THE AERO-ENGINE VALUE CHAIN UNDER FUTURE BUSINESS ENVIRONMENTS: USING AGENT-BASED SIMULATION TO UNDERSTAND DYNAMIC BEHAVIOUR

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Abstract:

Agent-based modelling is gaining popularity for investigating the behaviour of complex systems involving interactions of many players or agents. In this paper an agent-based simulation modelling technique is applied to understand the long term implications of strategy decisions for an aerospace value chain. The industry has unique elements including new business models, high levels of collaboration, long product lifecycles and long periods before positive paybacks are realised. Forecasting market conditions over this long term lifespan is inherently problematic and adds further complexity when devising a strategy. The model described includes all the major players and entities in the value chain and their interactions. Illustrative results are presented to demonstrate how the simulation approach can be used to evaluate strategy and policy decisions and their operational implications over the long term.

Keywords:

Value Chain, Simulation, Agent-Based, Business models, Aerospace

1. INTRODUCTION

This paper describes the application of a simulation developed using the principles of agent-based modelling to understand future aero-engine business environments. In contrast to alternative modelling techniques, an agent-based approach follows bottom-up principles. Each agent runs as an independent simulation interacting with other agents in the system. Agent-based models are comprised of distinct units modelled at a relatively detailed level with particular focus placed on capturing boundary interactions and exchanges. Collective behaviour and interactions create the dynamics of the system [3]. The approach allows interactions to be studied at the micro-level and also large scale system behaviour.

The agent-based model developed here captures business processes, decision rules and exchanges of information and materials. The aim of the work is to understand the implications of the business strategy and business models adopted in an aero-engine value chain over a long project lifecycle. The value chain encompasses original equipment supply, aftermarket services and consumables supply. Each player in the value chain is represented as an agent, allowing detailed capture of individual business processes, logic, attitudes to risk and responses to changes in the market place.

2. THE AERO-ENGINE MARKET STRUCTURE

The context for the case study is the European Aero engine industry for commercial jets. The commercial aerospace industry has some unique characteristics, being affected frequently by government actions and support. This is perhaps most often seen within the airline sector where many current carriers have previously been publicly owned national ‘flag’ carriers. Despite the recent trend of privatization, government protection is still evident. During the most recent downturn (2000 to 2003) it is estimated that US airlines received government support of approximately $5 billion and yet still made a collective loss throughout 2001, 2002 and 2003 [2]. Further government influence can be seen through the use of bankruptcy protection. Although less common in Europe, US airlines have frequently used ‘Chapter 11’ legislation to enable restructuring. Without normal competition dynamics to balance supply and demand, government protected over-capacity tends to remain, as do the financial problems of declining seat yields [2].

Over-capacity and low yields lead to instability and the effects of any disturbances within the global economy cannot be absorbed and hence heavily impact on the aerospace industry.

Economic problems for airlines are compounded by the high investment required in airframe and engine fleets. The typical 7*X*7 airframe has a list price in the region of $250 million with engines adding a further $35 million [9]. Although such hardware purchases may have typical lifecycles of at least 25 years, the industries susceptibility to global incidents means that airlines investing in new aircraft are taking a considerable future demand risk.

For the aero-engine OEM and the value chain, the consequence of customer uncertainty and high risk has placed downward pressure on the purchase price of new hardware. Discounts on list price may be as high as 70%. OEMs therefore become reliant on aftermarket revenues (spare parts and maintenance) to ensure profitability. This is sometimes known as a ‘time and materials’ approach. Thus the OEM may cross subsidise the sale of original equipment with aftermarket sales, and in so doing may implicitly absorb risk from the airline, creating a situation where both the airline and the OEM are reliant on customer (seat) demand to be profitable.

This shared risk is now part of the OEM business model; however, to counteract the effect, OEMs now strive for airlines to enter into business deals, guaranteeing long term relationships and the required aftermarket revenues. This is achieved through business deals where payment to the OEM is generated from the usage of the engine. In this paper such deals will be referred to as ‘usage contracts’. These are a bundled product offering of engines, on-going maintenance services and spares supply. Payment is linked to the usage of the engine on a per engine flight hour (EFH) and per engine flight cycle (EFC) basis. This differs to the historic norm for aftermarket sales, when work is undertaken on a ‘time and materials’ basis charged per incident and shop visit. For the airline, ‘usage contracts’ reduce risk as costs are linked to engine usage. For the OEM the creation of long term relationships guarantees aftermarket revenues.

Industry dynamics are further complicated by the relationship adopted between OEMs and upstream value chain partners where risk is may also be mitigated through Risk and Revenue Sharing Partnership (RRSP) agreements. This has the dual benefit of promoting inter-company collaboration by linking reward to the success of the project and sharing the risk incurred in the development of a new engine programme, which could be as high as $500 million. The RRSP agreements are structured with the value chain partner ‘buying’ a proportion of the programme and receiving a percentage share of the revenues generated. As such, any changes in revenue flows may have implications for the entire value chain.

These issues highlight some of the complexity of managing an aerospace business; the implications of business decisions are difficult to evaluate and, coupled with the long product lifecycles, the long-term nature of paybacks and the uncertainty of future demand, it is often difficult to made fully informed decisions.

3. TOOLS FOR STRATEGY DECISION SUPPORT

Grant [3] considers business strategy as a theme adopted by a company to give coherence and direction to the actions and decisions of an organisation’s management. He argues that implementing a business strategy is not a matter of intuition or good fortune and that a number of concepts and methods can be applied to formulate effective strategies. In practice however, many of these tools are conceptual, providing a way to visualise a strategy and ‘imagine’ potential scenarios. There are few attempts to play a strategy out over the longer term [7].

Simulation is a proven technique that has been applied frequently within the operations management discipline using either discrete event simulation or System Dynamics. Discrete event simulation is event and process orientated and therefore lends itself to capturing high detail level systems, such as manufacturing or service processes [7]. System Dynamics take a ‘systems thinking’ perspective to understand the complex dynamics produced through interactions of feedback and control mechanisms from a high ‘tree top view’. The concept can be used to understand how a high level system behaves and undergoes state changes [7]. It has been used previously within the aerospace sector to understand the business cycle [6].

System Dynamics concepts are frequently applied to strategy problems. Well-known successful applications include General Motors and Shell [7]; in both cases system dynamics gave decision makers the opportunity to 'play out' the implications of their decisions and understand that the optimum short term decision, where analytical techniques can work well, may not be the best possible over the long term. However, System Dynamics works at the aggregate level, using rates of change over time to show how complex feedback mechanisms can combine to produce unexpected results. For the aerospace value chain, it might be possible to model how the market could evolve using systems Dynamics but it would be very difficult, if not impossible to capture a detailed understanding of the behaviour of different players in the market place.

Agent-based models have the potential to overcome this problem. Each agent may have elements of a discrete event or system dynamics approach within them, but each is built as a self contained entity responding to external inputs. The computer based simulation developed for this problem models value chain performance over an engine development programme. The agents modelled include the prime partner, customers, the 1st tier Risk and Revenue sharing partners, the 2nd tier materials suppliers, and the engine (the engine is modelled as an agent, allowing the variability in the aftermarket to be captured). Each of these agents displays bespoke characteristics and behaviours.

4. USING AGENT-BASED SIMULATION FOR STRATEGY DECISIONS

The model has been built to understand dynamic behaviour of the market and evaluate how each agent will perform under a future business environment. To achieve this, a mechanism is needed to allow for the development of realistic business scenarios within which a strategy can be evaluated. Scenario building allows managers to consider potential changes in a range of industry drivers and then build a 'future business environment' [1]. To facilitate this within the aerospace sector the Virtual Interactive Business Simulator (VIBES) has been previously developed as a visual scenario capture tool [3]. By linking this to an agent-based modelling technique, it will be possible to build and explore future business environments under a range of parameters, structures and operating policies.

The top level hierarchy for the model is shown in Figure 1.

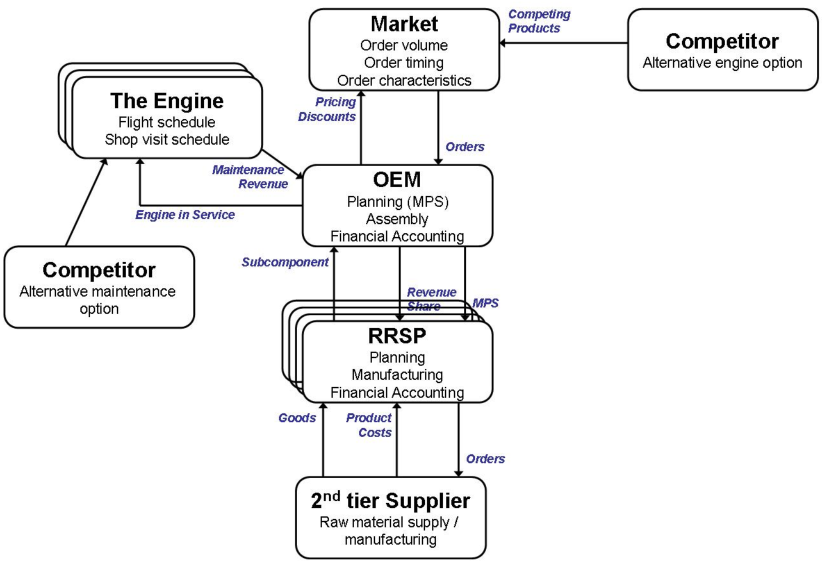

Figure1. Top level description of the components of the agent model

Figure 2 gives greater detail on how the conceptual models for the agents are built, including the market place, the OEM and the Engine agents. Each agent is relatively simple, despite the overall complexity of the model and the questions to be answered.

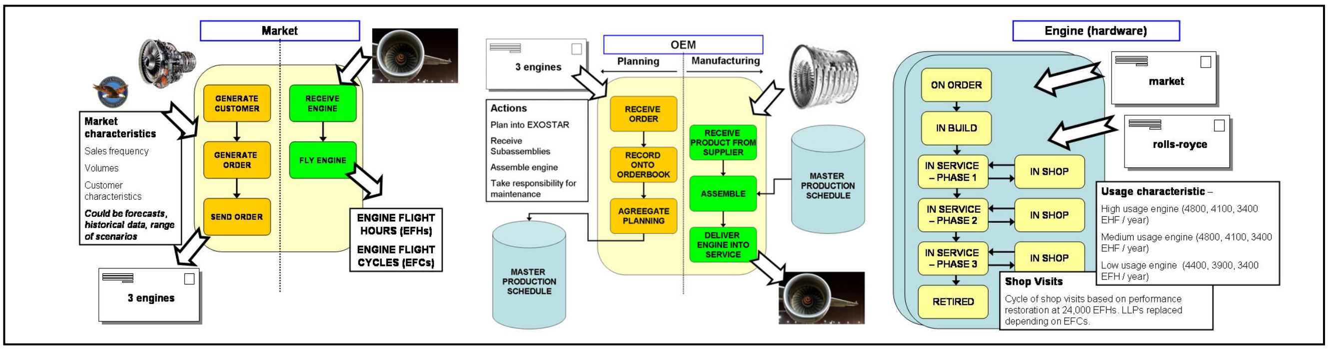

Figure 2. Features of major model agents

The engine is included as an agent because it is the driver for revenue and cash flows between partners, both through initial sales and through the accumulation of engine flight hours (EFHs) and engine flight cycles (EFCs), as well as maintenance and consumables whilst in service. The engine is a replicated agent, which means that there are multiple instances of engines in the model at any point in time. Each of these engine instances exhibits its own individual behaviour dependent on external factors. For example, in this model, engine usage has a variety of characteristics (e.g. flying hard/flying easy, short/long haul, preventative maintenance/maintain when fails) dependent on the attitude, the business model and the approach of the airline customer.

The model runs throughout the lifecycle of the engine programme, from initial product development, the product being launched, engine sales, engines in use and ultimately engine retirements. Activity between agents is generated by the an engine sale, which gets planned and assembled by the OEM, leading to orders being placed on the supply base. As the engine is delivered to the customer, its flight life begins and usage is simulated. This triggers demand and activity in the aftermarket. A simulation run therefore may represent as long as 50 years. Each agent has parameterised inputs, which can create different behaviours and thus influence decision making.

The simulation model has been developed using the AnyLogic^{TM} software (www.xjtek.com/ anylogic/). This is an object orientated Java-based simulation tool that is ideal for agent-based logic. Integrated into the model is an SQL Server 2005 database to provide a simplified ePlatform to simulate inter-company communication and data sharing, and financial accounting tools for the recording of data used by each agent for decision making. These represent the mechanism for the exchange of data seen in the real system.

5. RESULTS – AN EXAMPLE EXPERIMENT

The experimentation conducted to date has been done to illustrate the potential applicability of the model to support strategy decision making. Table 1 shows potential scenarios considered. The results explore what this may mean for the value chain partners. The demand slump in scenario 4 captures the implications of a significant sudden disruption to the demand for new engine sales and the usage of the existing fleet, reflecting an event similar in magnitude to ‘9/11’. The model can be used to understand how such an event may impact on the value chain under a range of different business strategies. Figure 3 shows the payback curves of a sudden slump situation occurring at year 8 of the programme with a staged recovery over a 5 year period, and the comparable ‘non-slump’ simulation run. The scenarios vary from engine sales predominantly based on the bundled product and service ‘usage contracts’ offer to engine sales predominantly based on maintenance sold on a ‘time & materials’ basis.

These experiments are purely illustrative. They use hypothetical data and do not reflect any particular policy or strategy of any company.

Name	Description of future business environment
1. Time and Material dominated	The model is run using a predominantly 'Time and Materials' sales environment (80% of transactions). Aftermarket revenue based on sales of spare parts and time worked on overhaul and repair of engines.
2. Move towards more deals being 'usage contracts'	This simulation experiment represents a move from scenario 1, with 60% of sales based on 'usage contracts'.
3. 'usage contract' dominated	A continuation of the trend in scenario 2, with 'usage contract' sales now at 80% of all transactions.
4. Demand slump	A comparison between scenario 2 and 1 with a sudden slump in demand at year 8 and recovery over a 5 year period (e.g. a major event, such as a 9/11, with immediate mothballing of aircraft and suspension of new sales. Parked engines gradual re-introduction at year 2 and sales begin to recover to previous levels.

Table 1. Examples of the experiments conducted

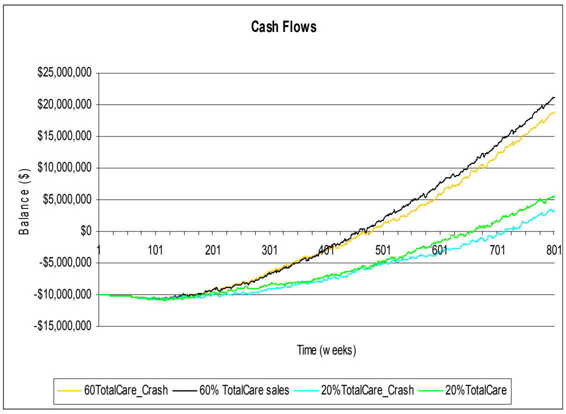

Figure 3. Simulated performance of a value chain partner

Description	60% 'usage contract' / 40% 'time and materials'	60% 'usage contract'. Demand crash year 8	20% 'usage contract'/ 80% 'time and materials'	20% 'usage contract'. Demand crash year 8
Break even point (week)	466	481	662	717
Break even point (year)	8.96	9.25	12.73	13.79
NPV at 10 years	**-$4.34 million**	**-$4.75 million**	**-$7.6 million**	**-$7.86 million**
NPV at 20 years	$2.41 million	$1.65 million	**-$3.86 million**	**-$4.75 million**
IRR (20 year analysis)	14.00	13.00	7.00	6.00

Table 2. Payback analysis for a value chain partner

In both the 'time and materials' and the 'usage contract' experiments the crash delays the breakeven point. However, there is variability between experiments in the duration of the effect – in the 'time and materials' simulation experiment, the delay is 55 weeks (an additional 8%), and for the 'usage contract' this is only 15 weeks (3%). Therefore, the strategy of adopting a 'usage contract' may create a revenue system that is more robust and resilient to the impact of dramatic changes in demand. This demonstrates how the model can be used to inform decision makers about the long term consequences of their actions.

6. Conclusions

By its nature it is difficult to plan and evaluate business strategies. Scenario building techniques can assist managers in conceptualising possibilities, but will not provide a clear understanding of what the implications for the business may be over extended timescales.

The agent-based modelling tool described shows that aggregated performance for a system can be modelled as the result of micro level interactions. The agents may be relatively simple but their interactions may lead to complex dynamics that may be difficult to capture, represent and evaluate using other approaches. Agent-based models can be used to understand how strategies applied at each level of the value chain may work over a long lifecycle. Initial results have shown that the approach has value in demonstrating the consequences of strategy decisions.

Future work will show the flexibility of the simulation model in exploring and interpreting strategy decisions. However, strategy decisions have many operational and tactical implications and the model has the potential to consider many of these. Table 3 outlines some of strategic and operational scenarios of real interest to the sector that are being investigated.

Name	Description of value chain scenario
The agile Value Chain	Higher volume exerts more pressure on value chain members and, where problems exist, they may have a more significant impact. This scenario is therefore more operationally focussed, considering how the operations systems and management approaches perform for high volume manufacturing.
The 'disposable engine'	Considers a more simply constructed engine with a short lifecycle, regular disposal and reverse logistics and parts reclamation and less important aftermarket. The value chain operates in a high volume environment.
World Regions	Structuring demand and engine characteristics based on Asian, European and North American markets.
PMA Threat [1]	PMA involves the copying of *original* parts by competitors and represents a significant threat to the industry. As margins remain high in the aftermarket (subsidising new engine sales) competitors may be tempted to enter this market.
The Collaboration Hub	Currently information is shared using linear communication tools and message passing. The collaboration hub would create a work-share environment that will enable parallel working and increase data visibility.
Capacity modelling	Examining where and how capacity can be structured to meet the requirements of the customer.
Sub-RRSPs	To reduce the risk for a tier 1 RRSP, agreement could be shared with tier 2 suppliers.
Hub-society [1]	In a hub society, larger aircraft may be dominant, which may alter the mix of engines and spares requirement for the industry – fewer aircraft engines will be required.
Aircraft age [1]	A variety of scenarios involving aircraft and engine retirement age can be modelled. With concerns for the environment and pressures on oil resources, engines may be retired earlier or require major mid-life modifications.

Table 3. Future scenarios which could be explored

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BIOGRAPHY

Bart MacCarthy is Professor of Operations at the University of Nottingham, Business School. He has research interests across Operations Management and Management Science. David Buxton and Richard Farr are Research Fellows on the VIVACE project (VIVACE project reference: www.vivaceproject.com) investigating future business environments for the aerospace sector and their manufacturing and logistics requirements.