A pragmatic mapping of factors behind routine deviations in aircraft maintenance

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Abstract: In this paper, we present four cases of deviating actions from prescribed procedures during a base maintenance check of a Dash8/Series100 aircraft by an aircraft maintenance organization in Greece. The detailed analysis of these cases let us identify specific factors that determined the concrete courses of action of maintenance technicians; from the most normative (e.g. manuals) to the most contextual ones (e.g. personal comfort, schedule pressures). These factors combined, pragmatically delimit the technicians' courses of action. We propose that by modelling these factors as networks of determinants, we gain intimate knowledge on the cognitive nature of deviations. The acceptance of deviations as inevitable and the intimate knowledge of their structural aetiology may help us move towards a more pragmatic management in maintenance, supporting technicians to take more "informed" decisions.

Keywords: Resilience, safety critical systems, aircraft maintenance, deviations, work practice

Introduction

Organizing work is often based on axioms of predictability and formalization, where work as performed would ideally be the exact realization of exhaustively predefined tasks; an ideal of absolute top-down control. Towards this direction, exhaustive prescriptions are introduced in work communities by various supervising entities, to define what needs to be done and how it should be done. Nevertheless, organizing through top-down prescriptions does not imply that people working within a work community will simply follow what is predefined, in order to accomplish certain tasks. Workers often face ambiguity in their day-to-day conduct and find themselves in the midst of certain dilemmas. To resolve dilemmas, workers have to judge, decide and develop certain modes of action. Actual work might then deviate from what is prescribed. Over time, such arrays of activity, through repetition, regular contextual distinction, and historical evolution tend to become stable and shared within a work community. Such more or less stable, historically developed and partially unacknowledged arrays of activity, which are at the basis of successful action in a particular work-setting are defined as work practices (Nathanael & Marmaras, 2008a).

The traditional way to tackle the observed discrepancies between practice and prescription is by the concept of conformance through exhaustive control of deviation or amendments to prescriptions. This strategy however ultimately tends towards vicious cycle of more prescription resulting to more deviations and vice versa. Such strategy although intuitive and easy to understand and apply at first is fundamentally flawed. It supposes that the lived reality of work can ultimately be rationalised and become totally predictable. Indeed, this is true, up to a certain level of systematization. However as Charles Perrow (1984) has demonstrated almost thirty years ago, organizational oversize leads to interactive complexity and over systematization to tight coupling; the result is unpredictability. And unpredictability calls for resilience (Woods & Hollnagel, 2006). In order to enhance resilience, organizations must be able to adapt or to absorb disturbances, disruptions and change (ibid). In this line of thought it has been suggested that, organizations should provoke a constant dialectic between what is prescribed and what is actually done (Nathanael & Marmaras, 2008b). In other words, in order to enhance organizational resilience, one needs to acknowledge the mute confrontation between what is actually experienced – i.e. work practice – and what is prescribed. It is by accepting this confrontation and uncovering it (i.e. into a dialectic) that ultimately an organization gains in ability to absorb diverse threats and adapt accordingly.

On Research Method

In this paper, we present four cases of deviating actions from prescribed procedures. Three of them were observed during a base maintenance check of a Dash8/Series100 passenger aircraft by a long established aircraft maintenance organization in Greece. The fourth one was observed during our field observations at a same type aircraft on which an unscheduled maintenance act had to be performed. The scheduled check was conducted by a team of mechanics and avionics technicians. Each member was appointed to a certain role (team leader, authorized technician, assistant technician). The majority of team members had worked jointly under the supervision of the maintenance organization for the past 3 years in equivalent maintenance teams. The experience of the team members ranged from 6 months to 25 years. The maintenance check lasted a total of 20 work days, on one shift per day. One researcher carried out field work, including systematic observations and interviews with the personnel. The field work lasted in total 12 days, 5 hours per day. A familiarization period preceded the field work period, in order to become as native as possible to the work team, according to standard ethnographic practice. During the observations period, the researcher was closely following and observing the actions of one of the technicians per task, having in hand the task instruction being carried out. Hence, only a proportion of the total actual maintenance actions was observed. The observations were enough, though, on our pursuit of deviating acts. The researcher tried not to distract the technicians during the performance of maintenance acts and semi-structured interviews were taking place in idle periods, after work or during breaks. The personnel was probed to verbalize and justify their actions. Any data collected during the field work was recorded by non-intrusive (pen and paper) means. Following the field work, the researcher exhaustively studied all the manuals (manufacturer's and organization's) concerning the maintenance actions observed.

The deviation cases concerned both tasks carried out for the first time by maintenance technicians and tasks which have been repeatedly carried out by the maintenance team. For example, the first case, concerns a local (one time, one person) deviating act where a single technician had to modify the pedal bell cranks beneath the pilots seats by adding steel bushings on the bell cranks clevis holes. The fourth case, concerns a repeated team deviation where the technicians had to remove a damaged power plant and install a serviced one, a job they regularly perform as a team.

The detailed analysis of the above cases let us identify specific factors that by large determined the concrete courses of action of maintenance technicians; from the most normative (e.g. manuals) to the most contextual ones (e.g. personal comfort, schedule pressures etc.). We claim that these factors combined, pragmatically delimit the technicians' courses of action. We represent specific sets of factors as a flat network of determinants mutually conflicting or reinforcing. For example, there are cases where in order to remove a component from a power plant, the technician needs to unscrew and screw back the screws in a certain order, under schedule pressure, using certain torque values for screwing and without a torque wrench at hand. This introduces a conflict between schedule pressure and formal task demands also further aggravated by the possible technician's fatigue. The space for 'officially acceptable' courses of action satisfying all the above determinants may often be null. The technician will inevitably deviate (either in terms of schedule or in terms of work quality). Such deviations may stay local and sporadic. However they may also become routine and move towards institutionalization.

We propose mapping these factors as networks of determinants during actual deviating courses of actions. Technician verbalizations are used to identify the direct determining factors for each decision point in schematized decision – action paths. This basic structure of direct determinants allows us then to make informed assumptions about possible indirect organizational determinants. Doing so allows us to gain intimate knowledge on the organizational and cognitive nature of deviations. The acceptance of deviations as inevitable and the intimate knowledge of their structural aetiology may help us move towards a pragmatic pro-active management in maintenance, supporting technicians to take more "informed" decisions.

Cases Analysis / Results

1. Bushing addition in brake pedal bell cranks

The operator's CAMO (Continuous Airworthiness Maintenance Organization) engineering department received a service bulletin from the aircraft manufacturer. The manufacturer demanded the addition of steel bushings to the rod attachment clevis holes of the brake pedal bell cranks. The task instructions provided by the manufacturer in the service bulletin were distributed to the maintenance personnel through a modification order form, issued by the operator's CAMO engineering department. The task instructions specified that a technician must remove two panels beneath pilot's and co-pilot's seats, to access the working area and then disconnect the rod assemblies from bell cranks on pilot's and co-pilot's sides. After widening the clevis holes' diameter on the bell crank assemblies using a reamer, the technician must install the steel bushings. The bushing installation instructions are provided by the aircraft maintenance manual. According to the bushing installation instructions, the technician must soak the steel bushings in liquid nitrogen before the installation for the contraction of the bushings' diameter. Installation must be done as quickly as possible to prevent expansion of the bushings' diameter. The recommended maximum time for the installation of each bushing is no more than one minute. After the inspection for proper installation of the bushings, the technician must reconnect the rod assemblies to the bell cranks. The technician must check for full and free movement of the pedals by moving the pedal adjustment mechanism fully aft and operating the rudder pedals forward and aft. The task ends with the installation of the removed panels by the technician. It was the first time for this particular technician to perform such task. The modification order and the aircraft maintenance manual were consulted for the proper installation of the bushings. However, liquid nitrogen was not available at the hangar at the time of the task performance. This impelled the technician to pursue an alternative course of action to the prescribed one. The official way of dealing with such cases (means/tools unavailability) is either to halt the task and wait for the means to be available for use, or to officially report to the engineering department and ask advice for further actions. Nevertheless, the technician's task schedule was very demanding as he also had to complete three individual and time consuming tasks after the bushing installation in the brake pedal bell cranks. In addition, the shift leader demanded the task to be finished as soon as possible due to the task's criticality for on time completion of the overall maintenance schedule. The above factors combined (the technician's schedule pressure and the shift leader's pressure for the timely delivery of the aircraft) led the technician to take the decision not to halt the task or ask for official advice but rather to seek for alternative means to accomplish the bushing installation. The technician examined thoroughly the tools available in order to install the bushings. After being consulted by an adept technician who was executing another task nearby, the use of a pressing tool was decided as an alternative to the instructions proposed by the manufacturer. Nevertheless, the adept technician warned that the use of a pressing tool for the installation of the steel bushings could form surface dents at the steel bushings that could afterwards progressively damage and eventually cut the rods attached to them. During the installation, the technician was very careful not to cause surface dents at the steel bushings. A minor surface distortion was revealed during the inspection of the steel bushings after their installation. The surface damage though, according to the technician's judgment was not serious enough to lead to rework. When asked why a pressing tool was used despite the manufacturer's instructions the technician mentioned that there was no liquid nitrogen available in store and that the use of the pressing tool was a good alternative. He also commented that this process will probably not cause any malfunction to the aircraft afterwards.

The mapping of factors for this case is illustrated in Figure 1.

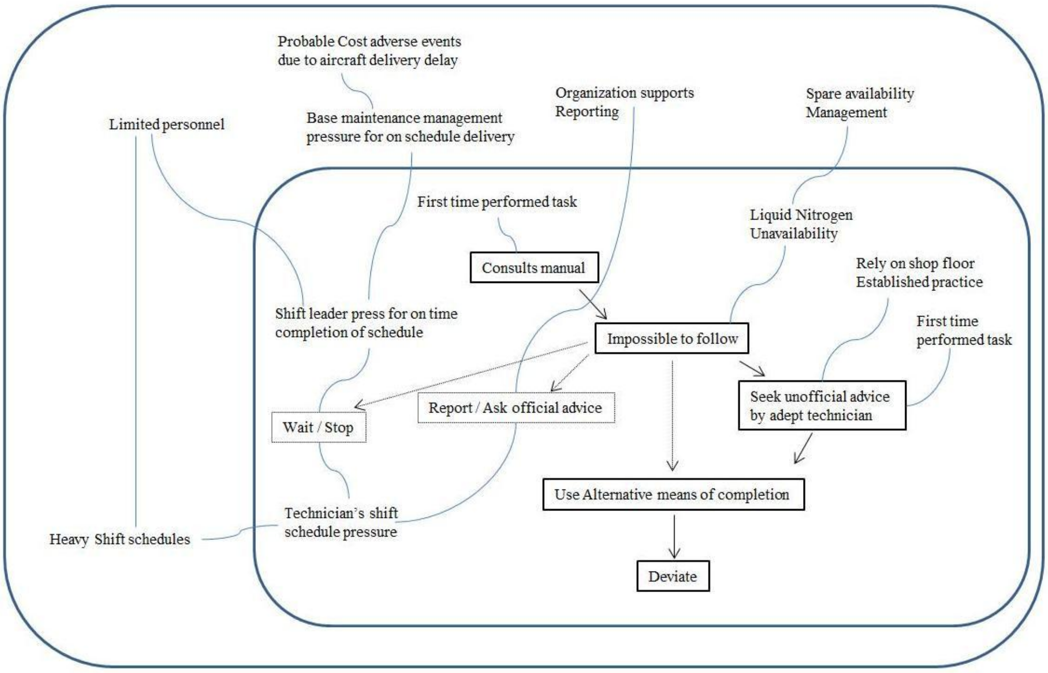

Figure 1. Technician's decision-action path, in solid boxes and solid arrows; alternative action paths -not chosen- in dashed boxes and lines. Direct, local factors influencing the decision path (inner area) include: 1) Unavailability of Liquid Nitrogen, 2) personal shift schedule pressure, 3) shift leader pressure 4) reliance on unofficial practice (i.e. rely on method received from a person having technical knowledge without the organizational responsibility). Indirect organizational factors (outer area) may include a combination of the maintenance organization's limited number of technicians to perform aircraft checks coupled with heavy shift schedules, the reporting practices and spares management.

2. Functional check of the bleed air overtemperature switches

The function of the bleed air system installed on every aircraft is to provide a source of air to operate the rear fuselage air conditioning pack for cabin temperature control and pressurization. The bleed air system receives hot bleed air from the compression section of each engine through its high pressure and low pressure ports. The system consists of several parts and components such as switches, flow control mechanisms, check valves and filters. Two bleed air overtemperature switches close when the duct air temperature falls outside the range of 287°C and −5°C. Each switch consists of a normally open, single pole thermal switch with a bi−metal element. According to the manufacturer's Maintenance Planning Document, every 5000 Flight Hours a functional check should be performed for each switch. For the functional check the switches need first to be removed from the aircraft by a technician. The removal process is described at the manufacturer's aircraft maintenance manual. Then, in order to perform the functional check, the technician must connect each switch to an indicator light circuit and place it in a preheated fluidized bath with aluminum oxide as fluid medium. The technician repeatedly increases and decreases the fluid medium temperature from 270°C to 295°C making sure that the switch closes when the fluid medium temperature ranges from 282 to 293°C and opens at 282°C minimum. The switch's opening or closure is indicated by the indicator lamp's status (when the lamp goes off the switch opens and when comes on the switch closes). After the check is performed and the switches function properly, the technician must reinstall them on the aircraft. During our observations a technician had to remove the switches and perform the functional check as described above. The technician was aware of the manufacturer's instructions for the performance of the functional check. Although all the means needed to perform the functional check (fluid medium, heater, indicator light circuit) were available, the technician bypassed the check and installed new bleed air switches to the aircraft. At the time of the task execution the technician shift had already ended and the technician was working overtime. He claimed freely that he was exhausted due to heavy workload during his shift. On our question why the functional check was bypassed, the technician replied that according to his estimation the switches had surpassed their lifetime and that the functional check would have surely confirmed it. In addition, he claimed that the installation of new switches is a safe shortcut of the prescribed procedure that does not compromise the aircraft's airworthiness. The technician also informed us that his next working shift was for next morning and that he wanted it to be clear of previous incomplete tasks. We also asked him whether the removed switches are further inspected for serviceability and he replied that he tagged them us unserviceable and they would probably be thrown away. As he claimed: "The stores trust the engineers. Nobody checks nothing, after us, until there is a serious reason to do so!" We also checked whether there are any consequences on the technician in cases of excessive use of spares during the task performance. Although there is full control of the stores' tools, parts and components to be used by the technicians, in cases as the above, where a check must be performed to ensure the functionality of a removed part, a spare part is always available for the technician.

The mapping of factors for this case is illustrated in Figure 2.

3. Removal of the fuel tank panels

The internal area of an aircraft wing consists of several parts and components, such as the fuel tanks, fuel transfer pumps, fuel de-icing and flight controlling mechanisms, electrical wiring and joining elements. The maintenance task card manual of the aircraft describes the inspection process of the wings internal, by mentioning the types of inspections to be carried out on each part or component category, e.g. "Inspect each Wiggins coupling for corrosion and general condition". In order to get access and perform the inspections, maintenance personnel must remove specific panels located at the top surface of the wings.

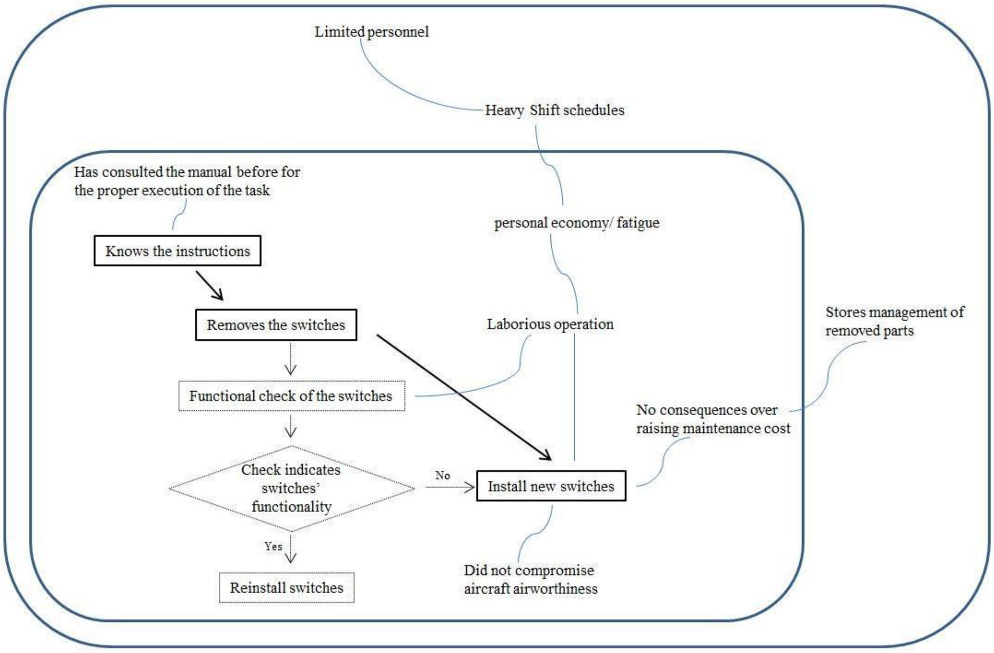

Figure 2. Direct Factors influencing this particular decision-action path (inner area): 1) personal economy/fatigue, 2) laborious operation, 3) no personal consequences for technician 4) no compromise of airworthness. Indirect organizational factors may include (outer area): 1) limited personnel resulting in heavy shift schedules and 2) spare management practices.

The panel removal process is mentioned in the task card manual as a prerequisite task and a reference to the aircraft maintenance manual is provided for its description. The number of technicians working on the task was defined by the shift leader, as there is no such prescription. The shift leader distributes the personnel, according to his estimations on task needs. For the removal of the panels, four technicians (one authorized mechanic and three assistants) were working on each wing. Prior to the removal of the panels the technicians lifted and leveled the aircraft at a stress relief position. This process was not included in the manual.

The technicians explained that the lifting/leveling process prior to the wing panels' removal was always performed at several aircraft types that had been maintained by the organization in the past. It is therefore a shared work practice among the group of technicians. The technicians justified the need for lifting/leveling the aircraft, by referring at the panel screws' bending caused by the wings' own weight and maintenance personnel's weight working on. Nevertheless, the maintenance manuals of the specific aircraft type do not require lifting and leveling for the panels' removal task to be performed. By lifting and leveling the aircraft, not only the technicians bypassed the manual instructions, but also blocked several on-board tasks that could had been performed in parallel, as no personnel is allowed to work on-board while the aircraft is lifted/leveled.

The mapping of factors for this case is illustrated in Figure 3.

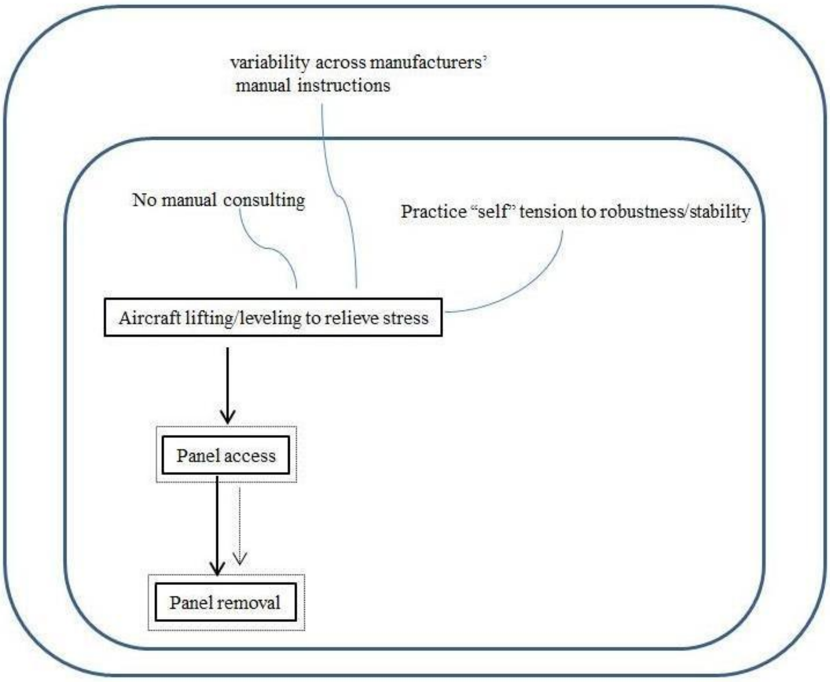

Figure 3. Direct, local factors influencing the decision path (inner area) include: 1) the historically successful repetition of the same shared course of action, 2) no manual consulting. Indirect organizational factors (outer area) may include the variability across manufacturers' manual instruction for the same task (i.e. some manufacturers ask for aircraft lifting and leveling prior to the panels' removal, whereas others do not prerequisite them).

4. Power plant removal, stripping, buildup and installation

The aircraft is powered by two power plants. Each power plant consists of an engine core, a propeller system, a power control system (engine and propeller), engine mounts, fire seals, a drain system for waste fuel and oil and accessories necessary to provide fuel and air for proper engine function under all operating conditions. The engine is secured to the nacelle upper structure by resilient mounts, to reduce vibration and engine/propeller torque effect and is enclosed by a nacelle mounted cowl installation. The operator's P145 Maintenance Department has no authority to perform maintenance actions at an aircraft's engine core. Therefore, whenever a need for maintenance at an engine core arises, the aircraft power plant has to be removed from its nacelle and stripped by the operator's maintenance personnel according to the aircraft and engine maintenance manuals, so that the engine core and the other components of the power plant are isolated. The engine core is then transferred to an authorized maintenance center. The aircraft maintenance manual provides instructions for the proper removal of the power plant from its nacelle and for the removal of the propeller from the power plant while the engine maintenance manual provides instructions for the power plant stripping after its removal from the nacelle and after the propeller removal. Both manuals also provide instructions for the proper buildup of the engine core and for the installation of the power plant to its nacelle. During our field observations at the hangar, a power plant had to be removed from its nacelle and stripped. The engine core had to be transferred to an authorized maintenance center for overhaul, due to findings (swarf) at the engine chip detectors. Before the arrival of the aircraft with the damaged power plant at the hangar, the working team was performing scheduled maintenance tasks at another aircraft nearby. By the time of the aircraft arrival at the hangar, the team members were informed by the shift leader that they had to stop their ongoing scheduled work and immediately work on the damaged power plant. The aircraft with the damaged power plant had to return to service as soon as possible. The maintenance personnel had to build up a serviceable engine core and install the power plant back to its nacelle. The maintenance team consisted of authorized mechanic and avionic technicians and assistant technicians. During the removal of the damaged power plant and during the installation of the serviceable one, the maintenance team was working according to the manuals. They permanently had the manuals at hand and they occasionally halted the removal/installation processes to consult them. Nevertheless, during the stripping and buildup processes, they barely opened the manuals. After the removal of the damaged power plant from its nacelle and the removal of the propeller from the power plant, they placed the damaged power plant next to the serviceable engine core. They afterwards removed each power plant accessory component from the damaged power plant and installed it on the serviceable engine core one-by-one. The working team had performed several times before removal/installation tasks in a similar manner. On our question why they stripped and built up in parallel the damaged and the spare engines, they replied that they always do it in that way, because it's much easier than consulting the manuals. On the other hand, on our question why they closely follow the manuals during the removal and installation of the power plants they replied that it's crucial to tighten and untighten the nuts and bolts that join the whole assembly with the correct order and with the proper torque values, so as not to damage the power plant, the propeller or the nacelle. They mentioned that the correct order is difficult for them to remember and the proper torque values change occasionally.

The mapping of factors for this case is illustrated in Figure 4.

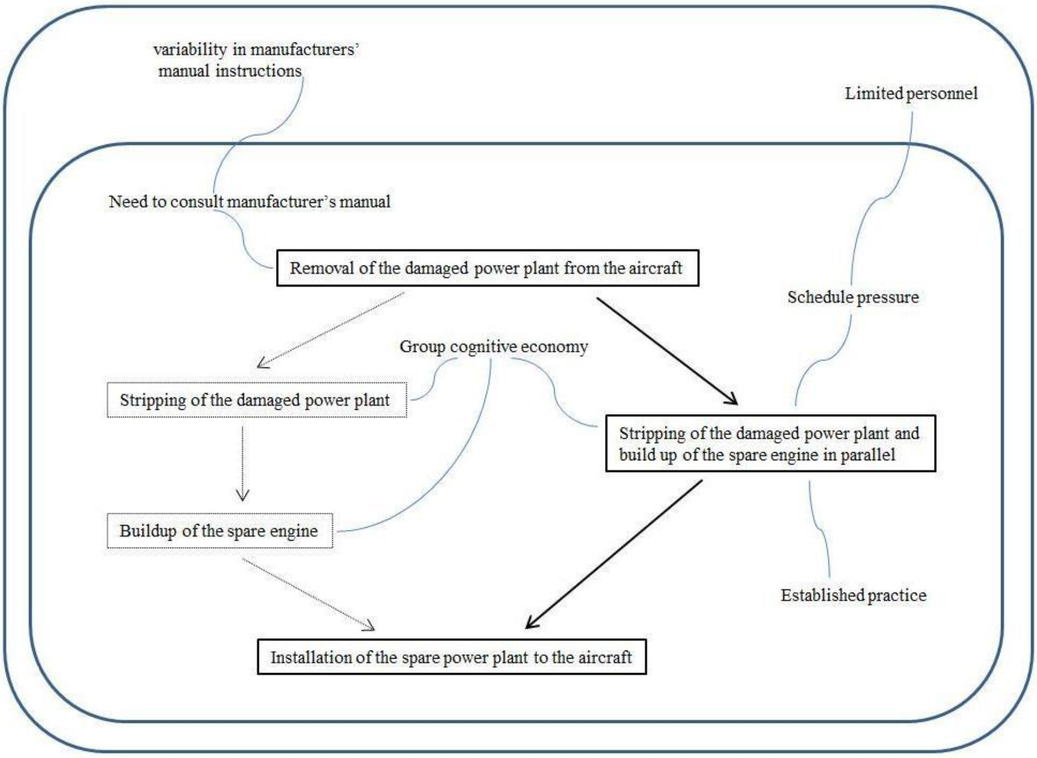

Figure 4. Direct, local factors influencing the decision path (inner area) include: 1) Schedule pressure, 2) established practice (as a successfully repeated course of action), 3) Group cognitive economy (as the technicians mentioned: "working on the engines in parallel helps us better remember what goes where, rather than consulting the manuals to do the job") 4) need to consult the manuals (i.e. for screwing with certain torque values). Indirect organizational factors (outer area) may include organization's limited personnel and the variability in manufacturer's manual instructions (torque values are updated frequently and need frequent checking)

Discussion

In the present communication we map factors that directly influence maintenance technicians' concrete courses of action during deviating maintenance activities. We demonstrate that empirically informed mapping of proximal factors, as observed and/or expressed by technicians thenselves, may help us get insight on the probable relation between proximal and distal factors lying behind the observed deviating actions, and in an attempt to relate them with wider organizational issues such as systemic trade-offs (Hoffman and Woods 2011). We claim that by doing so we may gain a intimate understanding of the cognitive the organizational nature of deviations in concrete and context specific terms. Pragmatic approaches that acknowledge the impossibility of total conformity have long shown their utility in controlling drift towards the boundaries of acceptable performance (Rassmussen 1994). It is our contention that the same principles can become operationalized in methods of self or externally assisted participatory audits (e.g. reflection-on-action sessions), (Schön, 1983, Nathanael & Marmaras, 2008a, Kontogiannis & Malakis, 2012). Indeed, externalizing the reasoning that justifies a particular course of action and discussing their relation to concrete organizational parameters may play a sifnificant role in promoting a more mature level of safety culture (Reason) and contribute towards a more disciplined co-evolution of prescription and actual practice.

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