Roadmap to Self-Serving Assets in Civil Aerospace

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Abstract

The "intelligent object" paradigm first occurred in holonic manufacturing, where objects managed their production. The "self-serving asset" is a further evolution of those early concepts from manufacturing to usage phase. The usage phase bestows a different set of requirements including maximisation of the asset's life-in-service and benefits to the asset's stakeholders. Addressing these requirements with a self-serving asset may lead to more streamlined decision-making in service operations, reduce erroneous or suboptimal decisions, and enable condition-based maintenance. We present a future direction for service systems by considering self-serving assets in the aerospace industry, and outline a technology roadmap for the transformation.

Keywords: Multi-agent systems, Self-serving asset, Intelligent object, Aerospace service supply chain

1 INTRODUCTION

The intelligent object has a unique identity, is capable of communicating with its environment through sensors and languages, and can participate in decisions concerning its destiny [1]. Unique identity can be possessed using barcodes or automated identification systems such as Radio Frequency Identification (RFID). Communication ability can be obtained using sensors, wireless networks, common interfaces and languages. Participation in decisions can mean providing raw data to processing mechanisms such as Decision Support Systems (DSS) to help users understand the current state and decide on the future state of the object, or it can mean the object making decisions autonomously, by a built in decision making mechanism.

In a recent review of the intelligent object across the product lifecycle [2], we found that most research focused on the beginning of life – in the form of holonic manufacturing, and in the middle of life – in the form of objects monitoring their health. The former granted autonomy to objects in driving their production, usually with the use of multi-agent systems [3-5]. The latter coupled products with sensors, and enabled data provision to decision support systems for *external decision makers* to undertake courses of action [6-12]. Therefore the latter application of the intelligent objects did not yet give true autonomy at the individual product level to decide and act upon its service needs.

We introduce the *self-serving asset* paradigm to grant this autonomy to the intelligent object at the middle of life. The functionality we seek to add to the asset is a survival goal, and the capability to manage its own service lifecycle by balancing the interests of its various stakeholders. For instance, an aircraft component may monitor its health and expiry date, store and transmit its service life history, and schedule or trigger maintenance operations when required. The asset decides on the supplier based on a number of criteria such as its location, cost, previous performance, contractual obligations, and the fit of offered components. It can engage in negotiations with other assets requesting the same services to determine who will get serviced first. The result is an open, largely autonomous service chain, where decisions are traceable and transparent. Such an "active decision-making" capability is in sharp contrast with today's notion of object intelligence, which enables the object to provide information required to support decisions made by another system (i.e. passive decision support).

Thus our self-serving asset must:

1. *be self-aware*, in terms of identity, location, health, expiry dates, and operation schedule
2. *have the goal to maximise its life in service* by autonomously deciding on its service needs, managing the procurement of their replacement parts, taking into account its resources, and perceptions from its environment,
3. *act on the interests of its different stakeholders*, such as selecting a supplier based on its previous performance, or deciding on service schedules to minimise disruption to operation cycle,
4. *have the ability to engage in communication with other assets or intelligent systems* when searching and competing for resources.

In the remainder of this paper we briefly review service and maintenance in aerospace and extract needs resulting in the self-serving asset vision. We then present a roadmap toward the realisation of the self-serving asset, highlighting market drivers, necessary systems, standards and adoption, and evolution of technology. Finally we summarise risks awaiting the vision, and conclude our findings.

2 SERVICE and MAINTENANCE IN AEROSPACE

This section briefly examines the current aerospace service supply chain structure based on data obtained from maintenance activities of three aerospace companies, and identifies key stakeholders that has led to our notion of a self serving asset. The following are the different types of health management activity in aerospace:

- Scheduled: This type of maintenance is conducted for preventative reasons before the failure of a component occurs. The actual condition of the part is unknown before the service. It is done with static time intervals for inspection, repair or overhaul. Schedules may be determined using modelling and simulation.
- Reactive: This type of maintenance is reactive to failures and operates in an unscheduled manner. If we have sophisticated integrated diagnostic hardware and

software available, the events that led to the failure can be reconstructed to ease the troubleshooting process, leading to diagnostic service such as Integrated Vehicle Health Management [13]. Real time usage data is necessary to operate in the diagnostic service style, which is obtained by the use of embedded sensors that monitor various usage parameters.

- Prognostic: This maintenance style takes the diagnosis process of the fault based maintenance a step further, and schedules maintenance based on forecasts on remaining component life. Actions taken have the goal of maximising remaining service life rather than solely solving the current problem. This is the best style in terms of fitting in with the aircraft's schedule, and maximising the remaining life of the component.

Currently the commercial aviation industry focuses predominantly on preventative, scheduled maintenance but hopes to move towards diagnostic and prognostic health management, categorised under the term: condition-based management (CBM) [14-15]. This will enable parts to be serviced before a failure occurs, maximising their life. It also enables streamlining of service operations, as schedules for prognostic failure can then be drawn more efficiently, as opposed to unscheduled, reactive maintenance. This goal is in line with the self-serving asset vision as assets are self aware and are capable of providing condition based health management, given appropriate data processing capabilities. In CBM, determining the equipment operating status is accomplished in three ways:

- Embedded sensors in equipment and monitoring on-the-fly
- Portable devices that connect to an interface to gather data from embedded sensors; or
- Applying an external sensor on the part, using stand-alone wear instruments or gauges such as tire-wear

Using the above technologies, a scheduled inspection is performed by analysing the data collected. Once a course of action is decided (which may involve using decision support systems (DSS)), a service/replacement order is given if required. The inspection process involves manually checking paperwork and entering data on service information systems, which takes an average of 25 minutes per part (averaged across three companies that were studied as part of this work). Procurement officers at the maintenance, repair and overhaul (MRO) facilities select suitable external vendors if the part cannot be repaired or replaced in house. This decision is made mainly based on time limitations, costs and maintenance capabilities. A higher level decision needs to be made when maintenance needs to be outsourced, and would be based on factors such as contracts and relationships with external vendors (e.g. external repair agents, OEMs). If there are no available parts, e.g., if they are out of production, the issue is referred to a manufacturer. The capabilities of the manufacturer may have been recorded at the MRO or can be obtained by personnel at the MRO. Once the service provider is decided upon and agrees to provide the service, a maintenance schedule is drawn, taking into account the flight-schedule and current/future location of the aircraft, and logistics providers are alerted.

Analysis using MEDA, a tool designed by Boeing for investigating factors that contribute to maintenance errors, found that documentation and operator errors are the most frequent contributing factor to maintenance errors, highlighting the need for traceability, autonomy and visibility to meet the future challenge of managing a global service supply network.

Another issue is the increasing complexity of the aerospace service supply chain. Suppliers are globally sourced, and competition to provide more streamlined and less costly service operations is increasing. Leasing of the aircraft brings in multiple stakeholders on the parts. The stakeholders include: the airline, owning or leasing the plane, the MRO shops that repair and maintain parts for an airline, and the third party suppliers of parts. Their common goals include the maximisation of aircraft availability and minimisation of time on ground. The result is a requirement for simpler, consistent, cheaper, and cooperative service systems.

When considered in the light of the above challenges in current service supply chain operations, the key benefits that the self-serving asset brings include:

- CBM is incorporated as asset is aware of its health and expiry. "Awareness" and "goal-directed behaviour" can be facilitated using intelligent software agents tied to a part through a unique identification such as RFID. Agents perceive their environment through sensors, and process the data. Wireless networks and common communication languages can facilitate the data exchange. The agents execute actions based on this perception, to reach to their encoded goals. Asset self-awareness in real-time leads to the reduction of unplanned maintenance, benefiting stakeholders, i.e. the airline, MROs and the OEMs, of increased life in service.

- Through automated decision-making, decisions are taken faster, leading to a more responsive supply chain and simpler flow of operations. Decision making is traceable and consistent.
- Through automation, errors and time of operations are reduced, and a leaner approach to lifecycle management is formed, which in turn increases aircraft availability.

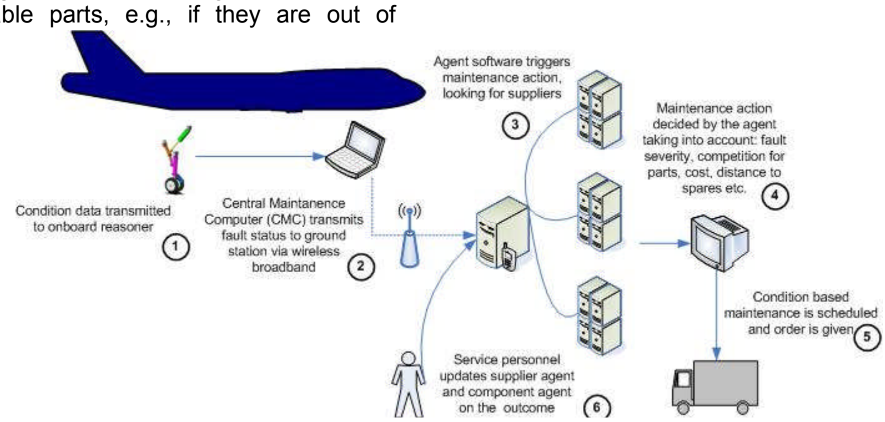

Figure 1: Service operation with the self-serving asset

3 THE SELF-SERVING ASSET: A VISION

Figure 1 shows a snapshot of the new service operation based on the self-serving asset. Each part is represented by its dedicated software agent, accessible by a unique identifier recorded on an asset identification tag. Complex serviceable and critical assets such as landing gears, engines, fuel systems are monitored by onboard or embedded sensors which collect asset state information such as hydraulic pressure, temperature and flow rates of fluids. Less complex, replaceable assets (such as oxygen generators or life vests) would not need sensors, but have expiry dates embedded in their agent software's belief sets. Data is collected on the central maintenance computer and transmitted to ground station via wireless communication channels. The servers on ground have the assets' representative agents that process the data.

On the event that a fault is detected or predicted, asset agents evaluate the current circumstances and execute a plan of action. For instance, an asset agent may start searching for suitable suppliers by communicating with supplier systems. Asset agents are able to choose suppliers, award contracts and trigger logistic operations. Asset agents also communicate with one another in the face of competition and resolve any conflicts that arise. Once they issue an order (service request), the monitoring phase starts until an operator completes maintenance and interacts with the software to confirm that maintenance has been carried out successfully. Asset agents then update the configuration and condition of the aircraft, as well as the supplier's performance in their belief set. In the next section we discuss the roadmap towards achieving this vision.

4 ROADMAP TOWARDS SELF-SERVING ASSETS

In this section, we describe the roadmap, starting with the market drivers, and highlighting each item that will help bring us closer to the self-serving asset. Evolution of technology, market drivers, standards and legislation as well the standing point of stakeholders all have an impact on the vision. In order to outline the requirements as well as a technology evolution pathway, we have developed a roadmap for the deployment of the self-serving asset concept on the aerospace service supply chain (Figure 2). The roadmapping methodology have been taken from [16]. Technology roadmapping is a methodology to help companies plan in achieving their technology related visions. First the roadmap is structured with the various factors impacting the self-serving asset vision, including systems, market drivers, standards, adoption, and technology enablers. Next unstructured interviews were carried out with Boeing personnel and the Cambridge research team to develop an understanding of the self-serving asset vision. Then a literature survey is conducted to extract the state of the art and develop how the various aspects considered should evolve over a given time horizon such that the self-serving asset vision is brought to life. The roadmap is then further developed and validated with a total of five industrialists from aerospace service sector, each from different companies. The interviews also helped extract risk drivers awaiting the self-serving asset vision. The roadmap considers the following aspects:

- Market and business drivers: Unlike the military aerospace industry, where performance is the major driver of change, civil aerospace requires drivers of change that emanate from the market place, from government legislation, from compelling economic rationale or some combination of these to justify a new product/technology development. We identify external market drivers reflecting the business motivations. They are grouped into short-medium and long term.
- System: This section shows the set of systems that needs to be developed to bring the self-serving asset to life.
- Standards: The commercial aviation industry relies heavily on information exchange between trading partners. In line with this reliance, we outline data exchange standards and legislations required before new technology can be introduced.
- Adoption: Since the roadmap encompasses the entire service supply chain, collaboration is essential for successful deployment of the self-serving asset. This layer captures actions to be undertaken by different stakeholders.
- Technology enablers: There are various technology requirements to bring the above scenario to life. This section shows the various technology requirements to enable the self-serving asset.

4.1 Market Drivers

High prevailing fuel costs: Non-fuel costs have decreased in recent years with reductions in labour, and increases in operation efficiency [17]. Although this is likely to continue, fuel cost as a percentage of operating expenditure has a general upward trend, meaning that more efficiency increase in the aerospace operations are needed to decrease costs and balance the increase of fuel costs.

Reduction of no-fault found: Aviation data suggest that there are in excess of 400,000 of no-fault-found cases per year, where a false alarm is given and no fault is found after the investigation. The number represents 23% of all (1.76 million) component removals. With an average cost of $800 per removal, including labour, tracking, testing, no-fault-found removals cost the industry approximately $300 million per year [18]. "The only quotable estimate, provided by Airbus, was published 10 years ago by the Air Transport Association. At that time, Air Transport Association estimated annual no-fault-found costs for an airline operating 200 aircraft at $20 million, or $100,000 per aircraft per year [19]".This points a strong market driver in automated condition-based maintenance.

Restructuring of MRO market: As the civil aviation market expands, competition among airline operators, independent service providers and original equipment manufacturers (OEMs) will intensify for taking a share of the service and maintenance market. [20] indicates that airline maintenance companies currently account for nearly 60% of market share, followed by independent service providers and OEMs and suggest that with the globalisation of third-party MRO providers consolidation will lead to increased buying power for these players and an accompanying reduction in inventory pools. The process of consolidation will continue until a leaner, more efficient MRO operation structure emerges. Leaner service operation environments will be necessary to simplify the service operations.

Global sourcing of suppliers: The commercial aviation industry's globalisation process is in its infancy. Significant investments particularly in India, China and Russia are taking place. As a result, engineering partnerships with Western OEMs have begun to accelerate the development of the capabilities of emerging markets. In developing new aircraft, the involvement of suppliers from different parts of the world creates complex management, integration and coordination challenges giving rise to new collaborative models.

Increasing demand for air travel: The Department for Transport in U.K. forecasts short haul traffic is expected to grow at an average of 4.8% per year over 2005-2020, slightly less than the long haul growth rate of 6.1% over the same period [21]. Demand for aircraft in emerging markets is increasing, with China, India, Russia are expected to purchase more than 3,500 planes (roughly 15% of global demand) over the next two decades [22].

Global penetration of low-cost carriers: A consequence of the passenger delivery growth is strong airline fleet expansion among low-cost carriers [23]. This is a significant development for the maintenance sector since low-cost carriers typically contract their MRO requirements to third-party providers, leading to higher pressures for collaborative, consistent service provision.

Switching to fly-by-the-hour: OEMs are actively pursuing a new fly-by-the-hour business model. Rolls Royce predicts that the 40% of civil engines under TotalCare in 2004 will grow by 80% by 2010 [24].The new model has numerous advantages over the traditional model – including lower cost of asset ownership by allowing airline operators to treat an asset as a service. Payment is based on asset usage, with outsourced partners taking on MRO responsibility. This switches focus from capital spending to variable costs, allowing airlines to focus on their core business, expecting fast, reliable service delivery.

Example set by the military sector: The military sector is primarily driven by performance, and is the pioneer of condition-based aircraft maintenance. An example is the Joint Strike Fighter Prognostic Health Management Programme (1997-2037) [25-26]. The nature of commercial aerospace market is fundamentally different because the airline customers rarely request dramatic technological innovation; instead, their approach to improving aircraft performance tends to be incremental, with a heavy emphasis on cost [18]. The civil aerospace companies will adopt a condition-based health management system only when the economic benefits are realised in the military sector, and when the technology is proven reliable, mature and safe.

Mandates for lower emissions: The European Commission proposed to include carbon dioxide emissions in the European Union Emissions Trading Scheme for commercial flights arriving or departing European Union airports, including US registered aircraft. The proposal aims at capping carbon dioxide emissions at the average emission levels between 2004-2006 [27]. The Advisory Council for Aeronautics Research in Europe have created the “Vision 2020” for European aeronautics which sets out a number of ambitious targets such as 50% reduction of carbon dioxide and 80% reduction of NOx emissions [28]. In order to achieve these targets, aircraft manufacturers and suppliers need to modernise and expand their fleet with more environmentally friendly aircrafts; also in the wider context of life cycle management of aircrafts.

The above market drivers show the changing face of the civil aviation industry and point to requirements for a leaner, more collaborative and transparent service supply chain. The self-serving asset emerges as a key bundle of technology in help companies move towards this goal.

4.2 Systems, Standards and Adoption

In terms of systems, standards and adoption, incremental improvements to the current systems are needed to be undertaken. A primary factor is achieving a uniform method of uniquely identifying assets with an agent representation on the network. This will ensure data integrity and quality throughout life, and support agent activities when facing multiple suppliers. Solutions can be found in maintaining and extending the existing 1D or 2D barcode identification to all aircraft parts that need to be serviced, a development which all suppliers, OEMs and MROs shall adopt. Another enabling technology that is being adopted by the aerospace industry is Radio Frequency Identification (RFID), for uniquely identifying objects using microelectronic transponders that communicate wirelessly with dedicated systems. Unique and automated identification is a key requirement for the self-serving asset, making developments in RFID technology critical for its realisation.

In 2005, Federal Aviation Administration (*FAA) approved the* use of passive Radio Frequency IDentification (RFID) tags on ground in its Spec2000 specification[1]. This calls for the industry to establish a standard for compatible interfaces between proprietary systems. RFID tags can be integrated with existing barcodes and are likely to coexist with RFID for several years. As tag costs become lower their use is expected to increase. Different assets require different tag data storage capacity, to support service operations as well adhering to regulatory mandates. For example, a life vest would only require a low memory passive tag with a unique ID whereas a hydraulic pump or actuator could require high-memory tags for storing sensor data as well as maintenance data and service history [29]. This observation points a requirement for a system that facilitates the use of different types of tags together.

There are different regulations regarding the use of RFID across various regions of the world. This becomes an issue as the MRO markets globalises. For instance, RFID uses licence free parts of the electromagnetic spectrum and these allocations are different depending on the regulatory bodies in that region. For example, the widely deployed UHF RFID Systems must use the 840.25 to 844.75 MHz and 920.25 to 924.75 MHz ranges approved by China's State Radio Regulation Committee (SRRC) in that country but RFID UHF bandwidth across the European Union ranges from 865 MHz to 868 MHz while RFID UHF bandwidth in North America ranges from 902 to 928 MHz. These differences add to the complexity and the cost of the ultimate system. Systems that manage these regulatory differences will be necessary.

A major concern for the use of RFID is the security and integrity of data. Commonly used cryptographic mechanisms rely on large complex computations and computing resources that are generally available in embedded systems. However these mechanisms are not suitable for low power, low cost resource constraint devices such as passive RFID tags [30]. There are many ongoing research projects that are addressing both security and privacy concerns posed by RFID technology, a review of which can be found in [31].

Standards regarding data exchange, encoding of service related data on tags, are to be developed to facilitate data exchange in the aerospace service supply chain,

[1] http://www.spec2000.com/10.html

Decision making models and conflict resolution models used by the self-serving asset need to be accepted across the supply chain, as well as the concept of automated decision making.

Regarding data transfer, current info bus systems provide the ability to transmit flight information, including sensor data, flight controls and safety systems; as well as data from non-essential systems to the central maintenance computers where the information is processed. An extension to improve the *central info bus* technology can be achieved by *segmenting the info bus* into layers and giving safety-critical system data the priority for transmission. Based on the criticality of data, different communication networks can be used. For example, real-time monitoring data are processed directly by onboard health management systems. If a fault is detected and maintenance is required; a signal is sent to notify the ground stations. Other non-critical data are recorded in a no volatile *memory* and later be downloaded to a central repository for analysis off board. A possible improvement to this system is *direct wireless download* to a central repository.

Due to complexity of analysis, currently much of the *prognostic reasoning* is performed *off- board*. In the future, more *onboard reasoning* could be achieved if more server space and computational power is available. By shifting the reasoning capability onboard increases efficiency of response to maintenance and service needs by mitigating delays associated with ground based DSS that require data to be sent through manual or wireless channels. In addition, data transmission services to ground base are only available when an aeroplane is at a certain distance from airport facilities therefore it is critical to use the available time to organise and schedule maintenance and service activity to minimise disruptions to airlines and flight schedules.

A key aspect of the self-serving asset is autonomous decision making. Decisions to be made include the type of maintenance needed as well as timing, tools, parts and selection of suitable suppliers. Today decision support systems (DSS) are common place, which inform decision makers about trade-offs and available options based on inputs of current circumstances such as resources availability, flight schedules and cost of replacement parts from various supply chain options. However DSS usually ask for an external decision maker to make the decision. A step forward from DSS is distributed and autonomous decision making, comprising a smart system based on emergent behaviour such as agent based systems. These will require real-time update of information on supplier availability and pricing, a conflict resolution model and a scalable, high speed computational architecture. Low-level decision making is increasingly automated enabling companies to manage their global supply network more efficiently.

Finally, all the deployed systems across multiple parties must be integrated to achieve a truly distributed system. This requires standards for data exchange and corporate trust for open information exchange between collaborators. Partners can then securely *share timely information* and give each contributor appropriate access to the information over the internet using a common data exchange standard. For instance, two existing standards, the EPCglobal EPCIS interface [32] and STEP standards for product data exchange [33] can be considered to provide appropriate metadata models for data exchange.

4.3 Technology Enablers

The self serving asset concept is primarily based on leveraging developments in various technology fields such developments in computer processors, energy harvesting, Micro-Electro-Mechanical Systems (MEMS) technology and microelectronics,

High-speed computation architectures are required for supporting increased processing requirements of systems hosting agent based software. Current developments in multi-core processors as well the developments in 64 bit processor architectures capable of supporting increased capacities of Random Access Memory for more in memory operations and processing of data are critical for the deployment of agent based systems in large scale.

Continued miniaturisation of sensors, through development in MEMS leading to *nano sensors* as well as developments in wireless sensor networks supported by energy sources developed through energy harvesting will allow sensors to be embedded more extensively to increase the state space monitored by current systems while satisfying a key requirement in reducing the extra weight added onto the aircraft to bring the system to life.

Advances in RFID technology to develop more reliable, cost effective, high memory and secure tags will be able to support the requirements of automating manual records of service and maintenance activity as well as support the link to asset agents executing on networked systems.

Eventually large scale integration and miniaturisation of microelectronics will pave the way for ultimately running lightweight agents onboard assets capable of forming an intelligent entity capable of managing its operational life in its totality.

Previous research had found that multi-agent systems (MAS) are particularly suitable to model a supply chain where each party has its partial own view of the environment, its own goals and behaviour results in an emergent system [34]. Autonomous decision making capability is also natural to MAS. However the use of MAS to represent each serviceable part and provide autonomous decision making capability will depend on improvements in the *scalability of agent software* as this has been an issue in past industrial applications [35].

Developments in communication technology such as ZigBee [36], which is a low-cost, low-power, wireless mesh networking standard, are required to provide short range communication between intelligent assets in a reliable and secure manner. Developments in new communication technology will also play a role in advancing self-organizing ad-hoc digital radio networks, which will allow intelligent assets to organise into intelligent entities and support inter agent communication at a time when the agents are onboard assets as opposed to being on a ground based facility.

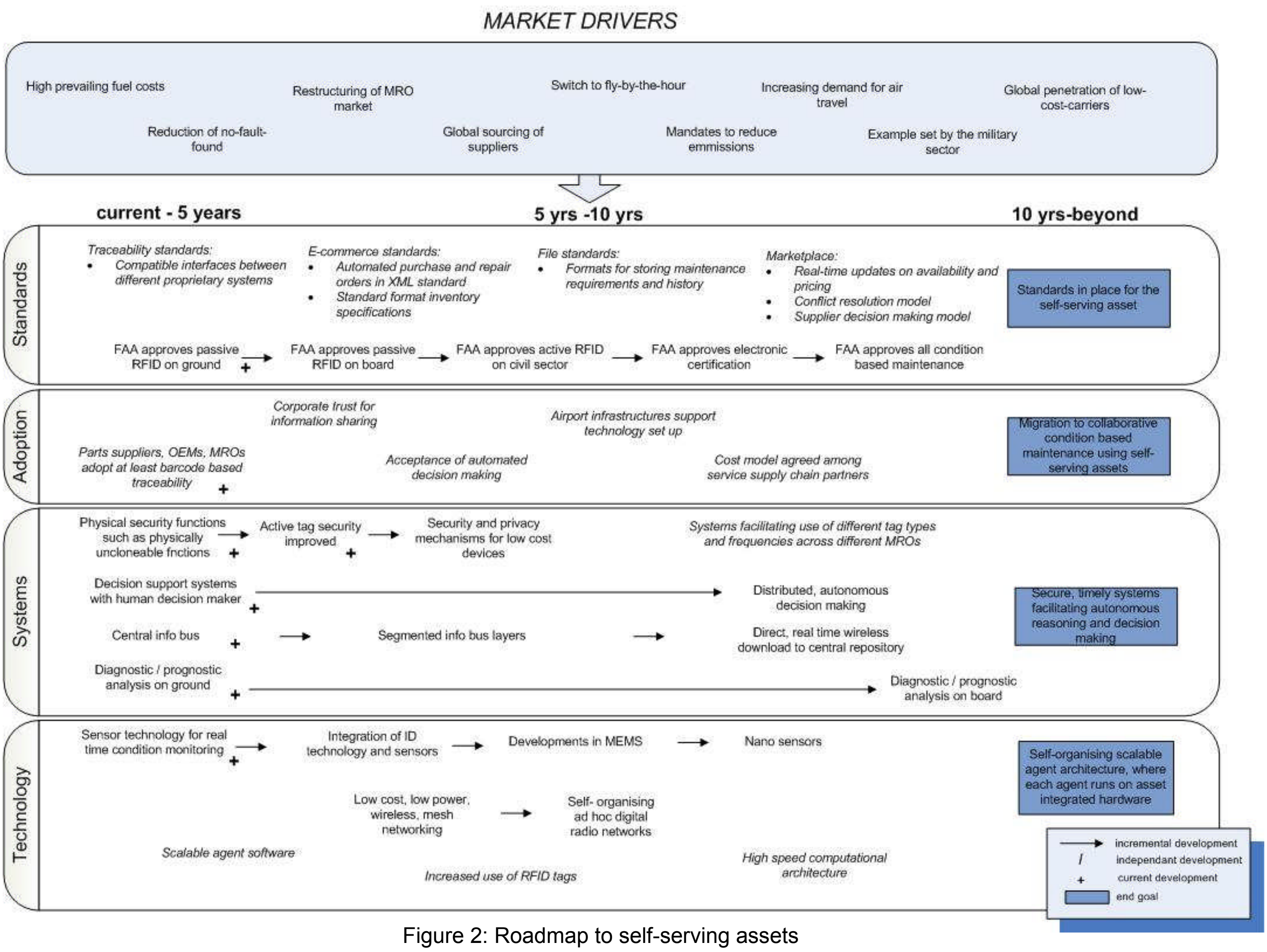

Figure 2: Roadmap to self-serving assets

5 BENEFITS and RISKS AWAITING the SELF-SERVING ASSET VISION

A preliminary risk assessment for migrating from today's practice to the future self-servicing asset model is performed using data from three aerospace companies. A total of five respondents, all of whom have held positions dealing with the aerospace service operations were interviewed using semi-structured interviews. Although a larger sample size is needed, we present a preliminary risk assessment from this basic exercise. When presented with this roadmap and the self-serving asset vision, an even spread of risks in technology, industry, social, legislative and economical areas emerge (Figure 3).

In terms of technology, unexpected breakdowns in the IT system were of most concern, given the reliance on autonomous software. The maturity level of sensor and diagnosis technology and complications in global networking were other concerns. Acceptance of automated decision making, security breaches, and transparency in the supply chain were found to be the risk factors in social and cultural terms. The industry's potential reluctance to move to condition-based maintenance in the fear of losing steady revenue, lack of collaboration are among the risk factors in industrial terms. Costs of implementation, the difficulty of the business case, and management scepticism on the technology might be the economical factors impacting

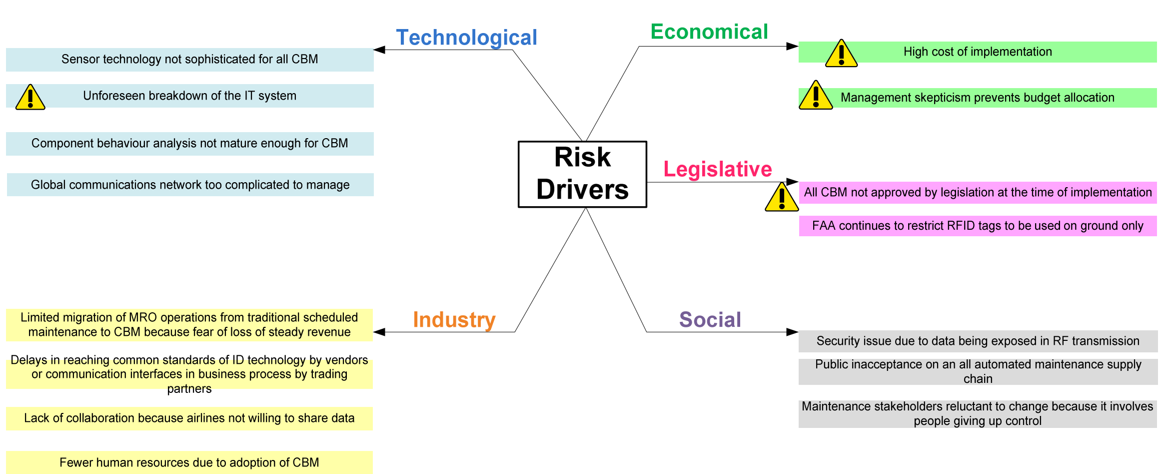

Figure 3: Self-serving asset risk drivers

deployment. Finally, approval of the condition-based maintenance processes, and technology as well as approval of the use of RFID tags in aircraft (which provide the important unique identifier to the assets) were identified as legislative risk factors.

The risk factors highlighted above are critical in deploying the self-serving asset vision. Further investigations to quantify the risks and linking them to different stakeholders on the service supply chain is needed, followed by a comprehensive risk mitigation strategy.

6 CONCLUSIONS

Current service and maintenance in civil aerospace is facing major market changes. Increasing fuel costs, demand for air travel, and global outsourcing, are some factors that require lowering the cost of service provision and increasing the quality of service, to enable suppliers and manufacturers to remain competitive. The sector is under increasing pressure to deliver better service with fly-by-hour contracts, and mandates to better manage parts lifecycle. The *self-serving asset* comes about as the result of such market drivers: a technology that aims give autonomy to aircraft parts in monitoring their health, deciding when to order service, and where to order it from. The self-serving asset has the goal to maximise its life, and serve to its multiple stakeholders. The vision comes with a set of requirements for technologies, systems, standards and adoption to facilitate its realisation. Standard regulations regarding data exchange, tag encoding, secure, high speed wireless communications, integrated systems for different tag types and frequencies, integrated sensor networks, development of scalable agent architectures, form some of these requirements. A preliminary risk assessment shows management scepticism, high costs, lack of regulatory approval, and system breakdowns being among the highest risk factors. With this short assessment we aim to provide researchers and practitioners a common view on this new vision emerging from needs of the current service sector, and draw attention to the necessary developments that are highlighted on the roadmap.

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