UTILIZING BÉZIER SURFACE PATTERN RECOGNITION FOR INTEGRATING QUALITATIVE AND QUANTITATIVE ANALYSIS OF MILITARY TACTICS

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This paper describes how to develop and utilize a method based on Bézier surface pattern recognition, which could be used for the overall military tactical analysis of a company's attack. This paper also explains how this method could be applied to an integrated analysis of the most important tactical factors affecting the success and task fulfillment of an attack together with the effects of the leader's decision-making and his or her tactical solutions.

Key words: *Military tactics, decision-making, company, attack exercise*

1. BACKGROUND

The tactical basic research, "The Success Factors of Infantry Company's Attack" (SCA research), which was carried out in the Finnish Defence Forces (FDF) during the years 2004-2007 forms the empirical background of this paper. The SCA research focused on analyzing different individual effects of selected explanatory measured variables. The variables were selected from the areas of tactics, situational awareness, battle task load, human factors, background factors and response variables. During this research, 59 attacks by infantry companies were analyzed.

This paper presents a comprehensive evaluation method for tactical analysis. The development of the method started from constructing the data collection matrix. Later on in this paper, the method is called the CMEP method (Command and control, Manoeuvre, Effect, Performance Maintenance) and its data collection matrix is entitled the CMEP matrix. This matrix is presented in **Figure 1.**

The construction and order of the rows and the columns of the CMEP matrix are based on the observations collected in the SCA research and supported by literature research. For example, Liddell Hart [1] has emphasized such comparable

contents as "Freedom of action" and "Clear intention" and Bellamy [2] has emphasized such comparable contents as "Terrain and circumstances", "Use of performance", "Battle readiness", "Concentrating on the essential", "Execution capability", "Flexibility", "Battle pull", "Battle support" and "Releasing new reserve".

TACTICAL ELEMENTS/ PRINCIPLES	COMMAND AND CONTROL	MANOEUVRE	EFFECT	PERFORMANCE MAINTENANCE
KNOWLEDGE OF ADVERSARY AND OWN	1 FREEDOM OF ACTION Shaping the threat Possibilities of achieving effect Common tactical understanding Position and condition info Avoiding force binding	2 TERRAIN AND CIRCUMSTANCES Restrictions of adversary Own force strengths Dominant terrains Relative agility	3 USE OF PERFORMANCE Choosing the right object/target Avoiding passive formality Active use of deceptive actions Economic use of force Profitable synchronization	4 CONCEALMENT Variation of action styles Own battle plan secrecy Situation picture of adversary Effect-based decentralization
ACTIVENESS	5 SITUATION EVALUATION AND POSSIBILITIES Seeing the possibility Courage to utilize Will to take initiative Reconnaissance-pull Sensitivity of thinking	6 BATTLE READINESS Adaptation to situations Responding to the unexpected Continuity of movement Leadability Positioning	7 COMBAT TECHNIQUES Firing situations (opening fire) Adversary on move when fired Own units positioned when firing Active use of battle composition Proper utilization of strengths	8 FORCE PROTECTION Keeping up preparedness Ensuring early warnings Own performance capacity Terrain adaptation Air protection and -defence
SIMPLICITY	9 CONCENTRATING ON THE ESSENTIAL Main attention on adversary Battle task clear in mind Action competence (training) Utilization of own example Short communication (signals)	10 EXECUTION CAPABILITY Effect and speed (queues) Standardized starts (STP) Weapons quickly to positions Aim to concentrate effect Mobility improvement	11 CLEAR INTENTION Fulfilling the battle task Maximizing casualty production Minimizing own force casualties Satisfactory input-output ratio Battle task tactics	12 FLEXIBILITY Broad method spectrum Fast adaptability Speed of situation variation Security
CONCEN- TRATION OF EFFECT	13 BREAKING THE BATTLE PLAN OF ADVERSARY Stopping the manoeuvre Forcing adversary to react Aiming at surprise Active choice of time and place	14 BATTLE PULL Advantageous positions Several effect directions Adjusting the movement Profitable battle formations Situational speed	15 BATTLE SUPPORT Producing enough casualties Overall profitable use of all fires Proper centre of gravity Co-effect of supporting branches Breaking adversary's cohesion	16 BATTLE SERVICE Material readiness Support to acting readiness Foreseeing needs Advanced fulfilment of needs Pushing principle in service
RESERVE AND EXERTION OF IT	17 PREPARING FOR VARIATION OF SITUATION Readiness for the unexpected Active use of situation picture Evaluating options Searching culmination Effort to take initiative	18 CONTINUITY Keeping up initiative Aiming at battle culmination Attention to possibilities Focus after battle engagement Keeping up battle engagement	19 UTILIZATION OF SUCCESS Developing initiative Creating culmination Keeping up adversary's pressure Using the possibility windows Perseverance	20 RELEASING NEW RESERVE Utilization of initiative Utilization of culmination Possibilities of continuing Developing battle situations Adversary's pressure growth

Figure 1. The CMEP matrix

2. QUALITATIVE ANALYSIS

In the Finnish Defence Forces' Field Manual 2008 [3], the central tactical principles are described with the words, "consciously, actively, simply, concentrated and continuously". The sequence of the tactical principles, which is the sequence of the rows in the CMEP matrix, is determined based on the causalities found from the literature and the qualitative analysis of the source data collected from the SCA research. According to the Field Manual [3], tactical principles should always be integrated with the time dependent result. Based on these facts, the sequence of the rows in the CMEP matrix, should be "knowledge of adversary and own, activeness, simplicity, concentration of effect, reserve and exertion of it".

According to the Field Manual [3], the tactical elements are command and control, manoeuvre, effect and performance maintenance. The tactical principles become apparent in the interaction with the tactical elements of the battle. According to the Field Manual, the purpose of the manoeuvre near the adversary is to move one's own troops safely to the position from which it is possible to affect the adversary effectively with fire. Further, command and control can be seen as a factor which aims to integrate the other tactical elements of the battle field. When considering the chronological order of the tactical elements, the sequence is command and control, manoeuvre, effect and performance maintenance. The tactical elements (columns of the CMEP matrix) of the CMEP matrix are the same as the tactical elements in the battlefield according to the Field manual. (Infantry Company's Battle Guideline, 2008) The tactical elements presented in the columns of the CMEP matrix can be evaluated by utilizing the adverbs presented in the rows of the CMEP matrix (consciously, actively, simply, concentratedly and continuously). For example, command and control could simultaneously be conscious, active, simple, concentrated and/or continuous). This viewpoint has lead to the 5*4 - CMEP matrix and enables the qualitative tactical evaluation of an attack.

From the tactical viewpoint, the central aspect which connects the rows and columns of the CMEP matrix is time. As illustrated in Figure 2, the time dependent structure of the CMEP matrix makes it possible

to study in the desired time window both what actions have been taken and in what way these actions were carried out.

Within the CMEP matrix, a part of a tactical phenomenon could be expressed as "conscious command and control" in the time window "tw1" or it could be entitled "active manoeuvre" in the time window "tw2" if it is relevant to limit the size of the time window to illustrate just a small part of the tactical phenomenon. From the viewpoint of the battle result, the study of tactical phenomena could be extended in the time window "tw3", which covers several checkers of the CMEP matrix (several tactical actions have taken place and are carried out in different ways).

Because both the tactical elements and tactical principles are time dependent and there is causality which establishes the sequence of them, there is also a time axis passing along the diagonal of the CMEP matrix.

The CMEP matrix construction makes it possible to describe the tactical grounds so that e.g. good command and control could be simultaneously based on situational awareness (consciousness) and activeness, or, on the other hand, effect could be simultaneously concentrated and simple. In addition to the description of these types of separate tactical reason-consequence relations, the CMEP matrix construction makes it possible to study comprehensively different integrated tactical phenomena within the 5*4 field (see Figure 2).
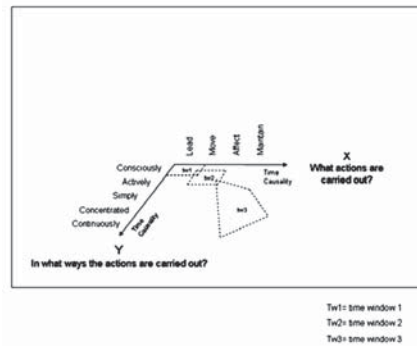

Figure 2. Utilization of the matrix construction for forming the tactical time windows

In this research the checkers, which are formed at the crossings of the rows and columns of the CMEP matrix, are called CTVs (Central Tactical Variable) and the aspects they can be divided into are called tactical items. The contents of the tactical variables and items are established by the qualitative analysis of the source data collected from the SCA research. The qualitative analysis is carried out by applying the principles presented by Miles & Huberman [4].

3. QUANTITATIVE ANALYSIS

The next logical step after the qualitative analysis, which resulted in the construction of the CMEP matrix, is the quantifying process of the collected data to be entered into the CMEP matrix as numerical values of each CTV. When quantifying the qualitative results, the numerical values of each CTV value were calculated by classifying the number of positive/ neutral/ negative perceptions. The source data comes from the SCA research [5].

The presentation can be developed in a more illustrative manner by constructing a surface model from these numerical values. This is performed by changing the numerical values of the matrix into the height values of the surface model. As an essential part of this quantitative analysis, formulated Bézier surfaces were used as resulting surfaces, which indicate the goodness of the tactical solutions and performance of an attack. In addition to the formulation of the surface, a specialized surface ratio curve is calculated to be able to evaluate the attacks by using quantified grading.

Based on the qualitative viewpoint, we already know how the columns of the CMEP matrix describe "what is done" (lead, move, affect, maintain) and how the rows of the CMEP matrix describe "in what ways these actions are carried out" (consciously, actively, simply, concentratedly, continuously) when a company carries out an attack. When we integrate the third dimension with the matrix (z-axis), it is possible to evaluate from the viewpoint of tactics the success of each action and the success of an attack. This principle is illustrated in **Figure 3**.

If we regard the numerical value of each central tactical variable as its assessment related to the success of the corresponding action described with this variable, the surface model constructed based on the numerical values of each CTV can be regarded as an overall assessment of the analyzed attack. The height values evaluate "how well" knowledge of the adversary and one's own force, activity, simplicity, concentration of effect and reserve and exertion of it

have been carried out in relation with command and control, manoeuvre, effect and performance maintenance.

The height values of the surface model change depending on time, which makes it possible to study the tactical phenomena at different moments during the progress of an attack or after the end of an attack.
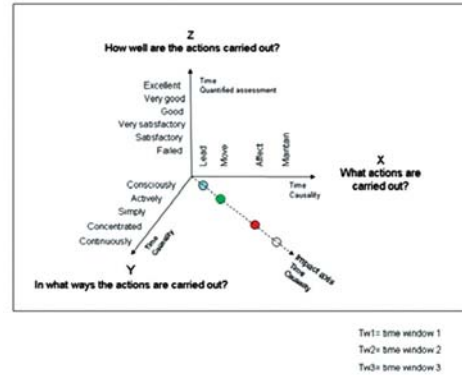

Figure 3. Integrating the z-axis with the CMEP matrix

The quantitative evaluations of task fulfillment and casualty data were integrated into the presentation by positioning the surface at the z-axis according to the given numerical values of task fulfillment and casualty data. In the same way it would be possible e.g. to change the positioning of the surface depending on the difficulty level of the task. This quantifying process is presented in outline in **Figure 4**.
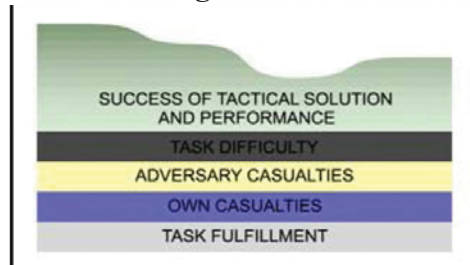

Figure 4. Quantifying process

As shown in Figure 4, the basic height values of the surface are calculated by summing the scaled numerical values describing the task fulfilment and casualties. These values can be regarded as basic assessment criteria of success in the battle and therefore their scaled values are added to each central tactical variable to move the surface to the higher or lower level, which indicates how well the task is fulfilled and what the casualty ratio was after the battle. The additional quantified and scaled values of each central tactical variable are summed with these basic values.

An example of the Bézier surface, which is calculated based on the measured data in the SCA research [5], for successful attacks is presented in **Figure 5**.
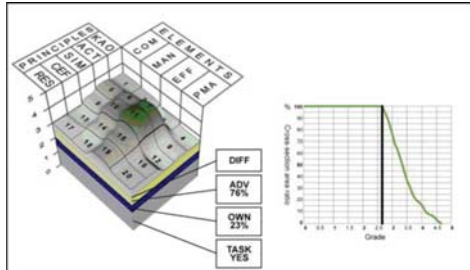

Figure 5. Calculated Bézier surface and the grading curve

4. CALCULATING THE SURFACE AREA RATIO CURVE

From the produced surface model of the CMEP method, it is possible to cut different slices along xy-, yz- or zx-planes to evaluate different tactical aspects or to conduct a time dependent analysis of them. The calculated grading curve (surface area ratio curve) of the CMEP method makes it possible to carry out an exhaustive and overall evaluation of the attack exercise. An example is presented in **Figure 6**.
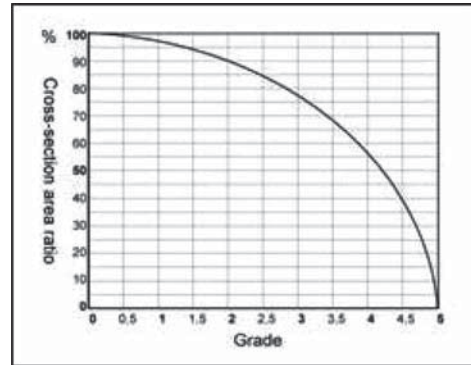

Figure 6. The surface area ratio curve

From this curve, it is reasonable to read how large a relative portion of the CTVs have reached the required grading level. On the other hand, it is possible to set a grading value which divides the battles into successful or unsuccessful ones. This curve also shows how wide the basis for success has been or if only a few CTVs affecting success have reached the required level. This grading curve is an application of the Abbott-Firestone curve, which is applied to surface analysis [6].

5. BÉZIER SURFACE MODELING

Bézier surface presentations are utilized to support both decision-making and to integrate the results of several design or reasoning stages, e.g. in optimum shape design, according to Vucina et al. [7]. Also Sohel et al. [8] have evaluated the possibilities to utilize Bézier curves in different

types of practical applications to improve the local information gained from the surface model. They have presented enhanced Bézier curve models. Extensive research has also been conducted to find means to describe the shape information of Bézier surfaces [8] for interpreting different modeled phenomena. These aspects are of great interest when there is a need to integrate qualitative and quantitative measurement results to support tactical analysis.

When evaluating the reliability aspects of the surface modeling, two main points were checked: How the selected Bézier surface calculation differed from other possible modeling techniques in relation to pattern recognition and what the difference is in grading.

The viewpoint of interest focuses to the higher levels of the surface, which start above the layers describing one's own and the adversary's casualties together with task fulfillment. Four different surface modeling techniques were compared: Bézier, Mozaic, Pyramid and Block surfaces. Basically, the Mozaic model describes exactly the measured values of each item in all twenty CTVs. Compared to this, the Block model summarizes the values of different items within each of the twenty CTVs and it shows correctly the summarized values of each CTV. The Pyramid model is otherwise the same, but only the peaks are illustrated with the sharp vertex of twenty cones.

The idea of the CMEP method is to combine time aspect into both CMEP matrix axes, which means that the heights of the neighboring bars should change smoothly according to the tactical phenomena. Unlike the other modeling techniques, the Bézier surface is able to illustrate this feature due to its mathematical properties. The comparison results of different grading curves and the surfaces of each modeling techniques are presented in **Figure 7**.
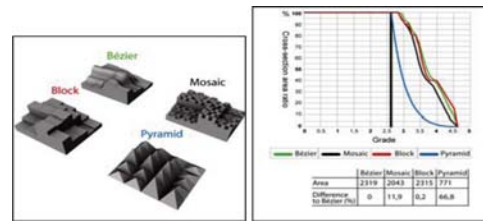

Figure 7. Comparison of different surface modeling techniques

6. INTERPRETATION OF BÉZIER SURFACE PATTERNS

As a part of computing advances in military OR (Operations Research), especially in tactical decision-making, the surface interpretation is based on recognizing some geometrical shapes from the surface pattern. This recognizing process is supported by a picture series describing the most relevant surface shapes which are assumed to present some tactical phenomena and their success.

The comparison of the calculated Bézier surface is performed with theoretical surfaces. Based on these theoretical surfaces, a set of definition maps were produced to support the interpretation process of military tactics. The comparison is divided into the following three parts:
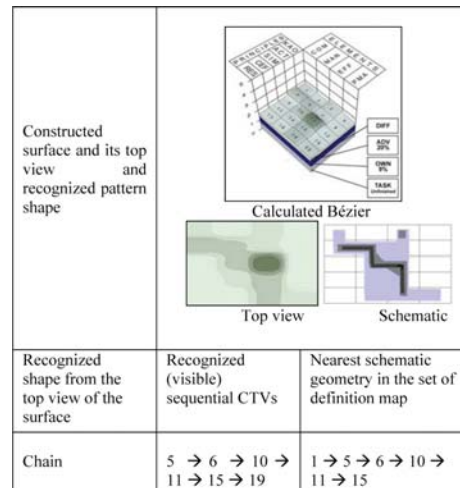
• Geometric similarity of the definition maps and the calculated surface pattern;
• Tactical dependency between researched viewpoints;

• Synthesis of the surface patterns.

From the top view of the calculated surface, it can be proved that surface patterns at different height levels of the surface indicate and highlight by different weightings the aspects which have an effect on the result of the battle. It is as important to recognize these surface patterns at different height levels as it is to recognize the surface pattern at the highest (=most visible) surface level. This shows that several aspects simultaneously have an effect on the result of the battle. It also shows that depending on the battle situation, the impact factor of these aspects varies. As documented in Table 1, in this case example, only one chain is named and analyzed. In this case, according to tactical interpretation, in order to enable initiative in battle, the leaders have ensured the freedom of action by maintaining the possibility to affect in creative ways and by avoiding force binding. In addition to this, the leaders have been open to looking for new possibilities and to taking initiative. Initiative in manoeuvres, effects and other actions has shown in proactive actions to varying situations and the unexpected actions of the adversary. The leaders have had a strong understanding of utilizing the unit's and its subunits' execution capability and they have understood the necessary functions to carry out the planned, prepared and trained actions before the adversary has had time to force them to do so. Both the leaders and the subunits have had the courage and the justification to find and use the effects of supporting branches in a simple and creative way to fulfill the battle task.

7. DISCUSSION AND CONCLUSIONS

The aim of the CMEP method is to integrate several different variables and affecting factors into one overall tactical analysis according to the leaders' decisions, solutions, and orders and according to the unit's actions and according to the events in the battle space.

Constructed surface and its top view and recognized pattern shape		
Recognized shape from the top view of the surface	Recognized (visible) sequential CTVs	Nearest schematic geometry in the set of definition map
Chain	5 → 6 → 10 → 11 → 15 → 19	1 → 5 → 6 → 10 → 11 → 15

By integrating a qualitative and quantitative analysis of an attack within the Bézier surface model, it is possible to extract and identify certain key points of the battle:

• Was the battle task fulfilled and the battle victorious?
• At what cost was the outcome of the battle achieved?
• Timing compared to the correctness of created solutions and selected actions.
• Were the decisions and actions actively justified?
• What were the key variables and culmination points of the attack?

Because the surfaces are produced from measured data into the form of Bézier surfaces, it is possible to add

mathematical comparison and pattern recognition in the CMEP method.

The primary challenge was in finding an appropriate way to handle several qualitative parameters describing tactical aspects. The sensitivity analysis of the CMEP method consists of interaction between three main analyzing stages, which are 1) the accuracy of the measured data, 2) the mathematical sensitivity of the CMEP method and 3) the sensitivity of the CMEP method's definition maps to support relevant interpretations dealing with the analyzed tactical phenomenon. The sensitivity analysis of the CMEP method shows that it is possible to affect the resolution of the surface model by tuning the scaling of different layers of the surface model. However, a sufficient amount of source data is more critical to ensure that the height differences of the surface model are clear enough to illustrate different tactical aspects.

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