Corporations require well defined strategies and successful implementation of strategic solutions in order to survive, facilitate growth, and remain competitive. In the current internet enabled economy, software development plays an increasing role in the implementation of corporate strategic solutions. The development of software product solutions aligned to corporate strategy help facilitate business success. The focus of this thesis is to present the Morphological Analysis Perspective (MAP) as an effective methodology that provides a link between corporate strategic planning processes that identify strategic problems and software engineering project processes used to implement solutions to corporate problems. The MAP enables the visualization of the total problem set, facilitates the reduction of a large total problem set to a smaller manageable solution set, and provides traceability between high-level strategic goals and software engineering project requirements.
USING THE MORPHOLOGICAL ANALYSIS PERSPECTIVE (MAP) IN SOFTWARE ENGINEERING PROJECT MANAGEMENT

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by
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USING THE MORPHOLOGICAL ANALYSIS PERSPECTIVE (MAP) IN SOFTWARE ENGINEERING PROJECT MANAGEMENT

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CHAPTER 1: INTRODUCTION

Corporations require well defined strategies and successful implementation of strategic solutions in order to survive, facilitate growth and remain competitive. In the current internet enabled economy, technology plays an increasing role in the implementation of corporate strategic solutions [1]. The development of software product solutions aligned to corporate strategy helps facilitate business success. According to Mike Mannion and Juha Savolainen, a successful software product line has clear business goals, a clear business strategy, a focus on a target market and an aligned technical strategy [2].

However, corporate strategic issues have become exceedingly complex. John C. Camillus describes corporate strategy issues as “wicked” problems [3]. In this context the definition of wicked is: “A wicked problem has innumerable causes, is tough to describe, and doesn’t have a right answer” [3]. Wicked problems are multidimensional. Multidimensional problems present two (2) issues. First, multidimensional problems have large problem sets that are hard to visualize and this complicates problem definition. Second, large problem sets are difficult to analyze.

The focus of this thesis is to present the Morphological Analysis Perspective (MAP) which is an iterative application of General Morphological Analysis (GMA) to a software engineering project (see Appendix A for a full description of GMA). This thesis explores and recommends use of the MAP as an effective methodology that provides a link between corporate strategic planning processes that identify strategic problems and software engineering project processes used to implement solutions to corporate problems. The MAP enables the visualization of the total problem set, facilitates the reduction of a large total problem set to a smaller manageable solution set, and provides traceability between high-level strategic goals and software engineering project
requirements. The ability to visualize each solution scenario enables a robust discussion that ultimately leads to the selection of a solution scenario in an unbiased way.

The MAP method has the following advantages:

1. The MAP facilitates a robust conversation between key stakeholders that minimizes the creation of a biased solution.

2. The MAP uncovers relationships or configurations between parameters that are not easily visible.

3. The morphological field and the cross-consistency matrix represent audit trails that facilitate traceability.

4. The analysis and cross-consistency assessment discussions provide a thorough understanding of each technical problem and possible solution.

This thesis contributes to software engineering for corporate business solutions by:

1. Providing a framework to capture and analyze strategic technical problems

2. Providing a process for the creation of well-defined software engineering project requirements that are aligned to business strategy

3. Providing a link of high-level strategic goals to software engineering project requirements that facilitates traceability

This thesis is organized as follows. Chapter 2 presents the Morphological Analysis Perspective (MAP). Chapter 3 presents a case study with research results, and Chapter 4 presents the conclusion.
CHAPTER 2: THE MORPHOLOGICAL ANALYSIS PERSPECTIVE (MAP)

2.1: MAP Research Background

The research of the Morphological Analysis Perspective (MAP) began with a literature investigation of Software Engineering Project Management (SEPM). SEPM is defined as the act of managing a software development project [9]. According to Richard Thayer, Arthur Pyster, and Roger Wood, SEPM is plagued with many problems [10]. Richard Thayer and Arthur Pyster updated their research 20 years later and identified slow progress in SEPM [11].

The MAP research focus then turned to the definition of success for software engineering project activities. However, a clear cohesive definition of project success proved to be elusive. Project success was ultimately determined to have a definition that is broader than project management success [12]. Project success definitions in the 21st century included meeting strategic goals of client organizations [12]. According to Janet Davison and Robert Sternberg the problem of strategic goal definition falls into the ill-defined class. There are two main classes of problems – classes that are considered well defined and others that are considered ill-defined. Solutions to ill-defined problems are challenging [13].

Some of the inputs to the strategic goal definition problem are: the corporate vision and mission statement, understanding the current competitive environment, and understanding current capabilities. The problem of strategic goal definition takes considerable work, and multiple revisions are required. Upon completion of the strategic planning process it is best practice to align technology projects with strategic goals [14]. However, the linkage between corporate strategy and technology projects is not well established [15]. The Morphological Analysis Perspective (MAP) provides a mechanism that facilitates the linkage between software engineering projects and corporate strategy.
The corporation where research for the Morphological Analysis Perspective (MAP) was conducted follows a standard portfolio management methodology based on the guidelines from the Project Management Institute (PMI). Business projects are grouped into business programs, and business programs are grouped into business portfolios. PMI defines a program as “A group of related projects, subprograms, and program activities that are managed in a coordinated way to obtain benefits not available from managing them individually” [16]. PMI also defines a portfolio as “A collection of programs, projects, or operations managed as a group to achieve strategic objectives” [17].

The portfolio management process at this corporation is distinctly separate from the Software Engineering Project Management (SEPM) process. The software engineering project manager has limited visibility to the strategic goals that prompted the creation of the project. Business projects have a four (4) phase project life cycle that is comprised of the standard PMI phases: define, plan, execute and close. The need for a technical solution is identified during the plan phase. The execute phase of the business project includes the assignment of a technical project manager and other technical resources. The requirements, design, build, test, and deploy processes of the Software Development Life Cycle (SDLC) are started during the execute phase of each business project when a technical need is identified. This sometimes led to duplication of software development efforts across lines of business and resulted in duplicate or similar technology solutions deployed across the corporation that only addressed the needs of individual siloed business area.
2.2: The MAP Overview

The MAP Framework (see figure 1 below) describes the process to capture and analyze strategic problems, creates well-defined software engineering project requirements that are aligned to business strategy, and provides a link of high-level strategic goals to software engineering project requirements that facilitates traceability.

As discussed in the introduction, corporate strategic objectives have become exceedingly complex and they can be described as “wicked” problems. Rubik’s cube provides an excellent
visualization of the unique issues encountered during the definition of corporate strategic objectives. The cube is a puzzle that consists of 27 smaller cubes arranged in a 3 x 3 x 3 matrix with colored stickers on each of the exposed squares of the smaller cubes. The solved state of the Rubik’s cube occurs when each of the nine squares on each side of the cube are all the same color (see Figure 2).

![Figure 2: Rubik's Cube](image)

Each side of the cube can be twisted 90, 180, or 270° relative to the rest of the cube. The unsolved configuration occurs when the colors are scrambled by random twist and the goal of the puzzle is to get the cube back to the solved configuration using a coordinated sequence of twists. This is a difficult goal because of two main issues. First, the Rubik’s cube’s problem set is extremely large - there are $4.3252 \times 10^{19}$ different states that can be reached from any given combination [18] so the problem is hard to visualize or clearly define and according to Pierre Robillard, “we humans intuitively understand that good design emerges from the specification of a well-defined problem” [19]. Second, there is an interrelation between the sides, and they cannot be solved independently. This is a multidimensional problem where each side of the cube could be considered one dimension of the problem. The solution to the Rubik’s cube requires a perspective that can visualize a smaller manageable solution set from the large total problem set of possible twists. The approach should also provide visibility to the impact of each twist on the
progress toward a solution. The Morphological Analysis Perspective (MAP) provides such an approach.

Wicked problems that require SEPM use standard management functions (see Figure 3). Planning is the first phase of management followed by organizing, staffing, directing, and finally controlling.

![Figure 3: Standard Management Functions](image)

The Morphological Analysis Perspective (MAP) is the iterative application of GMA to a software engineering project during the planning phase. The goal of the software engineering project manager is to successfully complete the project. Success is a product of three abstract variables [20]:

1. A properly managed project
2. A competent manager
3. A mature software engineering environment

The assumption of this research is that the project manager is competent and the software engineering environment is mature. The focus, therefore, is on ensuring that the project is properly
managed. J. Lubelczyk and A. Parra define a properly managed project as a project with goals and objectives that are clear, communicated, and managed [20]. The focus of this research is further narrowed to the creation of a project perspective that has a clear, communicated, and manageable set of goals and objectives that are aligned with corporate strategy. A key step in the communication and management of clear goals and objectives is to frame the project as a business initiative and not just a technical one [14].
2.3: MAP Description

The first iteration in the creation of the Morphological Analytical Perspective achieves the goal of framing each technology project as a business initiative by creating a group that includes key decision-makers and subject matter experts from the business along with key technical subject matter experts.

Figure 4: First GMA Iteration

The input to the first iteration is the corporate strategic goals. The stakeholders in this iteration include technology architects that are responsible for the alignment of corporate strategic goals with the corporate technology architecture roadmap. The output of the first iteration is the scope of a business problem that is addressed using technology.

Figure 5: Creation of Technology Portfolio Backlog
The first GMA iteration is repeated using additional strategic goals as input (see figure 5). The Strategic Portfolio Management team creates the Technology Portfolio Backlog by grouping and prioritizing the scope items produced.

The first iteration proceeds as follows:

- **Step 1 - Define the business problem to be solved as concisely as possible.**

  This is accomplished in one meeting or a series of meetings based on the complexity of the problem. The group is led by the project manager through the discussion with a focus on the selected strategic goal. The goal of this discussion is the definition of a business problem that clearly communicates the business needs and requires a technical solution. The discussion during this step does not focus on problem solutions. For example using the strategic goal below:

  **Strategic Goal**

  Capture a larger segment of millennials - customers within the age group 18-29.

  The business problem is defined as:

  **Business problem definition**

  Only 6% of our millennial customers use our new web-based products. This percentage is low when compared with other competitors in the industry.

- **Step 2 - Define all the dimensions (or parameters) that are of importance to the problem and assign each dimension a range of relevant values or conditions.**

  This is accomplished using a brainstorming session that includes key decision-makers and subject matter experts from the business along with key technical subject matter experts. Each of the meeting participants are tasked with breaking the problem into at least three most important dimensions. Brainstorming captures all proposed dimensions and
dimensions that are similar are combined or discarded with care to ensure that no important dimensions of the problem are lost.

For each dimension that remains the participants are tasked with identifying conditions or relevant values. Brainstorming captures all proposed values and similar values are combined or discarded. See table 1 for examples of dimensions and values.

- **Step 3 - Create a morphological field using dimensions and values captured in Step 2.**

  This can be accomplished using a software application. However, for this research the morphological field was created in Excel. This resulting small morphological field had \(4 \times 4 \times 5 \times 4 = 320\) combinations which represent the total problem set. Each combination represents a possible project scope.

<table>
<thead>
<tr>
<th>Value</th>
<th>Education Level</th>
<th>Available Products</th>
<th>Customer Location</th>
<th>Customer Totals</th>
<th>Customer Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bachelor Degree</td>
<td>Web based</td>
<td>West Coast</td>
<td>&lt; 1000</td>
<td>Full time student</td>
</tr>
<tr>
<td>2</td>
<td>Graduate Degree</td>
<td>Non-web based</td>
<td>North East</td>
<td>&gt; 1000 &amp; &lt;10,000</td>
<td>Part time student</td>
</tr>
<tr>
<td>3</td>
<td>Some College</td>
<td>Physical with web interface</td>
<td>South East</td>
<td>&gt; 10,000 &amp; &lt;20,000</td>
<td>Unemployed</td>
</tr>
<tr>
<td>4</td>
<td>No college</td>
<td>Physical without web interface</td>
<td>Mid-South</td>
<td>&gt; 20,000</td>
<td>Full time employed</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Mid-North</td>
</tr>
</tbody>
</table>

Table 1: First Iteration Morphological Field Example

- **Step 4 – Conduct a cross-consistency assessment meeting with the goal to reduce the values in the morphological field to a smaller manageable set.**

  This is accomplished by assessing all the parameter values in the morphological field and comparing each value, pair-wise, with one another. A judgment is made to determine if
the pair can coexist, i.e. the pair represents a consistent relationship. As discussed in Appendix A, the three types of inconsistencies checked are:

1. Logical contradictions (based on the nature of the problem and concepts involved)
2. Empirical constraints (relationships judged to be highly improbable or implausible on empirical grounds)
3. Normative constraints (relationships ruled out on ethical, economic, or political grounds)

Figure 6: First iteration Cross-consistency assessment (CCA) matrix

Three assessment keys are used in Figure 6 are:

- “—” = The pair is not appropriate
- “NO” = The pair is not optimal
- “X” = The pair is possible and fully appropriate /optimal

In this example 176 pairs are checked, and 57 or 32% of the pairs are identified with inconsistent relationships.

- Step 5 – Conduct a review of the problem set using the morphological field to determine the optimal business scope.
The optimal business scope is identified using input parameters as drivers. The selected scope of the project now includes input from all key stakeholders. The scope can now be used as input to the second iteration.

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Value</th>
<th>Education Level</th>
<th>Available Products</th>
<th>Customer Location</th>
<th>Customer Totals</th>
<th>Customer Type</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>Bachelor Degree</td>
<td>Web based</td>
<td>West Coast</td>
<td>&lt; 1000</td>
<td>Full time student</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Graduate Degree</td>
<td>Non-web based</td>
<td>North East</td>
<td>&gt; 1000 &amp; &lt; 10,000</td>
<td>Part time student</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Some College</td>
<td>Physical with web interface</td>
<td>South East</td>
<td>&gt; 10,000 &amp; &lt; 20,000</td>
<td>Unemployed</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>No college</td>
<td>Physical without web interface</td>
<td>Mid-South</td>
<td>&gt; 20,000</td>
<td>Full time employed</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td></td>
<td></td>
<td>Mid-North</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2: First Iteration Morphological Field with possible scope and input driver (red)

At the end of the first iteration, the optimal scope is created using specific values as input drivers. Input drivers are represented in “red” in Table 2 above. In this example, the decision was made to target the largest customer population. The optimal scope for the example shown in table 2 is:

Increase the number of millennium customers with bachelor degrees who live on the east coast and are employed fulltime using the new web-based product.

The morphological field is now an artifact used for traceability.

The second iteration can now use the optimal scope as input. The group in this iteration includes: a key stakeholder from the business with ownership and authority to make decisions; key technical subject matter experts e.g. Business Analyst, Technology Quality Assurance Resource, Technology Infrastructure Resource, and Technology Security Resource.
Figure 7: Second GMA Iteration

The Technology Program Management team assigns a project manager to each scope item in the Technology Portfolio Backlog. The project manager then starts the second GMA iteration with the definition of the technical problem associated with each scope item assigned.

The second iteration proceeds as follows:

- **Step 1 – Using the business scope, define the technical problem to be solved as concisely as possible.**

  This is accomplished in one meeting or a series of meetings based on the complexity of the problem. The group is led by the project manager through the discussion with a focus on the selected optimal scope. The goal of this discussion is the definition of a technical problem that clearly addresses the business needs. The discussion during this step does not focus on problem solutions. For example:

  **Optimal Business Scope**

  Increase the number of millennium customers with bachelor degrees who live on the east coast and are employed fulltime using the new web-based product.

  **Technical Problem definition**
The current web statistics reflect low utilization of the corporate website within the millennium market segment. Data from customer service reflect usability issues when accessing the website using mobile devices.

- **Step 2 - Define all the dimensions (or parameters) that are of importance to the problem and assign each dimension a range of relevant values or conditions.**

This is accomplished using a brainstorming session. Brainstorming captures all proposed dimensions and each dimension is assigned a range of relevant values or conditions. Dimensions with similar values or conditions are combined or discarded with care taken to ensure that no important dimensions of the problem are lost.

**Step 3 - Create a morphological field using dimensions and values captured in Step 2.**

Table 3 shows a subset of possible dimensions with values. This resulting small morphological field had $4 \times 4 \times 2 \times 4 \times 2 \times 3 \times 3 \times 3 = 6,912$ combinations which represents the total problem set.

<table>
<thead>
<tr>
<th>Value</th>
<th>Infrastructure Requirements</th>
<th>Software Procurement</th>
<th>Developer Knowledge/Skill</th>
<th>Cost</th>
<th>Application Features</th>
<th>Mobile Application Platform</th>
<th>Software Dev Process</th>
<th>Required time to market</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hosted internally - Physical</td>
<td>Commercially avail off the shelf</td>
<td>Available in-house</td>
<td>Small</td>
<td>Mobile App all with features from existing web site</td>
<td>Apple OS</td>
<td>Agile</td>
<td>t &lt; 6 mths</td>
</tr>
<tr>
<td>2</td>
<td>Hosted internally - Virtual</td>
<td>SAAS</td>
<td>Not available in-house</td>
<td>Medium</td>
<td>Mobile App all with a subset of features from existing web site</td>
<td>Android OS</td>
<td>Waterfall</td>
<td>6 mths =&lt; t &lt;= 1 yrs</td>
</tr>
<tr>
<td>3</td>
<td>IAAS Solution</td>
<td>Build in house</td>
<td></td>
<td>Large</td>
<td></td>
<td>Both Apple &amp; Android</td>
<td>Hybrid</td>
<td>Multi-year</td>
</tr>
<tr>
<td>4</td>
<td>Hybrid using IAAS</td>
<td>Upgrade existing application</td>
<td></td>
<td>X-Large</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3: Second Iteration Morphological Field example

- **Step 4 – Conduct a cross-consistency assessment meeting with the goal to reduce the values in the morphological field to a smaller manageable solution set.**

Check the three types is of inconsistencies as discussed in Appendix A:
Figure 8: Second iteration Cross-consistency assessment (CCA) matrix

In this example 271 pairs are checked, and 102 or 38% of the pairs are identified with inconsistent relationships.

- **Step 5** – Conduct a review of the solution set using the morphological field to determine the high-level project requirements for the optimal technical solution.

The optimal technical solution is identified using input parameters as drivers. The solution now includes input from the key business stakeholder and all key technology stakeholders. The high-level project requirements can now be placed on the Software Development Program Backlog or used as input to a comprehensive project plan.

![Table](https://via.placeholder.com/150)
At the end of the second iteration, the high-level technical requirements are represented by the selected values. In this example two drivers are selected in “red”, “medium cost”, and “time to market less than 6 months”. This drives the “blue” selected values in the remaining dimensions. All selected values are grouped into a software development project and added to the Software Development Program Backlog.
The MAP Framework can also accommodate a waterfall development process. This requires changes to the Project Management section of the framework as see in figure 9 below.

Figure 9: The MAP Framework for Waterfall Projects
CHAPTER 3: CASE STUDY USING THE MAP

3.1: MAP Research Results

The research process for the case study was designed to maintain the confidentiality of the corporation’s corporate strategies. The steps of the process are listed below with results:

1. **Review the corporate strategic planning documentation to select a strategic problem for research.**

   This was accomplished in one meeting. The group was led through the discussion with a focus on a selected strategic goal. The goal of this discussion was the definition of a business problem that clearly communicates the business needs. The discussion during this step did not focus on problem solutions.

2. **The strategic dimensions of the problem were identified.**

   A team of subject matter experts from the business, including technology resources, participated in a brainstorming workshop to identify the strategic dimensions of the problem and the parameters of each dimension. Six (6) dimensions were identified.

![Figure 10: Strategic dimensions of the problem identified](Image)
3. **A morphological field was created.**

The morphological field shown in Table 5 was created. This resulting morphological field had $5 \times 5 \times 3 \times 4 \times 5 \times 5 = 7500$ combinations and represented the total problem set. Each combination represents a possible project scope.

<table>
<thead>
<tr>
<th>Strategic Dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
</tbody>
</table>

Table 5: Morphological Field with sample data from research project

4. **The total problem set is reduced to a smaller manageable set using Cross-Consistency Assessments (CCA).**

Figure 11 shows the resulting CCA sheet created with only 302 pair-wise comparisons required. The sheet was created using Step 4 of the first iteration in the MAP methodology.

Three assessment keys were used:

- “—“ = The pair is not appropriate
- “NO” = The pair is not optimal
- “X” = The pair is possible and fully appropriate /optimal

The result of Step 4 is a reduction to the original Morphological Field. The resulting Morphological Field shown in Table 4 has $5 \times 5 \times 3 \times 1 \times 1 \times 3 = 225$ combinations.
The smaller problem set can now be used to model the scope by selecting parameters from the set as input drivers.

![Cross-consistency assessment (CCA) matrix](image)

Figure 11: Cross-consistency assessment (CCA) matrix
(Showing the Table 5 morphological field requiring only 302 pair-wise comparisons)

<table>
<thead>
<tr>
<th>Strategic Dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter</td>
</tr>
<tr>
<td>-----------</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
</tbody>
</table>

Table 6: New Morphological Field showing parameter reduction
(The resulting morphological field is reduced from 7500 combinations to 225 combinations)
5. The new smaller morphological field was used to model the strategic problem and an optimal business scope was determined.

The CCA process facilitated the selection of parameters as input drivers, and the scope was identified as a technical problem containing the parameters CSC3 + EL2 + G3 + CS3 + SP2 + TG3

The scope was then used as input to the second GMA iteration and a technical solution was identified using the steps below:

![Diagram of technical problem]

Figure 12: Technical dimensions of the problem identified

1. The technical dimensions of the problem were identified.

A team of technology subject matter experts, including a business manager who was identified as the owner of the solution to the strategic problem, participated in a brainstorming workshop to identify the technical dimensions of the problem and the parameters of each dimension.
2. A morphological field was created.

The morphological field shown in Table 7 was created. This resulting morphological field had $5 \times 4 \times 4 \times 6 \times 3 \times 4 \times 2 = 11,520$ combinations that represent the total solution universe. Each combination represents a possible solution.

![Technical Dimensions Table]

Table 7: Morphological Field with sample data from the second iteration

3. The total solution set is reduced to a smaller manageable set using Cross-Consistency Assessments (CCA).

Figure 13 shows the resulting CCA sheet created with only 354 pair-wise comparisons required. The sheet was created using Step 4 of the second iteration in the MAP methodology.

Three assessment keys were used:

- “—” = The pair is not appropriate
- “NO” = The pair is not optimal
- “X” = The pair is possible and fully appropriate /optimal
The result of Step 4 was an elimination of 262 or 74% of the pairs from the solution space. The remaining 92 pairs were used as input to the solution model.

Figure 13: Cross-consistency assessment (CCA) matrix

(Showing the Table 7 morphological field requiring 354 pair-wise comparisons)

4. The morphological field was then used to determine an optimal technical solution.
   The CCA process facilitated the elimination of 262 pairs from the solution space.
   The parameters in the remaining 92 pairs where then used as input and output drives during the selection of requirements for the optimal technical solution. The optimal technical solution created can now be used to complete the planning phase of the project. The selected parameters represent the high-level requirements for the technical solution and are fully traceable back to the business strategic goals.
3.2: MAP Lessons Learned

Below is a list of lessons learned:

- **The MAP process requires additional team training**
  Key business stakeholders had to be reengaged to complete the first iteration. This initially caused confusion amongst stakeholders. However, after an explanation of the process and communication of the benefits of ensuring alignment to strategic goals, the stakeholders participated in the exercise.

- **Time to complete the Define and Planning phase was doubled**
  The completion of both iterations significantly lagged the requirements and design phase. Running the MAP process in parallel introduces significant bias that could possibly influence the output.

- **Running the MAP process in parallel to the legacy project process was not efficient**
  The research relied on voluntary input from the same key stakeholders that were involved in the legacy project process and the legacy project process took priority over the MAP.

- **Use of Excel was cumbersome and slowed the production of the morphological field**
  The process to produce the morphological field in Excel required manual manipulation of spread sheets to produce the visual input driver scenarios.

- **The morphology workshop facilitated the discussion of ideas and knowledge sharing between business and technology**
  The workshop participants concluded that the methodology has considerable value for strategic planning with the main advantage of developing shared concepts and a common working vocabulary.

- **The morphology workshop provided greater visibility to the strategic problem**
  The morphology workshop produced a problem space of $5 \times 4 \times 4 \times 6 \times 3 \times 4 \times 2 = 11,520$ combinations. The team agreed that this provided clear visibility to the problem. The visibility fostered a robust discussion during project scope definition.

- **The use of the cross-consistency assessment process successfully focused the participants on the data in the morphological field**
  The team agreed that the cross-consistency assessment was useful in focusing participants on the data. Project scope items and requirements that were not backed by data were easily discarded.
3.3: MAP Further Study

This research included the utilization of the MAP methodology as a proof of concept. Additional use of the MAP across multiple industries and strategic planning cycles would be valuable. Additional utilization should build on lessons learned. The start of further research should coincide with the start of the corporate strategic planning cycle. Study of the MAP methodology integrated standalone i.e. not run in parallel with existing planning process would provide additional data for research.
CHAPTER 4: CONCLUSION

The initial use of the MAP process was a successful proof of concept. In this thesis, the MAP is defined as a tool that: facilitates the capture and analysis of strategic problems, provides a process for the creation of a well-defined software engineering project scope that is aligned to business strategy, and provides a link of high-level strategic goals to software engineering project requirements. The MAP methodology facilitated the capture and analysis of strategic problems with the use of the morphological field and cross-consistency assessment. The cross-consistency assessment process also facilitated the reduction of the large strategic total problem set to a smaller manageable set used to develop the project scope. Capturing problem domains and parameters in the morphological field and conducting the cross-consistency assessment created data and documentation that facilitated traceability.

This new perspective using morphological analysis was not meant as a replacement to current modern software engineering processes. Instead it was meant to be used at the beginning of software engineering projects to improve the link between software engineering and corporate strategic planning thereby facilitating better alignment with high-level strategic goals and improving overall corporate outcomes [14]. The MAP utilizes a proven problem structuring technique [21]. The MAP met the criteria for developing a win-win situation [22]. It successfully separated individuals from the problem; focused them on common interests not biased positions; provided a visual that communicated options for mutual gain, and insisted on the use of objective criteria.
REFERENCES


APPENDIX A: INTRODUCTION TO GENERAL MORPHOLOGICAL ANALYSIS (GMA)

The term morphology originated from classical Greek (morpha) [4]. J. W. von Goethe (1749-1832) was the first individual to use the term morphology to represent an explicitly defined scientific method. Goethe used the term to denote principles of formation and transformation of organic bodies [4]. Morphology has subsequently been applied in many scientific disciplines. It has been applied in geology to study the characteristics and evolution of rocks and landforms; it has also been applied in biology to study the shape or form of biological organisms; and it is also applicable in linguistics to study word formation.

In the late 1940s, GMA was developed by Fritz Zwicky – a Swiss astrophysicists and aerospace scientists who was based at the California Institute of Technology [4]. Fritz Zwicky proposed a generalized form of morphological research [5]. General Morphological Analysis is essentially a method for identifying and investigating the entire set of possible relationships contained in a given problem [4]. It requires the identification of all the parameters or dimensions of the problem to be investigated. As described by Fritz Zwicky [6], the morphological method is comprised of five steps (see Table 8). The first two steps are the analysis phase of the method. The problem is concisely defined and the parameters (or dimensions) of the problem are identified. Each dimension is assigned a range of relevant "values" or conditions [4]. The next three steps are the synthesis phase of the method. For each parameter the defined range of relevant values or conditions are documented using a morphological field (see Figure 14) and a morphological box - also known as a "Zwicky box" is constructed (see Figure 15).
5 Steps of the Morphological Method

**Analysis phase:** Define the problem complex in terms of variables and variable conditions.

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>First step</td>
<td>The problem to be solved it must be concisely formulated.</td>
</tr>
<tr>
<td>Second step</td>
<td>All of the parameters that might be of importance for the solution of the given problem must be localized and analyzed.</td>
</tr>
</tbody>
</table>

**Synthesis phase:** Link variables and synthesize an outcome space.

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>Third step</td>
<td>The morphological box or multidimensional matrix, which contains all of the potential solutions of the given problem, is constructed.</td>
</tr>
<tr>
<td>Fourth step</td>
<td>All the solutions contained in the morphological box are closely scrutinize and evaluated with respect to the purposes that are to be achieved.</td>
</tr>
<tr>
<td>Fifth step</td>
<td>The optimally suitable solutions are being selected and are practically applied, provided the necessary means are available. This reduction to practice requires in general a supplemental morphological study.</td>
</tr>
</tbody>
</table>

Table 8: Morphological Method

The problem in this example has three dimensions or parameters [4]. The first two dimensions each have five relevant values and the third dimension has only three relevant values. We therefore have a morphological field with 75 combinations (5x5x3= 75). This can be represented as a Zwicky box containing 75 cells. The morphological field and Zwicky box are a representation of the total problem set. The total problem set represents a well defined problem which can now be reduced to a smaller set representing the solution space.

Figure 14: Morphological Field

Figure 15: Zwicky Box
The reduction of the total problem set is achieved using “cross-consistency assessment” [4].

Cross-consistency assessment uses the concept that many pairs of values in the morphological field are mutually incompatible. Therefore any consideration of values containing mutually incompatible values would also be mutually inconsistent [4]. To conduct a cross-consistency assessment a matrix is created of all the parameter values in the morphological field and each value is compared, pair-wise, with one another (Figure 16). A judgment is made to determine if the pair can coexist, i.e. the pair represents a consistent relationship [4].

Three types of inconsistencies are identified [4]:

1. Logical contradictions (based on the nature of the concepts involved)
2. Empirical constraints (relationships judge to be highly improbable or implausible on empirical grounds)
3. Normative constraints (relationships ruled out on ethical, economical or political grounds)
Normative constraints are not used in the initial cross-consistency assessment. The goal at this point is to judge what is possible before judging what is desirable. However, normative constraints can be used later in the assessment to assist in the selection of the most desirable solution [4].

Pair-wise comparison is useful because it facilitates the reduction of the problem set. The number of pair-wise relationships in a morphological field is small in comparison to the total number of combinations. Pair-wise relationships between values can be represented as a quadratic polynomial whereas the morphological field grows exponentially. For example, a morphological field with as many as 100,000 formal configuration requires only a few hundred pair-wise evaluations in order to create a solution space [4].

In his presentation to the Swedish Parliamentary IT Commission, Tom Richey discussed the Swedish Total Defense authorities’ use of morphological analysis to develop a strategy for the Swedish bomb shelter program after the Cold War [4]. A small heterogeneous group of specialists – no more than 5 to 7 people was formed. The individuals in the group represented different aspects of the issue; this included representation for financial, political, military, technical, security policy and ethical aspects of the issue. The primary parameters of the problem were defined along with their respective values (Figure 17).
The morphological field represented \((4\times4\times3\times3\times4)\) 2,304 possible configurations. The morphological analysis for this problem was completed using a computer application. The application facilitated entering the parameters along with their values and enabled the group to easily build the cross-consistency matrix and conduct pair-wise comparisons. This reduced the problem set of 2,304 possible scenarios down to a solution set with only 125 scenarios. The computer application also enabled the group to visualize possible solutions by using parameter values as a single input driver (Figure 18) or multiple input drivers (Figure 19).
Figure 18: Solution space (blue) with single driver input (red)

Figure 19: Solution space (blue) with multiple driver input (red)
According to the Swedish Morphological Society, GMA has been used in over 100 projects over the last 20 years. It has been used primarily for developing scenario and strategy laboratories and for structuring and analyzing policy spaces [4]. See Table 9 below for a partial list of projects:

### I. Society, Security and Safety
- Environmental Strategies for South East Asia
  (SIDA – Swedish International Development Agency — Bangkok, Thailand)
- Morphologies of Anonymous Communication over the Internet
  (Swedish Ministry of Justice)
- Modelling Climate Change Conflict Scenarios
  (FOI – Swedish Defense Research Agency)
- Modelling Future IT Needs and Disruptions
  (Information Development Agency – IDA, Singapore)

### II. Commercial
- The Future of Letters: Postal Service in the new millennium
  (Swedish Postal Service)
- Retail Sales Cycle Model
  (European Retail Consultancy Firm)
- A Generic Modelling Instrument for developing Education and Training Programs for new Systems Technologies
  (FOI – Sweden, TNO – Holland)

### III. Defense
- Methods for long-term planning and threat assessment for the Swedish National Defense
  (Swedish Ministry of Defense)
- Strategies for Future Defense Organizational Structure
  (Swedish Ministry of Defense)

### IV. Projects Proposed
- Poverty Reduction Strategies
  (SIDA – Swedish International Aid and Development Agency)
- Development of an Urban Good Governance Profile with Morphological Analysis
  (UN-HABITAT)

### V. Academic Research Support
- Corporate Sustainability Program Development
  MIT Sloan School of Business, Cambridge
- Political position models
  George Washington University (GWU), Graduate School of Political Management
- Corporate Strategy Development
  Warsaw-Illinois Executive MBA, University of Warsaw/University of Illinois

Table 9: Partial list of Morphological Analysis Projects from 1995 – 2015
GMA has also been used in the creation of marketing strategies to generate, organize and analyze a large number of ideas [7]. For example Kaj Storbacka and Suvi Nenonen introduced and utilized the Competitive Arena Mapping (CAM) a methodology for market innovation using GMA in Business Markets [8]. The research for this methodology was completed between January 2007 and June 2010. The research involved twelve (12) companies from different industries and sizes. The methodology successfully facilitated the identification and analysis of a large set of possible competitive arena configurations and enabled the companies to view a mapping of where to compete.