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DATA FARMING IN SINGAPORE: A BRIEF HISTORY

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ABSTRACT

This paper gives a summary of Singapore's involvement in Data Farming since 2002, tracing the country's progression from basically "zero" to a key partner in the International Data Farming community. It highlights how the Data Farming methodology, coupled with efficient experiment designs, visualization concepts, and evolutionary algorithms, has helped to extend the analytical capability of conducting studies and experiments. The paper also described some past and current Research and Development (R&D) projects inspired by the ideas shared among this highly interactive and dynamic international community. These include Systematic Data Farming (SDF), Automated Red Teaming (ART), Automated Co-Evolution (ACE), and modeling the effects of human intangibles. Last but not least, the way forward for Singapore in Data Farming is discussed.

1 INTRODUCTION

The Singapore Armed Forces (SAF) has been progressively transforming towards the vision of a 3rd Generation SAF (3G SAF) through sustained efforts in adopting new technologies, exploring new operational concepts and investing in human resources (Tay 2007). Keeping pace with this transformational roadmap, Modelling, Simulation and Analysis (MSA) continues to play an important role in our military's decision support framework, especially in the area of Operations Analysis (OA) and Experimentation. There is an increasing need to conduct OA studies and simulation-based experiments that help to explore new concepts of operations, investigate more scenarios, understanding the potential outcomes and capturing the surprises.

2 HOW WE GOT STARTED

The Operations Research Lab (ORL) in DSO National Laboratories `<www.dso.org.sg>`, Singapore's foremost defence R&D organisation, has been exploring novel ways to build up new capabilities to perform the MSA role better and overcome some of the challenges faced with existing methodologies. These challenges include (a) conducting OA studies and experiments on new operational concepts that current models and methodologies may not be able to support well, and (b) investigate a wide range of technology capabilities, many of which the technical specifications are not fully developed yet, in support of these new fighting concepts. It has become increasingly obvious that more efficient and effective models and methodologies are required to complement the existing ones.

ORL was introduced to the idea of Data Farming by Dr Gary Horne, who with Dr Alfred Brandstein, visited DSO in 2001 to talk about Project Albert. Project Albert was a research initiative by the US Marine Corps Combat Development Command (MCCDC) with the aim to study the effects of intangible factors and non-linearity in military conflicts (Dunyak 2005; Brandstein and Horne 1998). It adopted a questioned-based modelling and simulation approach whose goal was to help achieve transformational tactical and operational approaches to current and future warfare. Project Albert was successfully completed in September 2006.

Data Farming is a process made possible by a convolution of advancements in Agent Based Models, computing power and the ability to organise, analyse and visualise data (Horne and Meyer 2004; Horne et al. 2005). The objective of Data Farming is to generate and observe a large number of possible outcomes for the studied scenario and to obtain insights as to what factors drive the occurrence of each outcome.

Singapore's first involvement in Data Farming activities was in April 2002 when ORL sent a group of analysts to the Maui High Performance Computing Centre (MHPCC) to attend a Data Farming Course. This was followed by participation in the Project Albert International Workshop 5 (PAIW 5) held in July 2002 in Germany. The Project Albert International Workshop series was a key activity of Project Albert. It provided researchers and practitioners a platform to network and share ideas in new areas such as complex adaptive system, complexity theory, operational synthesis, Agent-Based Simulations (ABS) and Data Farming. International working groups were also formed to address a wide range of military questions. The PAIW series was transited to the International Data Farming Workshop (IDFW) series when Project Albert ended in September 2006, with the Simulation Experiments and Efficient Designs (SEED) Center at the Naval Postgraduate School (NPS) taken over the leadership. Currently, the key countries participating in this workshop series are USA, Canada, Germany, the Netherlands, Sweden, UK, New Zealand and Singapore.

In PAIW 5, a Singaporean team was formed for the first time, led by a military analyst from the Singapore Army and with support from ORL. Since then, Singapore has participated in every workshop, with participants coming from (besides ORL and the Singapore Army) the Singapore Armed Forces Operations Research Office (SAFORO), the Future System Directorate (FSD), the Defence Science and Technology Agency (DSTA), Nayang Technological University (NTU) and Singapore Technologies (ST).

The details of our work completed during these workshops were published in (Wan et al. 2003; Lee and Ang 2005; Sim et al. 2006; Wong et al. 2007; Choo et al. 2007). In fact, ORL also hosted two of the workshops in Singapore, PAIW 8 in April 2004 and IDFW 15 in November 2007. The workshops serve as excellent forums for Singapore to share and exchange new ideas in Data Farming, ABS, experiment designs, high performance computing, evolutionary algorithms and even operational concepts.

3 AREAS OF INTEREST AND DEVELOPMENT

ORL was, and continues to be, captivated by some of the research ideas of then Project Albert and what is now the International Data Farming Community. In particular, the ability of Data Farming to generate and observe a large number of possible outcomes for the studied operational problem, to discover surprises generated by counter-intuitive outliers, and to gain insights on what factors drive the occurrence of each outcome, provides a mean to overcome some of the challenges for MSA discussed in the earlier section. The following are some of the areas of interests that were cultivated through interactions in the International Data Farming Community:

- <u>Data Farming</u>. This methodology provides a more comprehensive understanding of the full landscape of possible outcomes, and offers the opportunity to discover outliers, surprises and uncover non-linearity in the system-of-system studied (Horne and Meyer 2004). All these insights will be useful when factored into the military decision making process.
- <u>Agent Based Simulation (ABS) Model</u>. These are fast running simulation models that take less time to set-up and focus on distilling the essence of operational scenarios. More often than not, the non-deterministic nature of ABS provides emergence behaviours that traditional models are unable to account for. The main ABS models shared among the International Data Farming Community are MANA from New Zealand (Lauren and Stephen 2002; McIntosh et al. 2005), Pythagoras from the USA (Bitinas et al. 2003; Henscheid et al. 2005) and PAX from Germany (Scharwz and Mosler 2005; Lampe et al. 2006).
- <u>Efficient Experiment Designs</u>. Large number of factors, taking on many different values, may be relevant for exploring new concepts. Efficient DOE methods such as the Latin Hypercube (LHC) can be employed to provide screening of large number of factors over wide range of values to gain a good preliminary understanding of the effects of each factor on possible outcomes (Kleijnen et al. 2005; Sanchez 2006).
- <u>Operational Synthesis</u>. This is a process which focuses on looking at systems as a whole rather than reducing into parts. Through utilising all of the tools that are available in order to explore and gain insight into a particular area of interest, the individual strengths of each component within the broad spectrum of simulation, modeling and decision support tools are synthesised. Accordingly, the goal of Operational Synthesis can be expressed as utilising each individual tool for what it is good at, and combining the result in a manner that synthesises the resultant wealth of information, so that there is a more comprehensive analysis (Brandstein 1999).
- <u>Automated Red Teaming</u>. Red Teaming is a term used in the military to define an effort to uncover military vulnerabilities, and as a result identify exploitable gaps in military operational concepts. Extending from the foundation work laid down by Data Farming, instead of farming for a full landscape of possible outcomes, it is possible to heuristically traverse the landscape by means of utilising Evolutionary Algorithms (EAs). Under the concept of Automated Red Teaming, an end goal of breaking the blue is first determined, and Evolutionary Computation is employed to find the parameters that will lead to the specified objective (Upton and McDonald 2003; Upton et al. 2004).
- <u>Co-Evolution</u>. Co-evolution is a continuous process of planning and decision-making in a competitively changing environment. The idea here is to explore a two-sided competitive co-evolution as a mechanism to understand the dynamics of compe-

tition in a military context through simulations (McDonald and Upton 2005). The take back is an understanding of the dynamics in an operational scenario, whether there is equilibrium where one side dominates or cyclical where no side dominates, and the range of possible competitive outcomes.
- Human Intangibles. This talks about incorporating effects of human related factors into combat models and studies. Commonly neglected in studies, this is an increasingly important analytical gap to cover (Horne and Meter 2004; Schwarz and Mosler 2005; Ilachinski 2004) due to greater emphasis on low intensity conflicts, humanitarian operations and urban operations,

Inspired by the above-mentioned ideas, ORL has embarked on a series of R&D projects with the key objective of augmenting the current MSA capability in performing OA studies and simulation experiments. The subsequent sections described some of these projects in greater detail.

4 SYSTEMATIC DATA FARMING

4.1 Scope of Project

In 2004, ORL started a project to develop a framework to perform systematic design and analysis of experiments. Inspired by the work in Project Albert and its three main concepts, namely Data Farming, Efficient Experiment Designs, and Data Visualisation and Analysis, the project was funded by FSD with an objective to develop a Systematic Data Farming (SDF) capability for the SAF Centre for Military Experimentation (SCME) to conduct such large scale multi-factor experiments.

4.2 Outcome of R&D Activity

Development of the SDF capability was completed in 2005. It consisted of three main components, namely a Data Farming Facility, an Excel-Based LHC Generator, and a Clustering and Outlier Analysis Data Mining (COADM) tool. Although these three components are all useful tools on their own, they should be employed as an entire experimental and analytical process in OA studies and experiments. As illustrated in Figure 1, the proposed SDF process involves the following steps (Choo et al. 2006):

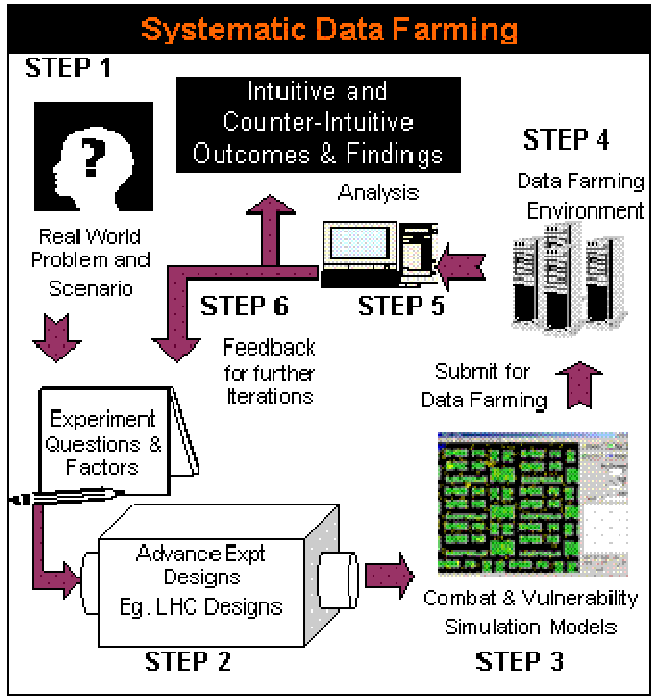

Figure 1: Framework for Systematic Data Farming

Step 1 - Scenario Specification. An appropriate vignette or scenario should be identified to scope the problem in the OA study or experiment.

Step 2 - Design of Experiment. Based on the questions to be identified in the OA study or experiment, a list of factors, each with the relevant range of levels, would be short-listed to be studied. The type of experiment design deemed suitable for the desired resolution and conduct of the experiment would be chosen, e.g. LHC designs.

Step 3 - Simulation Models. A simulation model would be created to capture the important aspects of the scenario, especially those that are short-listed as factors in the experimental design. To fit into the SDF process, the model should be data-farmable using the data farming environment in ORL.

Step 4 - Data Farming. The simulation model and the experiment design are submitted for data farming. The results would be collected for analysis.

Step 5 – Regression and Clustering & Outlier Analysis. The analysis of the results should involve the co-operative use of statistical tools and the COADM tool to visualize and make sense of the results. The COADM tool should be applied to the data sets to provide a good overview of the output landscapes and relationships, highlighting the more influential factors and the clustering of design points. Analysis of outlier cases in the data set can be performed using the COADM tool. At the same time, statistical analysis can be conducted to examine these factors and identify the significant effects and interactions between the factors.

Step 6 - End of Process or Conduct Further Iterations. If the results have met the objectives of the experiment, the process can be terminated. Otherwise, the analyst should revisit the steps, do necessary modifications and perform further iterations to obtain more results.

Components of the SDF capability have been applied in a number of OA studies and experiments. It was demonstrated that they were able to overcome some of the key challenges of conducting a simulation experiment that seek to explore many factors and each factor varied at many levels.

5 AUTOMATED RED TEAMING

5.1 Scope of Project

Following the completion of the SDF project, ORL continued with a project on Automated Red Teaming (ART) in 2006, funded by the Directorate of Research and Development (DRD). The objective was to conduct R&D to develop an ART framework to complement the human red teaming effort using fast-running simulation models, high performance computing and evolutionary algorithms.

Red teaming is a technique commonly used in the military to uncover system vulnerabilities or to find exploitable gaps in operational concepts, with the overall goal of reducing surprises, improving and ensuring the robustness of the Blue ops concepts. It is currently a manually intensive technique that typically brings together experts relevant to the system under consideration and who are then charged with identifying weaknesses. However, the vulnerability assessments made are usually "bounded" by the knowledge of these subject matter experts (SME).

By leveraging on the advancing technologies of Parallel Computing and Evolutionary Algorithms (EAs), many millions of simulation runs can be generated and investigated using an automated process. The goal is to fix the Blue parameters and search for Red parameters that result in the "defeat" of Blue. Information obtained during this process can then be used to either enhance or assist the manual effort. Figure 2 illustrates the broad concept to conduct Automated Red Teaming (Choo et al. 2007).

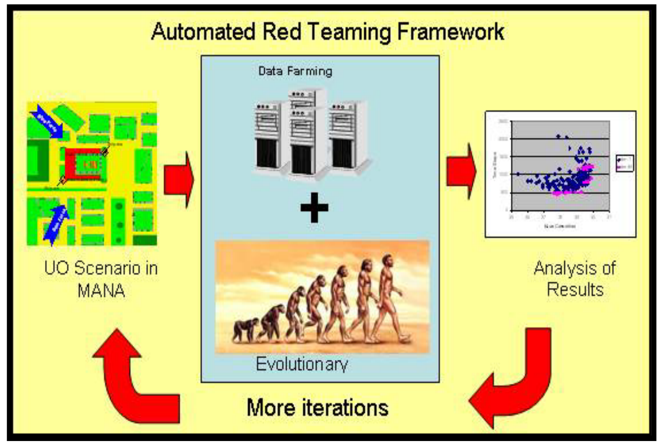

Figure 2: Concept of ART

5.2 Outcome of R&D Activity

The project was completed in 2007 and an ART framework that would provide a powerful, systematic and efficient capability to complement the manual red teaming effort was developed. The ART framework was designed and implemented with a modular ART architecture that allows additional no Man-In-The-Loop (MITL) simulation models and evolutionary computation algorithms to be "plugged in" with relative ease. Figure 3 illustrates the architecture for ART.

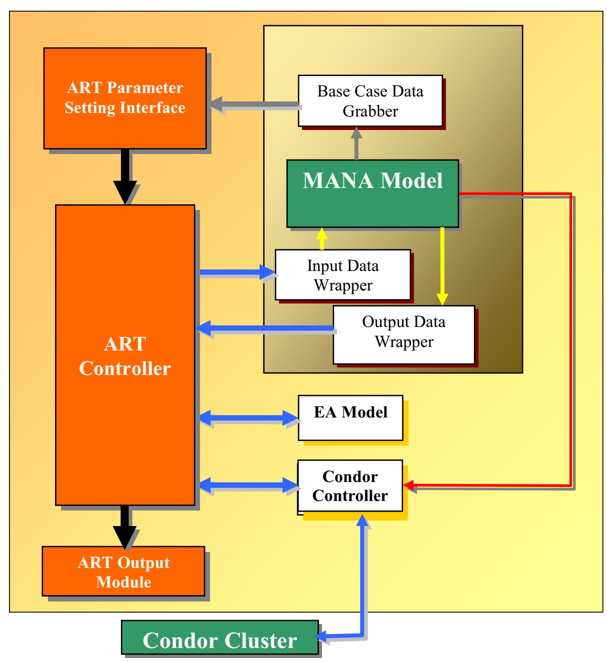

Figure 3: Architecture for ART

6 AUTOMATED CO-EVOLUTION

6.1 Scope of Project

The project on ART was completed in 2007. One obvious follow-up was to explore Blue Teaming, i.e. how the Blue could break the Red's plan. This naturally led to the concept of Co-Evolution, i.e. Red Teaming vs Blue Teaming. DRD continued to fund ORL to work on the concept of Automated Co-Evolution (ACE), to explore a two-sided competitive co-evolution as a mechanism to understand the dynamics of competition in a military context through simulations. Figure 4 illustrates the concept for ACE.

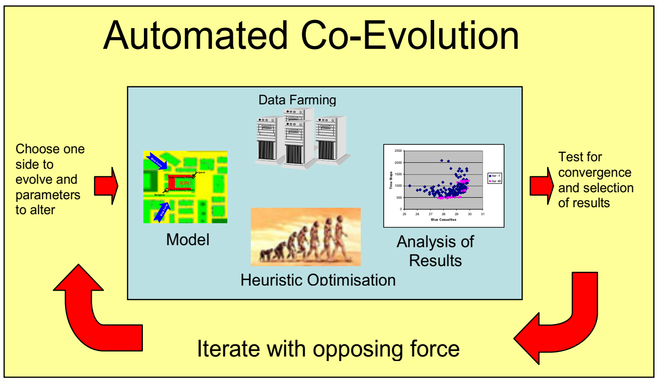

Figure 4: Concept of ACE

6.2 Outcome of R&D Activity

The project, to be completed in September 2008 involves R&D on key components and techniques that are required to develop an Automated Co-Evolution (ACE) framework that can provide a powerful, systematic and efficient capability to support automated co-evolution. The design of the framework follows the same modular approach in ART which will allow easy plugging in of no MITL models and other evolutionary computation algorithms.

The key benefit of ACE is to complement the manual actions-reactions process to develop a Blue plan that performs well and is relatively robust even in the face of an adaptive adversary. ORL is currently evaluating the ACE framework with some test cases. An update on the progress was presented at IDFW 16 in April 2008.

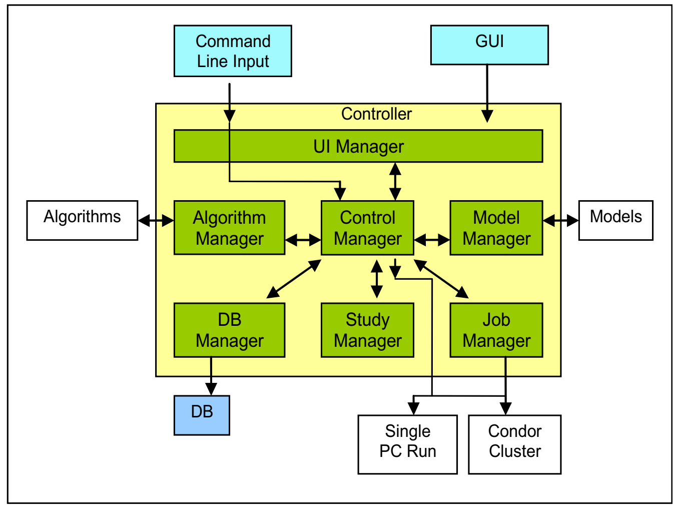

Figure 5: Architecture for ACE

7 MODELLING THE EFFECTS OF HUMAN INTANGIBLES

The human element is frequently the most important factor in determining the outcome of a battle. Intangible factors such as heat stress, fatigue, fear, motivation, cohesiveness and aggressiveness often play a far greater role in human conflict than do firepower, logistics, or mobility. However, these intangibles, because they are seemingly too complex or difficult to quantify, have been traditionally ignored in many combat models, which mainly focus on modelling physical systems such as weapons, sensors, communications and platforms. It is often "conveniently" assumed that the human (or soldier) performance will be consistent as they would be "appropriately trained" to handle the various combat situations accordingly.

With the increasing emphasis on Urban Operations (UO) and Operations Other Than War (OOTW), soldiers are now expected to have close encounter with adversaries and civilians. This is where the effects of human intangibles become even more significant. It is thus timely to revisit the assumptions made in existing combat models and explore on how these effects of human intangibles can be incorporated.

ORL's exposure to international R&D efforts on the modelling of Human Intangibles started with the involvement in Project Albert in 2002. This international collaboration brought to our attention several agent-based simulation tools that were designed to model human intangibles. MANA attempts to model human intangibles such as determination and aggressiveness through surrogate variables that contribute to the objective function. Pythagoras incorporate factors that directly model leadership and charisma in the agents. PAX is empirical based and examines key intangibles such as fear, hunger and aggression in Peace

Support Operations (PSO) such as check-point control, food distribution and administering elections.

Realising the importance of this gap and inspired by the work of our collaborators in the International Data Farming Community, ORL has just started a project on modelling the effects of human intangibles. The objective of this project is to conduct R&D on the main components that are required to develop a framework for modelling the effects of human intangibles on combat outcomes. These components include Physiological, Psychological, Social and Cultural (see Figure 6), and they will be handled at two main levels:

- Individual Level. These include the physiological (e.g. heat stress, fatigue, human reaction times, endurance) and psychological (e.g. fear, aggressiveness) factors that can affect individual performance during operations. For example, fear and fatigue can lead to poor operational performance.
- Group Level. This level looks at social and cultural factors that can influence the interactions between individuals to shape the group behaviour and performance. For example, a group that is disciplined, motivated and cohesive, and led by a strong and trust-worthy leader, can potentially overcome individual fear and fatigue to perform the operation successfully as a group.

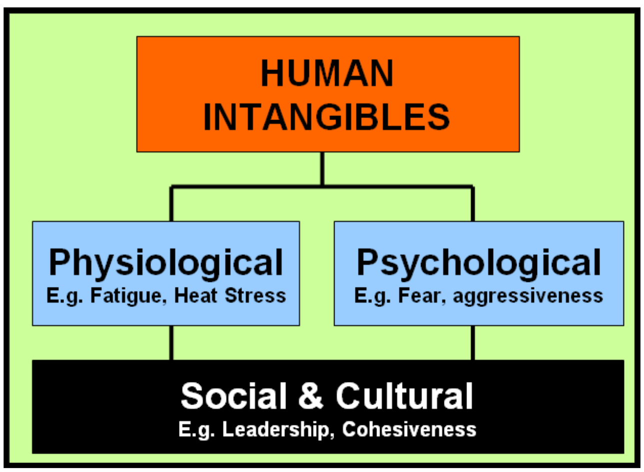

Figure 6: Concept for Modelling Human Intangibles

Inheriting the spirit of collaboration from the International Data Farming Community, ORL is currently in the process of identifying interested collaborators and partners for the two-year R&D project. In fact, ORL had co-facilitated with EADS from Germany, focus group discussions on human intangibles at IDFW 15 and IDFW 16. The idea of starting a common interest group online discussion forum for interested collaborators to carry out discussions and share knowledge was also mooted in IDFW 15 and since then the arrangements were made for ORL to host this online forum.

8 CURRENT DATA FARMING CAPABILITY IN SINGAPORE

Since the first participation in PAIW 5 in 2002, Singapore has evolved from a new player to an active partner in this international community. Today, Singapore has developed in-house capability to contribute to the international data farming community in areas of Data Farming, agent based modelling, efficient experiment designs, high performance computing and evolutionary algorithms. The 48-CPUs Data Farming facility in ORL supports a large number of ABS models used by participating countries – MANA, Pythagoras, PAX, NETLOGO, REPAST, and several in-house developed models. It has supported many PAIWs and IDFWs, and requests from the International Data Farming Community. Within Singapore, it has been used for OA studies and experiments on system acquisition, force structuring and tactics development.

9 THE WAY FORWARD

Besides working on the new project on modelling the effects of human intangibles and wrapping the work on ACE, ORL plans to convert more models to data-farmable and venture into Data Farming related research areas such as advanced analysis, advanced data visualisation, and enhancing ART and ACE frameworks with more EAs. The technical roadmap to realise the plan is given in Figure 7.

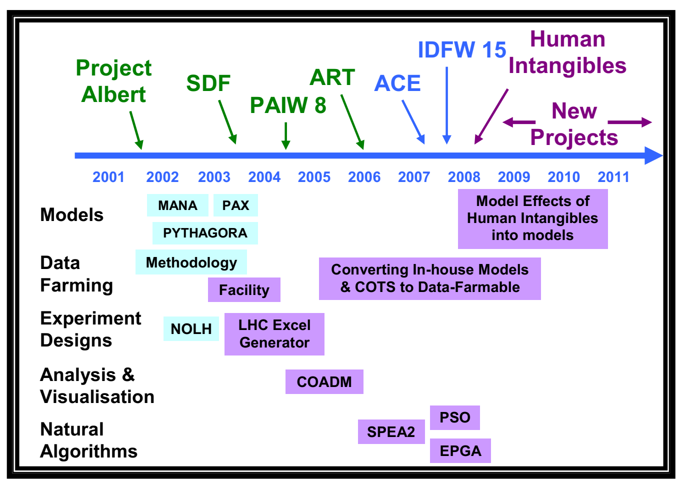

Figure 7: Technical Roadmap for Data Farming Capability

In country, ORL is also in the process of transferring knowledge to SARORO, Singapore Army and DSTA to promulgate the capabilities developed through our R&D efforts.

Within the international community, ORL is keen to forge stronger collaborations with researchers in the areas of ART, ACE, modelling the effects of human intangibles, efficient experiment designs and advanced data analysis and visualisation.

10 CONCLUSION

We have provided a short discussion of the motivations behind ORL and Singapore's interests in Data Farming, and presented some brief information of various R&D efforts that have sprung out of our participation in this international community. We have developed frameworks for SDF, ART and ACE, all of which have contributed towards a stronger MSA capability in Singapore. Lastly we identified our current R&D interest in modeling the effects of human intangibles and provided a roadmap of our future R&D interests.

Singapore's venture into the field of data farming has proved to be an exciting and fruitful journey. ORL started with many challenges in minds and along the way, made headway in meeting these challenges through the work together with the International Data Farming community. In fact, in the process of overcoming the original challenges and developing new capabilities, newer challenges were uncovered which would help push boundaries of OA and Experimentation capabilities in Singapore.

Singapore will continue to participate in future data farming activities and strive to develop new capabilities to provide better decision support to our military leaders.

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