc. (Wu et al., 2021). The 5G wireless technology transmission technology and Internet of Things accelerate the social reform, bringing huge changes to social development. If widely applied to sports, this technology not only can make up for the deficiency of workout space and skill training but also reduces body injuries due to difficulties of innovation (Wei & Hao, 2020).

This study involves the proposition of an assessment framework for competitive sports technology development, in which the DEMATEL technique is used to assess competitive sports technology development. In the beginning is the establishment of a complete assessment system based on relevant literature review and exploration. Next is the formation of an expert group, with whom important weights and correlations for development are acquired using DEMATEL method, and the crucial affecting development is determined by means of Influential Network Relation Map (INRM). That can help decision makers be more systematic in the process of decision and provide both sport players and coaches with more reliable implications of improvement.

Basic concept and calculation of Z-numbers

As proposed by Zadeh (2011), Z-numbers are a calculation method in a soft way and is used to calculate in an environment of not totally reliable information. In a nutshell, Z-numbers comprise two kinds of vague information, being assessed value and the reliability of its assessment (confidence). Where the certainty of a fuzzy event can be measured with probabilities and reliability, Z-numbers can transform these two kinds of information into a set of fuzzy numbers. For instance, Z-AHP (Azadeh et al., 2013), Z-BWM (Best Worst Method) (Aboutorab et al., 2018), Z-TOPSIS (Technique for Order Preference by Similarity to an Ideal Solution) (Yaakob & Gegov, 2016) and Z-VIKOR (Visekriterijumska Optimizacija i Kompromisno Resenje) (Shen & Wang, 2018). To elaborate more, this study will explicate how to convert regular fuzzy numbers into Z-numbers. Assume a Z-number, expressed by $Z = (\tilde{F}, \tilde{R})$, $\tilde{F}$ being the triangular fuzzy numbers of assessed value, and $\tilde{R}$ the reliability of $\tilde{F}$ (confidence). Also, $\tilde{F} = (f, \mu_{\tilde{F}})|x \in [0, 1]$ and $\tilde{R} = (x, \mu_{\tilde{R}})|x \in [0, 1]$ both are triangular membership functions. We can convert $\tilde{R}$ (reliability) into a crisp value, as Eq. 1.

$$\alpha = \frac{\int^x \mu_{\tilde{R}} dx}{\int^{\mu_{\tilde{R}}} dx} \quad (1)$$

Next, add the weight for reliability, α , to the assessed value, $\tilde{F}$, and the weighted Z-numbers are as Eq. 2.

$$Z^\alpha = \left\{ \left(x, \mu_{\tilde{F}^\alpha} \right) \middle| \mu_{\tilde{F}^\alpha}(x) = \alpha \mu_{\tilde{F}}(x), x \in \sqrt{\alpha}x \right\} \quad (2)$$

We can integrate the linguistic variables of assessed value and those of reliability and come up with a set of linguistic variables of Z-numbers. Here we assume there are n items in an assessment framework. These items should undergo pairwise comparisons to enable exploring their influence on one another, i.e., to assess the influence of c_r on c_f . the scales of assessment include No influence (N), Low influence (L), Medium influence (M), High influence (H) and Very high influence (VH). These linguistic variables are transformed into corresponded membership function (fuzzy number). The rules of transformation are as Table 2 shows.

Table 2 Scales of assessment in DEMATEL and corresponded membership functions

Linguistic variable	Code	Membership function
No influence	N	(0, 0, 1)
Low influence	L	(0, 1, 2)
Medium influence	M	(1, 2, 3)
High influence	H	(2, 3, 4)
Very high influence	VH	(3, 4, 4)

Now, the experts are requested to formulate the confidence in respect of the contents of their responses, i.e., the reliability of assessment. The scales of assessment include Very low (VL), Low (L), Medium (M), High (H) and Very high (VH). Table 3 lists the scales of rating for reliability.

Table 3 Scales of assessment of reliability of expert comments and corresponded membership functions

Linguistic variable	Code	Membership function
Very low	VL	(0, 0, 0.3)
Low	L	(0.1, 0.3, 0.5)
Medium	M	(0.3, 0.5, 0.7)
High	H	(0.5, 0.7, 0.9)
Very high	VH	(0.7, 1, 1)

Assume a set of assessment terms with assessment scale at medium influence (M) and reliability at medium (M), then, the corresponded Z-number $Z = (\tilde{F} = M, \tilde{R} = M)$ is calculated by the following procedure.

$$Z = [(1, 2, 3), (0.3, 0.5, 0.7)]$$

By Eq. 1, transform the membership function for reliability into crisp value.

$$\alpha = \frac{\int^x \mu_{\tilde{R}} dx}{\int^{\mu_{\tilde{R}}} dx} = \frac{\int_{0.3}^{0.5} x \left(\frac{x-0.3}{0.5-0.3} \right) dx + \int_{0.5}^{0.7} x \left(\frac{0.7-x}{0.7-0.5} \right) dx}{\int_{0.3}^{0.5} \left(\frac{x-0.3}{0.5-0.3} \right) dx + \int_{0.5}^{0.7} \left(\frac{0.7-x}{0.7-0.5} \right) dx} = 0.4998$$

Next, add the value of α to the assessed value, $\tilde{F} = M$.

$$Z^\alpha = \{(1, 2, 3) | \alpha = 0.4998\}$$

Then, the weighted Z-number can be transformed into regular fuzzy number.

$$Z' = (\sqrt{0.4998} \cdot 1, \sqrt{0.4998} \cdot 2, \sqrt{0.4998} \cdot 3) = (0.707, 1.414, 2.121)$$

For example of calculation of other Z-numbers, reference can be made to Zadeh (2011) and Aboutorab et al. (2018).

From Tables 2 and 3, we can arrive at a total of 25 combinations of Z-numbers. by calculating in the same way, we can arrive at the linguistic variables for Z-numbers and their membership functions, as Table 4.

Table 4 Membership function of Z-NUMBERS

Reliability	Influence level				
	N	L	M	H	VH
VL	(0, 0, 0.316)	(0, 0.316, 0.632)	(0.316, 0.632, 0.949)	(0.632, 0.949, 1.265)	(0.949, 1.265, 1.265)
L	(0, 0, 0.548)	(0, 0.548, 1.096)	(0.548, 1.096, 1.644)	(1.096, 1.644, 2.192)	(1.644, 2.192, 2.192)
M	(0, 0, 0.707)	(0, 0.707, 1.414)	(0.707, 1.414, 2.121)	(1.414, 2.121, 2.828)	(2.121, 2.828, 2.828)
H	(0, 0, 0.837)	(0, 0.837, 1.673)	(0.837, 1.673, 2.510)	(1.673, 2.510, 3.347)	(2.510, 3.347, 3.347)
VH	(0, 0, 0.949)	(0, 0.949, 1.897)	(0.949, 1.897, 2.846)	(1.897, 2.846, 3.795)	(2.846, 3.795, 3.795)

Process of DEMATEL data analysis

The DEMATEL technique is capable of identifying the correlation of influence between factors and constructing an influential matrix, also generating an INRM to allow decision makers a clear view of the weights of items and the cause-effect relations between them. The icons of INRM are made of directional arrows, of which the starting points usually indicate causes and the end point effects, whereby for us to understand the cause-effect relationship between items. Yet, it is difficult for experts to reflect their true feelings with crisp values in a complex assessment environment full of uncertain factors.

Though many methods of fuzzy theory combine with DEMATEL to consider uncertainties, it is a pity that those methods ignore the confidence of experts for assessed values. In this study, Z-numbers are introduced into DEMATEL, which not only can learn of the reliability in assessment by the decision taskforce, it also maintain to calculate in the form of triangular fuzzy numbers so as to avoid loss of information. The use of Z-DEMATEL can achieve a set of influential weights for the items, where the modified Z-DEMATEL technique has the steps detailed as follows:

Step 1. Develop a set of items of assessment

A decision taskforce comprising a number of experts establishes a set of appropriate items of assessment (c_i). In this study, we take competitive sports technology development as the items of assessment herein, $c_i = \{c_1, c_2, \dots, c_n\}$.

Step 2. Test the consensus among experts

To test, in this study, whether the assessed value for the influence of experts' rating item i and that of item j have consensus, Average Sample Gap (ASG), $(n(n-1))^{-1} \times \sum_{i=1}^n \sum_{j=1}^n (|t_{ij}^p - t_{ij}^{p-1}| / t_{ij}^p) \times 100\%$ will be used to examine consistence, where n is the number of criteria, p the number of experts, and i and j the assessed value in the matrix.

Step 3. Create direct relation matrix $\otimes A$

There are n items of development that need influence assessment. Each expert rates the direct relation between item i and item j by the rating levels of Table 2 and examines the confidence by the reliability levels of Table 3. This step introduces the concept of Z-numbers in every copy of DEMATEL questionnaire.

In order to avoid the extreme comments by part of the experts causing inaccuracy to the assessment results, an optimized model is given to arrive at group judgment (Wu et al., 2017). The model is as Eq. 3.

$$\begin{aligned} \min z = & \sum_{k=1}^K (l_{ij} - l_{ij}^k)^2 + \sum_{k=1}^K (m_{ij} - m_{ij}^k)^2 + \sum_{k=1}^K (u_{ij} - u_{ij}^k)^2 \\ s. t. & \begin{cases} \min_k l_{ij}^k \leq l_{ij} \leq \max_k l_{ij}^k, \\ \min_k m_{ij}^k \leq m_{ij} \leq \max_k m_{ij}^k, \\ \min_k u_{ij}^k \leq u_{ij} \leq \max_k u_{ij}^k, \\ l_{ij} \leq m_{ij} \leq u_{ij}. \end{cases} \end{aligned} \quad (3)$$

where k is an expert, $k = 1, 2, \dots, K$. In addition, l_{ij} , m_{ij} and u_{ij} are the minimum value, medium value and maximum value of group judgment. Jiang and Shang (2015) and Wu et al. (2017) demonstrated the best solution to this model. By taking partial derivative of l_{ij} , we can arrive at Eq. 4.

$$\begin{aligned} \frac{\partial z}{\partial l_{ij}} = & 2 \sum_{k=1}^K (l_{ij} - l_{ij}^k) \cdot 1 = 0 \\ l_{ij} = & \frac{\sum_{k=1}^K l_{ij}^k}{K} \end{aligned} \quad (4)$$

Similarly, using the same process on m_{ij} and u_{ij} can arrive at Eq. 5 and Eq. 6

$$m_{ij} = \frac{\sum_{k=1}^K m_{ij}^k}{K} \quad (5)$$

$$u_{ij} = \frac{\sum_{k=1}^K u_{ij}^k}{K} \quad (6)$$

The comments by all the experts are gathered to form direct relation matrix $\otimes A$ by Eq. 3 to Eq. 6, as Eq. 7 shows.

$$\otimes A = [\otimes a_{ij}]_{n \times n} = \begin{bmatrix} \otimes a_{11} & \otimes a_{12} & \cdots & \otimes a_{1j} & \cdots & \otimes a_{1n} \\ \otimes a_{21} & \otimes a_{22} & \cdots & \otimes a_{2j} & \cdots & \otimes a_{2n} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ \otimes a_{i1} & \otimes a_{i2} & \cdots & \otimes a_{ij} & \cdots & \otimes a_{in} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ \otimes a_{n1} & \otimes a_{n2} & \cdots & \otimes a_{nj} & \cdots & \otimes a_{nn} \end{bmatrix}_{n \times n}, i = j = 1, 2, \dots, n \quad (7)$$

where $\otimes a_{ij} = (a_{ij}^L, a_{ij}^M, a_{ij}^U)$

Here, DEMATEL requires that the diagonal elements of $\otimes A$ are $\otimes a_{ij} = 0$ (when $i = j$).

Step 4. Obtain the normalized direct relation matrix $\otimes X$

Given the range of value of $\otimes a_{ij}$ being 0 to 4, we can transform the assessed value to 0 – 1 by normalization (Eq. 8 and Eq. 9).

$$\otimes X = [\otimes x_{ij}]_{n \times n} = \begin{bmatrix} \varepsilon \cdot \otimes a_{11} & \varepsilon \cdot \otimes a_{12} & \cdots & \varepsilon \cdot \otimes a_{1j} & \cdots & \varepsilon \cdot \otimes a_{1n} \\ \varepsilon \cdot \otimes a_{21} & \varepsilon \cdot \otimes a_{22} & \cdots & \varepsilon \cdot \otimes a_{2j} & \cdots & \varepsilon \cdot \otimes a_{2n} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ \varepsilon \cdot \otimes a_{i1} & \varepsilon \cdot \otimes a_{i2} & \cdots & \varepsilon \cdot \otimes a_{ij} & \cdots & \varepsilon \cdot \otimes a_{in} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ \varepsilon \cdot \otimes a_{n1} & \varepsilon \cdot \otimes a_{n2} & \cdots & \varepsilon \cdot \otimes a_{nj} & \cdots & \varepsilon \cdot \otimes a_{nn} \end{bmatrix}_{n \times n}, i = j = 1, 2, \dots, n \quad (8)$$

where $\otimes x_{ij} = (x_{ij}^L, x_{ij}^M, x_{ij}^U)$

$$\varepsilon = \min \left\{ \frac{1}{\max_i \sum_{j=1}^n a_{ij}^U}, \frac{1}{\max_j \sum_{i=1}^n a_{ij}^U} \right\} \quad (9)$$

Step 5. Generate the total influence matrix $\otimes T$

The normalized direct relation matrix (Eq. 10) can be integrated into a total influence matrix $\otimes T$ by the calculation with Eq. 11. This step sums up all the direct relations and indirect relations of $\otimes X$ to 1st power till infinite power. As the operation process with Eq. 11 is tedious, we can induce from Eq. 12 a faster equation for solutions.

$$\otimes T = [\otimes t_{ij}]_{n \times n} = \begin{bmatrix} \otimes t_{11} & \otimes t_{12} & \cdots & \otimes t_{1j} & \cdots & \otimes t_{1n} \\ \otimes t_{21} & \otimes t_{22} & \cdots & \otimes t_{2j} & \cdots & \otimes t_{2n} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ \otimes t_{i1} & \otimes t_{i2} & \cdots & \otimes t_{ij} & \cdots & \otimes t_{in} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ \otimes t_{n1} & \otimes t_{n2} & \cdots & \otimes t_{nj} & \cdots & \otimes t_{nn} \end{bmatrix}_{n \times n}, i = j = 1, 2, \dots, n \quad (10)$$

where $\otimes t_{ij} = (t_{ij}^L, t_{ij}^M, t_{ij}^U)$

$$\otimes T = \otimes X + \otimes X^2 + \cdots + \otimes X^\infty \quad (11)$$

$$\begin{aligned} \otimes T &= \otimes X + \otimes X^2 + \cdots + \otimes X^\infty = \otimes X (I + \otimes X + \otimes X^2 + \cdots + \otimes X^{\infty-1}) \\ &= \otimes X (I - \otimes X^\infty) (I - \otimes X)^{-1} = \otimes X (I - \otimes X)^{-1} \end{aligned} \quad (12)$$

where $\otimes X^\infty = [0]_{n \times n}$ and I are unit matrices.

Step 6. Establish the INRM to identify the relation between items of development

By using Eq. 13 and Eq. 14, sum up all the columns of the total influence matrix $\otimes T$ to reach $\otimes r$. Similarly, by using Eq. 15 and Eq. 16, sum up all the rows to reach $\otimes s$.

$$\otimes r = [\otimes r_i]_{n \times 1} = (\otimes r_1, \otimes r_2, \dots, \otimes r_i, \dots, \otimes r_n) \quad (13)$$

$$[\otimes r_i]_{n \times 1} = [\sum_{j=1}^n \otimes t_{ij}]_{n \times 1} \quad (14)$$

$$\otimes s = [\otimes s_j]_{1 \times n} = (\otimes s_1, \otimes s_2, \dots, \otimes s_j, \dots, \otimes s_n)^T \quad (15)$$

$$[\otimes s_j]_{1 \times n} = [\sum_{i=1}^n \otimes t_{ij}]_{1 \times n} = [\otimes s_i]^T_{n \times 1} \quad (16)$$

Where superscript T represents matrix transposition; in addition, $\otimes r_i = (r_i^L, r_i^M, r_i^U)$ and $\otimes s_i = (s_i^L, s_i^M, s_i^U)$.

Then, adding $\otimes r_i$ and $\otimes s_i$ will arrive at the intensity indicator of influence of the items and being influenced ($\otimes r_i + \otimes s_i$). On the other hand, $\otimes r_i - \otimes s_i$ represents the level of net influence. A greater $\otimes r_i + \otimes s_i$ means higher level of influence of Item i on the assessment system. If $\otimes r_i - \otimes s_i > 0$ (with positive sign), it means Item i has more significant effect on other items, where it is called a causal factor; reversely, if $\otimes r_i - \otimes s_i < 0$ (with negative sign), it means Item i is more affected by other items, and it is called an affected factor.

Here, defuzzify the fuzzy value (e.g., $\otimes \lambda = (\lambda^L, \lambda^M, \lambda^U)$) by using the centroid method to achieve crisp value (λ), as Eq. 17.

$$\lambda = \frac{\lambda^L * 1 + \lambda^M * 2 + \lambda^U * 3}{4} \quad (17)$$

Next, with $\otimes r_i$ and $\otimes s_i$ put to defuzzification with Eq. 17, we can obtain r_i and s_i . Taking $r_i + s_i$ as x-axis and $r_i - s_i$ as y-axis can clearly plot the positions in relative coordinates of every item. Identity the influence between the items with the total influence matrix $\otimes T$ and in turn plot the arrows (representing the directions of influence) to generate a systematic INRM.

Step 7. Obtain the weights for the influence of items of development

Here, $r_i + s_i$ reflects the total influence of the items on the assessment system; thus, we can construct the weights $w_i = \{w_1, w_2, \dots, w_n\}$ for the influence of items by Eq. 18. The total weight here must be 1 (Lo et al., 2020).

$$w_i = \frac{(r_i + s_i)}{\sum_{i=1}^n (r_i + s_i)} \quad (18)$$

Results

This study involves case analysis of competitive sports technology development in Taiwan, whereby to demonstrate the effectiveness and utility of the assessment model proposed herein. With expert interview conducted, nine copies of questionnaire were collected. That was followed by using the DEMATEL method to obtain the weights for the items and plotting the diagram of network influence to reach the relations between the competitive sports technology development in Taiwan.

Identifying the relations between the items of competitive sports technology development using DEMATEL

Expert interviews in this study resulted in information of interview questionnaire with modified Z-DEMATEL. The process of interview included detailed explication on the concept of modified Z-DEMATEL and scales of assessment. The researchers began to ask questions and record responses after having made sure that the experts understood the contents and procedure of interview. Take one of the questions for example, when asked “among the competitive sports technology development, how wearable sensing devices affect 3D printing technology?”, Expert No.1 responded that the influence of C_1 on C_2 was “low” and the reliability of rating level was “high”. All the items were compared in pairs in the same way of interview; that resulted in a 7×7 matrix. The interview with each expert was limited to 6 hours, with 4 breaks during the process to avoid fatigue to the interviewed. The interview was conducted at the meeting room of each expert’s own workplace. As the sessions of interview were all different in terms of place and time, the judgment of any expert would not affect the others. The contents of interview were calculated and analyzed only on the day following the interview when they were further confirmed with the experts for correctness. Table 5 is the investigative data with modified Z-DEMATEL from Expert No.1.

Table 5 Data of questionnaire on Taiwan’s competitive sports technology development assessment responded by Expert 1

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
C_1		L, H	H, VH	L, VH	L, VH	H, VH	N, VH
C_2	H, VH		N, H	N, VH	L, H	H, H	L, H
C_3	H, H	L, VH		L, H	L, H	M, VH	N, H
C_4	VH, H	H, H	VH, VH		VH, VH	H, H	M, VH
C_5	VH, VH	H, H	H, H	H, H		H, VH	M, VH
C_6	H, M	H, VH	M, VH	N, VH	M, H		N, VH
C_7	VH, VH	H, H	VH, H	VH, H	VH, H	H, H	

To examine whether the assessed values by the members of expert decision taskforce for competitive sports technology development in Taiwan had consensus, ASG was applied to test for any gap. And the calculation result showed an ASG at 2.5%, indicating a significant confidence level at 97.5%, which was greater than the recommended 95%. That means a consistent consensus among the experts and that these data were suitable for subsequent data analysis with DEMATEL.

Then, Eq. 7 to Eq. 12 were used to obtain the normalized direct relation matrix $\otimes X$ and the total influence matrix $\otimes T$, followed by the determination of $\otimes r_i$ and $\otimes s_i$ by using Eq. 13 to Eq. 17, and further by the determination of the weights for the items by using Eq. 18. Table 6 lists the total influence, net influence of and ranking of weights for competitive sports technology development.

The research results showed that C_7 had the greatest net influence ($r_7 - s_7 = 0.825$), which means C_7 is the major factor affecting other items. C_1 had the least influence ($r_1 - s_1 = -1.027$), meaning C_1 is heavily affected by the other items. Additionally, $r_i + s_i$ can be considered as the specific importance of the total influence in the entire evaluation framework. The influence weight for each item can be determined by using Eq. 18. Within the entire assessment framework, C_5 was the most important, with ($r_5 + s_5 = 8.955$) and a weight, W_5 at 0.151. When weights sorted for the competitive sports technology development, $C_5 > C_4 > C_7 > C_6 > C_1 > C_3 > C_2$.

Table 6 Total influence, net influence and weight ranking of the items

	r_i	s_i	$r_i + s_i$	$r_i - s_i$	Weight	Rank
C_1	3.673	4.700	8.374	-1.027	0.142	5
C_2	3.638	3.978	7.616	-0.340	0.129	7
C_3	3.843	4.170	8.013	-0.328	0.135	6
C_4	4.788	4.077	8.865	0.711	0.150	2
C_5	4.762	4.193	8.955	0.569	0.151	1
C_6	4.124	4.535	8.659	-0.411	0.146	4
C_7	4.756	3.931	8.687	0.825	0.147	3

Using the data of Table 6 can generate an INRM to understand how the items affected one another. $r_i + s_i$ and $r_i - s_i$ are used as Y- and X-axes, as Fig. 1 shows. The items on the top right have higher total influence and net influence, as C_7 , C_4 and C_5 show. On the contrary, the items on the bottom left mean affected items, as C_2 , C_3 , C_1 and C_6 show. C_2 and C_3 had less relation with the other items in the entire assessment framework. In this study, after the discussion by the experts, a threshold for relation was set at 1.616, exceeding which the relation lines were plotted. We learn from Fig. 1 that 5G(C_7), AI(C_4) and IoT(C_5) affect wearable sensing devices (C_1) and the image recognition technology (C_6).

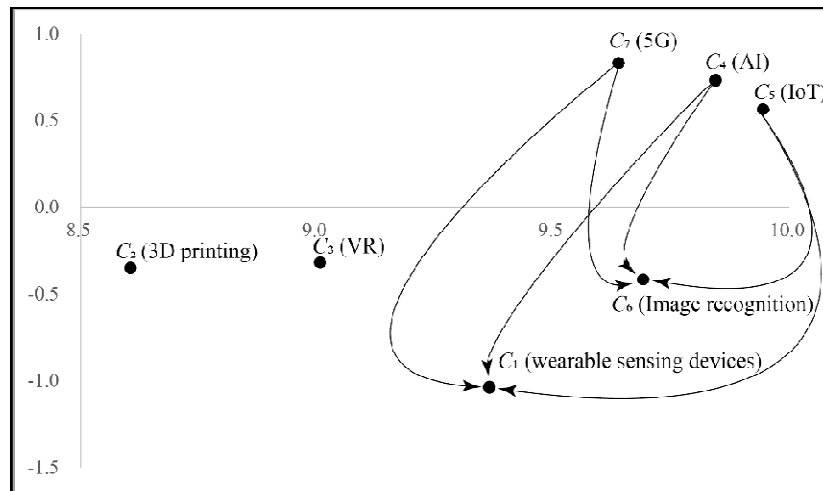


Fig. 1 Influential Network Relation Map

Dicussion

The research results indicated that IoT(C_5) had the highest total influence, with a value at 8.955, and the weight for this criterion was 0.151, ranking the top, which was a result consistent with the view of Li et al. (2020), who also considered the IoT technology as the most important. We speculate that the reason is the IoT technology that is becoming mature becomes a basis for many other technologies to rely on to develop. Given that in past literature the IoT technology has been applied to explore the issues in competitive sports environment (Du, 2021; Jin et al., 2021), the IoT technology is a very important industrial trend in the future among sport

technology development. It becomes clear from Fig. 1 that AI(C_4), IoT(C_5) and 5G(C_7) effectively affect the image recognition technology (C_6) and wearable sensing devices (C_1). Where 5G(C_7) has the greatest net influence, with a value of 0.825, meaning many technologies are affected by it. That research result was consistent with Massaro and Kim (2021), and Xiao et al (2020), who both considered IoT, 5G and AI affected wearable sensing devices and the image recognition technology. With past research summarized, we discovered that IoT did help connecting many technologies, that AI technology has been applied to take the place of manual data statistics and formulation of skills and tactics, and that 5G was used to increase the speeds of message transmission. These technologies have been used to improve the training methods for sport players and enhance training effects and sporting performance.

Conclusions

Based on the research results, we propose several conclusions. (i) For technological R&D teams: To construct the IoT that is associated with sports to acquire the physiological data and action data in respect of players. Should any software be successfully developed, it will bring satisfactory effectiveness to the sport players of the nation as well as bring about massive economic benefit by selling the technology to other nations. (ii) For sport players and coaches: Sport players can use wearable sensing devices in the future to collect information on actions and physiological data, with large amount of information stored and transmitted through IoT for integration by AI, which will shorten the time to distinguish the physiological condition of sport players. Last, with 5G network, the resultant physiological data will be communicated rapidly to the coaches to enable more sound planning and training for the players. (iii) For national government: Government agencies encourage the private sector to present projects in relation to sport technology or establish scientific research centers to facilitate scientific research teams and national professional sport players to be committed to competitive sports technology development.

The methods used in this study to explore the weights for competitive sports technology development as well as the relations between the technologies still have certain limitations to the research in competitive sports technology development. Therefore, we recommend for future research the following:

Competitive sports technology development should not be limited to these seven technologies. As technology development keeps advancing, there will be more emerging technologies that can be applied to the environment of competitive sports, and it is recommended that subsequent research broaden the scope of assessment. The technologies assessed in this study were analyzed by applying DEMATEL in terms of weights and relations, however, in reality we still do not understand how far the technologies are being applied in the environment of competitive sports. It is thus recommended that future research further introduce the methods of performance assessment to explore how far technologies are applied in the environment of competitive sports in Taiwan; whereby to infer the importance of such technologies and the difference in the extent of their applications, to offer more flexible and more complete decision information.

Conflicts of interest - The authors declare no conflict of interest.

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