Routines, "Learning-by-Using" and Networks:
the case of aircraft maintenance

Luis Araujo

Department of Marketing,

The Management School

University of Lancaster

Lancaster LA1 4 YX

United Kingdom

e-mail: **L.Araujo@lancaster.ac.uk**

João Mota

ISEG

Universidade Técnica de Lisboa

Rua Miguel Lupi 20

1200-725 Lisboa

Portugal

e-mail:**joaomota@iseg.utl.pt**

Abstract

The purpose of this paper is to explore the notion of routines and its connection to the evolution of "learning-by-using" in a complex network setting, aircraft maintenance. Despite continued theoretical interest, there has been a dearth of empirical studies in how routines emerge and develop in the field. In addition, few studies have considered how routines intersect and interact across conventional organisational boundaries. Aircraft maintenance stands at the junctions of a number of relationships that define and constrain how maintenance operations are to be performed, namely airframe manufacturer-maintenance station and maintenance station-aircraft operator. In addition, aircraft maintenance is governed by a highly formalised set of rules involving formal institutions and regulatory bodies (e.g. industry associations, civil aviation authorities). A system governed by tight routines might be expected to learn only gradually and slowly. The paper discusses how the combination of routines with the accumulation and rapid diffusion of "learning-by-using" mechanisms at different levels of the network of actors directly and indirectly involved in aircraft maintenance.

Paper prepared for the 20th IMP Conference, Copenhagen Business School

1. Introduction

The purpose of this paper is to explore the notion of routine and its connection to the notion of "learning-by-using" (Rosenberg, 1982) in a network setting, aircraft maintenance. Despite continued theoretical interest on routines, there has been a dearth of empirical studies in how routines emerge and develop in the field (but see Narduzzo et al, 2000). In addition, few studies have considered how routines intersect and interact across conventional organisational boundaries despite the odd nod towards interfirm routines (Dyer and Singh, 1998).

In Nelson and Winter (1982), routines are seen as the organisational equivalent as individual skill and as encapsulating organisational knowledge and memory. Selection pressures dictate that routines evolve in response to environmental change. This paper proposes a wider focus on routines, linking the development of firm-based routines to mechanisms of selection deliberately designed to enhance learning in a network environment.

The empirical setting of our study is particularly promising for examining the role of routines and the evolution of know-how. Civilian aircraft maintenance stands at the junction of a network of relationships that define how maintenance operations have to be performed and how they evolve over time. A civilian airliner is a complex artefact formed by many systems, subsystems and components (e.g. propulsion system, avionics, landing gear) and has a long useful life. As Rosenberg (1982, p. 122) points out, the performance characteristics of this type of durable good cannot be understood until after prolonged experience with it. As a result, the only way to determine the optimal performance characteristics of this type of product is to learn through extensive use ("learning-by-using"), namely through servicing and maintenance activities whose schedule is also subject to evolution through cumulative experience.

Needless to say, safety and reliability issues are paramount in the design of programmed maintenance for aircraft. Aircraft maintenance and repair stations are prime examples of "high reliability" organisations (Weick and Roberts, 1993; Roberts and Bea, 2001).[1] This emphasis on safety and reliability has led to a close regulation and monitoring of the activities and resources involved in maintenance programmes.

---

[1] The literature on "high reliability" organisations is primarily concerned with the design of organisational structures and systems to prevent, mitigate or avoid accidents in environments where accidents can have catastrophic consequences (e.g. aircraft crashes, nuclear plant accidents, chemical-plant explosions). A review of this literature is outside the scope of this paper.

Maintenance activities involve a variety of actors from flight crews, maintenance and repair stations, airframe manufacturers, airline associations and regulatory agencies at the national and international level. At another level, maintenance and repair activities constitute a key source of new ideas for the evolution of maintenance programmes as well as to the design of new components and systems.

Rosenberg (1982) distinguishes between two types of "learning-by-using": disembodied and embodied. In the first and purest form of "learning-by-using", prolonged experience with hardware leads to better understanding of its performance and operating characteristics. Disembodied learning may lead to new practices for increasing the productivity or lengthening the life of hardware as well as determine better repair schedules. Embodied learning by contrast, describes a situation when early experience with a complex technology leads to a better understanding of the relationship between the characteristics of components and their performance. In this case, the result is design modifications and improvements embodied in new generations of components and subsystems.

The key question we will attempt to answer in this paper is: how does the know-how involved in the maintenance of aircraft evolve as a result of experience with use and deliberate learning activities at the network level? On one hand, the existence of rigid routines would suggest that the focus of learning would be localised and aimed at stepwise improvements in routines. On the other hand, safety concerns mandates the rapid circulation of knowledge concerning problems and solutions that have not been foreseen by troubleshooting manuals. The apparent paradox between the need for tight routines and flexible, rapid mechanisms for diffusing learning is at the heart of this paper.

The structure of the paper is as follows: in the second section we will undertake a brief review of the literature on routines and capabilities. In the third section, we focus on the nature of programmed aircraft maintenance based on our primary research, involving a series of interviews with specialists in a maintenance and repair station, as well as a range of secondary sources. In the fourth section we attempt to integrate our theoretical and empirical material to examine the relationship between routines and "learning-by-using". Finally, we draw some conclusions and implications from our study.

2. Routines and Capabilities

The routinisation of social life has occupied organisational theorists and social scientists for a long time. At the most basic level, the routinisation of social encounters is seen as key to binding social structures and contributing to the apparent "fixity" of institutions (Giddens, 1984). Sayer (1992) argued that social life would be impossible without some degree of artificial closure of social systems and routinisation is critical to that closure. [2]

March and Simon (1958) provided the first serious attempt at analysing the role of routines in organisational life. For March and Simon (1958, p. 139) both individual and organisational activities can be traced back to specific stimuli. Responses to stimuli vary depending on past experience and learning. At one extreme, a stimulus evokes a routinised response in the form of what March and Simon call a "performance programme". A performance programme is not a completely rigid response and it may be adaptive to a number of the characteristics of the stimulus that triggered it. A set of activities is deemed to be routinised to the extent that choice has been simplified by the invocation of a fixed response to a particular class of stimuli. Conversely, an activity is unroutinised to the extent that it is preceded by programme developing activities and problem solving (*ibid*, p. 142).

March and Simon regard the pattern of programmed activity as a mosaic of interrelated programme executions, each programme responding to appropriate stimuli (*ibid*, p. 149). In organisations facing complex problems, tasks can be factored into a number of nearly independent parts so that each subunit can handle its own part without having to understand the whole. Greater specialisation by subprogram leads to the greater interdependency amongst the different subunits that form the organisation. Interdependency *per se* does not cause problems if the pattern of interdependency itself is relatively stable. In this event, coordination can be effected

---

[2] "A considerable part of human labour and communication is devoted to the creation of closed or quasi-closed systems, with the aim of taking advantage of and controlling mechanisms of value for us, be it photosynthesis in edible plants or the synchronisation of labour in a factory. *Many forms of social organization tend to produce approximate regularities in patterns of events by enforcing rules or by subordinating workers to machines, which routinise and control the spacing and timing of particular kinds of action*" (Sayer 1992, p.124, emphasis added)

by plan. If the pattern of interdependency is changeable, coordination will require intermittent communication and feedback.[3]

March and Simon (1958, p. 170) produced a valuable insight into the relationship between short and long-term adaptiveness:

"If an organisation has a repertory of programmes, then it is adaptive in the short-term insofar as it has procedures for selecting from this repertory a programme appropriate to each specific situation that arises. The process used to select an appropriate programme is the "fulcrum" on which short-term adaptiveness rests. If, now, the organisation has processes for adding to its repertory of programmes or for modifying programmes in its repertory, these processes become still more basic fulcra for accomplishing longer-run adaptiveness. *Short-run adaptiveness corresponds to what we ordinarily call problem-solving, long-term adaptiveness to learning*." [emphasis added]

Cyert and March (1963), pursuing the same argument, viewed firms as short-run adaptively rational entities governed by set of behavioural rules which they labelled "standard operational procedures". Standard operational procedures provide stability and a framework for decision making, constitute a form of collective memory and change at slow rates. Thus standard operating procedures are the result of long-term adaptive processes by which the firm learns and provide a framework to channel short-term decision-making.

Nelson and Winter (1982) acknowledged their intellectual debt to the behavioural tradition and added significant refinements to the notion of routine. Routine is seen as a general term covering all that is regular and predictable about the behaviour of firms. But unlike their predecessors, Nelson and Winter (1982, p. 14) harnessed the notion of routine to explain the evolution of populations rather than single firms:

"In our evolutionary theory, these routines play the role that genes play in biological evolutionary theory. They are a persistent feature of the organism and determine its possible behaviour (though *actual* behaviour is determined also by the environment); they are heritable in the sense that tomorrow's organisms generated from today's (for example, by building a new plant) have many of the same characteristics, and they are selectable in the sense that organisms with certain routines may do better than others, and, if so, their relative importance in the population (industry) is augmented over time".

Routines are the organisational equivalent of individual skill and may encapsulate tacit or difficult to codify elements. Organisations "remember by doing" and repetitive performances are essential to hone routines. In extreme cases, routines become what Starbuck (1983) has called action generators – routines that require no

---

[3] Thompson (1967) later elaborated on this scheme adding coordination by standardisation to March and Simon's categories and changing the label of coordination by feedback (mutual adjustment).

specific stimuli and are activated through clocks, calendars, job assignments and so on. Furthermore, routines constitute truces in intraorganisational conflicts amongst members with divergent interests and responding to different incentives. Innovation involves changes in routines or the recombination of routines, and it is typically path-dependent and incremental. In Nelson and Winter's (1982, p. 131) words, "…reliable routines of well-understood scope provide the best components for new combinations". The implication of routines for an evolutionary approach is clear:

> "…it is quite inappropriate to conceive of firm behaviour in terms of deliberate choice from a broad menu of alternatives that some external observer considers to be available to the organisation. The menu is not broad, but narrow and idiosyncratic; it is built into the firm's routines, and most of the "choosing" is accomplished automatically by those routines. (…) Efforts to understand the functioning of industries and large systems should come to grips that highly flexible adaptation to change is not likely to characterise the behaviour of individual firms". (*ibid*, p. 134)

In summary, routines fulfil a number of important functions. They simplify and frame choices; most choices are automatic responses to pre-specified stimuli. Secondly, they provide a degree of stability and continuity in the evolution of the firm through their quasi-closed nature and their persistence over time.[4] And, finally routines link up and evolve in combinations that confer idiosyncratic characteristics to individual firms.

The literature on routines is ostensibly biased towards short-term adaptiveness even in the face of environmental maladaptation. Starbuck (1983, p. 93) went as far as saying that routinisation means that organisations "…act unreflectively and non-adaptively most of the time". This fits well with an evolutionary agenda but the flipside is that firms are condemned to "learning-by-doing" through local, incremental searches. Nelson and Winter escape this predicament by conceiving innovation as guided by investment and search routines triggering changes in lower-level routines.

Since Nelson and Winter (1982) the literature on routines has evolved in a number of directions not least through the separate efforts of both authors. Winter (1990) proposes that repetitiveness, embodiment in physical and human assets and ease of identification are the defining hallmarks of routines. Winter (1990, p. 276) makes an important distinction between cognitive rules and routines as performances: "…it is the pattern of activity, the process, the organisational performance that is the routine –

---

[4] Thompson's (1967) provided a clear argument as to why firms needed to buffer their inner core from unstable environments. Penrose (1959) views the growth of the firm as dependent on the relative balance of managerial services available for current operations and for planning and executing expansion programmes. Routinisation of operations frees up managerial resources for expansion.

not the diagram, device, plan or recipe". Reynaud (2002) makes a similar distinction, looking at cognitive rules as abstractions waiting interpretation, whereas routines constitute the pragmatic interpretation and enactment of rules.

Feldman and Pentland (2003) adopt the opposite view, emphasising that routines display both ostensive and performative aspects - or "know that" and "know how" in Ryle's (1949) terms. For Cohen and Bacdayan (1994, p. 555) and Feldman and Pentland (2003, p. 115) routines are produced by a variety of people, are distributed over space and time and interact with a variety of streams of action, making it difficult to identify their boundaries. The implication is that routines are less protected from sources of variability than Nelson and Winter assumed, and have further potential for change than is commonly recognised. Narduzzo et al's (2000) empirical study on routines in the field concluded that routines in the narrow behavioural sense of repetitive, tacit behaviours played a marginal role in the activities they observed. Instead, routines are seen as embedded in more complex patterns of action in which interpretation and reasoning play a key role.

The 1995 Santa Fe symposium achieved a modicum of convergence on the definition of routines but in the process, further blurred the distinction between "know how" and "know that" (Cohen et al 1996, p. 683):

"A routine is an executable *capability* for repeated performance in some context that has been *learned* by an organisation in response to *selective pressures*" [emphasis in original]

Subsequently, a number of authors have attempted to clarify the distinction between routines and capabilities. Nelson (1991) looks at firms as hierarchies of routines and defines the organisation's core capabilities by the existence of lower-level skills and higher order routines to invoke the necessary combination of skills to perform a particular task. Most of this knowledge is tacit and resides not in the heads of individuals but in teams of individuals sharing common experiences and with only a partial and incomplete view of what constitutes a particular routine. For Langlois and Robertson (1995, p. 16) routines refer to actual performance whereas capabilities also include potential performances if resources were reallocated. Winter's (2000, p. 983) adds little clarity to the debate by defining a capability as:

 "…a higher level routine (or collection of routines) that together with its implementing input flows, confers upon an organisation's management a set of decision options for producing significant outputs of a particular type".

Loasby (1999) recasts the relationship between routines and capabilities in the wider setting of the division of labour and the growth of knowledge. Loasby (1999) anchors the definition of capabilities in the "knowledge-how" required for productive activities. "Know-how" is the domain of skilled performance, learned through situated practice and emulation of experienced performers. Loasby makes a further distinction between direct and indirect "know-how" - we may either know how to do something ourselves or how to get something done for us.[5] Capabilities thus belong to the realm of direct and indirect "know-how".

Routines become a special case of capabilities. All decisions require partial closure and routines are instrumental in providing that closure. Routines reduce cognition costs, save time, provide stable patterns on which evolution can work, and leave room for the development of indirect capabilities which further help to impose coherence on the activities of an organisation. A further characteristic of routines is that, at least in their broad outline, they are widely known and shared by skilful practitioners operating in a particular field of activity as Nelson and Sampat (2001) remarked. In this sense, routines can be seen as relying on widely available social technologies, embodying cumulative public knowledge from which practitioners can selectively draw and apply in specific contexts.

Rather than stick to the definition offered by Cohen et al (1996), Loasby proposes that we should better advised to recognise the variety of performances within which elements of routines may be usefully recognised. Moreover, what appears to be routine may be a manifestation in a stable environment of a capability that can effectively cope with a variety of situations, perhaps with little or no conscious thought. In fact, as Nelson and Sampat (2001, p. 43) recognise, routines themselves vary enormously in the degree to which they are articulated and the extent to which they are based on consolidated knowledge. Loasby ponders on the advantages and pitfalls of turning "know how" into "know that". Even if codification can reduce disagreements and simplify coordination, "…ambiguity and even conflicts between perceptions and established patterns are the conditions of creativity" (Loasby 1999, p. 67).

---

[5] Nelson and Winter (1982, p. 125) noted that: "Organisations can get a great deal accomplished that they do not know how to do, by drawing on the capabilities of other individuals and organisations".

Finally, recent contributions have attempted to recast the relationship between short-term adaptiveness and long-term adaptation in a new light. Zollo and Winter (2002) characterise dynamic capabilities as systematic patterns of activity aimed at the generation and adaptation of operational routines. Dynamic capabilities are developed through the co-evolution of three mechanisms: first, repetition tacit accumulation of past experience, as in the traditional learning curve mechanism (Argote and Epple, 1990). Secondly, articulation of tacit knowledge allows the sharing of experience and the improved understanding of cause-effect mechanisms through extended dialogue and benchmarking. Finally, the codification of knowledge in the form of manuals, tools and procedures can develop new knowledge (e.g. codification may help sharpen the understanding of cause-effect mechanisms) as well as diffuse existing knowledge. Loasby (2002) conceives of knowledge as system of variable and dynamic connections. This knowledge is not abstract and disembedded but consists of solutions to problems that have been satisfactorily resolved and carried forward as a generative system of connected elements. New knowledge proceeds through the creation, maintenance and destruction of these connections. Institutions are a response to the limitations of the incompleteness and dispersed nature of knowledge but they are also an important supplement to the structure of internal cognition. As Loasby (2002, p. 1235) puts it:

 "Knowledge itself is organisation, produced by trial and error, and always subject to challenge, including changes in its form and its relationships to other bodies of knowledge; it is the product as well as a precondition of decisions. Knowledge lies in the particular connections between elements rather than the elements themselves…"

Nelson (2003) regards know-how as widely distributed amongst individuals and groups and as needing effective coordination to be marshalled in appropriate directions. Nelson contrasts physical and social technologies; physical technologies involve recipe or blueprint-like operations, which may require highly specialised skills as well as artefacts. Social technologies, by contrast, are associated with effective structures for the division of labour and procedures for the coordination of distributed and specialised tasks. The evolution of know-how depends on this mixture of articulated and tacit knowledge, on the shifting alliance between physical and social technologies, on "off line" activities such as R&D labs and "on-line" experimentation and tinkering.

A number of conclusions emerge from the preceding discussion. First, routines are not easy to isolate and identify from streams of activities in organisations unless they are reducible to simple programmes often embodied in physical technologies (e.g. LIFO inventory systems). Secondly, routines are manifestations of capabilities that have been artificially stabilised in quasi-closed systems through investments in appropriate human and physical resources. Thirdly, routines are embedded in systems of activities that require coordination amongst routines at an intra and interorganisational level. The coordination of routines requires an appropriate administrative structure (Penrose, 1959) with its own set of higher level routines, which looks after both changes in individual routines as well as changes in the way routines interface with each other and whole configurations of routines are rearranged. Some of these routines may be simple search and innovating routines as in Nelson and Winter (1982), whereas others may involve complex patterns of coordination and integration of knowledge across firm boundaries (Pavitt, 2002).

3. The Aircraft Maintenance Study

Our case study has involved a number of semi-structured interviews with senior managers, engineers and mechanics of a maintenance and repair station attached to an airline operator, as well as the consultation of a wide range of secondary sources. Amongst these secondary sources, publicly available documents from regulatory authorities as well as magazines such as *Aircraft Technology Engineering Maintenance* have proved particularly valuable. Our focal repair station is certified[6] to carry out inspections on its parent company's fleet of Airbus aircraft (A310, A320 and A340) plus a number of other aircraft types that were at some stage operated by its parent namely Boeings 707, 727 and 737 as well as the Lockheed Tri-Star L1011. It currently employs over 1,800 people and markets its aircraft, engine, component and engineering services to third parties as well as performing in-house work. Its annual turnover from third parties reached €77.7 million in 2003.

---

[6] In this case, the repair station holds two certificates: JAR 45 and FAR 145. JAR 45 is issued by the European Joint Aviation Authorities (JAA), an associated body of the European Civil Aviation Conference (ECAC) representing the civil aviation regulatory authorities of a number of European States who have agreed to co-operate in developing and implementing common safety regulatory standards and procedures. FAR 145 is the equivalent certificate issued by the American Federal Aviation of Administration (FAA). In recent years, there has been a significant effort to harmonise European and American standards.

3.1. The Environment of Aircraft Maintenance Work

The companies that operate in the civilian airline industry (e.g. airliners, airframe and engine manufacturers, repair stations) face a highly regulated context. Different regulatory authorities[7] construct a set of rules establishing what is acceptable, desirable or mandatory in what concerns all activities and resources involved in the operation and maintenance of aircraft. These rules emanate to a large extent, from a process of codification of distributed knowledge and experiences generated by the whole industrial system and are subject to evolution over time.

These rules in turn, generate routines of aircraft maintenance embodying particular safety and reliability logics. Maintenance programmes have evolved in recent years and became more flexible in order to reflect the different technical and economic requirements faced by aircraft operators. It is common in the industry's parlance, to distinguish between the traditional approach based on "hard time" and modern approaches, less rigid in terms of the frequency of inspection, repair or replacement of aircraft parts.

The traditional "hard time" approach was based on the principle of preventative maintenance, where structures and components were overhauled at set intervals. This approach, dominant until the 1960s, began to be regarded as uneconomical as well as having an adverse effect on reliability and safety[8]. As one of our interviewees put it:

> "The philosophy was to tinker with everything and repair parts before anything was wrong (…) It was an intrusive maintenance (…) we risked disturbing stable regimes by removing components and sending them to the workshop, even if they were working fine and without apparent faults".

Not only could "hard time" inspections lead to maintenance-induced errors and faults, but new evidence was also pushing towards a new framework for programmed maintenance. In a bid to increase the length of service intervals, airlines and airframe manufacturers regularly submitted to regulatory authorities selected samples of components with longer life cycles than originally forecasted. The planning of

---

[7]For example, the Federal Aviation Administration (FAA) in the US, the Civil Aviation Authority (CAA) in the UK, the Association of European Airlines (AEA).

[8] Rosenberg (1982, p. 136, footnote 26) remarks: "It is known that taking complex things apart creates some nontrivial likelihood of putting them together incorrectly. Thus, the possibility of identifying a defect by more frequent maintenance is offset by the possibility of doing something wrong and therefore of creating new hazards as well as reducing existing ones".

inspections, removal and repair of a variety of parts and systems operating under different maintenance regimes proved harder than expected whilst the emergence of self-diagnostic kits made planned some planned maintenance tasks obsolete.

In the early 1960s, the FAA formed an industry committee to look at alternatives methods to ensure reliability. These efforts eventually led to the formation of a team designated as Maintenance Steering Group (MSG), including airframe and engine manufacturers, airline operators and regulatory authorities. The MSG documents produced by the Air Transport Association (ATA) set up a framework of decision rules, which served as a platform for developing maintenance programmes for specific aircraft. The first version of this document the MSG-1, was first developed with the Boeing 747-100 in mind and the publication of the MSG-2 in the early 1970s was applied to the two rivals of the B747, the Lockheed Tri-Star L-1011 and the McDonnell-Douglas DC-10.[9]

The MSG documents changed maintenance philosophies in radical ways. The notions of "on condition" and "condition monitoring" allowed a drastic reduction of the number of overhauls, compared to the "hard time" method by as much as a factor of ten. Components remained "on condition" if suitable inspections could be carried out to determine the serviceability of a component until the next scheduled maintenance. Condition monitoring required the setting up of systems to track the "mean time between failures" and the "mean time between removals of components". When these mean times exceeded pre-specified levels, action was initiated to investigate and rectify the problems.

In 1979, an ATA task force met to consider the result of the MSG-2 experience, it became obvious that changes in aircraft technology were beginning to impact on maintenance methodologies. For example, there was a need to distinguish between functional failures that had an impact on operational safety and those that didn't. If a failure was deemed not to affect operational safety or have negligible economic repercussions, a routine maintenance activity was considered unnecessary.[10]

The current version of MSG-3 contains a system of rules intended to act as guidelines for the setup of maintenance schedules for four areas: systems/ power plant, aircraft structure, zonal inspections and lightning/ high intensity radiated fields). For example,

---

[9] A European version (EMSG-2) was applied to the Concorde and the Airbus A300.

[10] The MSG-3 document introduced in 1980 is still in operation under revision 2003.1 entitled *ATA Operator / Manufacturer Scheduled Development Maintenance (MSG-3).*

as far as systems/ power plant is concerned, the construction of a maintenance schedule must start by defining the systems, subsystems and components that comprise the systems/ power plant area. Once this is done for each of these elements and based on technical information and past experience, maintenance significant items (MSI) are identified. Maintenance schedules for these items are constructed based on a flowchart method featuring steps such as ease of detection of failures, the impact of failures on safety, as well as other technical and economic criteria.

Functional failures are classified in different categories according to their potential for detection and impact, and for each potential cause of failure there are defined maintenance activities: servicing/ lubrication, operational/ functional check, general visual inspection, detailed inspection, special detailed inspection, restoration or replacement. To the extent that airline operators differ in the pattern of usage of aircraft, the intervals for scheduled maintenance are defined taking into account dominant parameters. The more frequently used parameters are calendar time, flight hours / cycles, engine / auxiliary power unit hours/ cycles. The initial definition of these parameters is usually unavailable before the equipment enters service. Previous experience with similar equipment may serve as an initial guide and revisions to these parameters, which will be ongoing through the operating life of the equipment.

 The MSG framework document highlights a number of issues. First, the emergence of a wide consensus on altering maintenance philosophies from a hard-time, intrusive maintenance to a more flexible approach. The various systems, subsystems and parts of an aircraft vary widely in terms of their performance after intrusive inspections, of their functional and economic relevance and in the ease with which faults can be detected and rectified. To deal with this variety would be impossible with a "hard time" based maintenance schedule, where a large number of parts need to be inspected at fixed intervals.

Secondly, the MSG document establishes only a generic framework and rules that need to be adapted to specific contexts, namely for particular aircraft models. This creates some room for variety in the construction of maintenance schedules as explicitly recognised in the ATA MSG-3 document. [11]

---

[11] "This document contains recommended specifications that have been developed for the covered topics. ATA does not mandate their use (…) There may be practices, standards, and/ or regulatory requirements applicable to your operations that exceed the requirements in this document" (ATA MSG-3, 2003, p. 1)

Thirdly, the MSG framework is diffused across the industry and tends to influence more specific maintenance documents at different levels. For example, a steering group constituted by airframe manufacturers, component suppliers, airline operators and regulatory authorities may use the MSG-3 framework for the development of a Maintenance Review Board (MRB) report concerning the initial maintenance requirements for a specific aircraft or even the redesign of maintenance schedules for older aircraft. The MRB is, in turn, used to construct the Maintenance Planning Document (MPD) of a specific type of aircraft, which includes additional optional maintenance items recommended by the manufacturer or from other sources (e.g. airworthiness notices).

The MPD is then used to construct the maintenance programme of a particular aircraft adapted to its operating context, which has to be approved by the respective national regulatory authorities. For example, the same model of aircraft can differ in terms of systems or subsystems depending on whether the aircraft is used for cargo or passenger transport. Every operator can organise maintenance tasks in accordance with its operational schedule and additional requirements. The seasonality of commercial operations or specific climatic conditions (e.g. high humidity) may dictate adaptations to maintenance schedules.

In the past, most airline operators had their own repair and maintenance facilities. These days for virtually all but the operators with large fleets, maintenance and repair are outsourced to specialist firms. In addition, reciprocal agreements between the maintenance arms of operators are a frequent occurrence – e.g. the station of one operator carries out maintenance tasks for another operator and vice-versa.

Fourthly, both specific maintenance programmes and the generic rules underpinning their construction evolve over time – a form of disembodied "learning-by-using" (Rosenberg, 1982). For example, MRB reports are seen as "living" documents that are constantly under review to reflect the lessons learned during an aircraft model's operation. The initial version of an MRB is built on generic assumptions, projected operational conditions and past experience. Maintenance schedules are constantly being updated not only because new systems are being added to particular aircraft models but also because of the cumulative operational and maintenance experience acquired by a variety of actors (e.g. operators, parts suppliers, airframe manufacturers, repair stations).

Finally, cumulative experience in maintenance, including non-programmed maintenance, constitutes a platform not just to improve maintenance schedules but also the design of systems, subsystems and components – disembodied turns to embodied "learning-by-using". The FAA and other regulatory authorities issue airworthiness directives every time problems are discovered and corrective action (e.g. redesign of a specific part) is required. The number of airworthiness directives issued against a particular aircraft type is an indication of the degree of problems experienced with that aircraft type.[12]

Experience with a type of aircraft, both in terms of chronological age as well as cycles and flight hours, is thus an invaluable source of know-how about an aircraft's performance. Aircraft models take years to be designed, manufactured and issued with appropriate operational certificates. It usually takes years of use and the accumulation of thousands of flight hours for an aircraft to go through heavier and longer inspection tasks. Only at this stage is it legitimate to extract conclusions about an aircraft's reliability and long-term performance. For older aircraft it is customary to include more non-routine man-hours in contract work. Corrosion and fatigue in particular, are responsible for much of this non-routine work.

Airline operators usually classify inspections according to their periodicity and scheduled downtime. Type A inspections are carried out frequently and in some cases do not even require hangar time. Type B inspections can be done every 400 to 500 flight hours, type C every 12 to 18 months and type D may be done every 8 to 10 years. In the latter case, scheduled downtime may be as long as 4 to 5 weeks and requires major structural checks. The differentiation of tasks and capabilities required for different type inspections is often institutionalised in the organisational structure of repair stations – e.g. operational and heavy maintenance divisions.

4. Analysis

Aircraft maintenance constitutes a particularly interesting setting to examine routines and "learning-by-using". A document such as MSG-3 on how to develop maintenance programmes can be seen as set of rules that trigger a set of routines in the sense of Nelson and Sampat (2001, p. 42), " … a collection of procedures, which taken

---

[12] Bearing in mind that the reasons for issuing a directive can range from fairly minor to safety critical.

together, result in a predictable and specifiable outcome". The specifiable outcome is in this case an airworthy aircraft and the procedures constitute the set of activities mandated by the maintenance schedule. The maintenance documents, namely the MPD, contain detailed information on how to assess the status of a particular system or part, how to carry out inspections and the sequence of steps that should be followed in order to decide what corrective action is required. Routines or, more accurately, sequences of routines are embodied and made effective through a set of documents, materials and equipment. Even the performance of the most mundane of maintenance tasks relies on equipment, tools and human skills that obey strict standards in accordance with the rules stipulated by regulatory authorities. Repair stations are certified to carry out maintenance on specific aircraft types but those certificates are temporary and require continued practice of those maintenance routines ("remembering-by-doing"). Regulatory authorities carry out periodic audits when all parts and equipment are checked for their approved sources and calibration certificates.

The notion of routines highlights that choices are made in the course of performing a routine but choices are seen as highly focused and automatic. Aircraft maintenance provides an excellent example of how routines can be embodied in highly codified set of practices, materials and equipment. These embodiments are what make repetitive, reliable and auditable performances possible in the first place.

At the same time, routines constitute good platforms for building variation in what, borrowing from Nelson (2003), we might call "on-line learning". By providing a stable background against which minor variations can function as a form of controlled experiment, routines enable different forms of on-line learning. On-line learning can occur at three levels. At the lowest level, mechanics learn their craft by carrying out tasks and solving problems by following manuals and troubleshooting guides. But only experience and socialisation can help interpret and provide resources for dealing with the limitations of manuals (Brown and Duguid, 2000). Problems and troubleshooting stories are discussed within maintenance groups that are usually split according to the division of knowledge embodied by the aircraft architecture (e.g. engines, aircraft controls and landing gear, avionics). There may be a degree of redundant knowledge across these groups where individuals have rotated from one group to another, but this tends to be a rare occurrence. Each maintenance subgroup constitutes a community of practice in its own right, bound by its common training

and shared experience in resolving a particular set of problems (Brown and Duguid, 2000)

At a second level, on-line learning occurs when problems become non-routine or when existing rules do not cover specific problems. One example was provided by a recurring problem with the landing system in an Airbus A340. When the aircraft was fully loaded and the angle of torsion in a tight landing strip was above 70 degrees, one of the centrelines in the landing gear broke under the strain – 4 episodes in 4 aircraft quickly alerted the operator to a systematic problem Dialogue between the repair station of the operator, the airframe manufacturer and the landing gear supplier led to an investigation which included installing new software and a component that acted as a fuse, its failure warning of impending and more serious problems.

At another level, there is a continuing dialogue between the different parties involved in maintenance. Mechanics uncover problems and consult maintenance engineers with problems as well as suggested solutions. If there is a resident representative of the airframe manufacturer, problems can be discussed and solutions agreed between the two parties. Parts supplier may also have to become involved as and when necessary.

Lastly, larger and non-routine problems that ground an aircraft for days are the subject of technical incident reports, which may lead the airframe manufacturer to alter the MPD of the aircraft type and in some cases, offer to repair items that have proved less reliable than expected. Regulatory authorities become involved in the promulgation and diffusion of airworthiness notices issued as a result of problems found with a particular aircraft model.

The bodies of expertise involved in aircraft design, operation and maintenance are highly specialised, diverse, distributed across many actors and are difficult to integrate and coordinate across intra and interorganisational interfaces. Nobody knows everything about how to design, operate and maintain aircraft, as Rosenberg (1982) noted. Some of these interfaces can be highly interactive and contribute to rich flows of know-how and experience (Araujo et al, 1999). Repair stations attached to airline operators can instigate systematic dialogue between aircrews and maintenance engineers and continuity of association can supply valuable feedback on solutions to specific problems. On the other hand, standalone repair stations tend to conform strictly to rules and have little or no opportunity to benefit from richer interactions. Airframe manufacturers tend to attach representatives to combinations of repair stations and airline operators, whenever the size of fleet justifies it. In these cases, a

triple interface between airframe manufacturer, operator and maintenance and repair station generates useful knowledge and data about aircraft performance in operation.

The preceding discussion sheds some light on the role of routines and the evolution of know-how in the case of aircraft maintenance. Aircraft maintenance can best be seen as a system of know-how embedded in a range of multiple relationships involving a variety of different actors, holding dissimilar but complementary knowledge. As we have shown, maintenance know-how is intimately connected with design and operational know-how and the interfaces between these three bodies of knowledge require careful coordination.

This coordination happens at three levels: at the lowest level, it is the interaction and coordination of maintenance, operational and design know-how that often have to confront non-routine problems and invent novel solutions. This is a highly interactive interface, with teaching and learning on both sides of the interface. In particular, airframe and air engine manufacturers learn a great deal from the range of operational experience their aircraft and engines get exposed to.

This corresponds to Rosenberg's (1982) "learning-by-using" but it adds a few details to this story. "Learning-by-using" is the product of multiple and dispersed interactions amongst heterogeneous bodies of expertise. In the case of disembodied "learning-by-using", it applies to changes in maintenance routines or additions to existing manuals or procedures. These minor changes may only involve the operational and maintenance know-how or require a simple approval by the manufacturer concerned. More serious problems may involve design know-how and require alterations to existing designs, as in the landing gear case mentioned above. In these situations, an upstream chain reaction may be triggered and involve component or subsystems suppliers. In the case of embodied "learning-by-using", as Rosenberg (1982) highlights, knowledge pooled from a variety of user experiences is fed back into the product development stage resulting in redesigned that are incorporated in new aircraft and replacement stocks.

At a second level, coordination and "learning-by-using" takes place at the multiple arenas where the different parties involved in aircraft design, operations and maintenance meet. Maintenance steering groups, in particular, aggregate experience from various interested parties namely airline operators and maintenance stations in the drafting of the framework of maintenance rules. Large operators with strong

maintenance engineering groups often play the role of lead-users in these steering groups (Von Hippel, 1986) and help shape new sets of rules.

Finally, at the top level (see figure 1) stand regulatory authorities at the national and international level. Their key role is to promulgate, diffuse and enforce rules covering all aspects of airline operation, including all activities relating to maintenance. As far as maintenance is concerned, strict rules apply to every step from the qualification of technicians to the approval of sources for equipment and the calibration of tools.
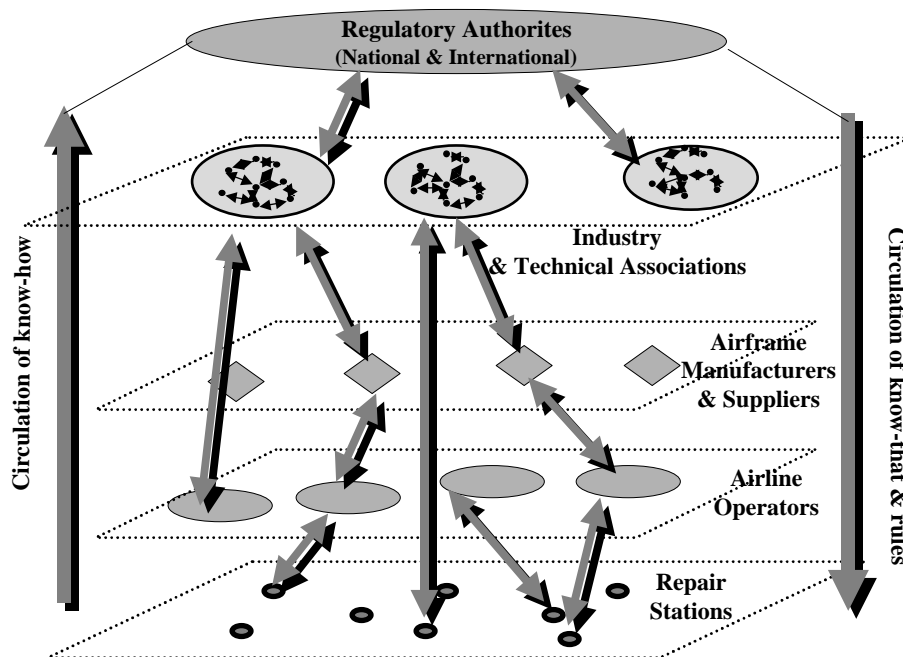

Figure 1

These rules translate into detailed and rigid routines embodied in a range of materials including manuals, troubleshooting procedures, inspection schedules, software, testing equipment and tools. The embodiment of routines in "harder materials" creates a quasi-closed system and ensures that sources of variability are minimised. But, as we have argued, systems can never be perfectly closed and throughout the lifecycle of the operation of an aircraft model, new and often unexpected sources of problems keep appearing.

Aircraft maintenance can thus be seen as combining a network of interrelated, rigid and readily auditable operational routines with a system that caters for the evolution of know-how, broadly understood as the generation and selective retention of novelty (Loasby, 2002). What is critical to this evolution is the presence of a reliable baseline

against which the effects of variations can be measured. As Loasby (2000, p. 307) put it: "Without variation there is no experience to act as a basis for learning; without a stable framework there is no assurance that any valid connections can be made between actions and outcomes that will have any future relevance".

The extra ingredient that explains the evolution of this know-how is organisation, namely the organisation of specialisms in categories and the coordination between these categories. Different types of organisation privilege different networks of connection and have differing abilities to select and carry forward different types of knowledge. Maintenance and repair stations carry forward important practical know-how on operational problems and faults, which tends to be more important the older an aircraft is and the more non-routine their work becomes. Operators subject aircraft to different schedules, flight conditions, landing cycles and accumulate valuable know-how and data on aircraft's performance, costs, etc. Airframe manufacturers and their suppliers learn from airlines and maintenance stations about new and unforeseen problems and sometimes, novel solutions to existing problems. Problems found during operation and maintenance lead to changes to maintenance practices and schedules (disembodied "learning-by-using") as well as the redesign of components or subsystems involving airframe manufacturers and their suppliers (embodied "learning-by-using").

Finally, regulatory authorities monitor that all activities are carried out in conformance with prescribed rules, codify and diffuse new knowledge through airworthiness directives and carry out detailed investigations on technical incidents and accidents. As a result of these more detailed investigations, they may enforce important changes in the design of parts and systems, maintenance schedules, tests as well as certification of the material and human resources involved in maintenance. These different organisations, as Loasby (2002, p. 1235) suggests, are the equivalent of differentiated species but they and their interactions embody purpose and imagination, internalise and accelerate the selection process and use the outcomes of selection for further trials and experimentation.

4. Conclusions and Implications

The argument developed in this paper sheds some light on the notion of routines and its relationship with the evolution of "learning-by-using". In aircraft maintenance,

routines are essential to ensure that tasks are performed repetitively, reliably and every aspect of their performance is traceable and auditable. As we have shown, routinisation is accomplished through the detailed codification of activities and the embodiment of procedures in human and physical resources such as manuals, software packages, tools, test kits, etc. In short, routines become a special case of capabilities that have been institutionalised and inscribed into a variety of resources and organisational devices (Patriotta, 2003). These different resources and organisational devices play a key role in creating quasi-closed systems that attempt to minimise sources of variability and to anticipate the sources of problems.

As we have shown, even in the admittedly extreme case of aircraft maintenance, there are plenty of sources of variability that cannot be shut out of the performance of routines and thus literal repetition is neither possible nor desirable. The quasi-closed system envisaged by airframe manufacturers in the "hard-time" maintenance era has progressively become more attuned to the diversity of operational conditions and the need to see the aircraft as an assemblage of different systems, subsystems and components requiring different maintenance philosophies and schedules. Reliability data and a richer experience with specific designs as well as technological advances in monitoring the condition of aircraft parts (e.g. self-diagnostics) have also contributed to these changes.

The pooling of experience across the whole civilian aircraft industry and the multiple relationships established between actors with complementary but dissimilar know-how created a system in which routines and the rapid evolution of cumulative know-how are tightly linked. Clockwork routines provide a stable baseline against which minor variations can be monitored. Close relationships and frequent interactions at multiple levels, headed and monitored by national and international regulatory authorities, lead to a knowledge sharing system more akin to a scientific commons than a commercial environment. On-line learning at the level of routines and situated practices of maintenance are supplemented by off-line learning mechanisms involving coordination of dispersed know-how by virtually all the relevant actors in the industry in bilateral and multilateral relationships, through multi-party groups that meet under the aegis of airframe manufacturers, industry and professional associations as well as regulatory authorities.

From a theoretical stance, the present study provides three suggestions for further research on routines. First, as others have found (Narduzzo et al, 2000) the study of

21

routines *per se* hides few mysteries. Elements of routinisation are present in many activities but it is difficult to identify the boundaries and an appropriate level for the study of routines. The inspection of an aircraft part is itself composed of many routines arranged according to sequential steps in flowcharts. A more useful avenue is to investigate the means used to construct routines and the different mechanisms used to ensure repetitive and reliable performances.

Secondly, routines at different levels have to be coordinated and articulated in particular combinations and for particular purposes. The need for specialisation and for developing know-how in particular areas often leads organisations to split themselves into subdivisions mirroring these specialisms. Thus operational and heavy maintenance tasks denote different specialisms and are best kept apart. The functional architecture of an aircraft is reflected in the division of maintenance specialisms (e.g. engines, aircraft controls) with virtually no overlap in specialist know-how. The counterpart to this fragmentation is the creation of coordination routines and relationships that attempt to bridge over the necessarily myopic specialisation embodied in operational routines. This is one area that has been somewhat neglected and is ripe for further research.

Finally, our study points to the limitations of the notion advanced by Levitt and March (1990, p. 16) that "... organisations are seen as learning by encoding inferences from history into routines that guide behaviour." Routines provide a valuable source of on-line learning. But at a broader level of analysis, learning requires a combination of on and off-line learning, of tacit "know-how" and codified "know-that", and relies on a variety of mechanisms and relationships to ensure the purposeful retention of successful variations both within and across a network of specialist actors. Nelson and Sampat's (2001) timely reminder that most routines rely on knowledge widely available in specialised communities of practitioners opens up an interesting avenue for further research.

References

Araujo, L., A. Dubois, and L.-E. Gadde (1999). "Managing Interfaces with Suppliers." <u>Industrial Marketing Management</u> **28**(5): 497-506.

Argote, L. and D. Epple (1990). "Learning Curves in Manufacturing." <u>Science</u> **247**: 920-924.

Cohen, M. D. and P. Bacdayan (1994). "Organizational Routines are Stored as Procedural Memory - Evidence from a Laboratory Study." <u>Organization Science</u> **5**(4): 554-568.

Brown, J. S. and P. Duguid (2000), <u>The Social Life of Information</u>, Cambridge, MA, Harvard Business School Press

Cohen, M. D., R. Burkhart, G. Dosi, M. Egidi. L. Marengo. M. Warglien and S. Winter (1996). "Routines and other Recurring Action Patterns of Organizations: Contemporary Research Issues." <u>Industrial and Corporate Change</u> **5**(3): 653-698.

Cyert, R. M. and J. G. March (1963). <u>A Behavioral Theory of the Firm</u>. Englewood Cliffs, NJ, Prentice-Hall.

Dyer, J. H. and H. Singh (1998). "The Relational View: Cooperative Strategy and Sources of Interorganizational Competitive Advantage." <u>Academy of Management Review</u> **23**(4): 660-679.

Feldman, M. S. and B. Pentland (2003). "Reconceptualizing Organizational Routines as a Source of Flexibility and Change." <u>Administrative Science Quarterly</u> **48**(1): 94-118.

Langlois, R. N. and P. L. Robertson (1995). <u>Firms, Markets and Economic Change: A Dynamic Theory of Business Institutions</u>. London, Routledge.

Levitt, B. and J. G. March (1990). Chester I. Barnard and the Intelligence of Learning. In <u>Organisation Theory. From Chester Barnard to the Present and Beyond</u>, edited by O. E. Williamson, Oxford University Press**:** 11-37.

Loasby, B. J. (1999). <u>Knowledge, Institutions and Evolution in Economics</u>. London, Routledge.

Loasby, B. J. (2000). "Market Institutions and Economic Evolution." <u>Journal of Evolutionary Economics</u> **10**(3): 297-309.

Loasby, B. J. (2002). "The Evolution of Knowledge: Beyond the Biological Model." <u>Research Policy</u> **31**(8-9): 1227-1239.

March, J. G. and H. A. Simon (1958). <u>Organizations</u>. New York, John Wiley.

Narduzzo, A., E. Rocco, and M. Warglien (2000). Talking about Routines in the Field. <u>The Nature and Dynamics of Organizational Capabilities</u>. G. Dosi, R. R. Nelson and S. G. Winter. Oxford, Oxford University Press**:** 27-50.

Nelson, R. R. (1991). "Why do Firms Differ, and How Does It Matter?" <u>Strategic Management Journal</u> **12**: 61-74.

Nelson, R. R. (2003). "On the Uneven Evolution of Human Know-How." <u>Research Policy</u> **32**(6): 909-922.

Nelson, R. R. and B. N. Sampat (2001). "Making Sense of Institutions as a Factor Shaping Economic Performance." Journal of Economic Behavior & Organization **44**(1): 31-54.

Nelson, R. R. and S. G. Winter (1982). An Evolutionary Theory of Economic Change. Cambridge, MA, Belknap Press.

Patriotta, G. (2003). Organizational Knowledge in the Making. How Firms Create, Use, and Institutionalise Knowledge. Oxford, Oxford University Press.

Pavitt, K. (2002). "Innovating Routines in the Business Firm: What corporate tasks should they be accomplishing?" Industrial and Corporate Change **11**(1): 117-133.

Penrose, E. (1959). The Theory of the Growth of the Firm. Oxford, Basil Blackwell.

Reynaud, B. (2002). Operating Rules in Organizations. Macroeconomic and Microeconomic Analyses. Basingstoke, Palgrave Macmillan.

Roberts, K. H. and R. Bea (2001). "Must Accidents Happen? Lessons from High-Reliability Organizations." Academy of Management Executive **15**(3): 70-78.

Rosenberg, N. (1982). Inside the Black Box. Technology and Economics. Cambridge, Cambridge University Press.

Ryle, G. (1949). The Concept of Mind. London, Hutchinson.

Sayer, A. (1992). Method in Social Science. A Realist Approach. London, Routlege (2nd edition)

Starbuck, W. H. (1983). "Organizations as Action Generators." American Sociological Review **48**(February): 91-102.

Thompson, J. D. (1967). Organizations in Action. New York, McGraw-Hill.

Von Hippel, E. (1986). "Lead Users - a Source of Novel Product Concepts." Management Science **32**(7): 791-805.

Weick, K. E. and K. H. Roberts (1993). "Collective Mind in Organizations - Heedful Interrelating on Flight Decks." Administrative Science Quarterly **38**(3): 357-381.

Winter, S. G. (1990). Survival, Selection and Inheritance in Evolutionary Theories of Organizations. Organizational Evolution: New Directions. J. A. C. Baum and J. V. Singh. Newbury Park, CA., Sage**:** 269-297.

Zollo, M. and S. G. Winter (2002). "Deliberate Learning and the Evolution of Dynamic Capabilities." Organization Science **13**(3): 339-351.