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BIOGRAPHICAL NOTES

Dotan Shvorin: Mr. Shvorin is a doctoral student in the Department of Industrial Engineering at Clemson University. He owned and operated a military training academy “Be Ready”, where he was training his students to command and lead solders in combat. He spent three years in that role, followed by two additional years in the high-tech private contractor military industry. Mr. Shvorin is now expanding his knowledge by pursuing the M.S. and Ph.D. degrees in industrial engineering. He is currently developing human performance concepts using quality engineering methodologies in conjunction with a game theory approach. Mr. Shvorin was a junior professional tennis player, and he enjoys working with professional athletes at the university. Mr. Shvorin is a member of a few honor societies and teaches self-defense classes for university students. He currently resides with his wife Meirav in Jefferson, Georgia. He can be contacted at dshvori@g.clemson.edu.

Kevin Taaffe: Dr. Taaffe is an associate professor in the Department of Industrial Engineering at Clemson University, and he has over 20 years of industry and academic experience. After receiving a B.S. and M.S. in Industrial Engineering from the University of Illinois, Dr. Taaffe worked at American Airlines and Sabre, managing many airport-related transportation projects. After a decade in industry, Dr. Taaffe returned to academia and received his Ph.D. in Industrial and Systems Engineering from the University of Florida in 2004. Dr. Taaffe has been conducting research in healthcare and humanitarian logistics, as well as in transportation and productions systems analysis. His research has been funded by various private and federal entities. In particular, Dr. Taaffe uses simulation and optimization-based techniques to address decision-making problems that arise in various contexts. He especially enjoys working on problems that bridge the gap between theoretical research and application. Dr. Taaffe can be reached at taaffe@clemson.edu.

IMPROVING TENNIS PLAYER PERFORMANCE USING SYSTEM DEVELOPMENT INTERPRETATIONS METHODOLOGY

ABSTRACT

This research demonstrates a unique analytical approach to improving a player's performance in the game of tennis. We introduce a system development interpretations (SDI) methodology for associating player characteristics and factors in a hierarchical structure. We then show how this tool is applied in a human performance environment such as tennis. This approach was developed as a multidisciplinary quality tool for process improvement that identifies factor dependencies and depicts their impact on the resulting player performance. From the implementation of the system development interpretations (SDI) methodology, the research was able to define the tennis player's difficulties and it has allowed the researchers to build an entire team profile of the Clemson University tennis program as well as to introduce importance conceptual foundations in this field.

KEYWORDS

Human performance improvement, Factor influence, Hierarchical relationships, Statistical analysis

INTRODUCTION

In order to achieve a high performance level in the tennis match, the tennis player must understand the relationship between different factors that affect his level of performance. Those factors can be divided into two main concentrations: internal and external. The internal factors could be characterized as internal inputs to our decision making process such as stroke technique, body resources management, and emotional intensity. The external factors could be characterized as external inputs to our decision making process such as court conditions, weather conditions, and the opponent game type. The key to achieving a high level of performance lies within the ability to translate the external inputs and the internal inputs into a winning game plan.

The process of developing a game plan is not an open loop process but rather a closed one. A game plan could change at any time due to a change in the internal or external inputs. A winning game plan can be considered similar in its process to quality methodologies seen in production systems. However, with human performance, system quality is more difficult to establish. When we consider a production process, there are many tools that are used to increase the quality of the process, the capacity of the production line, and the efficiency of the machines. Those tools can quantify data from the production process, thus allowing mathematical or statistical methods to be employed.

This research is attempting to create the same quality approach, which is embedded in the industry, to increase the tennis player's performance level. We have used the system development interpretations (SDI) methodology (Shvorin 2011), which was developed to improve the plastic injection manufacturing process. The SDI methodology is enabling us to identify the ways in which factors in manufacturing are related. In using the SDI method in the plastic injection manufacturing setting better machine tolerances were defined, which ultimately lead to manufacturing error reduction and material savings. Quality control protocols for material handling and work force quality assurance proceedings were created to ensure that a high level of performance was established. Furthermore, key performance indicators (KPI) were created in order to better schedule maintenance applications and to increase production efficiency.

However, we note that the implementation of the SDI methodology on human performance is not a simple "plug and play" methodology; it requires an understanding of how to define human behavior within an engineering approach. With the SDI method a team profile of performance measurements was developed. With the help of the tennis program coaches, behavior characteristics were identified and solution applications were implemented. An in depth literature review will provide information about the history of the tennis game development as well as a relevant range of the game's analysis methodologies. Next we will discuss the SDI methodology development and its implementation on the tennis game, with the creation of the tennis team profile. After analyzing the SDI methodology outcomes, we will open a discussion on the research findings and conclude the future possibilities for advance research.

LITERATURE REVIEW

The tennis game development takes us back to the 12th century as a part of a rivalry between two opponents. In those times, games were developed to test one person's ability to overcome an opponent. The outcome of the game or test was heavily considered in the ability to maintain a certain status, class and honor among the relevant societies. The name of the game refers to the word *tenez* in French, which means "receive," a key feature of the actual game. Over the last 100 years, the game has advanced in many ways (from equipment and venues to the ability of the players).. In particular, not only were the physical characteristics of the player advancing, but the mental approach to the game was also advancing. The need for the player to be better, stronger, faster, and more mentally prepared has opened the sport to the research of how to attain these qualities to achieve the desired outcome.

Since the game was orchestrated by the upper class, it was driven from knowledge, which was used to overcome the opponent. The rivalry of two opponents in the game can be defined from a wide range of behavioral characteristics of each player, such as the ability to perform, the techniques employed to execute a course of action, and other strategies and tactics. According to del Villar et al. (2007), there is a substantial difference between the levels of a player's performance that emerge from his or her decision-making capabilities. Experienced players consider more characteristics in their decision-making process and have a better ability to select the right approach in a certain scenario, in order to overcome their opponent. This line of research was first explored by Thomas et al. (1986) and McPherson and Thomas (1989). They defined three components in the player's performance characteristics that could signify the differences between the levels of a player: control skill, response selection skills and response execution. The first component measures the player's ability to technically perform a certain stroke or movement in a given situation. It refers to the player's coordination, perception of space, and his body biomechanics potential. The second component refers to the player's ability to select the suitable approach from a wide variety of possibilities in order to overcome his opponent. This component describes strategic and tactical choices that a player makes, based on his interpretation of the game. The final component measures the outcome implications from the selected approach execution. Those performance measurements proved themselves as a way to evaluate the level of a player and to identify his weaknesses as well as his strengths.

Since this research was based on observation characteristics only, it did not address the player's state of mind. In research by Gonzalez et al. (2012), a more rigorous approach was taken based on the same method, except that it now included an interview application during the player's match. They were able to classify a wider range of features to represent the player's level of performance. Lames et al. (2006) extended this point of view by adding time perspective and momentum building aspects to the performance and response characteristics of a player, which was similar to that discussed in Del Villar et al. (2007). Beyond the somewhat constant skills and abilities of an athlete, tennis contains a complex system of cause and effect interactions, which can result in a significant change in the actual performance level of the player. Performance level changes are time dependent, when fatigue takes its toll for example, or momentum dependent, when a player wins a few points in a row. The dynamic aspect creates numerous decision possibilities over time. As one response is perfect for one moment in time it could be devastating for another. For example, the player can be continuously searching for a successful strategic and tactic behavior, based on the actual score or based on the actions of the opponent.

One analysis method, used in Lames et al. (2006), is the relative phase concept. This analysis deals with the special features of the player, with respect to his court positioning, as a response to the opponent's reaction. A relative phase means that the player's court movements are relatively similar to one another. The relative phase is balanced when both of the players are in a proper position to hit the ball. As the point plays out, the balance of the relative phase begins to be unstable. The unbalanced phase ultimately results a point won or lost. This analysis was driven from signal detection theory as it allows calculating continuous relative phase, which is mandatory because we have comparatively few strokes in the rally. This research allowed considering three more characteristics in addition to the player's component descriptions such as time dependence, momentum buildup and court positioning functionality. Palut and Zanone (2004) further defined the relative phase concept as one of two relationships: In-phase or out- phase. They also addressed the transitions between them as another indicator for court positioning characteristics. The phases mentioned above simply tend to define the relationship between attacking and defending. When an attack is made, we can expect a phase out, which means that the balance of the relative phase is about to be broken. If a defensive course of action is taken then we can expect a phase in, which means that the relative balance is about to be restored.

Relative phase research provided further interpretation for the player court positioning characteristics in response to the executable course of action. One of the most dominating factors in the player's performance received its respectable attention in Akpinar et al. (2012). Their research dealt with anticipation abilities in racket sports. This research method of analysis used a Bassin anticipation timer, a LED bulb runway that creates the illusion of motion from the way that it operates. It is by adjusting the speed and stopping distance of the flashing red lights that the level of anticipation could be evaluated. The anticipation ability serves as one of the most critical attributes to the tennis player as it demonstrates prediction abilities. Once a player predicts the ball interception location, opponent movement orientation and a decision execution outcome, he has more time to prepare, adjust and select the best way to overcome his opponent. A shortage of this ability will result in a disadvantage, which will immediately affect the player's level of performance. This concept extends the research found in Lames et al. (2006), and it provides one feature that could make a huge difference in the player performance capabilities.

Beyond the internal characteristics of a player, the performance level of a player can be affected by external characteristics of the game, such as the surface of the court, weather conditions, and equipment. O'Donoghue and Ingram (2000) addressed the court surface attributes and how they affect the interaction between the players. There are four types of tennis court surfaces, each one with distinct features. The grass court poses a low level of friction, thus the ball slides on the surface instead of bouncing. For the same reason, the player's ability to accelerate and change direction decreases as well. In the red clay court, the characteristics are reciprocal to those in grass because clay poses the highest friction properties. The last two courts are the mitigation courts between the two extremes. The hard court and the light clay (blue, green) court demonstrate more friction then grass but less friction then heavy clay (red clay). These surfaces affect stroke variety selection and a player's execution abilities, and as mentioned earlier, each change requires a new game plan that affects the player's performance level.

In the last section of the literature review, we focus on the statistical characteristics of player decisions and performance over time. Research by Franc et al. (2001) tested individual game points in relation to each other from a statistical point of view. The research revealed that points are neither independent nor identically distributed. They found that the outcome and characteristics of the previous point affect the current point, and each point has a slim chance of being the same as the previous point. This concept proves that the game analysis could not be established from isolated characteristics but rather a chain of events. This means that the characteristics of each player affect the other and result in (time-dependent) performance ability.

Over the past three decades, there has been a wide variety of research conducted on tennis player performance. This review raises a need for a unique analysis platform that could establish the connection between the player's characteristics with the necessary statistical reliance in order to understand the path for performance improvement. In the next section, we will engage in a multidisciplinary quality approach in order to understand the player's characteristics and their relation to his ability to win or lose a point (i.e., his performance level).

SDI Methodology Development

Quality is a well-established discipline in the engineering management profession (Hopp and Spearman 2008). However, it took 50 years before it gained prominence as a means of process improvement in industry. It was during the 1970s and 1980s when Japanese companies gained a significant advantage over their competitors by implementing a Just In Time (JIT) methodology in their manufacturing processes. Other countries eventually recognized the improvements being made in Japan and began developing their own quality programs. In particular, it was not until the 1980s that American industry really took notice of the strategic potential of the quality approach. More recently, Lean manufacturing and Six Sigma continue to be ubiquitous programs for process and quality improvement in many industries today.

The main goal of quality improvement is to reduce process randomness, process variability and increase the overall process performance level. Our research methodology takes another step in the development of a quality approach by examining the characteristics of the variability and how they may contribute differently to the randomness above the process mean value or below the process mean value. Specifically, system development interpretations (SDI) analysis takes the next step in variability reduction by asking when and where variability reduction needs to occur. We can support this aspect of variability reduction by including defect analysis consideration into tolerance optimization. If we can assume that there is an optimum point of operation, then tolerance definition tells us that we can have a certain allowable variability around this optimum point, and the reduction of variability may be different in each direction from the optimum point (Shvorin 2011). Consider the following analogy. Assume that our goal is to find the balancing point of a beam when two people are sitting on opposite ends of the beam. Based on the weight difference of the two people, the balancing point will shift towards the heavier person until a balance can be established. This may cause more variability to exist on one side of the process, leading to a significant portion of outcomes that are outside the acceptable tolerance limits. If we cannot change the balancing point we need to reduce the distance from the heavier side to the optimum point in order to achieve a balanced system. In order to achieve balance in the system, we need to figure out which side is heavier (creates more defect in the system) when we consider variability definitions.

If we want to develop those concepts we need to take a step back and look at the cumulative effect of the deviations on the system. Once we can define the cumulative effects we will be able to characterize the variability behavior and adapt our tolerance definitions to increase our system performance capabilities. In order to achieve this point of view, the SDI analysis method was developed. The first application of this methodology was to improve a polymer injection manufacturing process. In the polymer production environment, the relationships between the process materials and the time window for their reaction were a key ingredient in the quality of the product. By identifying the material effects to one another, while considering a certain time reference, the SDI method was able to tune the manufacturing process to achieve a higher level of performance. The research was triggered when a leading irrigation equipment manufacturer was facing increased production levels while managing it with a reduced workforce. This led to a rise in the defect percentage. By using the SDI methodology, they were able to understand how those defects were created. Then, new machine tolerances were established and the defect percentage was reduced.

SDI combines the field research knowledge with information gained from experience to create a database of relational information. In order to create this database, the application of SDI (i.e., the SDI algorithm) is outlined below:

1. Map the defects of the process, and define the relative weight for each defect characteristic (Pareto Chart).
2. Determine the causes for each defect while integrating process capabilities and work force experience.
3. Create two values (if appropriate) for which the cause could be defined (with respect to some characteristic or action of a defect):
    a. Upper deviation from the optimum response within some tolerance.

   b. Lower deviation from the optimum response within some tolerance.
4. Provide a relative weight to the causes of the defect to maintain the relative influence of each cause on the process.
5. Calculate the cumulative effect of each cause for creating defects in the system.
6. Adjust the cause's tolerance when considering the cumulative effect on the system.
7. Create protocols for the new working environment.

The second part of the SDI methodology is the ability to map the connections that it establishes between dimensions of cause and effect. When applying the algorithm for the first time, we expose the first order connections. Depending on the environment, the algorithm can be applied a second or third time (to reveal second or third order indirect connections). These additional applications provide a more complete, dimensional relationship (or branch) between the source and its outcome. Once we map the dimensional connection chain from one point to another, we can detect significant pathways to achieve improved performance. In this manner there are two main points that characterize this process:

- It is possible to achieve a multiplicative (as opposed to a linear) improvement in system performance based on making a small (but significant) change in the source.
- The difficulty of imposing a change is increasing with further iterations of the SDI algorithm.

In the next section we will use this approach to analyze the Clemson tennis team in order to improve their performance level. First, we will define the analytical approach, and then we will explain the research findings.

SDI Methodology Implementation with the Clemson Tennis Program

Using the SDI methodology requires that we identify connections between factors that affect the performance level. One contributing area of research in tennis is negotiation theory. Similar to tennis where two opponents are battling to win the match, in negotiation, the two sides are trying to achieve the best deal for each other. The foundations of negotiation theory are decision analysis, behavioral decision making, game theory, and negotiation analysis (Alfredson 2008). Negotiation theory provides three concepts to characterize the interaction between two sides.

- The first concept that is integrated in to the SDI methodology from the negotiation analysis is strategy definition. Strategy can be only one of two things: uncompromised (Attack) or compromised (Defend). Similar in the conscious choice for deciding what to do (strategy), player first needs to decide whether to attack his opponent or to defend himself from his opponent's attack.
- The second concept inherited from negotiation analysis is tactical definition, which tells us how to perform the chosen strategy. Similar in the tennis game, the player needs to decide how he is going to execute his attack.
- The third concept, which is integrated here from negotiation analysis as behavioral decision making, is addressed in this research as a mental mode description. This concept forces the operator to understand why he chose this mode of operation. In tennis, this is a main feature of consideration because it points out to the player's decision making triggers.

In order to begin the SDI algorithmic approach we have to define a main concept that will guide us in the analysis process. In the SDI method we are identifying defects, but what are defects in the tennis player's game. A defect in the tennis player game, by definition in this research, is a wrong decision making in the player's game. A wrong decision does not necessarily mean that the player lost the point; it is a statistical consideration of the long run probabilities that he will lose that point according to his decision. For example, player A performs a Touch stroke and Player B did not pass the ball over the net such that player A won the point. However, if this scenario is played 10 times, player A would win the point only once while player B would win the point nine times. If player A decides to perform a Touch stroke against player B he statistically made a wrong decision. Next, we create an error list that characterizes errors based on all of the players on the team. In this stage the list is constructed from the knowledge of the tennis game and the experience learned from the team performance. With the implementation of the SDI method on the Clemson tennis team, over 50 observations of singles and doubles matches were gathered and analyzed by the coaches. Some of the matches were evaluated live and some were evaluated through a video recording system. As mentioned earlier, the definitions of the error list were made based on expert opinion from the input of the coaching staff.

In Table 1 we see the result of the error list creation. This list characterizes the team's cumulative profile, which can be used to develop a more purposeful training program for the team. The relative weight represents a Pareto distribution of the error list.

Error List	Relative Weight
No point construction pattern from the game plan	**45%**
Follow up reaction misses	**20%**
Wrong stroke selection misses	**15%**
Degraded performance under pressure	**10%**
Misses of strokes outside of the hitting comfort zone	**5%**
Misses of back movement strokes	**3%**
Easy put away misses	**1%**
Low motivation misses	**1%**

TABLE 1 - ERROR LIST & RELATIVE WEIGHT

Table 1 denotes eight errors (or defects in manufacturing terms) that are most common to the team's performance.

- From this list we can see that 45% of the errors occur because there was no point construction pattern from the game plan. This error definition means that the players deviated from their game plan, thus making an error that led to a point for their opponent.
- The second error is a miss from a follow up reaction. Approximately 20% of the errors occur due to second- or third-move misses of the point's construction application. As an example, a player hits a very powerful shot that forces their opponent to return a short ball. However, the player misses the next pressure shot and loses the point.
- The third error is when the players choose the wrong shot to execute. For example, after the opponent attacks, the player chooses to respond by attacking and loses control over the ball and, ultimately, loses the point.
- The fourth error is degraded performance under pressure, which means that in critical moments of the game the player does not execute their chosen course of action as well as they would have done otherwise. Examples of such pressure situations are break points, tiebreaker games, etc.
- The fifth item addresses the ability to react to a difficult challenge shot. For instance, a player loses the point due to failed shot execution from a difficult positioning.
- The sixth item refers to hitting the ball with a backward movement. This means that an error occurs when a player is moving backwards while trying to execute their shot selection.
- The last two items address those points that should not be missed and points where players do not possess the right attitude.

Once we defined our error list (defects) we can carry on with the analysis. The first group of factors are intuitively the first order connections to the decision making process. We can define those factors when we examine what attributes can contribute to the creation of an error from the error list. We will get a list of factors that can be classified to the three concentrations: strategy, tactics and mental mode. The second order list is created when we ask the same questions (activating the SDI algorithm for the second time) but now we are examining what elements could contribute to the factors that caused the first order error list. We can continue in this same pattern in order to identify all factor relationships and dependencies. These connections and dimensions are critical because once they are defined their contributions will aggregate throughout the SDI algorithm. Consider Figure 1 below:

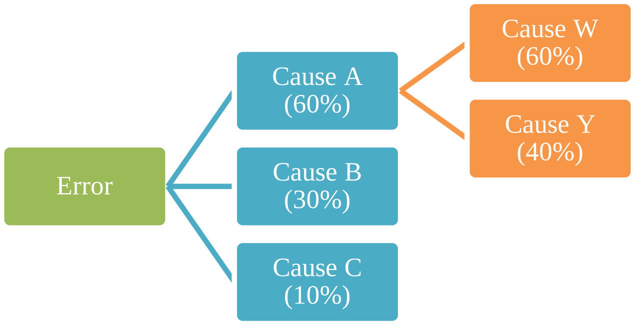

FIGURE 1 - SDI ALGORITHM EXAMPLE

We see that this error has three first order causes (A, B, C), with two second order attributing causes (W, Y) that lead to Cause A. We can also see that each cause has its own relative weight within the order level. The statistical attribution in this case is very clear, and we can evaluate how a second order cause can indirectly affect the creation of this error. Once a path or relationship is defined, this research will be able to identify those relationships with the highest statistical effect on the players' decision making, the players' performance level and the game training applications.

We now introduce the three levels of connections that we will specify as part of the SDI algorithm:

- The first order connections reveal the direct connections. Any change in these characteristics will directly affect the performance level of the players, which would change the error list percentile attributes.
- The second order connections will be characterized by indirect connections and an indirect effect on the player's performance level (e.g., a change in the second level will cause changes in the first level which will change the players' performance level directly). A change in this order level possesses the potential to affect the player's understanding of the game, thereby increasing his performance level beyond what can be done by focusing solely on the first order characteristics.
- The third order connections address core values (or building blocks) and their connection to making an error. These relationships possess a greater potential for performance improvement because they contain the ability to change the player's game perception, situational awareness, and behavior.

We propose that all errors can be classified as being caused by strategic, tactical and or mental mode failures. In order to classify characteristics as being of type strategy, tactics or mental mode, we adopt the following leading questions.

- What caused this error? (If a characteristic answers this question, then it is strategic.)
- How was this error created? (If a characteristic answers this question, then it is tactical.)
- Why was this error created? (If a characteristic answers this question, then it is mental mode.)

From the first implementation of the SDI methodology, we received an error list and a list of causes to each error. We then aggregate the relative weight of an error on to its causes in order to determine the extent to which each cause affects the error list. For simplification purposes, consider the example in Figure 2:

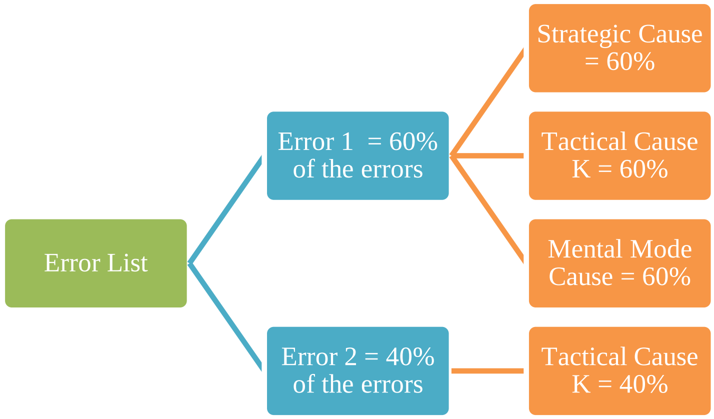

FIGURE 2 – SDI AGGRIGATING STATISTICS METHOD LOGIC

Here we see that there are two errors in our list. We can see that one error is occurring 60% of the time while the other error occurs 40% of the time. There are 3 causes for the first error – one strategic cause (which explains what causes the error), one tactical cause (which explain how the error is occurring), and one mental mode cause (which explains why the error is occurring). There is a single tactical cause for the second error. In order to apply the statistical weighting (or effect) to our three classifications of strategic, tactical, and mental mode, we apply the following logic:

$$Strategic\ weight = \frac{\sum Strategical\ cause_i}{\sum Strategical\ cause_i + \sum Tactical\ cause_j + \sum Mental\ mode\ cause_k} = \frac{60}{60+100+60} = 27.3\%$$

$$Tactical\ weight = \frac{\sum Tactical\ cause_j}{\sum Strategical\ cause_i + \sum Tactical\ cause_j + \sum Mental\ mode\ cause_k} = \frac{100}{60+100+60} = 45.4\%$$

$$Mental\ Mode\ weight = \frac{\sum Mental\ mode\ cause_x}{\sum Strategical\ cause_i + \sum Tactical\ cause_j + \sum Mental\ mode\ cause_k} = \frac{60}{60+100+60} = 27.3\%$$

In Table 2, we present first order relationship results from our actual case study. Using this same logic, we see that strategy (defined by three direct characteristics or traits) affects 47.5% of the error list. We also record the cumulative error effect of each characteristic. Identifying opponent strengths and weaknesses has a 19% effect from the strategic point of view, but this parameter affects 84% of the original error list in Table 1. This implies that these strategic characteristics are connected to many items in the error list, and the tasks affect each error in a different way. The second concentration of factors (i.e., tactical) affects 39% of the error list and it is also characterized by three direct characteristics or traits. The third concentration of factors (i.e., mental mode) affects 13.4% of the error list and it is characterized by three characteristics as well. With this structure in mind, we can now realize the most important elements of the direct connection for improved performance.

First Order Relationship

Strategy – 47.5%		
Direct Characteristic/Trait	**%**	**Cumulative Error Effect**
Identify opponent strengths and weaknesses	**19%**	**84%**
Classifying opponent game type	**14%**	**59%**
Comprehend and formulate a game plan	**14%**	**62%**
Tactics – 39.1%		
Direct Characteristic/Trait	**%**	**Cumulative Error Effect**
Stroke Adaptation	**9%**	**39%**
Court Positioning	**10%**	**45%**
Point Construction	**20%**	**85%**
Mental Mode – 13.4%		
Direct Characteristic/Trait	**%**	**Cumulative Error Effect**
Decreased level of physical ability	**2%**	**9%**
Decreased level of play	**6%**	**24%**
Error Replications	**6%**	**25%**

TABLE 2 - FIRST ORDER RELATIONSHIPS

From the first order relationships, we can identify two player characteristics that stand out: identifying strengths and weaknesses (strategy) and point construction (tactics). Both of these characteristics signify that most of the errors come from inappropriate decision making (both at the macro and micro level).

In order to understand the second level causes that affect the first level causes, we engage in the second iteration of the SDI method. We present the data in Table 3, where we can look at the micro effect of each classification (strategy, tactics, and mental mode) and the macro effect that transcends to the first level. The second order relationship characteristics have the same statistical structure as the first order relationship database. The SDI method was used to determine how to aggregate the relative weight on to the second order causes.

Second Order Relationship			
Strategy – 47.5%			
Indirect Characteristic/Trait	**%**	**Cumulative Error Effect**	
		High Value / Over Use	**Low Value / Under Use**
Probing Applications	**11%**	**30%**	**70%**
Stroke Variety	**14%**	**31%**	**87%**
Self-Awareness	**11%**	**67%**	**47%**
Clarity of Thought	**11%**	**33%**	**67%**
Tactics – 39.1%			
Indirect Characteristic/Trait	**%**	**Cumulative Error Effect**	
		High Value / Over Use	**Low Value / Under Use**
Reaction Time	**6%**	**40%**	**60%**
Stroke Power	**6%**	**56%**	**16%**
Stroke Angle	**8%**	**34%**	**80%**
Stroke Height Level	**10%**	**28%**	**98%**
Stroke Spin	**9%**	**13%**	**88%**

Mental Mode – 13.4%			
Indirect Characteristic/Trait	**%**	**Cumulative Error Effect**	
		High Value / Over Use	**Low Value / Under Use**
Confidence Level	**2%**	**54%**	**71%**
Self-Belief	**3%**	**65%**	**91%**
Fear Intensity	**2%**	**42%**	**64%**
Temper Implications	**2%**	**37%**	**75%**
Mental Pressure	**2%**	**77%**	**35%**
Stroke Motivation	**2%**	**58%**	**42%**

TABLE 3 - SECOND ORDER RELATIONSHIPS

The secondary causal relationships expose more parameters that take their toll in the performance considerations. However, different from Table 2, these relationships introduce the effect on errors based on both the over-use and under-use of any characteristic/trait. This is different than the “yes/no” mentality of the first order characteristics, where we evaluated whether or not a particular characteristic was present in a player’s performance. For example, the player will make more inappropriate strategic errors when he does not sufficiently probe (i.e., experiment to evaluate and gain knowledge about the opponent capabilities) his opponent. If he does not probe his opponent, and thus cannot identify the opponent’s strengths and weaknesses, then he will not be able to build a game plan accordingly. On the other hand, if the player over probes his opponent, this could result in confusion and difficulty in deciding on a specific game plan. Moreover, probing takes time, during which the player’s game plan hasn’t really been set yet. This will lead to the errors mentioned in Table 1. We summarize findings based on the subjective interpretation of the coaching staff, where the second-level SDI methodology data was applied.

- The strategic findings show that that the players (and team as a whole) should increase their probing abilities, stroke variety and clarity of thought (i.e., separating relevant information from irrelevant information). Reducing their self-awareness mainly implies that the player will increase his focus on the opponent.
- The tactical findings point out that the players need to increase their stroke angle, height and spin in order to improve their performance. In this case, we often see that the team uses more power than they are able to control, which leads to unforced errors.
- The mental mode findings indicate that the team needs to have more psychological preparation to deal with confidence, self-belief and temper control in order to improve their performance level.

Finally, Table 4 allows examination of the team profile at a deeper level of consciousness. This is an area where these characteristics can be analyzed and tested in training sessions. The last iteration of the SDI method, a key contribution of this research, defines how more fundamental personality traits and characteristics (as opposed to player skill and skill effectiveness from Tables 2 and 3) translate into performance and errors. These characteristics and traits can also be defined as the building blocks of our behavior. The most relevant characteristics to the game of tennis have been included in Table 4. By adjusting the intensity of any of these characteristics, a unique personality forms and a different result can be achieved on the tennis court. We present these characteristics below. The next table is founded on the most difficult data based that was put together in this research. There is very limited existing research in this area, and we must rely on the expertise of the coaching staff to help define important relationships. The database for this level required a unique and timely effort to analyze and translate certain features of the team’s behavior, while framing those features in to defined concepts of literature. For instance, seeing a player perform a return of serve when his body is moving away from the ball instead of moving towards the ball, means that he failed to anticipate where the ball is oriented by his opponent. This is only one instance where anticipation can be identified. In order to figure out how to aggregate the relative weight, the SDI methodology was used.

Third Order Relationship - Building Blocks			
	Strategy – 47.5%		
Characteristic/Trait	%	Cumulative Error Effect	
		High Value / Over Use	**Low Value / Under Use**
Anticipation	**14%**	**16%**	**84%**
Alertness	**16%**	**7%**	**93%**
Cleverness	**9%**	**49%**	**51%**
Intuition	**9%**	**52%**	**48%**
	Tactics – 39.1%		
Characteristic/Trait	%	Cumulative Error Effect	
		High Value / Over Use	**Low Value / Under Use**
Adaptability	**4%**	**16%**	**84%**
Aggressiveness	**2%**	**50%**	**50%**
Determination	**4%**	**14%**	**86%**
Endurance	**4%**	**18%**	**82%**
Patience	**4%**	**24%**	**76%**
Composure	**5%**	**0%**	**100%**
Precision	**4%**	**27%**	**73%**
Assertiveness	**5%**	**5%**	**95%**
Agility	**4%**	**16%**	**87%**
Imagination	**4%**	**9%**	**91%**
	Mental Mode – 13.4%		
Characteristic/Trait	%	Cumulative Error Effect	
		High Value / Over Use	**Low Value / Under Use**
Appreciation	**1.1%**	**21%**	**79%**
Honesty / Integrity	**1.2%**	**13%**	**87%**
Valor / Courage	**0.9%**	**66%**	**34%**
Principles guided	**0.9%**	**63%**	**37%**
Leadership	**0.7%**	**49%**	**51%**
Responsibility	**1.3%**	**6%**	**94%**
Enjoyment	**1.2%**	**11%**	**89%**
Motivation	**1.2%**	**11%**	**89%**
Reliability	**1.2%**	**11%**	**89%**
Self-discipline	**1.0%**	**27%**	**73%**
Compassion	**1.0%**	**27%**	**73%**
Professionalism	**1.1%**	**16%**	**84%**
Devotion	**0.8%**	**40%**	**60%**

TABLE 4 - THIRD ORDER RELATIONSHIPS

This table is one of the most fascinating findings from the SDI methodology. From the way that the coaching staff and the research knowledge interpret their value perception in a tennis player, we are obtaining aggregated statistical information of the team profile performance characteristics of behavior.

- The statistical analysis defines four main strategic values that characterize the necessary elements of behavior where the team needs to pay special attention, however two of them demonstrate higher effect. Anticipation is the ability to predict what is going to happen from the sensory input that we receive. For example, the ability to predict the opponent's movement direction, serve direction, next shot selection, etc. We can see that this element interacts with 83% of the second order characteristics. Therefore, it could cause a significant change in a player's performance capability. Alertness is the ability to detect the smallest changes in the environment. Players need to notice their environment (which includes changes in strategy, tactical and mental mode features of their opponent) in order to increase their performance level.
- The tactical analysis can characterize how a person should respond to a certain situation. It addresses the execution capabilities of the strategic decision. We can see that there is a significant difference between the shortage effect and the overage effect in most of the traits. Therefore, in order to improve the team's performance, the team needs to strengthen those values that possess a higher percentile effect when they are in shortage of use. Moreover, we can see that the effect of overage is pretty low by comparison. This implies that relaxing these values would have little effect on the team's performance.
- The mental mode analysis identifies thirteen items that characterize behavior. We can see that the dominant values are honesty, responsibility, enjoyment, motivation, reliability and professionalism. Improvement in each one of those traits would significantly increase the team's performance capabilities. Moreover, we can see that the overage of those traits (with the exception of valor, guiding principles, and leadership) does not have a great impact on error creation because of their positive effect on the team's performance capabilities.

The SDI methodology addressed three-level orders that are connected through the classification of strategy, tactics and mental mode. The analysis provided a database for improvement that could be used to increase the team's performance. Implementing these recommendations in the player's physical training program, game plan development education and in the tennis program structure will result in greater achievements.

Future Research

In order to advance to the second stage of the SDI methodology, which addresses cause and effect relationship with the addition of a time element and intensity scale, we will engage in computer simulation model development. The simulation model will allow the research team to explore the responsiveness of a player's current ability based on the time-based decisions (and level of intensity of those decisions) that are applied during game settings. The time scale would likely be different for each order level when considering the ability to create a performance change. For instance, creating a performance change based on first order characteristics would be relatively easy to implement, but its ability to result in long-lasting change is less likely. In contrast, creating a performance change based on second order characteristics would be much harder (from the former example) to implement, but its effect would likely last longer. In order to teach a child how to correct his spelling mistakes could be relatively easier when you correct his mistakes as he is speaking, but that correction last only momentarily. However, if a spelling mistake is explained to the child, it will be harder and take more time, but he may never make the same mistake again. We will further explore the long-term benefits of addressing second- and third-order traits via the simulation modeling approach.

We will also try to identify elements of human behavior that could create a trigger for performance improvement. Grunting, for example, is a physical element of performance when the player releases airflow while performing a certain shot, thus allowing his body to function without air congestion and to increase his motion. The improved motion could generate more power, faster reaction time, and greater stability. Interestingly, the physical aspect of grunting may not even be the dominant cause for performance improvement. The mental aspect of grunting seems to be more beneficial to performance improvement as it triggers positive outcomes in attitude, character and confidence. The connections to higher order performance effects will be investigated further.

Discussion

When we consider performance improvements methods, we need a method that would adapt itself to the real time measurements of key performance indicators (KPI). It is a closed loop concept that leads to continuous improvement. This research exposes the ability to define the KPIs, although for a tennis player KPIs are learned through many methods such as trial and error, video recordings of matches, books, papers and other sources. The SDI error listing, characteristics, and traits can be unique for each player, and using the player's feedback a continuous improvement approach can be achieved in the player's abilities. When considering the second and third-order characteristics, implementing this methodology may result not only in improvement in player's tennis game, but also in the individual's daily life.

Conclusions

Quality development is one of the most desired features in industry today. It began its journey almost a century ago with simple process charts and reached multidisciplinary tools for process improvements. The system development interpretation methodology (SDI) was developed as a quality development tool for improved performance. In this research, an implementation of the SDI method revealed interesting findings on the tennis player performance characteristics. Those findings resulted in the creation of a team performance profile for the Clemson University tennis team. While the current possibilities for improved performance have been outlined, the next stage of this research is to create a dynamic system where the player interacts with another player, and performance of each player is monitored and recorded. This can be accomplished through a mathematical tool such as computer simulation. Through the interaction between the players, the game features would be tested for their performance application. A statistical definition would be created to a certain strategy and the level of effectiveness could be measured. This is one of the fascinating research areas that take its first steps in the current field as it absorbs information and methodologies from the industrial engineering discipline and implements those techniques in professional sports.

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