Information Dynamics towards Serious Game

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Abstract

This paper is concerned with information dynamics towards serious game. This study demonstrates that the proposed methodology can provide useful information to analyze game and to predict the outcome, respectively, in terms of soccer and girl' height based on information dynamic model. A plausible prediction method for human height has been proposed by incorporating the information dynamic model. Girl's height at 10 years old is predicted until 25 years old, by knowing her height growth rate at starting year. It may be considered that this is a sort of breakthrough on game research: The information dynamic model has been mainly used to do post hoc analyses for the finished games, but it has also potential to predict the game outcome before the start, if initial conditions are given. As a popular and simple game, soccer has been analyzed and presented how advantage and certainty of game outcome depend on the time. In the data analyses, as evaluation function scores in addition to goal, shoot, corner kick, or penalty kick are adopted to conduct refined analyses. The game patterns have been categorized into see-saw, one-sided, balanced and others, and is defined quantitatively, to promote understanding game.

Keywords: Serious Game, Game Methodology, Human Height Prediction, Game Modelling, Game Pattern

1 Introduction

In short, game may be defined as an abstract creature consisting of start, play and end. It is, therefore, considered that annual ring of a tree, construction of dam or building, soccer, chess, shogi, judo or life of living things are a kind of games, in which methodology for modelling, analyses, prediction of outcome is common in many respects. Of course, serious game is no exception, and it is designed for a primary purpose other than pure entertainment, enjoyment or fun [1]. Serious games are storytelling in sequence, where the idea shares aspects with game simulation, but explicitly emphasizes the added pedagogical value of fun and competition. The goal of a serious game is to support learning/training for educator or nurse. The ultimate goal of soccer may share with that of serious game to some extent. For example, supervisor of a soccer team may be considered as an educator for the members: Daily activities of the supervisor educate players who are required to learn importance of fairness, cooperation, harmony or patience under the strict rules. It is known that ultimate goal of soccer is to bring up ladies and gentlemen, but not merely to win or to enjoy the game. It is believed that soccer provides players an ideal opportunity of education and training in addition to entertainment, enjoyment or fun, similarly to serious game

Making use of game design patterns, Kelle et al.[2] have implemented information channels to simulate ubiquitous learning support in an authentic situation. Lindley & Sennersten[3]'s schema theory provides a foundation for the analysis of game play patterns created by players during their interaction with a game. Lindley & Sennersten[4] have proposed a framework which is developed not only to explain the structures of game play, but also to provide schema models that may inform design processes and provide detailed criteria for the design patterns of game features for entertainment, pedagogical and therapeutic purposes.

Knowledge about game designs and play patterns has grown fairly well, but little advancement has been made to clarify game progress patterns, which denote how information of game varies with the time [5, 6]. Currently the information dynamic model [5, 6], in which simplicity and generality are characteristics, only makes it possible to treat and identify game progress patterns depending on the time. The usefulness of the information dynamic model has been well documented, and successfully applied to baseball [6], effect of medicine [7], soccer [8], shogi [10], or judo [5]. As far as the author is aware of, no existing model is useful, for the applicability is severely limited due to too much sophistication or lack of generality, which prompts the author to develop the novel model [5, 6]. Neumann's game theory [11], for example, provides only a few outcomes due to each the decision by players without considering how they depend on the time: The current game theory merely seeks for the way how to get the maximum gain by keeping the minimum loss.

Main purpose of the present study is to demonstrate that the proposed methodology can provide useful information to analyze game and to predict the outcome, respectively, in terms of soccer games and girl's height based on information dynamic model.

2 Method of Analyses

Elemental procedures for obtaining the advantage α, certainty of game outcome ξ, and uncertainty of game outcome ς will be explained by using soccer game between teams A and B, where only goal(s) is treated as the evaluation function score for clarity.

The advantage α is defined as follows: When the total scores of the two teams at the end of game $S_T \neq 0$,

$\alpha = [S_A(\eta) - S_B(\eta)]/S_T$ for $0 \leq \eta \leq 1$, (1)

where $S_A(\eta)$ is the current goal sum for team A(winner), $S_B(\eta)$ is the current goal sum for team B(loser), and η is the normalized time, which is normalized by the total time.

When α>0, team A (winner) gets the advantage against team B (loser) in the game, while when α<0, team B (loser) gets the advantage against team A (winner). It is certain that when α=0 the game is balanced. When the total scores of the two teams at the end of game $S_T = 0$, α=0 for $0 \leq \eta \leq 1$

The certainty of game outcome means what extent the game outcome (i.e., win or loss) is certain depending on the time during the game, and the extent is given by the normalized value ranging from 0 to 1. The word 'certainty' is replaceable with 'probability' without loss of generality, but the accustomed word may be preferable. The certainty of game outcome ξ during the game is defined as follows: When the total scores of the two teams at the end of game

$S_T \neq 0$,

$\xi = |S_A(\eta) - S_B(\eta)|/S_T$ for $0 \leq \eta < 1$

$=1$(completed game) or 0(drawn game) for $\eta=1$. (2)

At $\eta=1$, ξ is assigned to the value of 1, for at the end of completed game the information on the game outcome must be full certainty. Note that ξ takes always positive value, for it is the absolute value of advantage α. The reason why we take the absolute value of advantage α to get certainty of game outcome ξ for $0 \leq \eta < 1$ is that certainty of game outcome ξ is independent of the sign of advantage α: As the absolute value of advantage α increases (decreases), certainty of game outcome ξ must increase (decrease). In case of drawn game, certainty of game outcome ξ may be assigned to the value of 0 at the end of game $\eta=1$, for the game is right back where it starts. When the total scores of the two teams at the end of game $S_T= 0$, $\xi=0$ for $0 \leq \eta \leq 1$.

The uncertainty of game outcome ς during the game is defined as follows

$\varsigma = 1 - \xi$. (3)

Keeping in mind the forgoing elemental procedures to obtain the advantage α, and certainty of game outcome ξ, it is straight forward to apply them to actual soccer games. In soccer, It may be evident that goal is one of evaluation function scores, for it is a critical factor for the game. However, there must be the other evaluation function scores as to be discussed in Section 5. In computer shogi, evaluation function score for each of the piece move has been assessed by a human similarly to that in computer chess based on objective knowledge and experiences[10]. Since accuracy of the evaluation function score for each of the piece move has been improved by repeating trial and error in such a level that Bonkras(Computer Shogi World Champion in 2012) beats Kunio Yonenaga(Shogi Champion or *Meijin*). Today, evaluation function score for each of the piece move in popular board games such as chess, shogi and/or go can be calculated by using computer soft accurately.

3 Two Case Studies

In this section, investigated are two soccer games, which are the Final and the Semi-final at the 11th Shirayama-Hime Cup, U-11 Soccer Championship, held on September 24, 2018 at Tedori Garden, Hakusan, Japan. One is the Final, Kasama FC vs. Bujyo FC, and the other is the Semi-final, Kasama FC vs. Hakusan FC. This championship is organized by local volunteers directed by the author to educate and train boys and girls.

3.1 Final

This part is concerned with the case study of Kasama FC vs. Bujyo FC. Table 1 summarizes results of data analyses for the Final main game. The total time is 30 minutes, for the Final is 15 minutes half in this championship, and the total evaluation function scores are 19, where each of the shoot and corner kick is counted value of 1 as evaluation function score. Shoot may seem to be very different from corner kick, but if one looks at shoot and corner kick from the assessor's point of view, they contribute to the game outcome to the same degree sometimes. At this stage, it may be worth noting that occasionally the ball kicked from the corner goes into the goal directly. This is why corner kick is treated exactly same as shoot sometimes. When only goal is considered as the evaluation function score, too few numbers of the score may cause difficulty to analyze the game properly.

In the Final main game, after the kick off by Kasama FC, Bujyo FC gets the advantage until η=0.133. During this period, Bujyo FC makes one shoot and one corner kick. However, for all the rest time except at one time in the middle, Kasama FC attacks to Bujyo FC, so Kasama FC increases the advantage α with increasing the normalized time η as shown in Table 1.

Table 1 Game records of Final main game : Kasama FC vs. Bujyo FC

η	α	Kasama FC	Bujyo FC
0	0		
0.033	-0.053		
0.05	-0.105		
0.083	-0.053		
0.133	0		
0.2	0.053		
0.233	0.105		
0.5	0.105		
0.533	0.053		
0.567	0.105		
0.6	0.158		
0.633	0.211		
0.7	0.263		

0.733	0.316
0.8	0.368
0.833	0.421
0.85	0.474
0.867	0.526
0.917	0.579
0.933	0.632
0.983	0.684
1	0.684

shoot

corner kick

shoot

corner kick

corner kick

corner kick

corner kick

shoot

shoot

corner kick

shoot

corner kick

corner kick

corner kick

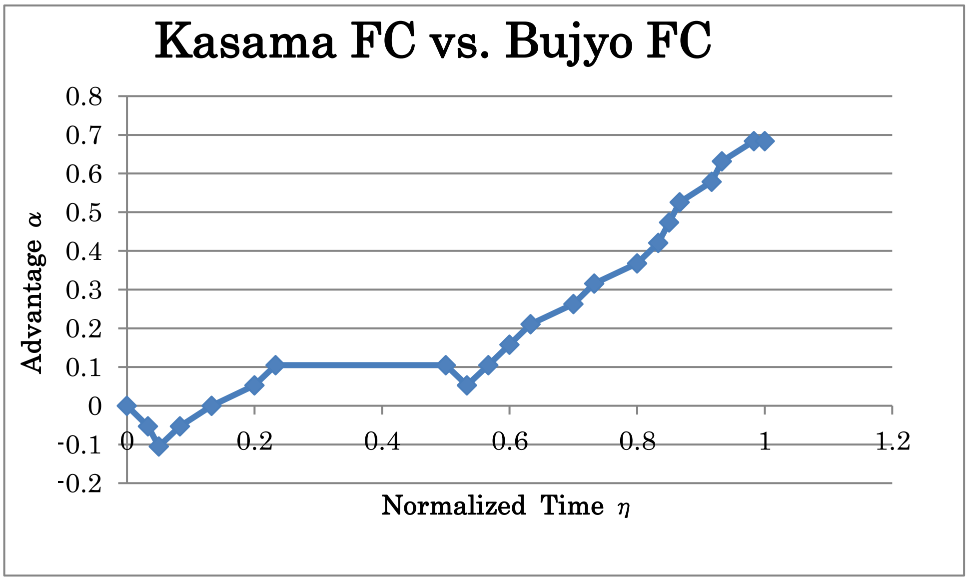
corner kick

shoot

corner kick

corner kick

corner kick



η Figure 1 Advantage α against normalized time η

Figure 1 shows the relation between the advantage α and the normalized time η for the Final main game, Kasama FC vs. Bujyo FC. It is evident from this figure that Kasama FC keeps the advantageous position against Bujyo FC except for the period between η=0 and 0.133 at the beginning.

No quantitative definition of game patterns is known so far. It is, therefore, necessary to define game patterns.

Let us define game patterns, for we often encounter the typical patterns such as see-saw, balanced, and one-sided games in baseball, soccer, boxing, chess, horse race, judo, or sumo. However, there has been no quantitative definition for game patterns, so that it may be worth proposing it for the promotion of understanding games. Considering the author's experience, games are categorized as see-saw, balanced, one-sided and others broadly, and it is proposed that these are defined, respectively, as follows,

(a) See-saw game: Sign in advantage α alters over 3 times during a game and the peak value of α at each of the periods must greater (smaller) than 0.05(−0.05).

(b) Balanced game: Absolute value of advantage $|\alpha|$ is always smaller than 0.05 during the game: $|\alpha| < 0.05$ for $0 \le \eta \le 1$, where η is the normalized time.

(c) One-sided game: Advantage α is greater (smaller) than 0.05(−0.05) over 80% of the normalized time η for $0 \le \eta \le 1$.

(d) Non-categorized game: All of the rest games other than the above three

patterns. The threshold value of 0.05 introduced in this categorization is not definite yet, and is arguable. It is be evident that more detailed categorization of game patterns is possible, but these are beyond the scope of this paper.

According to the above definition, Kasama vs. Bujyo is categorized as one-sided game.

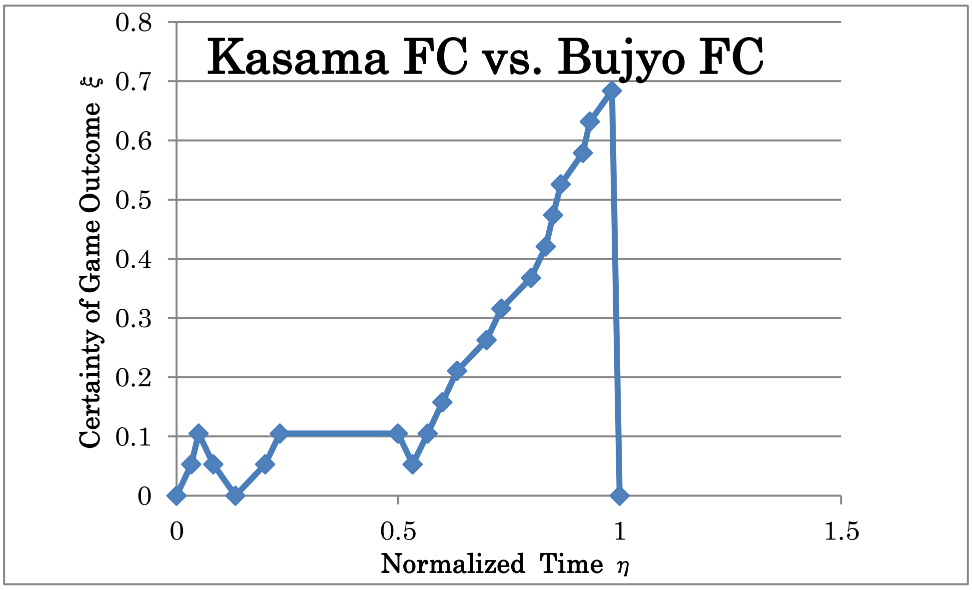


Figure 2 Certainty of game outcome ξ against normalized time η

Figure 2 shows the relation between the certainty of game outcome ξ and the normalized time η. This indicates that the certainty of game outcome ξ remains within 0.105 until the normalized time η=0.567. However, once η exceeds to this value, ξ increases rapidly with increasing η, reaches at the value of 0.684 at η=0.983 , and then ξ takes the value of 0, for this is drawn game according to the definition (2).

Since the Final main game is drawn, penalty kick match is held to determine the winner (or loser) between Kasama FC and Bujyo FC.

Based on the rules of championship, thee kickers of each the teams are competing for the penalty kick match: The first kicker of Kasama FC fails the kick, but the second and the third kickers succeed, while the first and the second kickers of Bujyo FC succeed. However, the third kicker of Bujyo FC fails the kick, so the game is right back where it starts. Then, the penalty kick match goes into the Sudden Death stage by the rules: The fourth kickers for the both teams succeed, respectively. The fifth kicker of Kasama FC succeeds, but that of Bujyo FC fails. As the result, Kasama FC beats Bujyo FC by the score of 4:3 in the penalty match, so Kasama FC becomes the champion finally, though the main game is drawn one by the score of 0:0.

3.2 Semi-final

This part is concerned with the case study of the Semi-final, Kasama FC vs. Hakusan FC. Table 2 summarizes results of data analyses for the game. The total time is 26 minutes, for the Semi-final is 13 minutes half match according to the rules of championship. Note that the total time of the semi- Final is different from that of the Final main game. The total evaluation scores are 14, where each of the goal, shoot and corner kick is counted value of 1 as evaluation function score. A goal may be different from a shoot and/or a corner kick, but they must be also counted value of 1 as evaluation function score when they are considered to be critical to the game outcome. It is believed that this enhances to conduct the refined analyses for the history of the game.

Table 2 Game records of Semi-final: Kasama FC vs. Hakusan FC

η α Kasama FC Hakusan FC

0	0
0.038	0.071
0.058	0.143
0.115	0.214
0.212	0.286
0.25	0.357
0.404	0.429
0.5	0.429
0.538	0.357
0.615	0.286
0.654	0.357
0.673	0.429
0.731	0.5
0.769	0.571

0.881	0.643
0.942	0.714
1	0.714

corner kick

shoot

corner kick

shoot

shoot

shoot

goal

shoot

corner kick

goal

corner kick

corner kick

corner kick

goal

Table 2 shows that Kasama FC always attacks to Hakusan FC except for goal at η=0.538, and shoot at η=0.615. Kasama FC beats Hakusan FC at this game by the final score of 2:1.

Figure 3 Advantage **α** against normalized time η

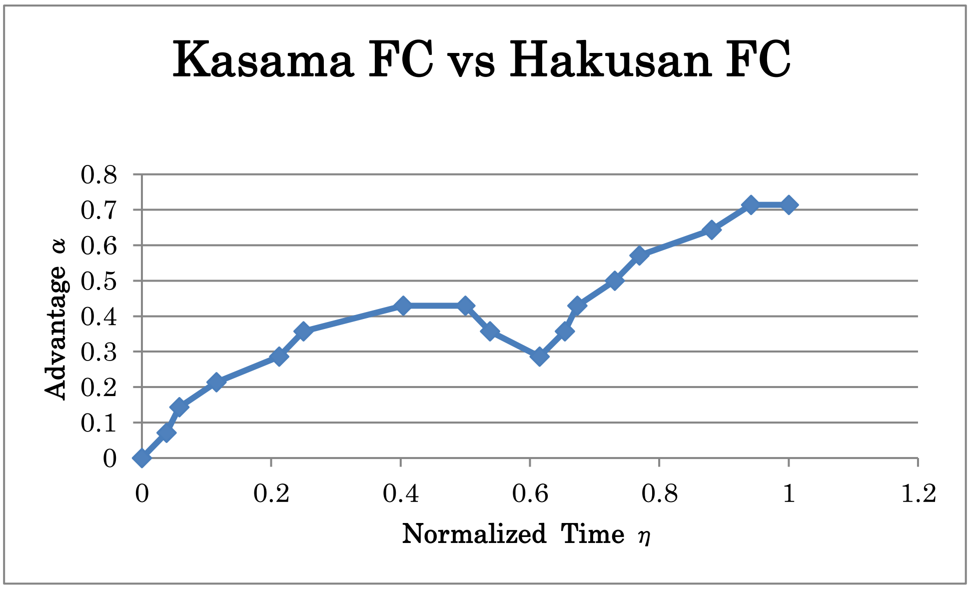


Figure 3 shows the relation between advantage α and normalized time η. Advantage α increases with increasing normalized time η except for two points at η=0.538 and η=0.615. Furthermore, Kasama FC always keeps advantageous position against Hakusan FC, so that this is a typical one-sided game according to the present proposed categorization.

Figure 4 Certainty of game outcome ξ against normalized time

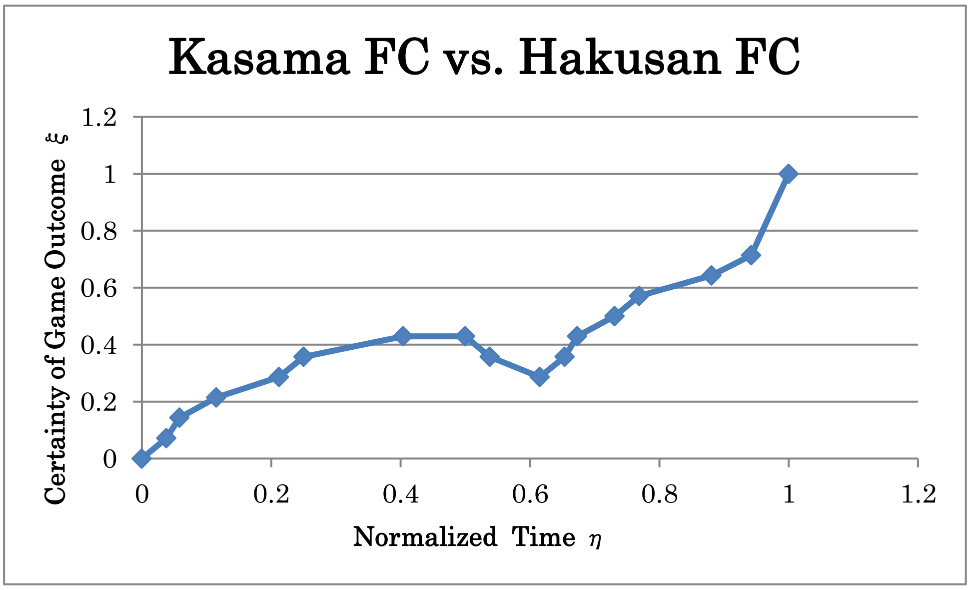


Figure 4 shows the relation between certainty of game outcome ξ and normalized time η.

The certainty of game outcome ξ increases with increasing the normalized time η except for the two points at η=0.538 and η=0.615 in the middle of game.

3.3 Game Point

The game point (to be defined later) in the Semi-final, Kasama FC vs. Hakusan FC will be discussed with reference to information dynamic model, which is expressed by

$\xi = \eta^{m}$, (4)

where ξ is certainty of game outcome, η is normalized time, and m is a positive real number. For full account of the information dynamic model, refer to Appendix.

Figure 5 Certainty of game outcome ξ against normalized time η

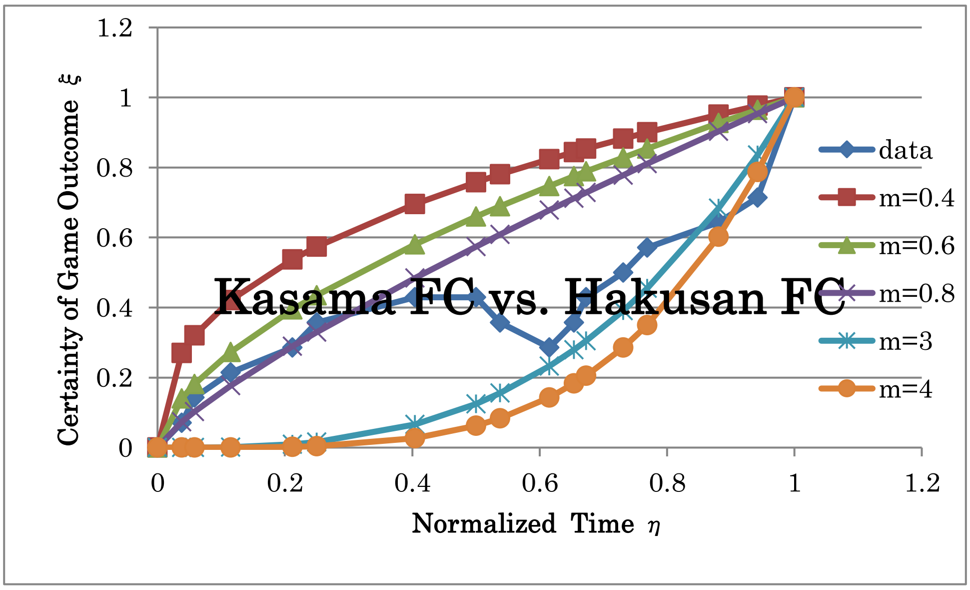


Figure 5 shows the relation between certainty of game outcome ξ and normalized time η, where game data of Kasama FC vs. Hakusan FC together with five curves of the information dynamic model $\xi = \eta^{m}$, where m=0.4, 0.6, 0.8, 3, and 4, have been plotted concurrently.

It may be evident that until η≈0.3 this game proceeds almost along with model curve $\xi=\eta^{0.8}$, but from η≈0.6 it follows to another model curve $\xi=\eta^{3}$ approximately until the end. Note that this transition is caused by Hakusan FC's goal at η=0.538, and shoot at η=0.615.

Nakagawa & Minatoya [5] has proposed a new notion coined 'game point', which is the cross point between certainty of game outcome ξ and uncertainty of game outcome ς. It is considered that once time exceeds to the game point, one team(or player) gets the safety lead against the other team(or player). It is certain that in case of a drawn game, the game point is meaningless, and even if number of game point is plural apparently, only the latest is the real one.

Let us discuss the effect of Hakusan FC's goal and shoot on the game in terms of game point.

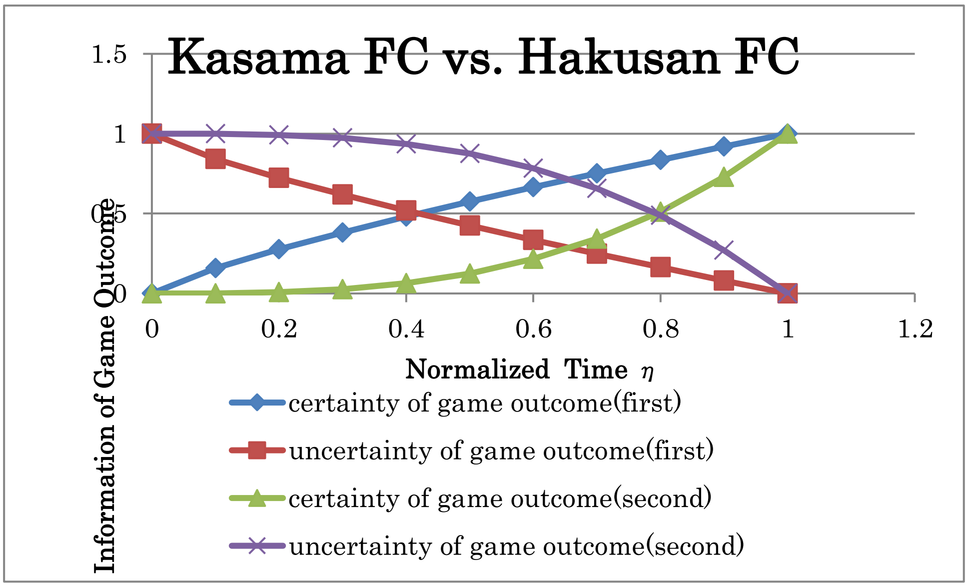


Figure 6 Information of game outcome against normalized time η

Figure 6 shows the relation between information of game outcome and normalized time η, where $\xi=\eta^{0.8}$ is the first curve for certainty of game outcome, and $\varsigma = 1 - \eta^{0.8}$ is the first curve for uncertainty of game outcome.

At the game point, certainty of game outcome ξ is equal to uncertainty of game outcome ς, and both of the curves take the common value of 0.5. It can be noted in Figure 6 that in this case the game point is at $\eta \approx 0.40$. Thus, if this game can be modelled by the curve $\xi=\eta^{0.8}$ from η=0 to 1, Kasama FC's win is expected at $\eta\approx0.40$.

In Figure 6, the second curve for certainty of game outcome $\xi=\eta^3$, and the second curve for uncertainty of game outcome $\varsigma = 1 - \eta^3$ are also plotted. In this case the game point is at $\eta \approx 0.8$. Thus, if this game is modelled by the curve $\xi=\eta^3$ from η=0 to 1, Kasama FC's win becomes definite at $\eta\approx0.8$.

The effect of Hakusan FC's goal and shoot on the game is, therefore, significant, for it is considered that they alter the game point from $\eta\approx0.4$ to 0.8. In another words, they shift the game point toward the end by about 40% of the total time. It is important to point out the implications of the game point for a game analysis. Recalling that the meaning of game point is the time when one team (or player) gets the safety lead against the opponent, one can, for example, view the game point when a medicine becomes fully effective against the disease. The patient will be getting better and better from game point, and is completely cured in the end. Another example is for a teacher to evaluate achievement quotient of the pupil in mathematics. In this case, game point must be the time when the achievement quotient becomes large enough, say 80%, so that mathematical ability of pupils will be developed until the quotient reaches at 100% after the time.

4 Prediction of Height for a Girl

It is critical to demonstrate and prove that the information dynamic model can predict game outcome. Using initial conditions such as team (player)' s ranking, record or quality of players, value of the parameter 'm' of the information dynamic model $\xi=\eta^m$ in (4) may be obtained before the game starts. It is clear that once this value becomes definite, the game will proceed along one of the model curves in Figure 10 from start to end. The information dynamic model is applicable to predict future trends in social problems such as GDP (Gross Domestic Product), population, temperature, effect of medicine, and/or achievement quotient of pupils in school. It may be evident that this approach is applicable to any game. The problem how human height changes depending on the time during a specified period, is considered as an example. Before predicting the height of a girl at 10 years old, who is my dear granddaughter, it is necessary to find a standard curve how human height in general varies with time in terms of the data: These have been retrieved from the author's family, friends, and/or students in total of 253 persons so far: All of them are matured persons over 25 years old, so that their height growth is already stopped. Table 3 and Figure 7 show how to derive the standard curve for the human height prediction, where the initial height growth rate line, and the information dynamic model curve $\eta^{0.65}$ are plotted concurrently. In order to obtain the initial height growth rate of 6.5 cm/year, all of the retrieved data are averaged. In Figure 7, data and the fitted curve are also plotted. In Table 3, time history of the initial height growth rate, the information dynamic model $\eta^{0.65}$, the fitted curve and the data has been listed. In Figure 7, the data and the fitted curve have been also plotted. It may be evident from this figure that the data curve is between the initial height growth line and the information dynamic model curve, but is closer to the former line. Then, it is realized that each of the current data value at each point η is on the curve expressed by 0.6*[Initial height growth line + Information dynamic model curve], approximately. That is, the wanted standard curve S for the height prediction is expressed by

$$S = 0.6\{I(\eta) + M(\eta)\} \text{ for } 0 \leq \eta \leq 1, \quad (5)$$

where I(η) is the initial height growth line, and M(η) is information dynamic model curve.

Table 3 Towards the standard curve for the human height prediction with the real data.

η	I(η)	M(η)	Fitted Curve	Data
0	0	0	0	0
0.0667	0.17	0.172061	0.205236	0.168
0.1334	0.34	0.269992	0.365995	0.336
0.2001	0.51	0.351407	0.516844	0.5035
0.2668	0.68	0.423663	0.662198	0.647
0.3335	0.85	0.489793	0.803876	0.8215
0.4002	1	0.551417	0.93085	0.905

0.4669	1	0.609531	0.965718	0.946
0.5336	1	0.664799	0.998879	0.956
0.6003	1	0.717694	1	0.97
0.667	1	0.768567	1	0.982
0.7337	1	0.817687	1	0.994
0.8004	1	0.865266	1	1
0.8671	1	0.911475	1	1
0.9338	1	0.956456	1	1
1	1	1	1	1

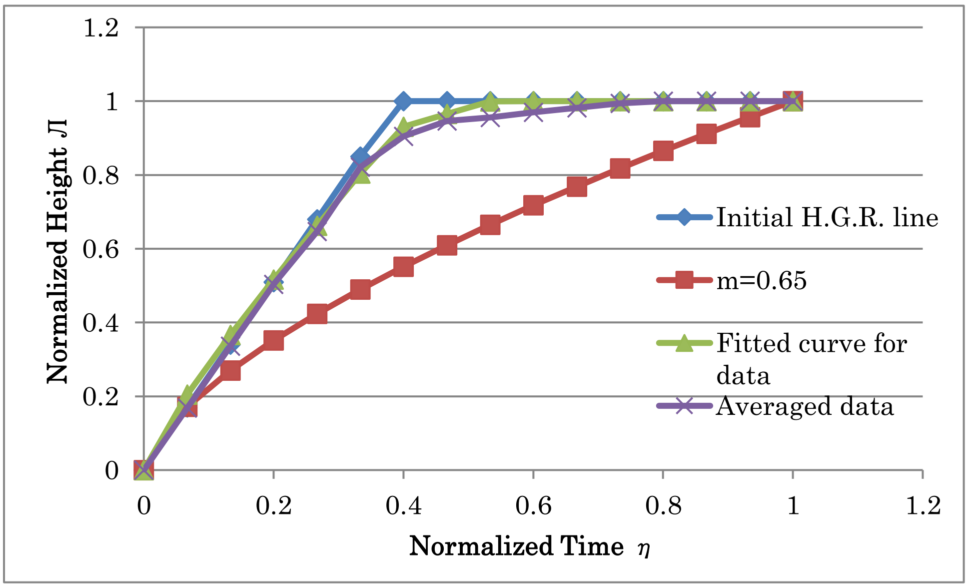


Figure 7 Sketch for explaining how to derive the standard curve for human height prediction

By knowing the standard curve for height prediction, it is possible to predict the height history of the girl by the following procedure:

1. Draw the initial height growth rate line by using the girl's initial height growth rate of 5.25 cm per year.

2. Select the information dynamic model that contacts with the initial height grow rate line at the origin.

3. Draw the relevant model curve.

4. Get the wanted prediction curve by using the relation S expressed by (5).

5. Draw the prediction curve.

In this way, history of the initial height growth rate line, the information dynamic mode $\eta^{0.69}$, and the predicted height have been calculated, as listed in Table 4, and these are plotted concurrently in Figure 8.

Table 4 Prediction of the girl's height from 10 years old to 25 years old η I(η) M(η) Prediction

0	0	0	0
0.0667	0.145	0.1544	0.17964
0.1334	0.29	0.249091	0.323454
0.2001	0.435	0.329504	0.458702
0.2668	0.58	0.401854	0.589112
0.3335	0.725	0.468744	0.716247
0.4002	0.87	0.531583	0.84095
0.4669	1	0.591241	0.954745
0.5336	1	0.648304	0.988983
0.6003	1	0.703192	1
0.667	1	0.756218	1
0.7337	1	0.807621	1
0.8004	1	0.857594	1
0.8671	1	0.906291	1
0.9338	1	0.953839	1
1	1	1	1

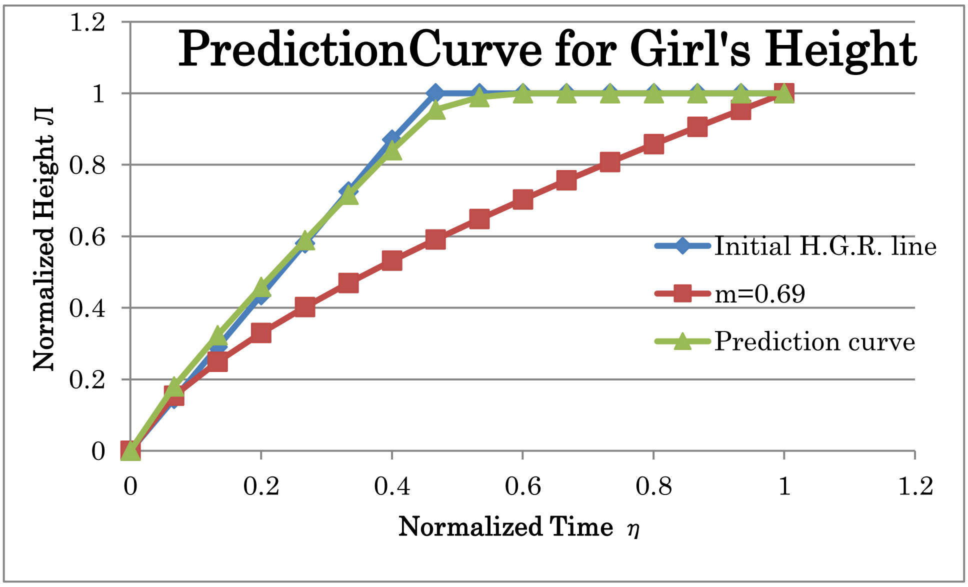


Figure 8 the prediction curve for a girl's height from 10 years old to 25 years old

It can be noticed from Table 4 and Figure 8 that the girl's height growth will be stopped at 19 years old when her height reaches at 164.25 cm. This is because the initial height growth line with the growth rate of 5.25 cm per year reaches at the full value of 1 at 7th year from the origin. This gives us her total growth height of 36.75 cm by multiplying 5.25(cm) with 7(year) , but she grows slightly slower than the initial height growth line and reaches at that value two years later, when she is 19 years old. Thus, we obtain her expected height of 164.25 cm by adding the growth height of 36.75 cm to her height at 10 years old of 127.5 cm. It is certain that the girl's height at each year from 10 years old to 25 years old can be easily obtained by using the data in the column of prediction curve in Table 4.

5. Discussion

Let us discuss choice and assessment of evaluation function scores in soccer. There is no question that the choice and assessment are critical to do valuable analyses. Candidates of evaluation function score in soccer may be goal, shoot, penalty kick, free kick or corner kick, but the assessor(s) is required to decide which one should be chosen and counted as the evaluation function score among the candidates. It is essential to set weights of evaluation function score as simple as possible to let the assessor easy to record game data and enhance the analyses. So, in this study, the weights are limited to either 1 or 0, where value of 0 denotes that its play makes no contribution to the game. That is, in case of penalty kick match, evaluation function score of successful kick must be counted as value of 1, while unsuccessful kick is counted as value of 0. Furthermore, if course of the ball is out of the goal mouth, and/or speed of the kicked ball is too slow, evaluation function score of a shoot or free kick may be counted as value of 0. On one hand, even if course of the ball is out of the goal mouth, a strong shoot and/or free kick toward the goal mouth may be counted as value of 1, for these are worth to the game at almost the same level as a goal sometimes. Whether free kick is counted as evaluation function score or not, also depends on the case that it is direct or indirect. A direct free kick should be treated as a shoot, but an indirect free kick may not. In case of corner kick, it is known that sometimes the kicked ball goes into the goal directly either by the rotation of ball that causes the side force with respect to flight direction of the ball due to Magnus effect after Heinrich Magnus (1802-70), wind, or own goal. When the kicked ball reaches at or near the goal area, it is, therefore, necessary to judge carefully whether it should be counted value of 1 or 0 as evaluation function score. It is realized that though in soccer goal is quite important and unique, consideration of the other candidates such as shoot, penalty kick, free kick or corner kick is essential for analyzing the game faithfully. In the present study, weights of the evaluation function score are either 1 or 0 only, but there is an obvious idea that events presented in the analysis such as goal, shoot, or corner kick should be given different weights of evaluation function score, respectively. Although this idea is reasonable, the analyses may become too tedious, but this is left for the future as it is beyond the scope of the present study.

4 Conclusions

In this section, new knowledge and insights obtained through the present study have been summarized as follows:

This study demonstrates that the proposed methodology can provide useful information to analyze game and predict the outcome, respectively, in terms of soccer and girl' height based on information dynamic model. A standard curve for the height prediction for human height has been proposed by incorporating the information dynamic model. Girl's height at 10 years old is predicted until 25 years old, by knowing her height growth rate at starting year. It may be considered that this is a sort of breakthrough on game study: The information dynamic model has been mainly used to do post hoc analyses previously, but it is proved that it can predict the game outcome before the start, if initial conditions are given. As a popular and simple game, soccer games have been analyzed and presented how advantage and certainty of game outcome vary with the time. In the data analyses, as evaluation function scores in addition to goal, shoot, corner kick, or penalty kick are adopted to conduct refined analyses. The supervisor, coach or player can reflect the past game and prepare for the tactic against opponent in future game. The game patterns have been categorized into see-saw, one-sided, balanced and others, and are defined quantitatively, to promote understanding game.

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Appendix Information Dynamic Model

Currently, information dynamic model only make it possible to treat and identify game progress patterns depending on the time. In this model, certainty of game outcome is expressed as a simple analytical function depending on the time. Simplicity and generality are characteristics of the information dynamic model, which will be introduced in this Appendix.

Modelling Procedure

The modeling procedures of information dynamics based on fluid mechanics are summarized as follows:

(a) Assume a flow problem as the information dynamic model and solve it.

(b) Get the solution(s), depending on the position (or time).

(c) Examine whether any solution of the problem can correspond to game information.

(d) If so, visualize the assumed flow with some means. If not, return to the first step.

(e) Determine the correspondence between the flow solution and game information.

(f) Obtain the mathematical expression of the information dynamic model.

The information dynamic model will be constructed by following the above procedures step by step.

(a) Let us assume flow past a flat plate at incident angle of zero as the information dynamic model (Figure 9).

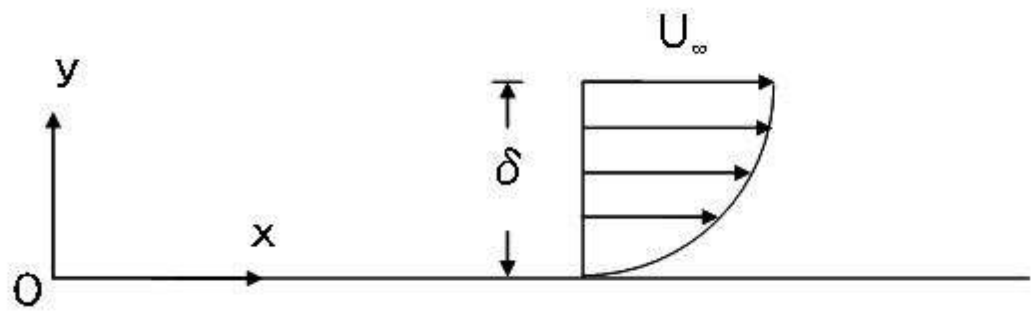

Figure 9 Definition sketch of flow past a flat plate at incident angle of zero.

An example of the application of the boundary-layer equations, which is the simplified version of Navier-Stokes equations [14], is afforded by the flow along a very thin flat plate at incident angle of zero. Historically this is the first example illustrating the application of Prandtl's boundary layer theory [13]; it has been analytically solved by Blasius[12] in his doctoral thesis at Göttingen. Let the leading edge of the plate be at x=0, the plate being parallel to the x-axis and infinitely long downstream, as depicted in Figure 9. We shall consider steady flow with a free-stream velocity U_∞, which is parallel to the x-axis. The boundary-layer equations [13, 14] are expressed by

$u\cdot\partial u/\partial x+v\cdot\partial u/\partial y = -1/\rho\cdot dp/dx+\nu\,\partial^2u/\partial y^2$, (5)

$\partial u/\partial x + \partial v/\partial y = 0$, (6)

$y = 0 : u = v = 0$; $y = \delta : u = U_\infty, v=0$, (7)

where u and v are velocity components in the x- and y- directions, respectively, ρ the density, p the pressure and ν the kinematic viscosity of the fluid. In the free stream,

$U_\infty \cdot dU_\infty /dx = -1/\rho \cdot dp/dx$. (8)

The free-stream velocity U_∞ is constant in this case, so that dp/dx=0, and obviously dp/dy =0. Since the system under consideration has no preferred length it is reasonable to suppose that the velocity profiles at varying distances from the leading edge are similar to each other, which means that the velocity curves u(y) for varying distances x can be made identical by selecting suitable scale factors for u and y. The scale factors for u and y appear quite naturally as the free-stream velocity, U_∞ and the boundary-layer thickness, δ(x), respectively. Hence the velocity profiles in the boundary-layer can be written as

$u/U_\infty = f(y/\delta)$. (9)

Blasius[12] has obtained an analytical solution in the form of a series expansion around y/δ = 0 and an asymptotic expansion for y/δ being very large, and then the two forms being matched at a suitable value of y/δ.

(b)The similarity of velocity profile is here accounted by assuming that function f depends on y/δ only, and contains no additional free parameter. The function f must vanish at the wall (y = 0) and tend to the value of 1 at the outer edge of the boundary-layer (y = δ), in view of the boundary conditions for $f(y/\delta) = u/U_\infty$.

When using the approximate method, it is expedient to place the point at which this transition occurs at a finite distance from the wall, or in other words, to assume a finite boundary-layer thickness δ(x) in spite of the fact that all exact solutions of boundary-layer equations tend asymptotically to the free-stream associated with the particular problem. The "approximate method" here means that all the procedures are to find approximate solutions to the exact solutions, respectively. When writing down an approximate solution of the present flow, it is necessary to satisfy certain boundary condition for u(y). At least the no-slip condition u = 0 at y = 0 and the condition of the continuity when passing from the boundary-layer profile to the free-stream velocity, so that $u = U_\infty$ at y = δ, must be satisfied.

The following velocity profiles satisfy all of the boundary conditions as the approximate solutions on the flow past a flat plate at incident angle of zero,

$u/U_\infty = (y/\delta)^m$, (10)

where m is positive real number. Eq.(10) is a series of solutions for the assumed flow. This is heuristically derived, and represents a series of the approximate solutions with each different value of m. When m=1, (10) coincides with an exact solution for the assumed flow, but all of the rest solutions are approximate solutions to exact solutions, if any, respectively.

(c) Let us examine whether this solution is game information or not. Such an examination immediately provides us that the non-dimensional velocity varies from 0 to 1 with increasing the non-dimensional vertical distance y/δ in many ways as the non-dimensional information, so that these solutions can be game information.

(d) Imagine that the assumed flow is visualized with neutral buoyant particles. Motion of the visualized particles is detected by the eye almost instantaneously through the lights and is mapped on our retina first [15], so that during these processes, motion of "fluid particles" is transformed into that of the "information particles" by the light carrying the images of fluid particles. This is why motion of the fluid particles is intact in the physical space, but only the reflected lights, or electromagnetic waves consisting of photons can reach at the retina. The photons are then converted to electrochemical particles and are passed along the visual cortex for further processing in parts of the cerebral cortex [15]. The photons and/or electrochemical particles are considered to be information particles. It is, therefore, natural to expect that the flow in the physical space is faithfully transformed to that in the information space, or brain including eye. During this transformation, the flow solution in the physical space changes into the information solution in the information space.

(e) Proposed are correspondences between the flow and game information, which are listed in Table 3.

Table 3 Correspondences between flow and game information

Flow	Game
u: flow velocity	I:current information
U_∞: free stream velocity	I_0: total information
y: vertical co-ordinate	t: current time
δ: boundary layer thickness	t_0: total time

(f) Considering the correspondences in Table 3, (10) can be rewritten as

$I/I_0 = (t/t_0)^m$ (11)

Introducing the following normalized variables in (11),

$\xi = I/I_0$ and $\eta = t/t_0$,

we finally obtain the mathematical expression of the information dynamic model as

$\xi = \eta^m$ (12)

where ξ is the certainty of game outcome, η is the normalized time, and m is a positive real number. Simplicity of this model may be noteworthy.

Figure 9 illustrates the relation between certainty of game outcome ξ and normalized time η, where a total of 10 model curves have been plotted concurrently for reference. This figure clearly indicates generality of this model (12), for each of the curves represents a game. Thus, this model can represent any game in principle, where each of games takes a unique value of m, number of which is limitless. The smaller the strength difference between both teams (or players) is, the greater the value of m, and *vice versa*.

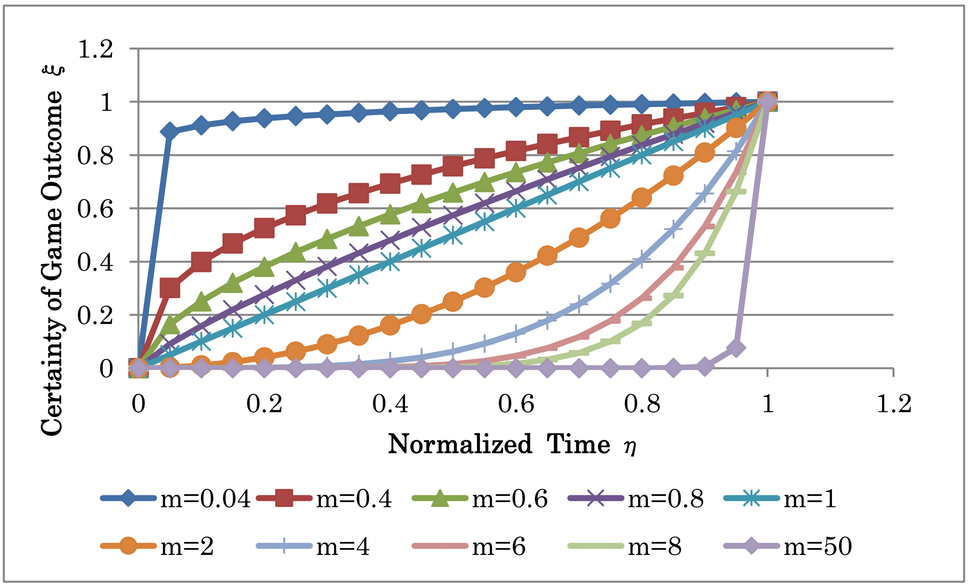

Figure 10 Certainty of game outcome ξ against normalized time η

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