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MAINTENANCE CONTROL IN AERONAUTICAL SYSTEMS AND ITS APPLICABILITY TO TERRESTRIAL WEAPONS SYSTEMS[1]

O CONTROLO DE MANUTENÇÃO EM SISTEMAS AERONÁUTICOS E A SUA APLICABILIDADE EM SISTEMAS DE ARMAS TERRESTRES

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Abstract

To accomplish its missions, the Portuguese Army (PA) must ensure the operational capability of its Weapon Systems (WS). To address the current financial constraints and shortage of Human Resources (HR), the PA must optimise its maintenance management processes to enable the operational sustainment of its modern WS. This study proposes measures to improve the efficiency of the Maintenance Management (MM) model used by the PA to manage the Pandur WS, base d on the models used by the aviation industry and by other North Atlantic Treaty Organization (NATO) Member States. The study used deductive reasoning, a mixed strategy, and a comparative and cross-sectional research design to analyse how the Portuguese Air Force (PoAF), TAP Air Portugal (TAP) and the Belgian Army (BA) use their maintenance management tools. This analysis served to identify the most important gaps in the MM of the Portuguese Army's WS, and to determine which features of the maintenance management tools can be optimised. The study proposes a set of changes to the MM model of the Pandur WS that will improve its response capacity and make it easier to oversee the sustainment process and allocate human, material and financial resources without significantly changing procedures.

Keywords: Maintenance Management, Airworthiness, Quality, Weapon Systems, Human Resources.

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Resumo

A operacionalidade dos Sistemas de Armas (SA) constituiu-se numa das principais preocupações do Exército Português (EP) para o cabal cumprimento das suas missões. No contexto atual, caracterizado por restrições financeiras e escassez de Recursos Humanos (RH), assume especial importância, otimizar-se a gestão da manutenção no EP, para assegurar a sustentação e operacionalidade dos seus modernos SA. O objetivo desta investigação visa propor medidas que contribuam para melhorar a eficiência do atual modelo de Gestão da Manutenção dos SA (GMSA) Pandur no EP, tendo como referência o setor aeronáutico e modelos seguidos por Estados-membros da Organização do Tratado do Atlântico Norte (OTAN). A investigação seguiu um raciocínio dedutivo, assente numa estratégia mista, consubstanciada num desenho de pesquisa comparativo e transversal, baseado na análise da aplicação das ferramentas de gestão da manutenção na Força Aérea (FA) Portuguesa, Transportes Aéreos Portugueses (TAP) e Exército Belga (EB). Este estudo permitiu identificar as principais lacunas na GMSA no Exército e esclarecer as funcionalidades das ferramentas de gestão da manutenção a potenciar. Nas conclusões, propõe-se um conjunto de melhorias à GMSA Pandur, ao nível da capacidade de resposta, controlo na sustentação e alocação criteriosa dos RH, materiais e financeiros, sem alterar significativamente os procedimentos.

Palavras-chave: *Gestão da Manutenção, Aeronavegabilidade, Qualidade, Sistemas de Armas, Recursos Humanos.*

1. Introduction

To retain its military edge and prevail in future operations, NATO must remain up-to-date on the latest technological advances, especially with regard to networking, which is enabled by ensuring interoperability among partners (NATO, 2018a). NATO member countries should have the ability to improve sustainment and logistics by leveraging autonomous technologies and systems that reduce the risk of failure and unnecessary redundancy in their processes (NATO, 2018a). The modernisation of the PA should be based on the principle of interoperability with the other AAFF branches and allies and on the principle of sustainment, as joint operations will be the norm in the future (NATO, 2012; Council of Ministers Resolution No. 26/2013 of 05 April).

To accomplish the Armed Force Missions (Ministry of National Defence [MDN], 2014b; Decision No. 4101/2018 of 12 April, p. 11677), the PA acquired new WS that must comply with the standards[2] of the aviation industry to be operated, which has led to some organizational and doctrinal changes in terms of maintenance. However, there is currently a shortage of HR, especially in the maintenance area. To reduce delays, the PA has approved level III technical maintenance support contracts with the manufacturers of the WS (Chief of Staff of the Army [CEME], 2018). This requires monitoring the work more closely and managing human and material resources more carefully in order to cut costs. Thus, the PA may have to change the

[2] The PA acquired its Pandur II 8X8 Wheeled Armoured Vehicles in 2010; the Leopard II A6 Tanks in 2011; and the Raven small Unmanned Aerial Vehicles and the URO VAMTAC ST5 vehicles in 2019.

procedures to sustain its new WS and streamline the maintenance process to comply with the rigorous quality, performance and safety standards that regulate the aviation sector (P. M. Belchior, face-to-face interview, 28 October 2019). The PA is currently transferring its data to the Integrated Management System (SIG)/MDN, on which the logistics information system is based. This makes this study particularly relevant because implementing the features of the current maintenance management tools in this new Information System (IS) is particularly challenging (Marques, 2016). If this problem is not solved, there may be gaps in the WSMM model that will render it more wasteful and less efficient (PA, 2016).

This study is thus relevant for three reasons: (1) to determine the suitability of the current model used by the PA to maintain its WS and to propose changes based on the models used by the aviation industry; (2) to facilitate the Army Logistics Command (CmdLog) mission of "administrating material resources" (PA, 2014b, p. 1), and the Directorate of Material and Transportation (DMT) mission of carrying out all logistic activities related to replenishment, transport and maintenance (General Staff of the Army [EME], 2015a, pp. 3-4); and (3) to clarify which features should be included in the maintenance management tools to address the current gaps and turn them into opportunities during the transition to the SIG/MDN.

This study on Military Sciences addresses the area of Military Operations, and the sub-area Military Logistics (Research and Development Centre of the Military University Institute [CIDIUM], 2019a). The study analyses the PA's WSMM model to identify measures to improve the model used to manage the Pandur WS.

The research is delimited (temporally, geographically and conceptually) (CIDIUM, 2019b): to the period from 2006 to the present day, during which the Army has had to change to "keep up-to-date with scientific and technological developments and to adjust to the requirements of a professional military force" (Decree-Law No. 61/2006 of 21 March, p. 2044); to the Units, Establishments and Services (UES) that perform maintenance tasks for the PA in the National Territory (NT) or in Theatres of Operations (TO) where the WS is deployed; and to the MM model of the Pandur WS, the Army's most consolidated maintenance model and its largest type of vehicle, which is also the most difficult to operate (CEME, 2018; CmdLog, 2018), as well as to the C-130 Hercules (C-130H) WS, a validated model of similar complexity as the PA's new WS. The study will also examine the maintenance management model used by TAP, a company that is an international benchmark in terms of airworthiness (TAP, 2020a), and the MM model used by the BA to manage its Pandur WS, also a validated model that, despite some differences, can be compared to the one used by the PA.

The General Objective (GO) of this study is to *Propose measures to improve the MM model used by the PA to manage the Pandur WS*. The GO will be achieved by accomplishing three Specific Objectives (SO):

SO: To analyse the WSMM models and the aeronautical system MM used by the PA, the PoAF, TAP and the BA;

SO2: To compare the MM models used the PA, the PoAF, TAP and the BA;

SO3: To propose changes that the PA can implement to optimise the MM of the Pandur WS.

To guide the study and accomplish the GO, the The following Research Question (RQ) was answered: What measures can be implemented to improve the MM model currently used by the PA to manage the Pandur WS?

2. Theoretical framework and methodological approach

This chapter presents the conceptual and methodological framework.

2.1. Conceptual framework

Several publications on the importance of logistics sustainment in military contexts confirm that the Armed Forces (AAFF) must modernise its processes to keep up-to-date with the most recent developments in information technologies and networked communication (Alves, 2017; Fragoso, 2017; Saúde, 2010; Silva, 2011), as these are essential tools to manage its stocks (Carrilho, 2008; Santos, 2012; Sterman, 2000) and maintenance tasks (Correia; 2012; Lopes, 2010; Ribeiro, 2009b) more efficiently. However, no studies have analysed, in an integrated way, the features and suitability of the WSMM tools used by the PA to determine how the system can be improved. This study is therefore innovative and relevant.

One of the main activities of the PA is logistics, or "the **science of planning and executing the deployment and sustainment of forces**" (Training and Doctrine Command – *Comando de Instrução e Doutrina* [CID], 2013, p. 2-(3)). Sustainment is "enabled by the performance of a variety of logistics roles (Replenishment, Deployment and Transport, Maintenance, Medical Support, Infrastructure, Procurement, Contracting, Disposal and Services)", both at the tactical and operational level (PA, 2014b, p. XI).

"Maintenance" includes all activities that aim to "maintain (preserve) equipment (materiel stocks) in working condition and repair [malfunctioning] equipment, or even modify [it]" (CID, 2013, p. 5-(2)). Due to their characteristics, WS "must be handled with special care" as they are expensive to maintain. The maintenance included in the use and sustainment phases of the Life Cycle (LC) (PA, 2014b, p. 6-(4)) can represent up to 80 % of the total cost of the useful life of a WS (CID, 2013).

To monitor maintenance effectively (Bravo, 2013; Henriques, 2016), the concept of "maintenance management" must first be clarified. According to the Portuguese Standard EN 13306, it consists of all management activities that define and monitor the implementation of maintenance goals, strategy and responsibilities (Portuguese Institute of Quality [IPQ], 2007). It requires mastering several areas, from planning, cost control, staff and material management to maintenance techniques, engineering and IT (Cabral, 2009; Portuguese Civil Aviation Authority [INAC], 2000; Pais, 2008; Pinto, 2002). Maintenance Management Systems (MMS) should follow a Plan, Do, Check, Act (PDCA) approach that includes continuous improvement and measurable objectives (Fuentes, 2006; IPQ, 2008). These systems should "standardise all processes that interact in maintenance and [...] clearly identify: the services that will be provided, the time at which [...] they will be provided, what resources will be required [...], how much time will be spent in each service, what will be the global and per unit cost [...], what materials will be applied and what machines, devices and tools will be needed" (Barreiros, 2012, p. 10).

With regard to the MM of WS and their respective equipment, the information generated and processed is increasingly important to the decision-making process, and managing it should be seen as a way to help organizations perform better, rather tha as an end itself (General Staff of the Air Force [EMFA], 2011, p. 1-(1)). Therefore, these tools, or MMS, are essential for Integrated Logistics Support (ILS) (NATO, 2019) because they provide a way to organize, plan and manage repairs and spare parts, and control costs (labour, materials and services) during the equipment's LC, in order to "perform a Cost Accounting Analysis" (PA, 2014b, p. 6-(16)).In addition to these features, they must include the following functional requirements (among others): allow managers to monitor operations in real time; plan preventive maintenance cycles; generate statistical reports (e.g. costs, incidents, completed and pending work orders, material in use and in stock); schedule the works using Maintenance Plans (MPla) that include scheduled maintenance and audits (Pereira, 2009); manage HR and materials; issue alerts for longer response times (GIAGI, 2007; Oliveira, 2017; Vasconcelos, 2009); keeping logs; and checking the status of equipment (operational, inoperational or undergoing maintenance) (A. M. Graça, face-to-face interview, 10 January 2020; C. M. Moreira, face-to-face interview, 25 November 2019). These tools must have an ISO 9001 certification issued by the International Organization for Standardization (ISO) (Portuguese Association of Certification, 2019; SGS, 2020). They are essential for WSMM because they streamline procedures and enable the "implementation of electronic communication channels in the Army Intranet between the user units and the maintenance execution and management services." (PA, 2014b, p. 6-(17)). In the PA, maintenance management is being transferred to the SIG/MDN, and one of the challenges is the creation of compatibility mechanisms that ensure data are not lost during the transition (PA, 2014b).

The following concepts are used widely in the aviation industry: "airworthiness", or "the ability of an aircraft or an airborne equipment or system to operate in flight and on land without significant risk to the crew, ground crew, passengers (if applicable) or third parties" (Regulation No. 539/2014 of 05 December, p. 30609); and "certification", which "[...] consists of verifying that a product, part, equipment, service, entity or person complies technically with the applicable requirements, and issuing a certificate, [...] or other equivalent document that formally recognises that it meets those requirements" (Regulation No. 539/2014 of 05 December, p. 30609).

The PA's procurement procedures specify that WS must be accompanied by a certificate of conformity, as defined in the contractual requirements (MDN, 2014c). While the decision to certify a given product, service or MMS is one that is taken voluntarily by organizations, it has several advantages, such as: "improving the image and credibility of the organization"; "Improving management capacity"; and "Preventing and minimising impact and risk" (DQA, 2019).

2.2. Methodology and Method

The study used a deductive reasoning methodology based on the premise that management tools are essential to maintain WS (EP, 2014b). By analysing and examining how these tools are used, the study inferred a list of opportunities and gaps, based on which measures were proposed to improve the maintenance management of these systems (CIDIUM, 2019b, p. 19). The study used a mixed strategy that combines quantitative and qualitative approaches "to maximise the advantages and minimise the limitations of each approach" (CIDIUM, 2019b, pp. 29-30). A comparative research design was used to study the models implemented in the PoAF, TAP and the BA and their respective contexts to identify the strengths and weaknesses of the current WSMM model used by the PA (Freixo, 2011). The study is cross-sectional and analytical (Vilelas, 2009) and the indicators selected to compare organizations are based on a three-dimension model (people, processes and technologies) (Prodan, Prodan & Purcarea, 2015; Rocha, Correia, Costanzo & Reis, 2015) and on demand management, one of the most widely used methodologies in the corporate world, which takes advantage of new technologies (Chase, 2016; Subramanian, 2015) (Figure 1).

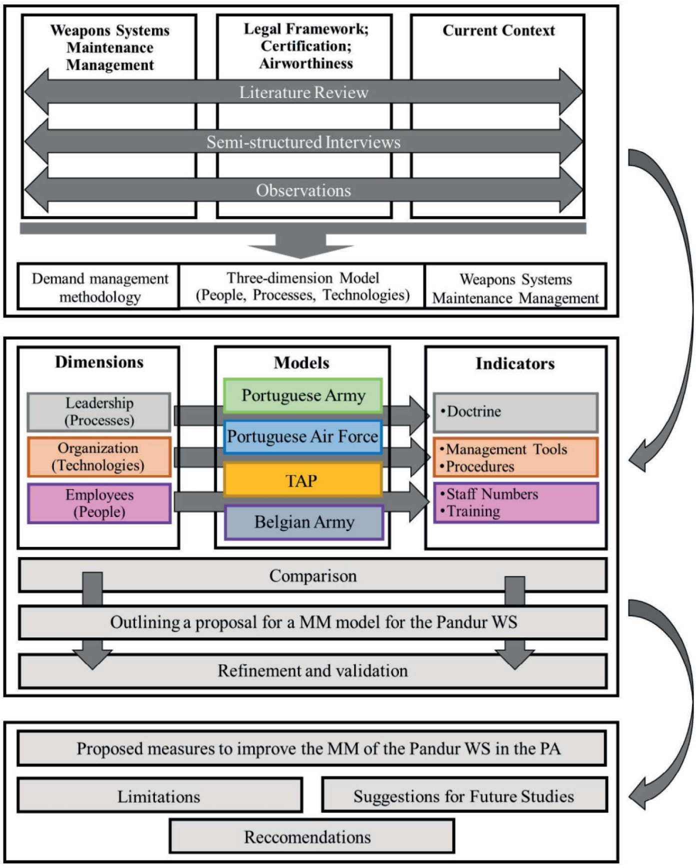

Figure 1 – Analysis model

With regard to method, the study sample consisted of maintenance officers from the PA, the PoAF, TAP and the BA (senior leadership, Fleet Manager(s) [FMan] and maintenance personnel): Major General Morgado Baptista, DMT/CmdLog/PA Director; Captain Costa Graça, Pandur FMan; Major Rodrigues Figueiredo, Maintenance Officer (MOf) in the Intervention Brigade (BrigInt); Captain Antunes Beltrão, Former Commander of the Maintenance Company (MCo)/BrigInt; Colonel Glória Belchior, Former Head of Airworthiness, Certification and Engineering of the Helicopter and NH90 Programme of the PA; Master Sergeant Silva Prates, Former Deputy at the Airworthiness, Certification and Engineering of the Helicopter and NH90 Programme of the PA; Major Pereira

Moreira, Deputy at the Air Force Logistics Command (CLAFA)/Logistics Area Information Administrator (AdIAL); Captain Batista Monteiro, C-130H FMan; Captain Jessen Sirage, C-130H MOf; Engineer Vítor Grilo, Director of Engineering and Airworthiness at TAP; Engineer Filipe Alves, Head of Airworthiness Management at TAP; Major Van Tilborg, Chief of System Managers Operational Vehicles / BA; Captain Nicolas Deschamps, Pandur Fleet Manager/BA.

The following data collection instruments were used in the study: a literature review; semi-structured interview surveys (face-to-face and by email); and structured non-participant observations (Carmo & Ferreira, 1998, p. 106; CIDIUM, 2019b, p. 74), which took place in the departments that handle MM for the Pandur (DMT) and C-130H (WS Maintenance Directorate [DMSA]) WS and at TAP (on the same day as the interview with each FMan), to observe how FMan use WSMM tools, and which features, and compare them in terms of the requirements listed above.

3. Maintenance management models used by the Portuguese Army, Portuguese Air Force, TAP and the Belgian Army to manage their weapons and aeronautical systems

To achieve SO1, this chapter analyses the maintenance management models implemented in the PA, the PoAF, TAP and the BA, based on the data obtained in the literature review and the interviews.

3.1. Portuguese Army

In 2006, an Army reform took place, "guided by the principles of rationalisation, simplicity and economy of means [...]" (Decree-Law No. 61/2006 of 21 March, p. 2044). This reform organized the Army Logistics System (ALS) by roles and centralised the maintenance, replenishment, deployment and transport roles at DMT/CmdLog. CmdLog is the Command, Administration and Management Service responsible for managing the PA's logistics activities. It is organized into Logistics Divisions that "manage logistics at the operational level, in an integrated manner" (PA, 2014b, p. 2-(2)).

After acquiring the new WS, the PA had to prepare a new maintenance concept, which was approved by Order No. 225/CEME/2011 (CEME, 2011) and included in the new doctrinal publication on the ALS (EP, 2014b). The document addresses the WSMM system that will allow the PA to achieve the level of ambition in terms of the capacity to deploy and sustain forces (MDN, 2014a). In terms of doctrine, maintenance activities used to be organized in five tiers and are now a three-level structure, in compliance with the DMT's Permanent Regulations (*Normas de Execução Permanente* [NEP]): Level I (Unit Maintenance); Level II (Intermediate Maintenance); and Level III (Base and Storage Maintenance). The maintenance tasks related to the Pandur WS were transferred from the lowest tiers (regimental structure) to the intermediate level, and now have a dedicated infrastructure, equipment and specialised personnel (Ribeiro, 2009a) (Table 1). The rules to schedule and log maintenance tasks are covered in a Technical Manual (TM), MT-9-2300-1 (CmdLog, 2012).

Table 1 – Maintenance Intervals

Maintenance levels	Level I	Level II				Level III
Maintenance intervals	Monthly (1M)	Biannual (6M)	Annual (1Y)	Biannual (2Y)	Quadrennial (4Y)	Storage Maintenance, carried out in the Army Materiel General Support Unit (UAGME)
	User Maintenance, carried out by the crews	Intermediate Maintenance, carried out in Units, by MCo/BrigInt		Intermediate Maintenance, carried out in the Maintenance Regiment (MReg), by the MCo/BrigInt		

Source: PA (2014b, p. 6-(5)).

To address the concerns with WSMM, successive changes were made to the Staff Plan (SP) of the DMT/CmdLog, the managing entity, which led to the establishment of the current Maintenance and WS Department (RMSA) in October 2015 (CmdLog, 2015b). Through the FMan, the WS Section (WSS)/RMSA/DMT oversees MM for the Pandur WS and supports the UES in the maintenance and replenishment of spare parts (DMT, 2017). The MOf of the Maintenance Secretariat (MScr)/BrigInt[3] sets the maintenance priorities in coordination with the MCo/BrigInt (PA, 2014b, p. 6-(6)).

The Pandur maintenance team uses two WSMM tools: ManWinWin, to manage maintenance and requisition spare parts; and a Stock Replenishment Management software for Windows (GRW) to requisition equipment and spare parts for the MReg (maintenance in NT) and the Transport Regiment (maintenance in TO). The GRW is used in all UES of the PA to requisition materiel, but is currently being replaced by the SIG/MDN[4]. ManWinWin is only implemented in the WS User Units (UU) and respective MScr/Brigades, in the MReg, in the WSS/RMSA/DMT and in the TO where the WS are operated. To ensure uniformity of procedures, this IS is only used by the Officers and Sergeants assigned to the maintenance of the WS (V. J. Beltrão, email interview, 3 January 2020).

The maintenance tasks and configuration management of the Pandur fleet are tracked using ManWinWin. This IS is connected to the Army intranet, in order to centralise and reduce the HR allocated to WSMM. ManWinWin is an "essential tool" for WSMM (PA, 2014b, p. 6-(17)) because it enables networking between the UU and services that manage and execute maintenance, including the National Deployed Forces (FND), through the respective MOf (PA, 2015). To increase efficiency in WSMM and adapt it to the established procedures, the WSS/RMSA/DMT/CmdLog coordinates with Navaltik Management, Lda, the ManWinWin developer, to improve this tool based on the lessons learned while using the software (A. M. Graça, op. cit.). These improvements were implemented in a new version, v. 5.5.1.0, completed in November 2017. This software is used to "plan and monitor the maintenance of the Pandur II fleet, including all maintenance activities carried out by the units that operate these vehicles (RC6, RI13, RI14, MReg and UAGME)" (EME, 2017, p. 2). As it also calculates the staff numbers and labour costs, materiel and services, it can be used to perform cost accounting analyses.

[3] This brigade has a Pandur WS.
[4] Uniforms, fuel and lubricants are already requisitioned using the SIG/MDN (DMT, 2015).

As for procedures, the MOf/BrigInt prepares the MPla for the Pandur fleet based on the information uploaded to ManWinWin by the WSS/RMSA/DMT, which is used to schedule the interventions defined in the TM. When a malfunction is detected, the Maintenance Sections (MSec)/UU open a maintenance ticket in ManWinWin, which is monitored by the MOf/BrigInt, to request an intervention to the MCo/BrigInt (DMT, 2013). When spare parts are not available, the Replenishment Platoon (RPla)/MCo/BrigInt responsible for managing the Support Level List (SLL) for the Pandur WS level I and II maintenance opens a purchase order in ManWinWin (Figure 2) to requisition the parts from the WSS/RMSA/DMT. When it receives the request, the WSS/RMSA/DMT: fills out a form in GRW to request the spare parts to the UAGME, which are later picked up by the RPla/MCo/BrigInt (PA, 2014b, p. 6-(19)); or procures them in the civilian market, mainly from the manufacturer of the Pandur WS, General Dynamics European Land Systems-Steyr (GDELS-Steyr), and later aquires them through the Procurement Directorate/CmdLog (MDN, 2005). Combined with the use of specialised mechanics, this replenishment flow ensures that MPla are executed in compliance with ISO quality standards (National Road Safety Authority [ANSR], 2020a; IPQ, 2005; Oliveira, 2016). In level III, when a malfunctioning part requires advanced technical skills to repair, it can be sent to GDELS-Steyr or similar companies (V. J. Beltrão, op. cit.).

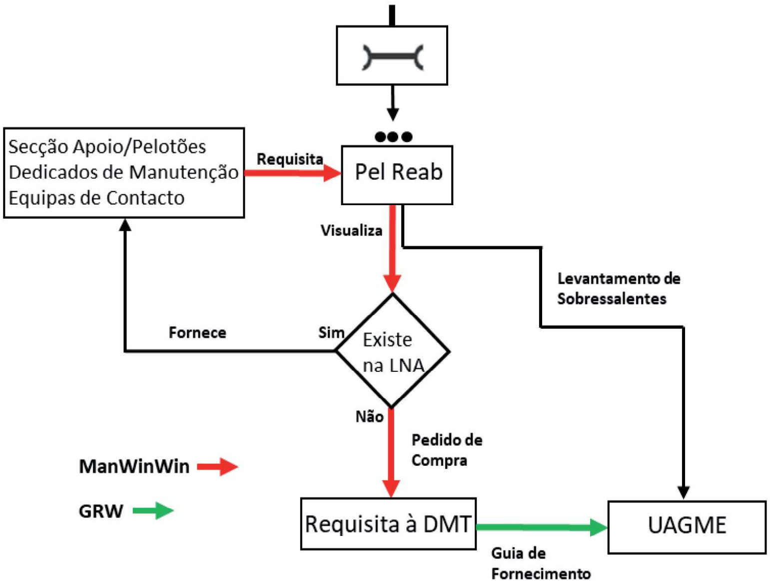

Figure 2 – Proposed replenishment flow chart for Pandur spare parts

However, the current WSMM model has some shortcomings, namely the technical training required to operate ManWinWin, which means that not all its features are used (A. M. Graça, op. cit.). Another downside of this tool is that it does not allow the FMan to access the maintenance schedule, only the logs created by the Heads of the Maintenance Team (MTea), which makes it difficult to monitor how the work is progressing (Valente, 2019, p. 27).

Furthermore, the lack of interoperability between ManWinWin and GRW makes it difficult to manage spares (material not registered in the Units' material lists) (F. M. Prates, face-to-face interview, 04 December 2019).

Moreover, due to the shortage of qualified staff to perform level II maintenance on the Pandur fleet, the structure that was implemented might not be feasible (V. J. Beltrão, op. cit.). This shortage of HR at the MCo/BrigInt leads to innefficiency in the execution of the MPla and, consequently, to delays that the UU and commanders find difficult to understand (RMSA, 2017b). These delays generally occur in the biennial maintenance (Table 1), which is the most time consuming and has the most tasks to perform, and often includes additional tasks to correct malfunctions that require replacing unplanned and complex components (Valente, 2019). Therefore, the PA has some difficulty keeping up with the technological evolution of the equipment and tools it has acquired (A. M. Graça, op. cit.). To minimise delays, the PA uses external contractors for level III maintenance (CEME, 2018) and participates in the annual meetings of the Pandur User Group since 2009 (CmdLog, 2009), where the countries that use this WS (Austria, Belgium, Slovenia, Portugal and the Czech Republic) share information (CmdLog, 2011; DMT, 2014b; RMSA, 2016; RMSA, 2017a) regarding spare parts, maintenance, configuration management and training (Memorandum of Understanding, 2010).

3.2. Portuguese Air Force

In 2009, faced with the need to establish rules and procedures to ensure the safe use of airspace, Portugal agreed to comply with the European Military Airworthiness Requirements (EMAR) set out by the European Airworthiness Authorities Forum, under the auspices of the European Defence Agency. The most recent version of EMAR 145 was approved on 19 January 2011. The document establishes common rules for European civil aviation, which is governed by the European Union Aviation Safety Agency (EASA). Thus, to comply with EMAR 145, Portugal has adopted a set of technical requirements and administrative procedures to regulate its military aviation maintenance, including products, parts and equipment (Regulation No. 431/2016 of 06 May). Based on these documents, the National Aeronautical Authority (AAN) has issued the Portuguese Military Airworthiness Requirements (PMAR), which it also enforces. To comply with the requirements, "the PoAF uses a Quality and Airworthiness Management System (QAMS) that essentially ensures that the requirements are met in an effective and efficient manner" (Monteiro, 2019, p. 1) and aims to "continuously improve performance" (EMFA, 2013b, p. 2-(2)) by "measuring and analysing specific indicators" (Moreira, 2016, p. 1). The AAN is the agency responsible for the regulation, inspection and oversight of all national defence aviation activities, as well as for enforcing the State's authority in the permanent strategic airspace of national interest, according to the guidelines defined by the MDN (AAN, 2019b; Portuguese Republic, 2020). This agency issues Airworthiness Certificates (AC) for military aircraft according to validated procedures (Té, 2014), and certifies national aviation entities through the AAN Office and the Air Policing Service. The Chief of Staff of the Air Force is also the head of the AAN, and, as the latter, reports to the MDN (Law No. 28/2013 of 12 April).

CLAFA has an Information Administration Office for the Logistics Area (GAIAL) that manages the data processed through the IS and provides WSMM support, and has defined a set of regulations for its MMS, both developed internally and acquired from external entities (EMFA, 2011, p. 5-(5)), based on NATO standards (NATO, 2007a; NATO, 2008a; NATO, 2008b; NATO, 2009a; NATO, 2009b).

Currently, the responsibility for the PoAF's Continuing Airworthiness Management (CAM) and WSMM is distributed by the DMSA, the Engineering and Programmes Directorate (DEP) and the Air Units Maintenance Squadrons (AUMSq). The DMSA is responsible for: the CAM of WS and for supporting the maintenance engineering teams (C. M. Moreira, op. cit.); providing ILS; preparing and updating the regulations on WS sustainment; ensuring that quality requirements are met; and participating in managing its technical staff by providing training, qualification and specialisation (EMFA, 2013a, pp. 9-(1)-9-(2)). The Department of Quality, Airworthiness and Environment is integrated in the DEP, and manages the QAMS, which defines how aeronautical maintenance is managed, conducted and monitored in the PoAF. This Department includes the Airworthiness Certification Centre, which provides support in the certification of new aircraft, systems or components, upon request. The DEP also includes an Engineering Department responsible for implementing modification projects and for supporting the FMan in the MM of WS (CLAFA, 2013a). The AUMSq perform maintenance and monitor it on site, as well as some management and airworthiness tasks (C. M. Moreira, op. cit.).

The MM of the C-130H WS is carried out using the PLUS-MGM IS, which is essential to monitor and plan the maintenance processes efficiently vis-à-vis the shortage of HR and materiel. The software displays the fleet status at any time, issues maintenance performance reports, and lists all components and the qualification level of the military personnel authorised to work on the aircraft (A. J. Sirage, face-to-face interview, 07 January 2020). This IS is interoperable with: PLUS-MGO (operations module); PLUS-MGP (staff module); SIGMA-ABAST; and SIAGFA-GESTMAT (J. M. Monteiro, face-to-face interview, 31 October 2019). SIGMA-ABAST and SIAGFA-GESTMAT, which are used for spares provisioning, display the status and location of the PoAF's components (C. M. Moreira, op. cit.).

In the MM of the C-130H WS, the FMan follows a maintenance programme based on the annual planned flight hours, whic determines the maintenance tasks and HR that will be required. The data are uploaded to PLUS-MGM IS and managed by the FMan. The implementation is monitored by the Planning and Control Area/Air Base No. 6 (BA6). This area used the IS to open the work orders that will be executed by the maintenance sector (J. M. Monteiro, op. cit.), analyses them and proposes the tasks required to restore the aircraft to the MOf/BA6. The MOf/BA6 coordinates with the Operations Officer to compare the maintenance and operational needs and to schedule the tasks that must be completed to accomplish the planned missions. The data on the airworthiness of aircraft and components can be consulted in PLUS-MGM. In the rare cases that have not yet been integrated in this IS (e.g. statistical data), protected Excel sheets are used and monitored by maintenance and WSMM staff. When the work requires technical skills that are not available in-house, the FMan/DMSA/CLAFA is informed and an external contractor is contacted (A. J. Sirage, op. cit.).

Sentieiro (2011, pp. 20-21) identified a shortcoming in the WSMM model used in the PoAF, which relates to the fact that the airworthiness, maintenance and operation management roles are distributed by the DMSA and the DEP, and that they should be separate from the logistics roles performed by the DMSA. According to Moreira (op. cit.), the "quality area should be removed from the DEP and become a CLAFA support body [...], independent from the technical areas. […]. The maintenance squadrons should not be integrated in the Air Units, but in an independent structure within the Base Unit, with squadrons dedicated to each WS", in order to separate "airworthiness management" from "maintenance monitoring". Other shortcomings that were identified concern IS updates, staff training, bureaucratic procurement processes and lack of HR and financial resources (A. J. Sirage, op. cit.).

3.3. TAP

TAP's institutional framework is based on: the guiding principles of the International Civil Aviation Organization (ICAO) for civil aviation, despite these principles not being legally binding (ICAO, 2020); the common rules of civil aviation established by the EASA, which are legally binding for European Union Member States (EASA, 2019); and on the National Civil Aviation Authority (ANAC), the agency responsible for certifying, authorising and approving the activities, personnel, aircraft, infrastructure, equipment, systems and other civil aviation capabilities, as well as for defining the technical requirements to issue the corresponding acts (ANAC, 2020a; Decree-Law No.º 40/2015 of March 16). As the owner of the aircraft included in its Air Operator Certificate, TAP is a certified CAM Organization, as set out in the requirements defined in Part M[5] (Regulation No. 1321/2014 of 26 November). These requirements (M.A.301, M.A.708 and M.A.901) include the following tasks: elaborating, approving and monitoring the aircraft maintenance programme and developing a reliability programme (INAC, 2015; Marques, 2015); planing scheduled maintenance to comply with the Airworthiness Directives (AD) (AAN, 2019a; ANAC, 2020b; EASA, 2020) and monitoring components with service limitations; correcting flaws detected during scheduled maintenance; performing pre-flight inspections; managing the process to approve and implement modifications; managing the process of keeping continuing airworthiness records; and keeping the AC of its aircraft up-to-date (Garcia, 2019).

TAP performs several services autonomously, including: line and component maintenance; engine repairs and overhaul; technical and engineering services, as set out in Part 145[6]; training, as defined in Part 147[7] (Regulation No. 1321/2014 of 26 November); and calibrations and physical and chemical analyses in a technical laboratory (TAP, 2020b). These tasks are managed by the Technical Director, who is in charge of a staff (EASA, 2015) of about 2,000 employees assigned to maintenance, engineering and airworthiness tasks, 160 of whom are senior managers (Garcia, 2019).

To ensure compliance with the CAM requirements, TAP uses a QAMS that defines

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[5] In addition to the maintenance standards, Annex I sets out the technical requirements, responsibilities and procedures related to airworthiness and certification.

[6] Annex II sets out the requirements to issue or renew the certification to perform maintenance on aircraft and components.

[7] Annex IV sets out the requirements to carry out training activities and assessments.

the internal processes contained in the TM and a set of maintenance and airworthiness management tools integrated in the COSMOS IS. As this IS integrates over 20 IS, some of which are not interoperable, it will be replaced by the AMOS IS, which includes most features provided by the softwares included in COSMOS (Swiss Aviation Software, 2019; V. M. Grilo, face-to-face interview, 08 January 2020). Figure 3 shows the main management tools included in COSMOS and their features.

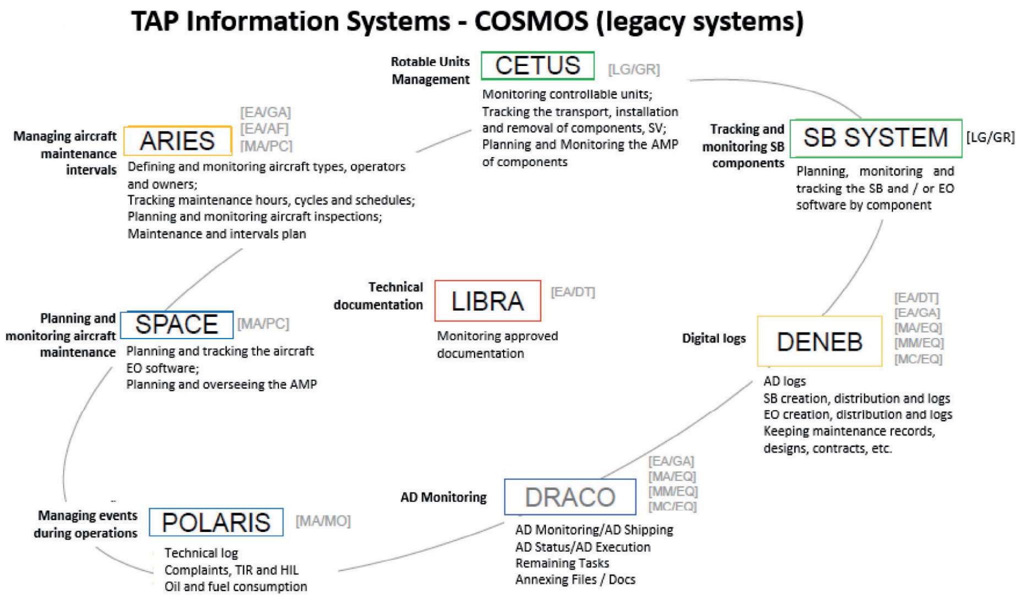

Figure 3 – MMS and Quality Management System used by TAP (2020)
Source: TAP (2020).

With regard to procedures, an Aircraft Maintenance Plan (AMP) is prepared and monitored periodically. This plan includes the scheduled tasks that must be completed, based on the manufacturer requirements (for the aircraft, engine and components) and on the experience acquired by TAP. The AMP is prepared by the fleet engineers, approved by the ANAC and monitored using the ARIES, SPACE and CETUS IS by: the planning area (aircraft maintenance); logistics (engine or component maintenance); and line maintenance (daily and weekly tasks). The effectiveness of the AMP is assessed by the reliability programme, and the plan is reviewed annually (Garcia, 2019).

All maintenance is carried out by a Part 145, and suppliers are assessed, audited and contracted as defined in Part M and managed according to a roster and a station list to ensure that all line maintenance needs are met. When flaws are detected during line maintenance, they are corrected before the aircraft is declared fit for service. If the flaw is detected during operation, the correction may be delayed due to lack of time, personnel, or materiel, as set out in the approved documentation (Minimum Equipment List, Structural Repairs Manual, or Aircraft Maintenance Manual) (ANAC, 2016). Pre-flight inspections are classified as: medium haul – inspections performed by the technical crew, except when maintenance tasks are required; and long haul – inspections performed by maintenance staff (Part 145). Any flaws or delays in correcting them are logged in the Aircraft Technical Log (ATL) by Part 145 or by the crew (INAC, 2011; Ministry of Planning and Infrastructure, 2014) using the POLARIS IS. If any situation that jeopardises flight safety is detected, the aircraft is considered unfit for service. To manage the process to approve and implement the modifications set out in the documentation (approved by the manufacturer, project organization or the ANAC), the respective engineering areas (aircraft, engine or component) perform an analysis and an Engineering Order is issued to update the aircraft's centre of gravity. Although most tests on aeronautical systems are carried out on the ground, when engines are replaced, a test flight is conducted to check if all aircraft features are operational. The lists of implemented modifications are issued by the technical documentation area and monitored using the LIBRA IS (Garcia, 2019).

The airworthiness area uses the DENEB IS to log and keep the continuing airworthiness records obtained during the aircraft's operation (ICAO, 2014; Coutu & Alblowi, 2014) in physical (e.g. ATL logs) and digital format. To ensure the airworthiness of its aircraft, TAP must keep up-to-date: the AC issued by the ANAC at the time of registration of the aircraft; and the Airworthiness Assessment Certificates (AAC), which have a validity of one year, with two annual extensions, and include an assessment of the aircraft's documentation over the last three years and an on-site audit (OGMA, 2018). TAP has a team of three airworthiness inspectors who issue the AACs for the whole fleet (Garcia, 2019), and uses a QAMS to implement the PDCA cycle of continuous improvement.

3.4. Belgian Army

The BA's WSMM model is based on NATO Standard AC327 (J. V. Tilborg, email interview, 06 April 2020), which regulates the LC management systems (NATO, 2007b) implemented in the ILS (NATO, 2013). This model includes a designated Working Group (NATO, 2018b). To ensure interoperability with NATO Member States, in compliance with Standardization Agreement (STANAG) 4107 (NATO, 2016), which aims to improve the quality of multinational support (Greenwood, 2018), the BA was restructured in 2018, and all Pandur mechanics were transferred to the MCo/ISTAR Battalion (N. Deschamps, email interview, 23 March 2020), which operates most of these WS (Defensie, 2020). Due to the shortage of mechanics, this MCo performs level O and I maintenance during the integration phase; level D[8] maintenance is performed by external contractors (N. Deschamps, op. cit.). The FMan manages all phases of the LC of the Pandur WS, receives specialised training for the role, and is assigned to the Directorate General of Material Resources (DGMR) (Odet, 2018), which manages the Belgian AAFF's logistics.

The MM of the BA's Pandur WS is carried out using the ILIAS IS throughout all phases of the LC, and can be adjusted as needed (J. V. Tilborg, op. cit.). Due to its features, this is the only

[8] The maintenance levels used by the BA – O (Organic), I (Intermediate) and D (Depot) – correspond to the PA's levels I, II and III.

WSMM tool used in all branches of the AAFF. Its management is centralised in the DGMR and it is developed in close cooperation with a Belgian civilian company (N. Deschamps, op. cit.). WSMM is a cyclical process (Figure 4) monitored by the FMan, who procures goal tracking software mainly from the civilian market (Farr, 2011). During the procurement and support phases, the BA works in close cooperation with civilian companies. Maintenance activities are uploaded to ILIAS and the software automatically calculates the minimum required stocks for each maintenance level (O, I and D), based on the consumption history of the previous year (N. Deschamps, op. cit.). Therefore, maintenance and replenishment are interconnected.

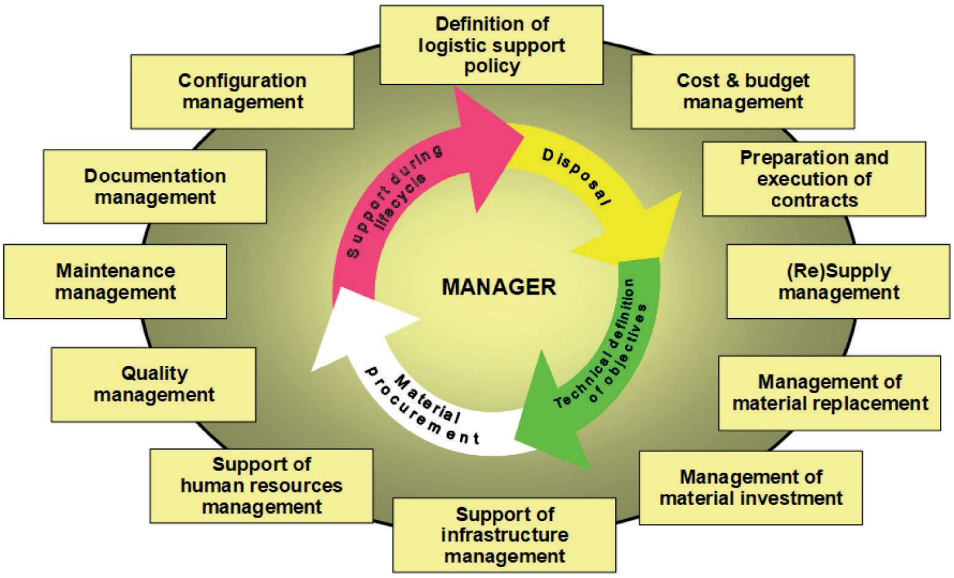

Figure 4 – The BA's WSMM process
Source: Tilborg (2020).

The main shortcoming of the MM model used by the BA for the Pandur WS is that the lack of qualified mechanics increases the need for external contracting and the cost of maintenance, which rises as the fleet becomes obsolete (J. V. Tilborg, op. cit.).

4. Proposed measures to improve the maintenance model of the Pandur weapon system

In this chapter, to achieve SO2, the WSMM models of the analysed organizations are compared in regards to the dimensions and indicators listed in the analysis model (Figure 1). The comparison was based on the analysis of the interviews and observations. Next, the changes that would improve the model used by the PA are outlined, thus achieving SO3.The RQ is then answered by proposing measures to improve the current Pandur WSMM model used by the PA.

4.1. Maintenance models

After analysing the WSMM used by the PA, the PoAF, TAP and the BA, these organizations were compared. Table 2 shows the features they have in common.

Table 2 – Common features of the analysed WSMM models

Dimentions – Indicators	WSMM in the PA, the PoAF, TAP and the BA
Leadership – Doctrine	– International regulations: based on STANAG (NATO, 2020), in the case of the PA and BA, and on the relevant legislation (EASA/EMAR/PMAR), in the case of the aeronautical sector (TAP/PoAF); – Maintenance is organized into three levels / tiers; – Known for the quality of its maintenance service; – Uniformity of procedures; – Organization is suitable and functional (L. A. Baptista, email interview, 04 April 2020; A. J. Sirage, op. cit.; V. M. Grilo, op. cit.; J. V. Tilborg, op. cit.).
Organization – Management Tools	– Maintenance is monitored at all levels (management / planning / execution) using MMS; – Only the staff involved in the MM of WS have (and should have access) to MMS; – See Table 4.
Organization – Procedures	– WSMM is monitored by the FMan (or by the IS Managers – TAP); – The maintenance tasks that were completed and the spare parts that were installed are uploaded to the MMS by the staff assigned to each level; – Level III maintenance is performed internally or using an external company, preferably the manufacturer; – The maintenance plans are defined by the manufacturer, but may be changed as long as they are replaced with a stricter plan; – External entities can only be contacted through the FMan; – Spare parts are requested to the FMan (or to the Procurement / Logistics departments in the case of TAP) using the MMS; – Spare parts / components are stored in a central warehouse (UAGME/PoAF General Material Depot); – The lower maintenance levels have available stocks; – Special tools are calibrated in a certified laboratory.
Employees – Numbers	– Shortage of qualified HR to perform maintenance tasks (this is less of an issue in the case of TAP); – Full compliance with the defined MPla dates / tasks; – Civilians can perform level III maintenance, but level II is performed by military personnel.
Employees – Training	– Mechanics are specialised in certain systems / equipment; – On-job-training is offered on a regular basis.

Table 3 shows the differences between the analysed WSMM models.

Table 3 – Differences between the analysed WSMM models

	EP	FA/TAP/EB
Leadership (Doctrine)	When the new maintenance concept, the staff was transferred from the UU (level I) to the MReg (level II), which has exclusive infrastructure and equipment.	PoAF/TAP – UU (AUMSq/BA6 and TAP) have suitable (certified) infrastructure and equipment. BA – UU have suitable infrastructures and equipment, but include levels O and I due to staff cuts.
	Level I carried out by the crew, as MSec/UU no longer perform maintenance tasks autonomously, which increases corrective actions and workload at Level II.	PoAF/TAP – 1st tier performed by specialised mechanics. BA – O-level performed by specialised mechanics (MSec/Company or Maintenance Platoon/Battalion).
	Commanders are not legally obligated to comply with the MPla and can decide to take the risk of postponing a task if the mission so requires (as in the BA).	PoAF/TAP – Compliance with MPla is a legal requirement to operate the aircraft. Guaranteed airworthiness. Uses a QAMS.
	The Communications and Information Systems Directorate (DCSI), which is responsible for responsible for managing information and IS, does not report to the CmdLog but to the Vice-CEME (PA, 2018).	PoAF – The DCSI reports to CLAFA, which has a GAIAL responsible for centralising and developing the IS (EMFA, 2011). TAP – The IT department is responsible for managing information and IS, and is integrated in the Maintenance and Engineering area. BA – The Directorate General of Communication is responsible for managing information and IS, reporting to the Chief of Defence.
	The DMT/CmdLog is responsible for the maintenance (with the exception of infrastructure), replenishment and transport of all the PA's materiel. The Quality Control Department (QCD)/CmdLog is responsible for the quality area.	PoAF – The DMSA/CLAFA manages the maintenance and CAM of the WS and support equipment, and includes a Quality Office that ensures the requirements are met (EMFA, 2013a). The DEP/CLAFA manages the QAMS of the quality, airworthiness and engineering areas, while the Supply and Transport Directorate/CLAFA manages replenishment. TAP – Maintenance, engineering and airworthiness are centralised in the Technical Department, but have separate Directorates. BA – The DGMR is responsible for managing all AAFF materiel.
	FMan assigned to the DMT/CmdLog.	PoAF – FMan assigned to the DMSA/CLAFA. TAP – IS Managers assigned to their respective areas. BA – FMan assigned to the DGMR, reporting to the Chief of Defence.
	Lack of job descriptions for WSMM roles.	PoAF/BA – Have job descriptions for WSMM roles. TAP – Training for managerial roles.
Organization (Management Tools)	ManWinWin – Suitable for all levels but underused, with 14 confirmed feature requirements (Table 4), but maintenance management will have to be carried out through the SIG/MDN, which is being migrated to the GRW software.	PoAF – PLUS-MGM is suitable, with 13 confirmed feature requirements, and will not be integrated into the SIG/MDN, which will make the investment more profitable and protect sensitive information. SIGMA-ABAST will be integrated in the SIG/MDN (C. M. Moreira, op. cit.). TAP – COSMOS (comprising about 30 independent IS), with 12 confirmed features, is obsolete and will be replaced by AMOS. BA – Uses a single IS (ILIAS) throughout the LC of the AAFF's WS and materiel, with 14 features (Table 4).
	MMS maintained and developed by a civilian company (contract), according to the instructions / requirements of the FMan/DMT in cooperation with the IT Section/DMT and DCSI.	PoAF – MMS developed by DCSI/CLAFA, according to the instructions / requirements of the CLAFA/AdIAL. TAP – MMS developed by IT/TAP. BA – MMS managed by the DGMR in close cooperation with the manufacturer (Belgian company).

[Cont.]

	EP	FA/TAP/EB
Organization (Procedures)	The MMS is used during the support phase of the LC of the WS, and the SIG/MDN during the remaining phases (as in the PoAF).	TAP/BA – COSMOS/ILIAS IS used throughout the LC of the aircraft / WS.
	The MOf oversees the implementation of the MPla and informs the UU (as in the PoAF/BA).	TAP – The Operations section receives alerts through Netline when the aircraft is scheduled for maintenance (F. J. Alves, face-to-face interview, 08 January 2020).
	Maintenance is based on estimates. Planning does not include WS mileage (km) per year. The FMan is responsible for stock creation (MCo/BrigInt warehouse – level II), based on consumption indicators (last three years – ManWinWin).	PoAF/TAP – An annual plan is prepared to determine the planned flight hours (flight profile). PoAF – The minimum stock level is maintained by the Supply Squadron/BA6, based on the Medium Time Between Failure formula, which includes the estimated repair time. TAP – Has stock (based on the manuals). BA – Has stock at levels O, I and D, calculated automatically based on the consumption history (ILIAS) of the previous years.
	Time-based maintenance (as in the BA).	PoAF/TAP – Regular inspections before / between / after flights and scheduled inspections.
	Tools are calibrated by certified companies; however, the requirements are not always met (as in the BA).	PoAF – Tools are monitored individually by the Base Units and calibrated by the accredited Precision Measurement Equipment Laboratory/Air Base No. 5 or by an external contractor. TAP – Tools are managed in CASTOR and calibrated internally.
Employees (Staff Numbers)	Uses external contractors due to HR shortage and lack of technical capacity (as in the BA).	PoAF/TAP – Uses external contractors mainly due to lack of technical capacity. This prevents HR from becoming overworked, increasing safety (A. J. Sirage, op. cit.; Gomes, 2010).
	Of 13,891 employees (military and civilian) (Lopes, 2019), about 60 have roles related to the maintenance (execution and planning), management and quality of the Pandur WS (CmdLog, 2015b; EME, 2015c; RMSA, 2018b), which corresponds to 0.43 % for 188 WS (3.13 WS/Man). If the calculation includes only mechanics, the average has been 19 WS/MTea.	PoAF – Of the 6,380 personnel (PoAF, 2019), about 85 are have roles related to the maintenance (execution and planning); management; and quality, airworthiness and engineering of the C-130H WS (A. J. Sirage, op. cit.; CLAFA, 2013a; CLAFA, 2013b), which corresponds to 1.33 % for five WS (0.06 WS/Man). If the calculation includes only mechanics, the average has been one WS/MTea. TAP – Of 13,000 employees, 2,000 have roles related to maintenance execution and management and to engineering and airworthiness, which corresponds to 15% for 87 aircraft (0.04 Aircraft/Man) (TAP, 2020a). A total of 120 mechanics work 24/7 to meet the maintenance deadlines. BA – Of 9,750 personnel (IISS, 2019, p. 90), 20 mechanics and 10 managers have roles related to the maintenance of the Pandur WS, which corresponds to 0.51 % for 44 WS (1.47 WS/Man) (N. Deschamps, op. cit.).
Employees (Training)	Specialised mechanics are concentrated at levels II and III.	PoAF/TAP – 1st, 2nd and part of 3rd tier maintenance is carried out at BA6/TAP. BA – All Pandur mechanics are assigned to the ISTAR Battalion.
	FMan role does not entail a specialisation (as in the PoAF).	TAP/BA – FMan role entails a specialisation.
	Lack of trained staff to operate the MMS at all levels.	PoAF/TAP – Training is provided to HR at all levels, and covers the relevant regulations and MMS. TAP also offers training on its Safety Management System (SMS) to all employees, to encourage them to report errors immediately, without fear of punishment. BA – Staff is trained to use the MMS.
	Technical Training is adapted from the manufacturer and defined in training guidelines (RMSA, 2017c) (similar to the BA).	PoAF – Technical training in QAMS is provided as defined in NQA.P007.004/005 standards (QAMS, 2018a; QAMS, 2018b). Qualification is validated by the Quality Office. TAP – Training provided as defined in Regulation 1321/2014 of 26 November, subject to approval by the ANAC and Quality/TAP.
	Can carry out most level III maintenance (overhaul).	PoAF – 3rd tier maintenance is usually executed externally (e.g. OGMA). TAP – OGMA are only used when there are space constraints (and only rarely due to lack of technical capacity). BA – Mechanics are not qualified to execute D-level maintenance.

Table 4 shows a comparison of the observations of the WSMM tools.

Table 4 – Observations (feature requirements for each management tool – PA, PoAF, TAP and BA)[9]

Observations	PoAF		PA		TAP	BA
	PLUS MGM	SIGMA ABAST	ManWinWin	GRW	COSMOS	ILIAS
Is it possible to manage permissions?	•	•	•	•	•	•
Is it possible to consult the maintenance status at any time?	•		○		•	•
Is it user friendly?	•	•	•	•	•	•
Is it possible to monitor the MPla?	○		•			•
Does it show the date of the next preventive maintenance?	•		•		•	•
Does it show the status of the equipments?	•		•			•
Does it generate alerts?	○		•			•
Does it include a list of authorised maintenance staff?	•		•		•	○
Can it be used to extract statistical data?	•		•		•	•
Is it possible to consult the maintenance log of each equipment?	•		•		○	•
Is it possible to monitor the maintenance time of each equipment?	•		○		•	○
Is it possible to consult the spare parts required and used for each equipment?	•		•		•	○
Is it possible to consult the spare parts available in the SLL and in storage?	•	•	•	•	•	•
Is it possible to consult the purchase prices of spare parts?		•	•	•	•	•
Is it possible to insert the NATO Stock Number and Serial Number of spare parts?	•	•	•	•	•	•
Does it log the kilometres or flight hours for each equipment?	•		•		•	•
Does it keep a log of fuel consumption by equipment?			○			•

Table 5 shows the drawbacks and benefits of each WSMM model, which will serve as a basis to outline the changes that should be implemented by the PA.

9 The data on the BA do not include observations, and refer only to the interviews. They are included in the table as this will make it easier to compare organizations. Legend: • – observations confirm the feature requirement; ○ – observations partially confirm it; the remaining observations do not validate it.

Table 5 – Benefits and drawbacks of the GMSA models

	Benefits	Drawbacks
PA	– Maintenance flexibility; – MMS procured externally allows staff to focus on WSMM, albeit with associated costs; – Time-based maintenance is less time consuming for mechanics; – Mechanics can become specialised quickly (between one week and six months) (DMT, 2014a; MReg, 2014; MReg, 2018), which increases their availability; – The ability to do most level III maintenance increases autonomy.	– Risk of failure / malfunction H-High (occasional probability and critical severity) (CID, 2007; Reis, 2015); – Procedures for top management are not defined; – Lack of interoperability between ManWinWin, GRW and the SIG/MDN (F. M. Prates, op. cit.); – Lack of an approved SLL reduces flexibility; – Delays in calibrating the tool jeopardise the accuracy of the work; – Lack of skilled HR causes cumulative delays in maintenance; – Mechanics are not exclusively assigned to maintenance tasks; – Pandur mechanics are assigned to other vehicles; – The WS that must be maintained exceed the available crews, which delays maintenance; – Lack of training in MMS leads to underuse.
PoAF	– Uses a QAMS; – Risk of failure / malfunction M-Moderate (improbable probability and catastrophic severity) - certified staff; – MMS developed in-house can be adapted to needs, increasing information security; – Inspections based on WS mileage increase crew safety; – Monitoring tool calibration increases work accuracy; – Mechanics work exclusively on the C-130H.	– Maintenance plan is not flexible; – Merging the Airworthiness-Maintenance-Operation roles makes WS more difficult to manage (C. M. Moreira, op. cit.); – The aviation procurement process is highly bureaucratic; – SIGMA-ABAST is obsolete (C. M. Moreira, op. cit.); – Shortage of skilled HR leads to maintenance delays (A. J. Sirage, op. cit.); – Specialisation courses for mechanics are time-consuming (over one year); – Limited ability to conduct 3rd tier maintenance.
TAP	– Uses a QAMS; – Risk of failure / malfunction M-Moderate (same as PoAF) – certified staff; – Maintenance-Engineering and Airworthiness-Quality are separate areas; – 3rd tier maintenance is executed internally; – Complete oversight over tool calibration; – Qualified HR and available stock lead to maintenance efficiency; – Mechanics only work on one aircraft type; – SMS training provided to all employees reduces the severity of failures by ensuring they are quickly corrected.	– Maintenance plan is not flexible; – Multiple non-interoperable MMS (COSMOS); – Specialisation courses for mechanics are time-consuming (about three years) (F. J. Alves, op. cit.); – Mainly uses paper-based maintenance; – Developing MMS internally is time-consuming and uses too many resources (200 employees for an area that is not the company's core business), even though it provides a way to develop skills; – Maintenance programmes and suppliers must comply with rigorous requirements, which increases costs in the short term, but brings long-term rewards.
BA	– Maintenance flexibility; – AAFF use a single MMS (ILIAS); – The MMS is used throughout the LC of the Pandur WS; – Time-based maintenance.	– Risk of failure / malfunction H-High (similar to the PA) – Lack of qualified HR makes outsourcing necessary, which increases costs; – Pandur mechanics also work on other vehicles; – Depends on the civilian market for level D maintenance.

4.2. Changes and implications for the Army

To adopt a model identical to the one used in the aeronautical sector, the PA would have to comply, at all times, to the standards defined by the ANSR (ANSR, 2020b; Ministry of Internal Administration, 2003), to which WS and tactical deployments are not subject. Furthermore, both mechanics and workshops would have to be certified according to rigorous standards, including: ISO 9001 (workshops), ISO/TS 16949 (mechanics) (Santos & Neto, 2018) and ISO/IEC 17025:2017 (to accredit the measurements laboratory that would have to be created) (IPQ, 2018). This means that the IS used in the aviation sector, such as

AMOS, are too expensive and restrictive (V. M. Grilo, op. cit.). While the current Pandur WSMM model is conceptually suitable, it can be improved to address the lack of human resources and the underuse of maintenance management support software (L. A. Baptista, op. cit.), in order to reach the same high quality standards as the aviation industry (P. M. Belchior, op. cit.). Thus, the changes proposed here are based on the compatibility of the analysed organizational models, which have different maintenance goals and are governed by different regulations, and aim to bridge the identified gaps and adapt their advantages in an integrated and feasible manner.

One proposal is that the CmdLog set up a quality management system in the QCD (IPQ, 2005; Maça, 2015; Pires, 2004; Pires, 2012) similar to the QAMS, in the sense that it should include all the documentation, technical training and NEP that define how the maintenance of WS should be managed, maintained and monitored in the PA, thus addressing the lack of doctrine for senior leadership (A. M. Graça, op. cit.). This QCD/CmdLog should also be responsible for certifying suppliers (Mouta, 2011, p. 17), as well as for supporting the certification of WS and other components, and be an autonomous support service, separate from the technical areas.

Document management IS are considered essential by all organizations (V.M. Grilo, op. cit.). The PA already has a system (GesDoc) for all maintenance levels, which is clearly suitable as it is an effective and efficient tool that provides "all features required to monitor and manage documentation" (Sousa, Abrantes, Graça & Gomes, 2018, pp. 25-30). This requirement is thus met. However, this IS can also be used to archive and sign documents digitally. This would make it possible to send reports directly from the MMS, safeguarding the reliability and security of information. Therefore, the proposed change is to make these management tools interoperable.

The staff responsible for the MM of the Pandur WS at the different levels is satisfied with the features provided by ManWinWin. However, they need training to operate and maximise the use of this IS. This MMS is a credible software that has an ISO 9001 certification and is used by several reputable companies (ManWinWin, 2020b). It can be installed online and accessed through a dashboard that shows all the relevant information depending on the user's access permissions and profile (ManWinWin, 2019; ManWinWin, 2020a). Thus, as developing a new IS in-house is costly and maintaining it would take up too many HR (F. J. Alves, op. cit.), the most cost effective solution would be to procure a MMS externally. The Belgian IS ILIAS could be an option because this management platform is tailored to the military sector. It is adaptable and several NATO countries use it (ILIAS, 2019a), and has the advantage of having been tested in the military aviation sector (ILIAS, 2019b). However, in order to implement it, the MM of the Pandur WS would have to be adapted to fit this work model. This would require training staff to operate the tool and either appointing a technical support expert full-time or hiring a consultant.

Therefore, to capitalise on the financial resources already invested in ManWinWin, which is underused and has an active service provision contract with the supplier (A. M. Graça, op. cit.), this study proposes that the software manufacturer updates continue to be adapted to the WSMM requirements (EME, 2017). However, staff should be provided training to standardise procedures. Another proposal is to use the ManWinWin tool to manage the remaining equipment fleets (V. J. Beltrão, op. cit.) by making it compatible with the SIG/MDN for the purposes of stock replenishment, which is one of the shortcomings of the GRW software. Alternatively, the SIG/MDN will have to provide the same features as ManWinWin or be interoperable with this MMS, and have sufficient flexibility to integrate the new features that will be required to make the MM of WS more efficient, thereby avoiding the time-consuming process of transferring data to the new tool and training staff to use it. In both cases, procedure manuals should be prepared to ensure that the databases are filled out as required, both to improve response capacity and to serve as support materials during training (F. M. Prates, op. cit.). Due to legal requirements, maintenance must be managed using an SIG/MDN module (L. A. Baptista, op. cit.). Therefore, this study proposes that the software be used to manage the PA's remaining equipment, with the exception of WS, as in the PoAF, where PLUS-MGM is still used to monitor the maintenance of these systems.

Regarding the features of the Pandur WSMM tool, in addition to the list in Table 4, the following measures should be taken: the DMT Director and Brigade Commanders should be provided access to the MMS (L. A. Baptista, op. cit.); the FMan and MOf/BrigInt should be able to access the system using a laptop computer, through a Virtual Private NetWork, to provide support during exercises; the maintenance time for each WS should be monitored by the MCo/BrigInt and optimised by automatically updating the logs the moment you pick up the tools (Valente, 2019); the system should include the qualifications of the mechanics authorised to work on the Pandur WS (in addition to their permissions) (A.J. Sirage, op. cit.); it should also include a list of suppliers approved by the QCD/CmdLog, by item type (F. J. Alves, op. cit.); the price of spare parts (with price fluctuations) should be listed, as in TAP (F. J. Alves, op. cit.). This would allow the FMan more flexibility in managing the budgets allocated to fleet sustainment in the Military Planning Law (MPL) (Force Planning Division, 2018); the status of special tools should be included and the system should issue an alert three months before the date of the next calibration (to make up for bureaucratic procurement processes) (J. M. Monteiro, op. cit.); it should also include the shots fired by main gun of each WS (L.A. Baptista, op. cit.).

By adding these features, it will be possible to monitor the entire maintenance (Figure 5) and replenishment (Figure 6) process online, using a single MMS that can be accessed by all users, which will make it easier to detect any malfunctions and correct them immediately, in compliance with the SMS methodology used in the aviation industry (V. M. Grilo, op. cit.). Another proposal is that the PA directives for the next two years, which aim to implement the "best practices of modern management" (EME, 2015b, p. 1), and which include the planned commitments of the Pandur WS, be uploaded to the MMS to enable the calculation of the spare parts required to sustain the fleet, as this will align maintenance to how the equipment is actually used (P. M. Belchior, op. cit.) and ensure compliance with the CmdLog directives (CmdLog, 2015a). To do so, an approved SLL should be created, and an adjustable budget should be allocated to it, based on the consumption history of the last three years.

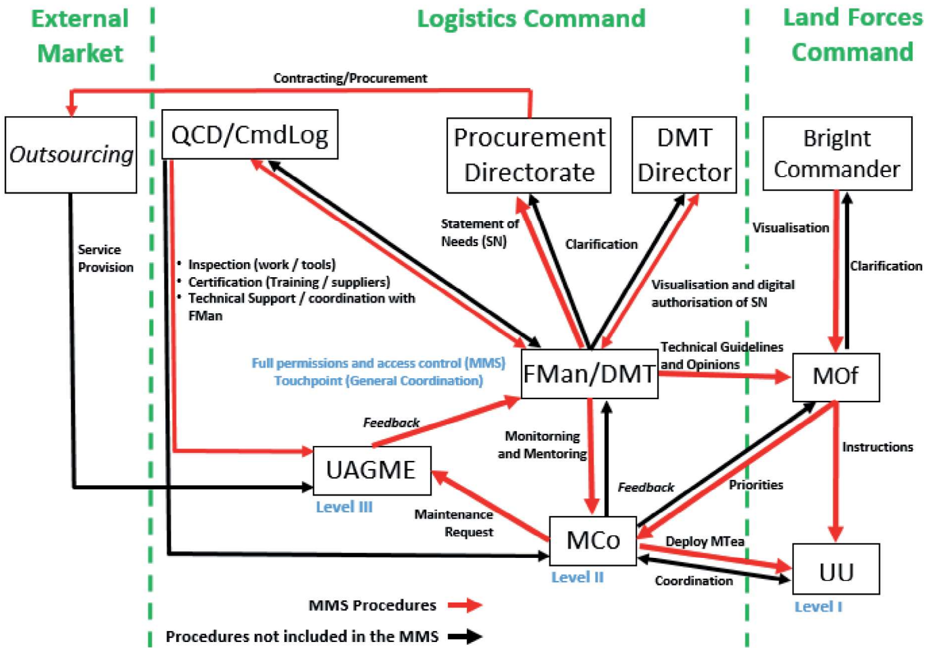

Figure 5 – Proposed WSMM model

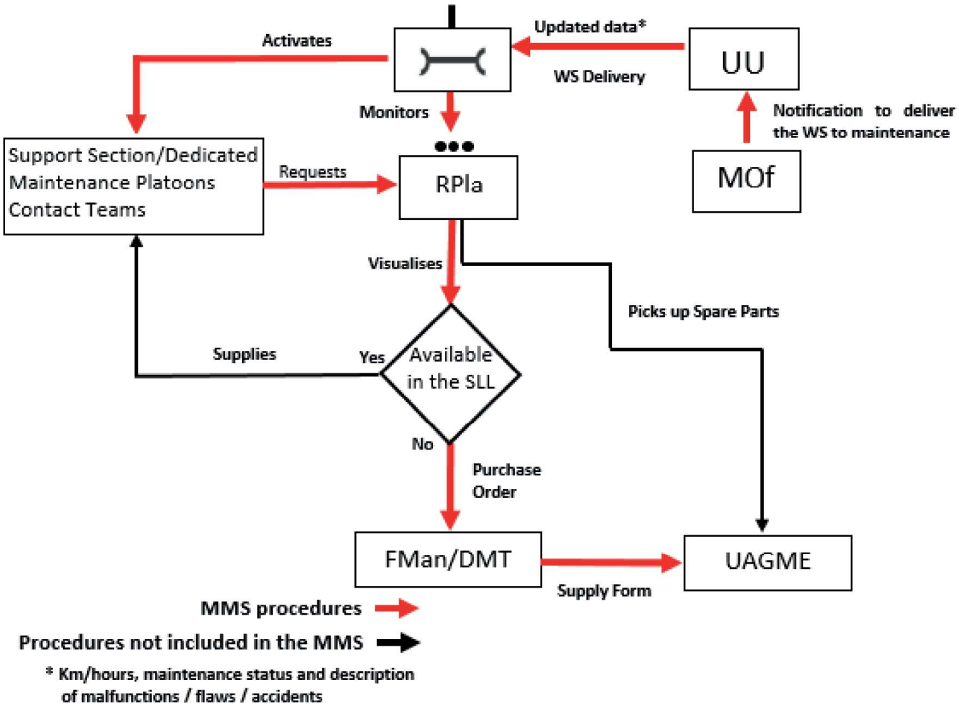

Figure 6 – Proposed replenishment flow chart

The lack of qualified HR that can perform maintenance on the Pandur WS will have to be addressed, as this WS cannot be sustained using only the current staff. This shortage of HR is even more problematic in the MCo/BrigInt, as the staff available is not enough to form more than two MTea[10] (EME, 2011), which is clearly insufficient to perform all the level II maintenance tasks that the Pandur fleet requires (RMSA, 2018b). To address this gap, part of the fleet (about 10%) should be transferred to "operational reserve" status, similarly to what happens in the BA (RMSA, 2018a, p. 7). This will require a thorough analysis to determine how many vehicles are required for training, exercises and FND. Using the same logic as the BA, the PA would keep approximately 19 Pandur in "park", or "extended storage", until the conditions exist to ensure their maintenance, as this would preserve the vehicles by storing them appropriately and conducting a storage inspection. Another measure is to adopt lean methodologies, such as installing magnetic boards with a task map at the MCo/BrigInt (Carneiro, 2013), and other methods (Botas, 2008; Ferreira, 2009) that can be used to reduce scheduled maintenance time (J. M. Monteiro, op. cit.). All Pandur mechanics should work on this WS on an exclusive basis and be assigned to the MCo/BrigInt, in order to cut training costs (P. R. Figueiredo, email interview, 05 April 2020). Civilian staff should continue to execute level III maintenance in the NT (UAGME) because these personnel will remain in their roles for longer (L. A. Baptista, op. cit.). This will free up military personnel for level II maintenance, where more delays occur, and to provide support during exercises for FND (J. V. Tilborg, op. cit.). The same logic should be used for external procurement, which implies more costs, closer monitoring of the maintenance work, and the risk of loss of autonomy and know-how (C. M. Moreira, op. cit.; Macedo, 2010; Pinho, 2018).

With regard to training, similarly to what happens in the PoAF, job descriptions should be prepared for each WSMM position, as this is considered a gap (A. M. Graça, op. cit.; CmdLog, 2015b), including the roles to be performed and the required and desirable qualifications and language skills, as this will facilitate the process of appointing staff (Silva, 2019) and improve skills and performance (Constantino, 2018). This will allow the PA to meet its NATO commitments (PA, 2014a), in compliance with the guidelines issued by the Training Directorate/PA (CID, 2015). The last proposal is that the FMan attend a specialisation in management or logistics (A. M. Graça, op. cit.; J. V. Tilborg, op. cit.) and a training course on project management and on the SIG/MDN, as provided for in the MPL (Bright Partners, 2016a; Bright Partners, 2016b).

5. Conclusions

Modernising the PA in the face of the current shortage of HR and financial resources will require an increasing effort by the ALS to ensure the maintenance and sustainment of the PA's WS. Due to their greater complexity, new WS usually require monitoring the maintenance work more closely and carefully managing HR and materiel according to the same high standards of quality, performance and safety as the aviation industry. This study

[10] The MCo/BrigInt should have 324 military personnel and ten exclusive Recovery Teams, but is currently at 12 % of the planned staff.

analysed WSMM models, and the analysis focused on maintenance management tools, as these IS are essential for planning and monitoring maintenance, in order to propose measures that improve the efficiency and quality of the maintenance performed on the Pandur WS, especially during the transfer and migration of data from the PA to the SIG/MDN.

To that end, the MMS used in the PA, the PoAF, TAP and the BA were analysed to identify features that can be adapted to the Pandur WSMM model. These organizations were compared by selecting indicators based on a three-dimension model (people, processes and technologies), according to the Demand Management methodology.

In the third chapter, to achieve SO1, it was confirmed that the PA intends to improve the ALS, and that its operational structure is supported by IS that can be used to centralise WSMM and reduce the number of staff involved in the process. To do so, it will integrate the IS in the SIG/MDN to manage the LC of its stocks. However, due to its technological specificity, the MM of WS is carried out by the FMan/DMT using ManWinWin, as this software enables full compliance with the MPla. As the aeronautical sector (PoAF and TAP) is governed by international laws that define all maintenance activities to be peformed, these organizations have had to implement a QAMS and an IS to ensure CAM. These organizations offer specific training certified by the AAN (PoAF) or by the ANAC (TAP), and have a quality control system. The BA centralises WSMM in the DGMR, and uses the same WSMM tool as the other AAFF branches. As there is a significant shortage of specialised mechanics, it only conducts level O and I maintenance and uses external contractors for the other levels.

In the fourth chapter, to accomplish SO2, it was confirmed that the aviation industry has implemented strict standardised procedures to minimise the risk of failure and maximise the investment made in training, which is especially time-consuming. Moreover, maintenance plans and suppliers must be monitored closely, which increases the costs involved in a procurement process that is highly bureaucratic. The MMS used by the PoAF is suitable but requires structural adjustments to separate airworthiness management from maintenance. TAP is certified to carry out its aircraft maintenance autonomously, but the lack of interoperability between IS makes the process inefficient. Even though the PA and the BA have MPla that are generally complied with, Commanders can authorise delays to meet operational needs. The BA's WSMM model uses the MMS throughout the LC of the AAFF materiel stocks and outsources all its level D maintenance to civilian contractors, whereas the PA carries out most of its level III maintenance autonomously but lacks qualified HR and the Pandur WSMM tools should be optimised. With regard to SO3, the PA should implement structural, procedural and technological changes in its data network to ensure interoperability between ManWinWin and the SIG/MDN, as well as integrate a set of features in a single MMS, as this will increase the number of processes and equipment that can be monitored online. Furthermore, the PA should assign more responsibilities to the QCD/CmdLog, invest in training to perform maintenance tasks and concentrate all mechanics specialised in the Pandur WS in the MCo/BrigInt. With regard to the GO, a quality management system should be implemented in the QCD/CmdLog and the responsibilities assigned to this area should be increased to provide technical support to the FMan/DMT, in order to standardise procedures and ensure high standards of quality in maintenance. To optimise the monitoring and process flow of the Pandur WSMM, interoperability between ManWinWin and the SIG/MDN should be ensured by integrating, in a single MMS, a set of management and monitoring features to enable the creation of access permissions for all personnel assigned to the WS throughout the LC, in order to facilitate the decision-making process. To perform this maintenance, measures should be taken to invest on and maximise the specialised training provided to staff, from the FMan to the mechanics, and the HR qualified to perform maintenance on the Pandur WS should be perform those roles on an exclusive basis. Another measure that can be taken is to transfer part of the fleet to the operational reserve, as this would free up personnel for the WS in use and preserve surplus equipment. This would significantly increase the response capacity of the Pandur WSMM and facilitate the process of allocating HR, material and financial resources because it would enable efficient sustainment, at low cost, and without requiring any major changes to the dynamics and doctrine of the PA.

This study's **contributions to knowledge** consist of determining which features of MMS are required to control quality efficiently and sustain the operational capability of the PA's WS, as well as the procedures to implement them. Maintenance management tools have proved essential to monitor the MPla closely and ensure efficiency in the process.

The study has one **limitation**, which refers to the fact that interoperability between ManWinWin and SIG/MDN was not analysed to confirm if these systems can be integrated and used to manage the maintenance of the Pandur WS, or if it will be necessary to transfer the data and features to a dedicated SIG/MDN module.

Thus, **future studies** are needed to analyse the combatibility between ManWinWin and the SIG/MDN in terms of WSMM, in order to implement the proposed MMS.

As for **recommendations**, when assessing the proposed measures, the WSMM should remain separate from the other equipment used by the PA, which require more rigorous assessments, given the wide range of items to be managed and the technological skills required to sustain these capabilities.

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