INVESTIGATION INTO ERP-BASED SYMBIOTIC SIMULATION PROJECT IMPLEMENTATION ON FORD ENGINE PRODUCTION LINE: CHALLENGES, OPPORTUNITIES AND PROSPECTS

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ABSTRACT

The paradigm of Symbiotic Simulation describes a close relationship between a simulation system and the physical system. This relationship is usually mutually beneficial, whereby the simulation system benefits from a steady supply of real-time data from the physical system, while the physical system benefits from the optimised decisions arrived at through what-if experiments executed by the simulation system. In furtherance of existing work towards developing symbiotic simulation systems anchored on integration with corporate information systems, this paper presents research into an industrial application of symbiotic simulation to improve the simulation project life-cycles at a major automotive engine production line controlled by a shop floor information system. We discuss inexorable issues associated with the implementation of the relatively novel concept of symbiotic simulation, highlight the challenges to successful implementation in a corporate change-averse culture, suggest solutions for surmounting them and discuss the impact and prospects for symbiotic simulation with ERP integration.

Keywords: Symbiotic Simulation, Corporate Information Systems, ERP, Data Management

1. INTRODUCTION

Symbiotic simulation is a system that interacts with a physical system in a mutually beneficial manner (Fujimoto et al, 2002). The results of what-if experiments performed by the simulation system can be used to provide decision support or to control the physical system. Conversely, the simulation system benefits from the continuous supply of the latest data to validate its outputs. This enables timely response to abrupt changes in the physical system, unlike traditional simulation systems constrained by long lead times for model update and validation.

ERP systems facilitate the corporate management of a business enterprise, seamlessly integrating individual functional systems such as manufacturing, finance, procurement, distribution and human resources. In the manufacturing environment, most operational data are stored in ERP systems, such as cycle times, bill of materials, etc. According to a survey carried out by Robertson and Perera (2002), majority of input data for simulation modelling are stored in ERP systems. This is especially so for the manufacturing sector (Skoogh et al., 2012). Research into the integration of ERP systems with simulation modelling tools has gained reasonable traction, with Moon and Phatak (2005) proposing DES for enhancing the functionality of ERP systems in obtaining more accurate lead times, being a case in point.

As is the case with any program of wide-ranging organisational change initiatives, the successful implementation of symbiotic simulation requires a paradigm shift in the socio-economic system, which in turn is intertwined with technology, task, people, structure, and culture. Organisational resistance to change therefore emerges as a critical success factor. Organisational fit and adaptation are important to the implementation of such an innovative concept that needs to coexist and interact with extant large-scale enterprise systems that were built with a pre-determined business process methodology and purpose.

Considering the benefits inherent in the application of symbiotic simulation systems, this paper analyses the issues associated with its implementation in a major automotive company. The lessons learned would be useful for other manufacturing companies in their efforts to successfully implement symbiotic simulation systems.

2. LITERATURE REVIEW AND RELATED WORK

The following literature review explores the state of the art in symbiotic simulation, ERP data management and interaction with simulation tools and corporate change-averse culture, with a view to identifying and demarcating the knowledge gap relevant to this research.

2.1. Symbiotic Simulation Systems and Applications

Symbiotic simulation has been implemented in various application domains. Low et al. describe a symbiotic simulation system for semiconductor manufacturing backend operation (Low et al. 2005), where upper and lower limits for queue lengths are used to make outsourcing decisions. Optimal limits are determined by analysing different settings using what-if simulations, with each simulation representing a different set of limits. A symbiotic simulation-based problem solver to automatically resolve decision making problems regarding the operations of the various tools in an entire semiconductor manufacturing fab has also been proposed. The problem solver agent detects the physical system and executes what-if scenarios to identify and solve some manufacturing problems (Aydt et al., 2011).

Symbiotic simulation has also been applied in the control of unmanned aerial vehicles (UAVs). Kamrani and Ayani describe how symbiotic simulation can be used for path planning (Kamrani and Ayani 2007), whereby what-if simulations are used to evaluate alternative paths. Mitchell and Yilmaz have also developed a symbiotic simulation system in UAV control (Mitchell and Yilmaz 2008) and described how symbiotic adaptive multi-simulation (SAMS) can be used for real-time decision making under uncertainty. Each what-if simulation is concerned with a combined model ensemble that combines parameters regarding unknown environmental conditions and possible system configurations. Unlike other symbiotic simulation applications, SAMS analyses how a particular system configuration performs under different possible environmental conditions.

Symbiotic simulation has also found application in the large gas turbine manufacturing process, where the architecture of an intelligent assembly quality control solution using symbiotic simulation that combines an ON-line Simulation Module (ONSM) with OFF-line Simulation Module (OFFSM) is introduced (Meng et al., 2013).

Symbiotic simulation model validation has been used in a radiation detection application (Aydt et al. 2009), where a highly accurate model of the environment is used to estimate the radioactivity at certain locations in the environment, given a particular kind of radiation source and its location. Different hypotheses regarding the radiation source are evaluated by means of simulations. The hypothesis which produces the closest results to the actual measurements can be considered as the likely location of the radiation source in the real environment.

An agent-based implementation for a generic symbiotic simulation framework for different applications has been developed by Aydt et al. (2008), that provides standard implementations for the various functional components that can usually be found in a symbiotic simulation system. The framework has been designed with requirements regarding applicability, extensibility, and scalability in mind.

2.2. ERP and Corporate Information Systems

The Corporate Information System is commonly encountered as Enterprise Resource Planning (ERP) systems in most corporate environments. Although simulation practitioners may still need to complement information from ERP systems with data from other sources for simulation modelling, there is a concerted effort towards establishing automated links between simulation models and corporate information systems as the main source of simulation data (Robertson and Perera, 2002; Randell and Bolmsjö. 2001).

ERP systems typically include the following characteristics:

- An integrated system that operates in real time (or next to real time), without relying on periodic updates.
- A common database, which supports all applications.
- A consistent look and feel throughout each module.
- Installation of the system without elaborate application/data integration by the Information Technology (IT) department.

Figure 1: Typical ERP System

Even though ERP systems have already become the dominant management software in manufacturing and distribution systems in today's competitive business environment (Ho and Ireland, 2012), they lack prognostic functionality and the capability of dealing with uncertainty. These are, of course critical factors for decision support in manufacturing and other domains (Addo-Tenkorang and Helo, 2011; Battista et al., 2011). Simulation tools, on the other hand, have the functionality to deal with such issues as decision support, time compression and expansion, what-if experimentation, problem and constraint identification, forecasting, visualisation, and requirements specification (Banks, 1999; Babulak and Wang, 2008; Jovanoski et al., 2013). Recent work to integrate ERP systems with simulation tools in the manufacturing environment have mainly focused in the following two areas:

2.2.1. Data Management within ERP Systems and Simulation Tools

Input data management is a crucial and time-consuming process for both ERP systems and simulation tools (Skoogh et al., 2012a). At the heart of an ERP system is the central database that feeds data into a series of applications supporting diverse enterprise functions (Davenport, 1998). ERP systems typically host most of the operational data, such as cycle times, set-up times, and bill-of-materials. The need for better integration between simulation tools and ERP systems in order to facilitate automation of data transmission between them has been articulated by Robertson and Perera (2002). A survey that investigated input data requirements of simulation tools in 2012 revealed that for manufacturing companies, 40% of the main and 77% of the common sources of data for simulation tools are stored in ERP systems. Results also showed that 77% of participants expected to implement a higher level of automation of input data for simulation tools (Skoogh et al., 2012b).

A framework for automated data transmission between ERP systems and simulation tools was proposed by Robertson and Perera (2002), along with the concept of an intermediary database to automatically extract and store data between ERP systems and simulation tools as shown in Figure 2. The need for an interface to automatically acquire data from ERP systems for simulation modelling has become more compelling and several products have been developed to meet it. A Generic Data Management Tool that automatically collects, processes and outputs critical simulation input data from ERP systems has since been developed and released as open source software by Skoogh et al. (2012a).

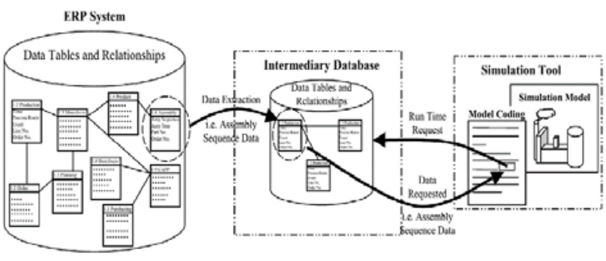

Figure 2: Automated data transmission between ERP systems and simulation tools (Robertson and Perera, 2002)

2.2.2. Interaction of ERP Systems and Simulation Tools

ERP systems are rightly considered as main sources for simulation data. Better integration between simulation tools and ERP systems is therefore not merely desirable but necessary to enable automatic data exchange between them (Robertson and Perera 2002).

A method has been proposed for linking discrete event simulation model with an ERP system to enhance the functionality of the ERP system in determining realistic production lead time data. A pump manufacturing factory test case demonstrated that lead-time data can be determined with a higher degree of accuracy (Moon and Phatak, 2005).

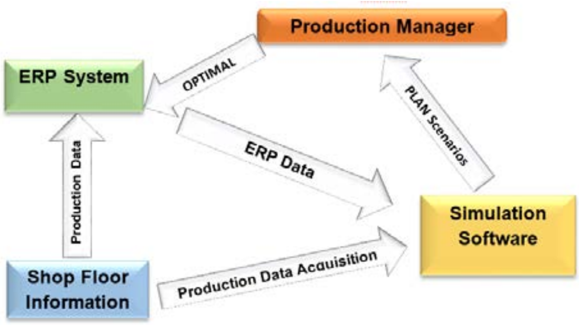

Figure 3: ERP/Simulation system interaction (adapted from Moon and Phatak, 2005)

The simulation tool acquires relevant manufacturing data from the ERP system and outputs simulated lead times. Comparing the simulated results with the actual due date, a production manager changes data by adjusting overtime and executes the simulation model again. This process is repeated until the manager is satisfied with the simulation results. The ERP/simulation system developed by Moon and Phatak uses traditional off-line simulation methods and lacks the facility of automatic validation. Here, optimisation and control of the physical system depends on the production manager, rather than being automatically generated.

2.2.3. Background of Simulation at Ford PTOME

Ford Power Train Operations Manufacturing Engineering (PTOME) has used simulation for over 30 years. In that time, significant progress has been made, not only in process design issues, but in the simulation methodology employed to make these improvements (Winnell and Ladbrook, 2004). The increasing requirement to simulate the effects of logistical and other ancillary operations is having a bigger impact on the work of the simulation team than basic changes to manufacturing procedures. Examples include the frequency of tool changes and the operation of offline metrology routines, which can often cause bottlenecks.

The current trend is towards integration through the construction of complete models in which every process is represented, rather than fragmentation through the addition of extra functionality. Work is already at advanced stages to enable the inclusion in simulation models of information about energy consumption on the shopfloor (Wilson et al, 2015). Another milestone in prospect is the construction of models that incorporate information about manufacturing operations out in the supply chain. This research on symbiotic simulation is a natural progression aimed at continuous improvement and keeping PTME simulation operations at the cutting edge of the latest technology.

The test case assembly line is in a configuration composed of different U-Sections as can be seen from a high level in Figure 4 below. The core component of the line is a moving conveyor with rollers, moving along the path of the bold lines indicated.

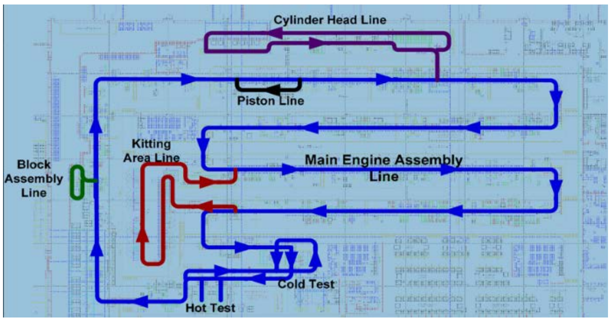

Figure 4: Layout of Test Case Engine Production Line

Details of individual machines and operations on the line cannot be disclosed for commercial confidentiality. The simulation model of the line built using the WITNESS simulation package is shown below.

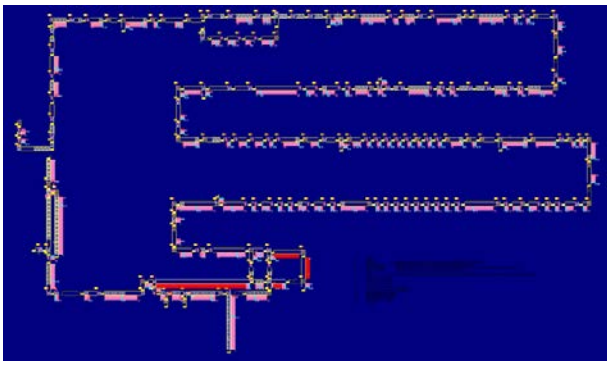

Figure 5: Model of Test Case Engine Production Line built in WITNESS.

3. IMPLEMENTATION FRAMEWORK FOR ERP-BASED SYMBIOTIC SIMULATION SYSTEM

Linking symbiotic simulation systems to manufacturing lines controlled by an ERP system is relatively new. Previous efforts have focused on data exchange and physical interaction between ERP Systems and simulation tools.

In the proposed implementation symbiotic simulation system (adapted from Tjahjono et al, 2015), is composed of three main subsystems:

- Symbiotic Simulation Forecasting System (SSFS)
- Symbiotic Simulation Anomaly Detection System (SSADS) and
- Symbiotic Simulation Decision Support System (SSDSS).

The framework also incorporates triggers and objects. These subsystems, triggers and objects should work collectively to:

- Exchange data from the Factory Information System (FIS, the ERP system)
- Evaluate trigger conditions
- Create and run what-if scenarios
- Optimize and analyse simulated results
- Visualize real-time states
- Forecast the future and
- Recommend solutions to an external decision maker.

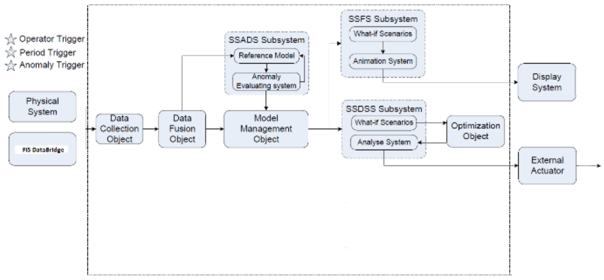

Figure 6: Conceptual Model of the Symbiotic Simulation System

3.1. Data Collection & Data Fusion Objects

The Data Collection Object automatically extracts raw data from Ford Motor Company's proprietary plant monitoring system known as Factory Information System (FIS) and passes it on to the simulation model in an accessible format. Data is extracted from FIS using an Excel interface with SQL queries embedded in VBA. The Data Fusion Object is essentially a collection of functions built in Witness to carry out data loading and manipulations, such as removing data duplication, between the Excel spreadsheet and the simulation model. Parameters are used to represent attributes of the modelled objects, such as machine cycle times. Variables store simulation results or object characteristics that are changing over time, e.g. lead times. Collections store, retrieve and manipulate aggregate data, such as queues or sequences.

3.2. Optimisation Object

The Optimization Object generates the optimum decision parameters that are passed on to an external decision maker. The Optimization Object determines parameter values that result in the maximum or minimum of the objective function, while adhering to constraints. The what-if scenarios generated by the Optimization Object are used to find the optimum decisions for predefined problems.

3.3. Model Management Object

When triggering conditions are met, notifications are sent to the Model Management Object. The MMO manages what-if scenarios and invokes the subsystems as appropriate. At start-up, MMO is used to assign data from the DFO to simulation parameters and update simulation models to the current or defined state. At runtime, MMO continuously delivers dynamic data from DFO to simulation models.

3.4. Symbiotic Simulation Anomaly Detection System

The Symbiotic Simulation Anomaly Detection Subsystem (SSADS) constantly monitors the information in the Data Fusion Object (DFO) and compares it with a reference model in order to detect anomalies. The SSADS detects anomalies from the physical and simulation systems by comparing the simulation model with the actual data in the DFO. In the event of a sharp drop in average weekly JPH, for instance, an anomaly notification would be automatically generated to trigger the MMO to invoke other subsystems. When the discrepancy between the simulation model and actual production data is beyond a certain tolerance, it is considered as an anomaly.

3.5. Symbiotic Simulation Forecasting System

The SSFS generates future prediction and visualization to the display systems. The essential part of the SSFS subsystem is the 'what-if' scenarios that can be used to forecast future events. It may contain animation systems to generate 2D/3D animations. MMO delivers static and dynamic data to the SSFS subsystem and invokes the what-if scenarios.

3.6. Symbiotic Simulation Decision Support System

The SSDSS requests the Optimization Object to generate optimum decision parameters, which are used as alternative decision parameters by an external decision maker. Unlike the Symbiotic Simulation Control System that implements the optimum decision directly on the physical system using actuators, the SSDS simply presents the options to an external decision maker.

4. CHALLENGES ENCOUNTERED

'Driving innovation in every part of our businesses' is a mantra that is trumpeted by most companies that seek to portray themselves as global leaders at the cutting edge of new technology. In practice, however, this is often no more than a slogan honoured more in the breach than in the observance. Novel methods with the potential to significantly enhance performance and positively improve return on investment typically have to contend with a change-averse and risk-averse corporate culture, resulting in overextended project lead times and outright abandonment of otherwise hugely beneficial concepts.

Embarking on the implementation of symbiotic simulation on Ford engine manufacturing lines was no exception. It was conceived by John Ladbrook, Ford Motor Company's Simulation Technical Specialist and designed as a PhD research project in conjunction with the University of East London, a Ford partnership called the High Speed Sustainable Manufacturing Institute (HSSMI) and the UK Engineering and Physical Sciences Research Council (EPRSC). The project has encountered a set of challenges, the most significant of which are outlined below.

4.1. Organisational Culture

In most companies, the cards are heavily stacked against the nurturing of innovation, especially the new ideas and 'disruptive' innovations that generally lead to major changes within the business. At the best of times, things hardly move at the "*speed of thought*" in large corporations steeped in longstanding traditions, especially those that have enjoyed considerable success. But whilst it took up to nine months and several meetings to obtain routine approvals for required access to information systems and databases, the support and enthusiasm from key players never wavered.

4.2. Management Buy-in and Funding

Funding applications and approvals take a minimum of one year, thereby making short to medium term planning extremely difficult for such a project, although it was conceived at the appropriate management level. It is pertinent to acknowledge the sheer size of Ford Motor Company, which has a multi-billion dollar R&D division, in order to situate this project within that context, for a proper appreciation of the gravity of this challenge from that perspective. Working to engender synergy among relevant business units in a multi-disciplinary project is always an uphill task. A periodic review of the business case for the project became necessary, as the rationale for resource allocation against alternative projects came into sharp focus in a climate of fiscal restructuring and budget cuts. Senior management support was decisive in the survival of the project to this stage of implementation.

4.3. IT Governance

Corporate IT governance rules and procedures are enacted for a good reason, with security, availability and robustness at the top of the list of priorities aimed at the alignment of business goals with the technology strategy. There is often a tendency for the IT department to selectively hide behind governance issues as an excuse to delay, deny and frustrate an IT-centric project that did not originally emanate from them. However, Ford IT has demonstrably gone the extra mile to facilitate this research. As curators and administrators of the infrastructure on which the project would be anchored, the IT department's adoption of the project helped to ensure adherence to Corporate IT governance.

4.4. Proliferation of Production Data Sources

Real-time production monitoring, ERP and other manufacturing shop floor information systems collect and store a large amount of data. This data is subsequently stored in a variety of databases, repositories and other proprietary or OEM systems that are not interlinked. Oftentimes these systems are also virtually not interoperable. Whilst this obviously presents a dilemma in the process of streamlining the simulation input data requirements against the variety of data sources, it conversely presents a goldmine of data from which useful knowledge and intelligence can be extracted, leading to the development and building of better models.

4.5. Development and Testing Environment

Notwithstanding the perception of autonomy and decentralisation prevalent in transnational corporations like Ford with global operations, the situation is more fluid in practice, where standardisation takes precedence over localised exigencies. Provision of an offline sandboxed development and testing environment required for the project therefore becomes a sticking point between IT central administration and the specific manufacturing plant hosting the project. The interpersonal skills developed in the course of complex interactions with various interdisciplinary business units have been immensely rewarding, although a decision is still being awaited on the provision of an intermediary simulation-centric database as well as a development environment.

5. EVIDENCE-BASED IMPLEMENTATION STRATEGY

Introducing any technological innovation into an organization presents a unique set of challenges different from competent project administration. Shepherding a technical innovation into routine use requires tact and experience to guide its development and manage its implementation. Although the effectiveness of any strategic framework for surmounting the challenges to the adoption of new technologies must be assessed within the context of organisational climate, lessons learned from this undertaking can have resonance across a wide spectrum of application areas.

In the course of this research into the implementation of an ERP-based symbiotic simulation system on a Ford engine production line, we have adopted an approach of turning stumbling blocks into stepping stones. The summary of our experiences and recommended strategy for surmounting some of the impediments to successful implementation are outlined in three broad steps: 1) First Reaction-Build the Case; 2) Investigate the Technical Performance and 3) Implement – Limit the Risk.

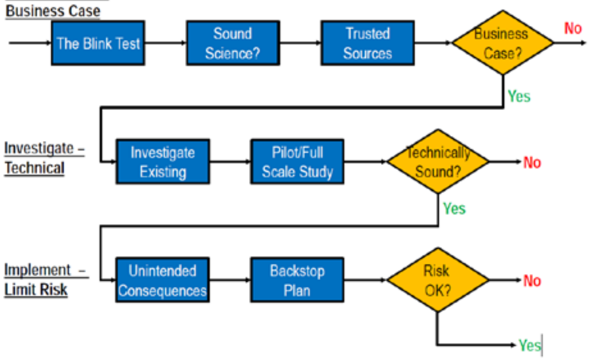

Figure 7: Implementation Strategy (Neethling, 2015)

5.1. First Reaction – Build the Case

1. Apply Malcolm Gladwell's "Blink" test - If it sounds too good to be true, it probably is. Let the factual evidence of the advantages speak for themselves.
2. Check the science/technology – Beware of obsolescence.
3. Check past experiences from trusted sources – Examine evidence from related implementations.
4. Make the business case favourable – Demonstrate the impact on return on investment.

5.2. Investigate the Technical Performance

1. Investigate existing implementations
   - Physical site visit, where possible
   - Question the operators & owners
2. Pilot test and/or Full scale tests
   - Determine site specific conditions
   - Operations assessment
3. Evaluate technology performance

5.3. Implement – Limit the Risk

1. Think of unintended consequences
2. Develop Risk Mitigation Plan for Implementation
3. Have a fallback option.

6. DISCUSSION

Research into symbiotic simulation systems is still relatively new and only a limited amount of literature is available, especially with ERP integration. This is a cross-disciplinary subject area encompassing simulation modelling, decision support, data fusion, man-machine interface and automatic control engineering (Lozano et al, 2006). Whilst traditional simulation has been standard practice in Ford Motor Company for over five decades, symbiotic simulation offers better prospects for enabling real-time planning, foreseeing real-time problems and proffering solutions, delivering performance improvements, making it possible to adapt to sudden and unexpected events, improving aspects of safety and security of the physical system and serving as operational decision support tools.

Although simulation has been identified as the most appropriate technique to generate and test out possible execution plans, it suffers from the drawback of long cycle times for model update, analysis and verification. It therefore becomes difficult to carry out prompt "what-if" analysis to respond to abrupt changes in these systems. Symbiotic simulation solves this problem by having the simulation and the physical system interact in a mutually beneficial manner (Low et al, 2005).

The progress made to date from a project management standpoint is a testament to the agile credentials of Ford Motor Company and its commitment to driving innovation in every aspect of the business, whilst forging meaningful partnerships with academia and other research institutions.

7. SUMMARY AND CONCLUSIONS

Ford Motor Company has a 113 year history and is one of the biggest and most successful automobile manufacturers in the world. It is therefore not difficult to understand why the adoption and implementation of any innovative technological concept would require the utmost diligence in order to surmount the challenges and impediments posed by an organisational culture entrenched by a corporate climate of long-term accomplishments, sheer size and values. The pitfalls inherent in approaching any such endeavour purely from a technical viewpoint without taking into account these characteristics would become apparent very quickly, with the likelihood of this resulting in the abortion of the project, regardless of how well-intentioned and beneficial to the company it might be.

The experiences outlined in this paper are intended to signpost some of these challenges, share the lessons learned and highlight the strategy that has guided the progress of the symbiotic simulation research project at Ford Motor Company. The contribution of this work lies in its value as a case study on the ERP-based implementation of symbiotic simulation on an automobile engine production line. To the best of our knowledge, this has not yet been successfully achieved as at the time of writing.

The scope of this work is limited to Ford Motor Company, but our thesis is that the challenges, opportunities and prospects are generic enough to be deemed applicable to similar project undertakings in automotive engine production in particular and the manufacturing industry as a whole.

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