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THESIS

CONFIGURATION MANAGEMENT OF SOFTWARE-DEFINED RADIO SYSTEMS

by

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December 2017

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**CONFIGURATION MANAGEMENT OF SOFTWARE-DEFINED RADIO
SYSTEMS**

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Submitted in partial fulfillment of the
requirements for the degree of

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from the

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ABSTRACT

In the past, radios of any type were uniform across the entire United States Marine Corps (USMC) arsenal and were completely interchangeable. Now that they are software defined, each radio can be unique. The configuration management challenge presented by this diversity in the radio inventory motivates the following research questions:

1. How can the USMC maintain the flexibility required to tailor equipment for unique missions without introducing interoperability issues?
2. How can the USMC achieve configuration management of software-defined radios to ensure reliable battlefield communications?

This thesis reveals an unintended consequence resulting from the development of software-defined radios and explores possible solution concepts. Three solution concepts were developed and analyzed to determine not only how well they answer these two key questions, but also how they might affect existing doctrine, organization, training, materiel, leadership, personnel, facilities, and policy (DOTMLPF-P) of the Marine Corps.

Although no single solution concept was selected over the others, this thesis explores the trade space among all three and points out strengths and weaknesses of each, and then goes on to recommend more future work that could be performed to take the exploration to the next level.

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LIST OF ACRONYMS AND ABBREVIATIONS

AAO	Approved Acquisition Objective
AMF	Airborne, Maritime, and Fixed
AN	Army/Navy
ATRT	Automated Test and Re-Test
BFT	Blue Force Tracker
BOC	Basic Officer Course
C2	Command and Control
CAC2S	Common Aviation Command and Control System
CCB	Configuration Control Board
CCI	Controlled Cryptographic Item
CCO	Combat Center Order
CE	Communication Equipment
CLB	Combat Logistics Battalion
CM	Configuration Management
COMSEC	Communications Security
CONOPS	Concept of Operations
COTS	Commercial Off-The-Shelf
DAU	Defense Acquisition University
DOD	Department of Defense
DOTMLPF-P	Doctrine, Organization, Training, Materiel, Leadership, Personnel, Facilities, and Policy
DTG	Date/Time Group
DVA	Dual Vehicle Amplifier
EHF	Extremely High Frequency
EPLRS	Enhanced Position Location Reporting System
EPS	Expeditionary Power Systems
FBCB2	Force XXI Battle Command Brigade and Below
GPS	Global Positioning System
HF	High Frequency
HMS	Handheld, Man-pack, and Small-form-fit

IEEE	Institute of Electrical and Electronics Engineers
IISR	Integrated Intra-Squad Radio
IP	Internet Protocol
JEM	JTRS Enhanced MBITR
JENM	Joint Enterprise Network Manager
JPEO	Joint Program Executive Office
JREAP	Joint Range Extension Application Protocol
JTNC	Joint Tactical Networking Center
JTRS	Joint Tactical Radio System
LAR	Light Armored Reconnaissance
LoS	Line of Sight
MAGTF	Marine Air/Ground Task Force
MANET	Mobile Ad hoc Network
MARCORSYSCOM	Marine Corps Systems Command
MBITR	Multi-Band Inter/Intra Team Radio
MCAGCC	Marine Corps Air/Ground Combat Center
MCTSSA	Marine Corps Tactical Systems Support Activity
MIDS	Multifunctional Information Distribution System
MNVR	Mid-tier Networking Vehicular Radio
MOS	Military Occupational Specialty
MRC	Ground Mobile Radio Communications
MWSS	Marine Wing Support Squadron
NDI	Non-Developmental Item
NED	Network Enterprise Domain
NS	Network System
NSA	National Security Agency
NSN	National Stock Number
PEO	Program Executive Office/Officer
PEO-C3T	Program Executive Office/Officer for Command, Control, and Communications - Tactical
PLI	Position Location Information
PM	Program Manager

PMO	Program Management Office
POR	Program of Record
PRC	Human-Portable Radio Communications
QFD	Quality Functional Diagram
R/T	Receiver/Transmitter
RCF	Radio Configuration File
SDR	Software Defined Radio
SH	Student Handout
SHF	Super High Frequency
SINGARS	Single Channel Ground and Airborne Radio System
SKL	Simple Key Loader
SRW	Soldier Radio Waveform
SVA	Single Vehicle Amplifier
SYSCOM	Systems Command
TAMCN	Table of Authority Material Control Number
TBS	The Basic School
TDL	Tactical Data Link
THHR	Tactical Hand-Held Radio
TRC	Transportable Radio Communications
UHF	Ultra-High Frequency
USMC	United States Marine Corps
VHF	Very High Frequency
VRC	Vehicle Radio Communications
VSQ	Vehicular Special Combination
WNW	Wideband Networking Waveform

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EXECUTIVE SUMMARY

In the past, radios of any type were uniform across the entire United States Marine Corps (USMC) arsenal and were completely interchangeable. Now that they are software defined, each radio can be unique. This diversity presents a configuration management challenge. Radios of a certain type are no longer uniform. They are now composed of various versions of software and firmware. Some combinations of software and firmware allow for special waveforms to be employed that enable specific communications.

Research was conducted to determine what, if anything, could be done to ensure that when Marines in the operating forces receive a receiver/transmitter (R/T) from their unit supply warehouse, it will perform the functions they require of it without having to send it back to the manufacturer for retrogrades to previous versions. The problem is first modeled to illustrate how the problem manifests itself. The models were developed using the Innoslate online modeling tool. The modeling tool allows for the entire problem to be graphically represented, interpreted, and analyzed. Then, three solution concepts were developed, modeled, and analyzed to determine how well they provide flexibility while ensuring interoperability. They were also evaluated to determine how they might affect existing doctrine, organization, training, materiel, leadership, personnel, facilities, and policy (DOTMLPF-P) of the Marine Corps.

Solution Concept #1 focuses on keeping all programs wait to upgrade until all programs are can accommodate the upgrade. Solution Concept #2 calls upon a configuration control board with voting members from all the disparate programs by which upgrading decisions are made. Solution Concept #3 suggests that an organization could automate permutations of all the possible combinations of software and firmware to make a determination regarding the risk of upgrading to each of the programs that employ a particular type of radio in their designs.

Based on the analysis, the best way to provide maximum flexibility while maintaining interoperability and minimizing long-term negative effects across

DOTMLPF-P, was Solution Concept #3 because it allows for programs to assess collectively how changes in any one of a collection of tactical radios can have undesired second order and third order effects upon other programs' platforms. This allows for analysis that can provide the maximum amount of flexibility and interoperability without requiring Marine units to restructure, reorganize, or conduct excessive amounts of training. This comes at the cost of the development of a materiel solution however whereas Solution Concept #1 and Solution Concept #2 do not. Future work should be performed to take this exploration to the next level.

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I. INTRODUCTION

As combat radios have evolved over time from simple to complex programmable communication devices, problems have resulted. Radios used to be hardware-centric and the logistical processes associated with them were similar to other hardware-centric equipment. In other words, they were used until they broke and then replaced with something nearly identical from the local supply of spares. They were interchangeable physical assets. If they looked the same, they were the same. Marines did not need software for their older hardware-centric radios, but with the advent of software-defined radios, this all changed. This change introduces inventory control and interoperability issues, which fall under the domain of configuration management. This thesis focuses on how configuration management (CM) complications have arisen from the advent of software-defined radios and explores possible ways to address the problem.

A. RESEARCH QUESTIONS

This thesis addresses the following questions:

1. How can the United States Marine Corps (USMC) maintain the flexibility required to tailor equipment for unique missions without introducing interoperability issues?
2. How can the USMC achieve configuration management of software-defined radios to ensure reliable battlefield communications?

B. BACKGROUND

Elements of Marine Corps ethos drive the USMC to improve its radios. Part of the Marine Corps ethos prescribes thinking in terms of “Shoot, Move, and Communicate.” In battle, if Marines do these three things well, they succeed. Another part of the Marine Corps ethos warns that “complacency kills.” Marines must always know their current capabilities and seek improvement. In keeping with these two paradigms, the Marines have evolved their communications systems from transistor radio technology to the software-defined radio (SDR) framework. This new framework allows for great flexibility at the operator level because the radios (being commercially available) are designed to allow the operator to download software and firmware from the vendor’s

website to augment the default capabilities. This flexibility introduces great variability in configurations among all radios in the USMC arsenal even among those that appear identical.

USMC radio sets have moved from simple to complex in just the last decade. “On” and “off” were at one time the only two configurations for USMC radio systems. Now, there are many variables including the receiver/transmitter (R/T) type, the firmware, and the software version. Each of these variables can be assigned multiple values, which result in many permutations. Often, the receiver/transmitter (R/T) is common across many radio systems that happen to be using different firmware or software versions. Confusion often results from radios looking identical when they are not the same at all. Operators must power up a radio and navigate through a series of screens to determine its configuration.

In today’s “we’ve got an app for that” world, Marines take it upon themselves to download software and/or firmware as soon as it becomes available from the vendor. This changes the composition of the radio. When an upgrade or new capability is developed by the manufacturer, it is released on all new products, and it is not uncommon for the new firmware or software to be made available for download.

C. STATEMENT OF THE PROBLEM

With the advent of software-defined radios, operators now have the ability to modify the capabilities and limitations of their radios using firmware and software from the vendor’s websites. Well-intentioned Marines might download the newest versions available from the websites to ensure they give the front lines the most up-to-date radios they possibly can. They are not aware of what interoperability problems result.

When a Marine in Afghanistan communicating securely using a man-portable radio with other Marine units in the same geographical area turns an inoperable radio in for repair he receives a replacement. He then returns to the front lines thinking it works exactly like the one he was just using because it appears to be the exact same device. Since software and firmware are configurable, he might learn that the replacement he just

received does not communicate with the rest of the Marine units due to software or firmware versions being incompatible.

Each radio has a receiver/transmitter (R/T) unit. The R/T is the most recognizable part of the radio. The same R/T is often used in many different radio systems as is evidenced in Table 1. Like Russian nesting dolls, the R/T is a component inside a radio system inside a larger program of record (POR). Although PORs sometimes incorporate them as-delivered, other times the PORs may need to tailor it to its own unique purpose. In tailoring the radio system, the POR selects an existing R/T and modifies the firmware and/or software to meet its needs.

Modifications made in the interest of any one POR could have far-reaching unintended consequences. Once the POR modifies an R/T in its radio system, the R/Ts are no longer interchangeable from one radio system to another without first downloading and installing firmware and/or software. They are interchangeable neither from one POR to another nor with the voice communication systems the Marines use on the front lines. If this modified R/T finds its way to the front lines, the software and firmware modified to suit the needs of another POR could render the R/T non-interoperable for front lines communications putting our forces at risk.

The Marines of the operating forces frequently have to determine what versions are being used by what systems, download the firmware and software from a vendor's website, and install the firmware and software to the radio. This might not seem like much of an issue, but in a bandwidth-constrained environment, a two megabyte download could take hours. Exacerbating this situation is the fact that if Marines get the firmware/software setting wrong, it might not be readily apparent. The indicators of having the incorrect firmware or software might not present themselves immediately. In some cases, they might not present themselves until some obscure feature is attempted to be used (e.g., secure encrypted data communications in a Tactical Data Link [TDL]).

D. RESEARCH METHOD

Research began with an exhaustive search for reports of similar configuration-management problems identified in the U.S. military. When the Marine Corps Tactical

Systems Support Activity's (MCTSSA) technical director was queried regarding technical information on the subject, he suggested consulting subject-matter experts from MCTSSA who had experienced interoperability problems with radios. The experts provided detailed information regarding their experiences that was used to create Innoslate process models to graphically depict the information. The entire process was mapped in Innoslate. It is an iterative process by which the problem identifies itself. The problem, when modeled may seem repetitive, but the repetitions are necessary to properly reflect that iterative process by which the problem is revealed. When the problem gets revealed, the model allows for an ease in analysis that assists in formulating possible solutions. Once the information pertaining to the problem was all entered, the model was analyzed, and potential solutions were derived. Information regarding potential solutions was then modeled in Innoslate as well. A quality function deployment (QFD) diagram is used to illustrate how the desired functions of flexibility and interoperability compare against the impacts upon the DOTMLFP-P. Finally, this research ends with conclusions and recommendations in which the results are discussed along with the opportunities for future related work that could further explore this topic.

E. CHAPTER OUTLINE

Chapter II discusses the basic reasons for introducing software-defined radios into the Marine Corps as well as the environments where they are used. The chapter also presents the problem of software for radio systems. Chapter III describes how the problem was modeled in Innoslate. Also in this chapter are potential solutions modeled in Innoslate. The models of potential solutions are then discussed at length. In Chapter IV, configuration management of the USMC arsenal of software-defined radio receivers/transmitters is treated as a system and examined holistically. The final chapter discusses the trade-offs between the possible solutions, thereby arming decision makers with necessary information to make well-informed decisions regarding the path forward.

II. CONCEPT OF OPERATIONS FOR SOFTWARE-DEFINED RADIOS

This chapter explores the benefits of employing software-defined radios (SDR) instead of simple voice-only radios. The Institute of Electrical and Electronics Engineers (IEEE)'s Computer Society defines a concept of operations (CONOPS) as a document that “describes systems characteristics for a proposed system from a user’s perspective. A CONOPS also describes the user organization, mission, and objectives from an integrated systems point of view and is used to communicate overall quantitative and qualitative system characteristics to stakeholders” (IEEE 1998). In the spirit of a CONOPS, this chapter explores the purpose of SDRs and some of their applications in the Marine Corps as well as uses and implications of this emerging technology.

A. SYSTEM PURPOSE

Software defined radios (SDR) were developed to meet a need that spanned the branches of service. The objective was to have a single radio capable of transmitting and receiving across the spectrum instead of being limited to just one of the bands—HF, VHF, UHF, SHF, or EHF. That was too lofty a goal, so the JTRS Program Office set out instead to develop a family of radios useful to all services. For this purpose, as noted in a *Crosstalk: The Journal of Defense Software Engineering* article, the Joint Tactical Radio System (JTRS) Program was initiated in 1997 (Nathans and Stephens 2007). The services pushed their program and project managers toward a joint solution to save money across the DOD. The USMC directed its tactical radio resources toward the JTRS program.

The JTRS program made significant progress, and remnants of the program have survived to the present day—but not without significant restructuring along the way. In the 2007 *Crosstalk* article, it was stated that the DOD restructured the JTRS program in a way that made all of its products fall under the control of the Joint Program Executive Office (JPEO) and at that time, JTRS programs were configured to include the ground domain; the airborne, maritime, and fixed (AMF) site domain; and the network enterprise domain. The ground domain in 2007 comprised ground vehicular radios, man-pack

radios, handheld radios, and special applications. “The AMF domain [included] standard airborne Multifunctional Information Distribution System (MIDS) JTRS, and 19-inch rack applications. The network enterprise domain (NED) included the waveforms, gateways, and common networking service products used by the other domains. Included within the NED programs [were] new networking waveforms based on Internet protocol (IP) standards that [allowed] interoperability and mobile ad hoc network (MANET) protocols for over bandwidth-constrained and potentially intermittent wireless links.” (Nathans and Stephens 2007) The JTRS ground mobile radio program was canceled in 2011 (Gansler 2012). The Army then assigned management of several radio programs to the Program Executive Office for Command, Control, and Communications–Tactical (PEO C3T) (Osborn and Heininger 2013). PEO C3T assigned a project manager (PM) who managed current force and commercial-off-the-shelf (COTS) tactical radios. The PM office for tactical radios then oversaw product managers for handheld, man-pack, and small-form-fit (HMS) radios, the network system (NS), the airborne maritime/fixed (AMF) station, and the mid-tier networking vehicular radio (MNVR) programs (Osborn and Heininger 2013).

The waveforms are integral to continuously improving the tactical communication networks as they enable faster upgrades that increase security and capability (Sarrantinos-Perrin 2015). As radio technology advanced, so did the way in which radios transmitted information over the airwaves, resulting in the “maturation of nonproprietary waveforms such as soldier radio waveform (SRW) and wideband networking waveform (WNW).” (Osborn and Heininger 2013) Advances in both radio technology and waveforms enabled the AMF and MNVR programs to be restructured as non-developmental item (NDI) programs (Osborn and Heininger 2013). The NDI designation means that the programs identify and integrate technically mature commercial-off-the-shelf (COTS) hardware solutions. These solutions consisted of various platform, weight, battery power, and size configurations. The COTS hardware can handle the waveforms housed in the Joint Tactical Networking Center (JTNC)’s information repository (Osborn and Heininger 2013). The DOD perceived the development and use of SDRs as a “key enabler for achieving a family of interoperable radios based on common waveforms, standards, and

interfaces with enhanced portability and reusability.” (Nathans and Stephens 2007) The reprogrammable SDR provides a highly configurable platform that is conducive to rapid development (Nathans and Stephens 2007). In summary, the reason the SDR was introduced into the Marine Corps arsenal was two-fold: to save money through joining forces with the other branches to procure multi-band radio solutions and to provide a platform that supports the rapid integration of advancements in radio waveforms and technologies.

B. LOCATIONS WITHIN THE MAGTF COMMUNICATION SYSTEM

The Marine Air/Ground Task Force (MAGTF) communications system is an amalgam of systems having the primary function of collecting, processing, and/or exchanging information. For differing sizes of forces, the equipment and the personnel that operate and maintain that equipment may change, but the overall architecture of the MAGTF and its communication system remain remarkably unchanged. The MAGTF communications system comprises many different component systems, some of which are shown in Table 1. The table shows how receiver/transmitters (R/T) relate to firmware and software for fielded USMC ground tactical radios. The data for this table was assembled by numerous radio subject-matter experts at the Marine Corps Tactical Systems Support Activity (MCTSSA) and provided as a personal communication to the author on 9 December 2014 by MCTSSA’s senior principal engineer for tactical networking systems.

Table 1. Software-Defined Radios by Receiver/Transmitter.

Configuration Management for Ground Tactical Radios						
Receiver Transmitter	Firmware	Table of Equipment Indicators				
		Mobile Radio Communications (MRC)	Portable Radio Communications (PRC)	Transportable Radio Communications (TRC)	Vehicular Radio Communications (VRC)	Vehicular Special Combination (VSQ)
RT-1949C(P)(C)/PRC	RT: 4.3.0 (RTs in OEF: 4.2.2)	AN/MRC-145B	AN/PRC-117G(V)2	N/A	AN/VRC-114(V)1 AN/VRC-114(V)2	N/A
RT-1523E	N/A	N/A	AN/PRC-119F	N/A	AN/VRC-92D	N/A
RT-1694D(P)(C)/U	RT: 1.5.2	AN/MRC-148	AN/PRC-150(C)	AN/TRC-209A(C)	AN/VRC-104A(V)3 AN/VRC-104B(V)3	N/A
RT-1796(P)(C)	RT: 6.0.1.10	N/A	AN/PRC-117F(V)1(C)	N/A	AN/VRC-103(V)2 AN/VRC-103(V)3	N/A
RT-1916(P)(C)/U	RT: 7.0.9C DVA: 4.0B SVA: 4.0B	N/A	AN/PRC-152(V)1	N/A	AN/VRC-110 AN/VRC-112	N/A
PRC-148 (MBITR)	RT: 2.36 Rev AA DVA: 1.09	N/A	AN/PRC-148(V)1 AN/PRC-148(V)2	N/A	AN/VRC-111	N/A
PRC-148 (JEM)	RT: 6.01.03.0248 SVA: 3.01	N/A	AN/PRC-148A(V)3 AN/PRC-148A(V)4	N/A	AN/VRC-113	N/A
RT-1720G(C)/G (EPLRS)	RT: 11.4.1.2.3	N/A	N/A	N/A	N/A	AN/VSQ-2D(V)1
PRC-153 (IISR)	RT: R17.01.01 (6.17)	N/A	AN/PRC-153(V)1 AN/PRC-153(V)2 AN/PRC-153(V)3	N/A	N/A	N/A

SVA = Single Vehicle Amplifier; DVA = Dual Vehicle Amplifier

The data for this table was assembled by numerous radio subject-matter experts at the Marine Corps Tactical Systems Support Activity (MCTSSA) and provided as a personal communication to the author on 9 Dec. 2014 by MCTSSA's senior principal engineer for tactical networking systems.

Table 1 shows which R/Ts—listed in the first column—have been used in radio systems. They span multiple mission areas, as indicated by the other column headings. How units employ their radios in each mission area determines the firmware and software configurations. As shown in the first row of Table 1, the MRC-145B, PRC-117G(V)2, VRC-114(V)1, and VRC-114(V)2 radios all share the same R/T, namely the 1949C. Subsequent rows indicate similar relationships among the R/Ts, firmware, and software. Although the outward appearance of the radio systems is distinct, the outward appearance for a given R/T is the same regardless of the radio system in which it is used.

To help illustrate the importance of interoperability, the following paragraphs describe in detail all R/Ts from Table 1 and indicate some of their various locations within the Marine Corps.

1. The RT-1949C(P)(C)/PRC

The RT-1949C(P)(C)/PRC is used throughout the MAGTF. It is the R/T in the AN/MRC-145B, AN/PRC-117G(V)2, and the AN/VRC-114(V)1.

- MRC-145Bs are fielded to all echelons of the MAGTF, primarily supporting company and platoon operations. The fielded system provides a self-forming/healing mobile ad hoc network, man-pack, and vehicular wideband networking communications capability. Network connectivity facilitates the exchange of critical information required for command and control (C2). The AN/MRC-145B enables mobile forces to collaborate and access information resources to exchange voice, data, and video. (MARCORSYSCOM 2013)
- The PRC-117G(V)2 is also fielded to all echelons of the MAGTF. For example, at each rifle company, there are typically six PRC-117s. One radio is housed with headquarters, one with each rifle platoon, and two with the weapons platoon. (Taylor 2009)
- One would likely find two VRC-114(V)1s at the regimental headquarters, five with the infantry battalions, and three with the combat logistics battalion (CLB). (MCAGCC CCO 3500.14A 2015)

2. The RT-1523E

The RT-1523E is used in the AN/PRC-119F and AN/VRC-92D systems. Sometimes referred to as Single Channel Ground and Airborne Radio System (SINCGARS) radios, respectively, they are prevalent within the MAGTF.

- AN/PRC-119Fs are found at regimental headquarters, the infantry artillery battery, the Marine Wing Support Squadron (MWSS), and the CLB.
- AN/VRC-92Ds are common in highly mobile units like artillery, light armored reconnaissance, assault amphibian, and tank battalions. (BOC CE SH B191716)

3. The RT-1694D(P)(C)/U

The RT-1694D(P)(C)/U is used in the AN/MRC-148, AN/PRC-150(C), AN/TRC-209A(C), AN/VRC-104A(V)3, and the AN/VRC-104B(V)3.

- MRC-148s are used at regimental headquarters, infantry battalions, tank companies, tank platoons, MWSSs, CLBs, artillery battalions, and light armored reconnaissance (LAR) companies.
- PRC-150(C)s can be found at regimental headquarters, infantry battalions, artillery battalions and batteries, MWSSs, and CLBs. (Marine Corps Air/Ground Combat Center 2015)
- TRC-209A(C)s are typically only located at regimental headquarters, MWSSs, and CLBs and, when used as a base station for PRC-150 communications, vastly increase communication range. (411th Contracting Support Brigade, Korea, Construction & Supply Team 1 2010)
- The VRC-104A(V)3s and 104B(V)3s provide the equipment complement necessary to transform the transceiver to a 150-watt vehicular system. (Harris 2011)

4. The RT-1796(P)(C)

RT-1796(P)(C)s are an earlier version of the aforementioned RT-1949C(P)(C)/PRC.

- They are used in the AN/PRC-117F(V)1(C), AN/VRC-103(V)2, and the AN/VRC-103(V)3.
- Not all of these R/Ts have been removed from service. In fact, some programs of record specify the use of this R/T instead of the newer one.

5. The RT-1916(P)(C)/U

RT-1916(P)(C)/Us are used in the AN/PRC-152(V)1, the AN/VRC-110, and the AN/VRC-112.

6. The PRC-152 and PRC-148

The PRC-152s and the PRC-148s comprise the tactical handheld radio (THHR) product.

- THHRs are Line-of-Sight (LoS) handheld radios.

The PRC-152 can be vehicle mounted and becomes the AN/VRC-110 while the PRC-148 when vehicle mounted becomes the VRC-111 or the VRC-113 depending on which variant of the PRC-148 R/T possessed.

- The PRC-148 Multiband Inter/Intra Team Radio (MBITR) R/T is in the AN/PRC-148(V)1, AN/PRC-148(V)2, and the AN/VRC-111.
- The PRC-148 (JEM) R/T is in the AN/PRC-148A(V)3, the AN/PRC-148A(V)4, and the AN/VRC-113.

7. The RT-1720G(C)/G

The RT-1720G(C)/G Enhanced Position Location Reporting System (EPLRS) R/Ts are used in the EPLRS program.

- The VSQ-2D is essentially an RT-1720 with a user readout that serves as the EPLRS Network Manager radio set in an EPLRS radio network.
- At one time, the EPLRS radio networks were the only tactical-radio-IP-capable networks in the USMC and they also reported blue force position location information (PLI).
- These capabilities are now more frequently seen being met by global positioning systems (GPS) and by Blue Force Tracker / Force XXI Battle Command Brigade and Below (BFT/FBCB2).

8. The PRC-153

Finally, the PRC-153 Integrated Intra-Squad Radio (IISR) R/T is fielded to the individual Marine level at infantry units.

The laydown of the radios throughout the Marine Corps as described earlier is not all-inclusive. It shows some of the locations where they can be (or are typically) used, but other variations exist as well. The main point is that the many variations are spread throughout the entire corps; therefore, the problem cannot be easily localized and treated individually as a “unit problem” that can and/or should be addressed at the unit level. The ubiquitous nature of all the disparate radios justifies a holistic solution.

C. PERFORMANCES AND USES

The SDR framework enables the radios to load waveforms and run applications. As stated in the US Army article, *Software Defined Radios Allow Soldiers to Adapt to*

Cyber Threats, “A waveform can be ported to different hardware platforms providing similar results. This reduces the overall cost of ownership since any changes—[performance or cyber]—are made only once in a single baseline, which can quickly be implemented in [multiple] hardware [platforms]. Since the waveforms are Internet protocol (IP) based, they can interoperate with other IP-based networks.” (Sarrantinos-Perrin 2015)

Furthermore, the article states, “The [waveforms can be] loaded and configured through the Joint Enterprise Network Manager (JENM), using Radio Configuration Files (RCF). After the radio network planner completes the network plan, the JENM application translates the mission data into the format required for each radio and then downloads the configuration files directly onto the radios.” (Sarrantinos-Perrin 2015)

The article also notes that “Alternatively, instead of downloading the RCFs directly to the radios, JENM can also download the RCFs to a Simple Key Loader (SKL).” Then, if a Marine needs to configure a radio, he can then use the SKL to download the correct configuration files to the radio. The networking waveforms that connect the radio to a network provide performance improvements and reduce the risk of cyber threats, thereby eliminating the need to provide each radio operator a new radio whenever a new cyber threat is identified. The RCFs also allow improvements to be pushed out to the radios without fielding new hardware. (Sarrantinos-Perrin 2015)

Once all the radios are configured, the radios perform as a network. If any of the aspects of the SDR are changed, it is possible that the radio might not use the same waveform as others in the network and, therefore, would not be capable of communicating on that network any longer.

D. IMPLICATIONS OF USING SDRS

Radio manufacturers modify their firmware frequently. In some cases, it is more frequent than necessary for Marine Corps purposes. Radio firmware is modified to add new capability or to correct software defects in a prior version. The Marine Corps’ current tactical radio providers have deliberate plans for growing their radio capabilities through modifying firmware and software. This is their roadmap for making their product

more appealing to more customers, and thus selling more radios. Along the way they also react to problems manifested in currently installed versions.

The radios in the Marine Corps today were bought as COTS products. JTRS, the last program of record tasked to produce radios made specifically for the military services in the traditional acquisition process, was canceled. Radio manufacturers like Harris Corporation sell their radios all over the world to military and non-military customers and have their own internal software CM plans, but they do not deliberately accommodate their customers' CM requirements.

There are indeed some joint waveform specifications remaining from the JTRS program. The joint waveform specifications hold the waveforms to a standard, but they do not do the same for the R/T configurations. The software that implements these standard waveforms in one manufacturer's product is incompatible with another manufacturer's product. The joint waveform is ported to the specific hardware configuration of each make and model of radio that implements it. Radios from different manufacturers that properly implement joint standard waveforms do interoperate, but this is not to say that the software is interchangeable.

Families of radios tend to consist of several variants based on a central component, the R/T. Add a battery box to the R/T, and it becomes a man-pack or handheld radio. Place the R/T in a vehicle adapter and it becomes a vehicular radio. Place the R/T in a transit case and it becomes a transportable radio. There is even the possibility of integrating the R/T into a platform or weapon like a Common Aviation Command and Control System (CAC2S), radar or howitzer. To date, it is the R/T that houses both the software and firmware in software-defined radios.

Multiple, independent programs of record may employ the same make and model of R/T. This all adds up to tens of thousands of R/Ts of the same make and model in the Marine Corps. Programs buy their radios at different times than other programs. Hence, the same model of R/T may appear in different systems, platforms, or weapons with different firmware versions, depending on what the manufacturer delivers at the time of purchase.

Early in 2014, MCTSSA started to observe anomalies when testing across different platforms. In Marine Corps testing, tests are typically broken down into test scenarios and each test scenario is broken down into test cases. One of the scenarios tested information exchanges using the Joint Range Extension Application Protocol type A (JREAP-A). CAC2S requires radios capable of supporting the JREAP-A protocol. For the CAC2S-embedded Harris PRC-117G to be capable of supporting JREAP-A, the PRC-117G had to be configured with a particular software and firmware version. Virtually none of the ground-domain systems require the capability of supporting JREAP-A, so there is no urgent reason for most ground-domain programs to change versions. Without any forcing function, the PRC-117Gs used in air-domain systems like CAC2S will be on the version that supports JREAP-A while other ground-domain systems will be on an older version that cannot support JREAP-A. Configurations will vary from one R/T to another depending on whether or not they are ground-domain or air-domain. This is one example of an actual observation of how an R/T's configuration loses its uniformity throughout the supply system.

E. CHAPTER SUMMARY

A natural conflict arises between keeping a standard configuration among all R/Ts throughout the entire Marine Corps and affordably managing individual programs on their own schedules and budgets. It is neither easy nor cheap to change all the radios in a system overnight. Arbitrarily modifying a radio that is tightly integrated into a system is risky, increasing the potential for individual programs to diverge from established firmware versions. It is not evident that the Marine Corps Maintenance Management System seamlessly accommodates variations in firmware embedded in otherwise identical R/Ts. Considering how a maintenance float works, if different systems use different firmware, it will not be practical for our Supply and Maintenance systems to guarantee a float item is issued with the right firmware. Radio firmware tends to consist of multiple baseline and option files. The end user does not control the options he receives; those are determined and paid for by the acquisition programs. Even R/Ts loaded with the same firmware version may have been purchased with different option files and thus differ in configuration and capability.

It is also possible that a firmware change requires a hardware change, which further complicates the matter. The Marine Corps must strike a balance between falling too far behind what our suppliers are providing and upgrading too often. The need for a solution will likely exist as long as the USMC uses software-defined radios in their systems. Chapter III discusses three different ways of striking that balance.

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III. MODELING

A model can be very helpful in illustrating problems that can arise from inconsistent configurations of software defined radios (SDR). There are many options for modeling software in the commercial marketplace today. For this thesis, the modeling software used was Innoslate. It was the clear choice for a few reasons. For one, Innoslate has a straightforward interface that does not require extensive user training prior to the successful creation of a model. Additionally, Innoslate allows for multi-user collaboration, but most importantly, it does not require administrative privileges on a user's workstation to use it. This last aspect allows for collaboration on models from Navy/Marine Corps Intranet workstations without emailing potentially enormous files back and forth (Giammarco 2015).

Due to the nature of the SDR configuration management (CM)—involving inadvertent actions of many different parties combined—it was determined that an activity model would be best for illustrating the SDR's CM problem and for identifying potential solutions. An activity model assigns each actor a branch or “swim lane.” The branches are logically concurrent, meaning the first activity on each branch begins to execute at the same time (Giammarco 2015).

Once the problem is modeled, potential solutions become apparent and are also modeled in Innoslate. This chapter models the way in which interoperability is impacted through interchanging receiver/transmitters (R/T) among disparate radio systems and different programs of record (POR).

A. MODELING THE PROBLEM

The interoperability problems of SDRs often manifest after various programs employ any number of different version releases, resulting in numerous disparate configurations existing in the supply system at the same time. In most cases, an interoperability problem only becomes apparent when one R/T is sent for repairs—sometimes called “floating it out”—and a replacement is sent in its place—sometimes called “getting a replacement from float.”

The activity model in Figure 1 contains action blocks in multiple swim lanes that show how the actors may inadvertently create multiple configurations of the same R/T in the supply system. The dark blue “start” circle that appears to the left of the swim lanes indicates where the activity model begins. The activity model appears as a set of parallel timelines. Each actor has his own timeline and conducts activities, shown in light blue blocks, as time progresses. The green parallelograms indicate triggers that cause additional actions in other swim lanes. The placement of the triggers is not constrained to just one time line but show precedence between one event in one actor and event in another actor. The original model in Innoslate reads from left to right resulting in one very long strip of concurrent swim lanes. Due to the page constraints of this thesis, the Innoslate model appears broken into smaller “frames” with directive arrows connecting one frame to another. Nevertheless, the model should be interpreted as continuous timelines from start to end.

Figure 1. SDR CM Problem Definition

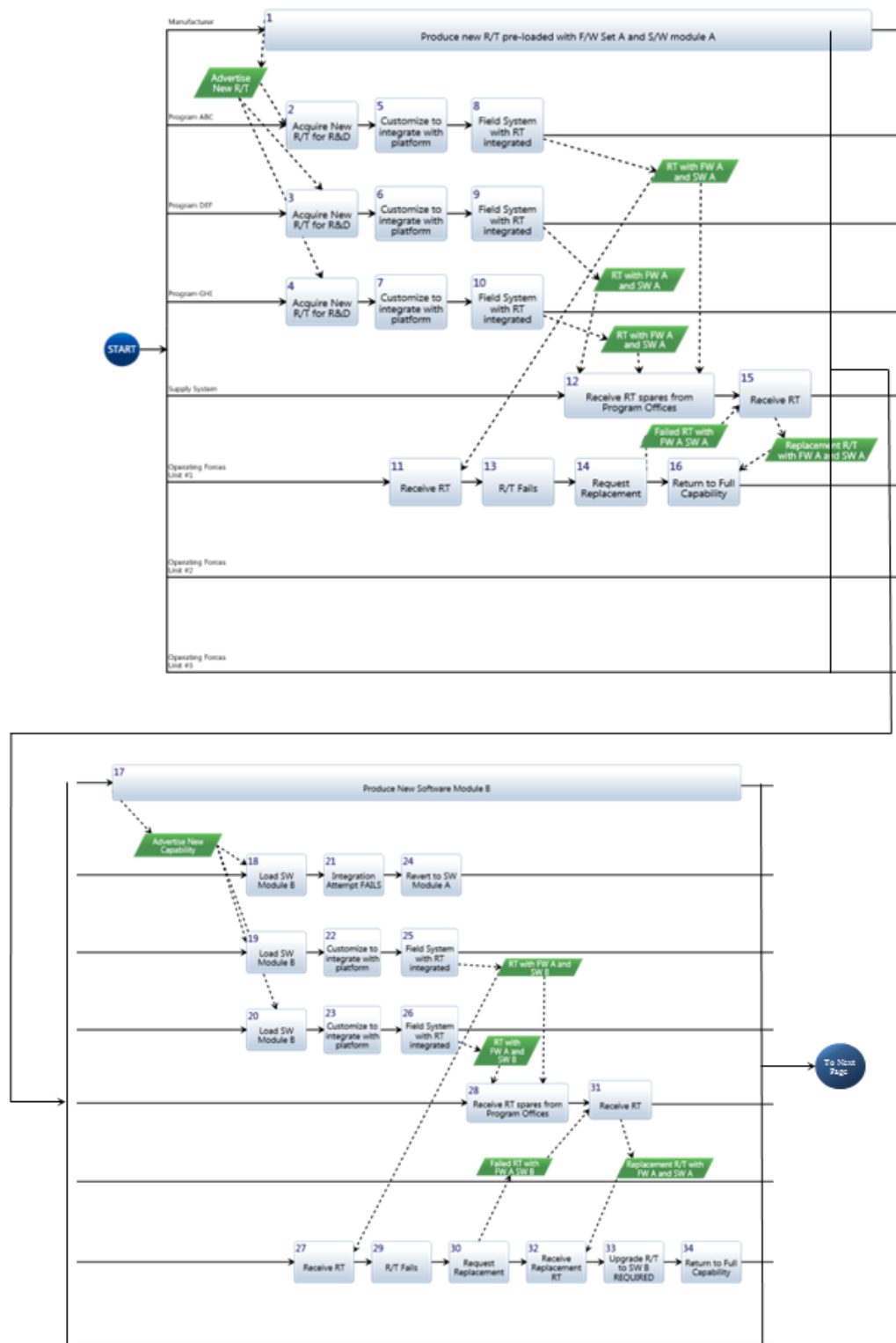


Figure 1. SDR CM Problem Definition (continued)

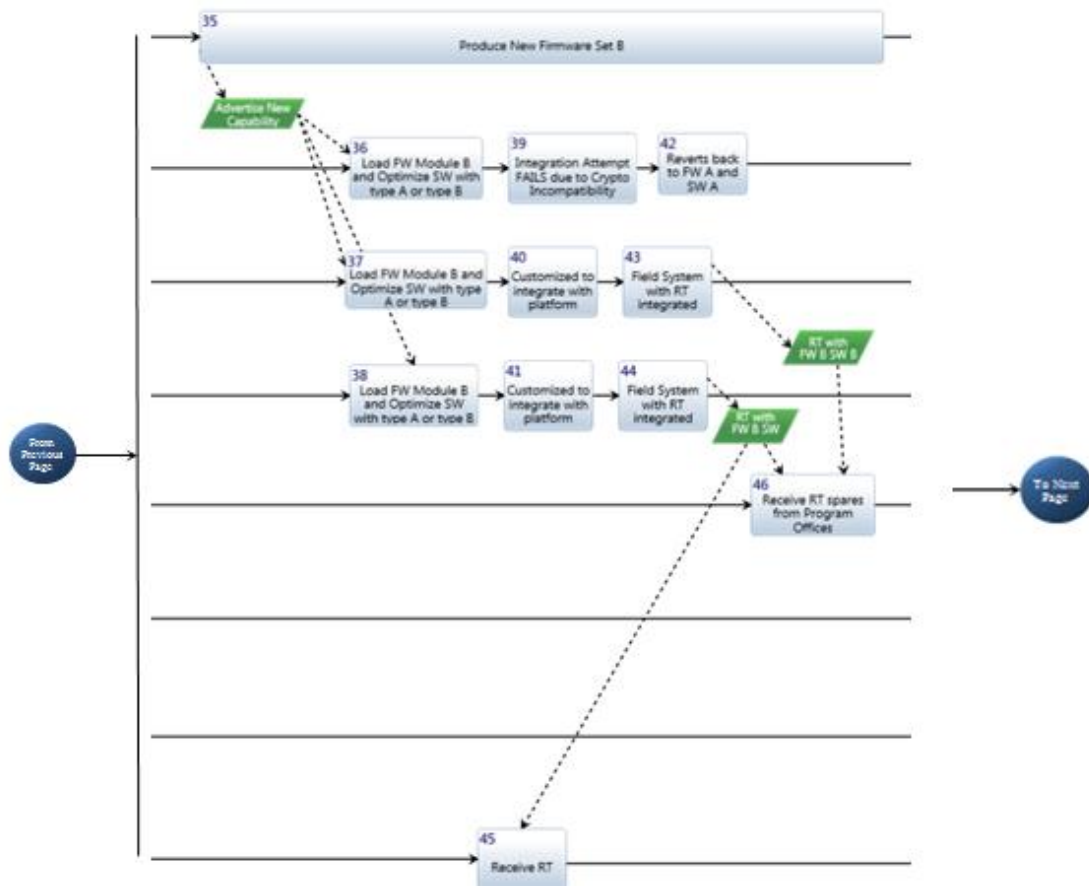
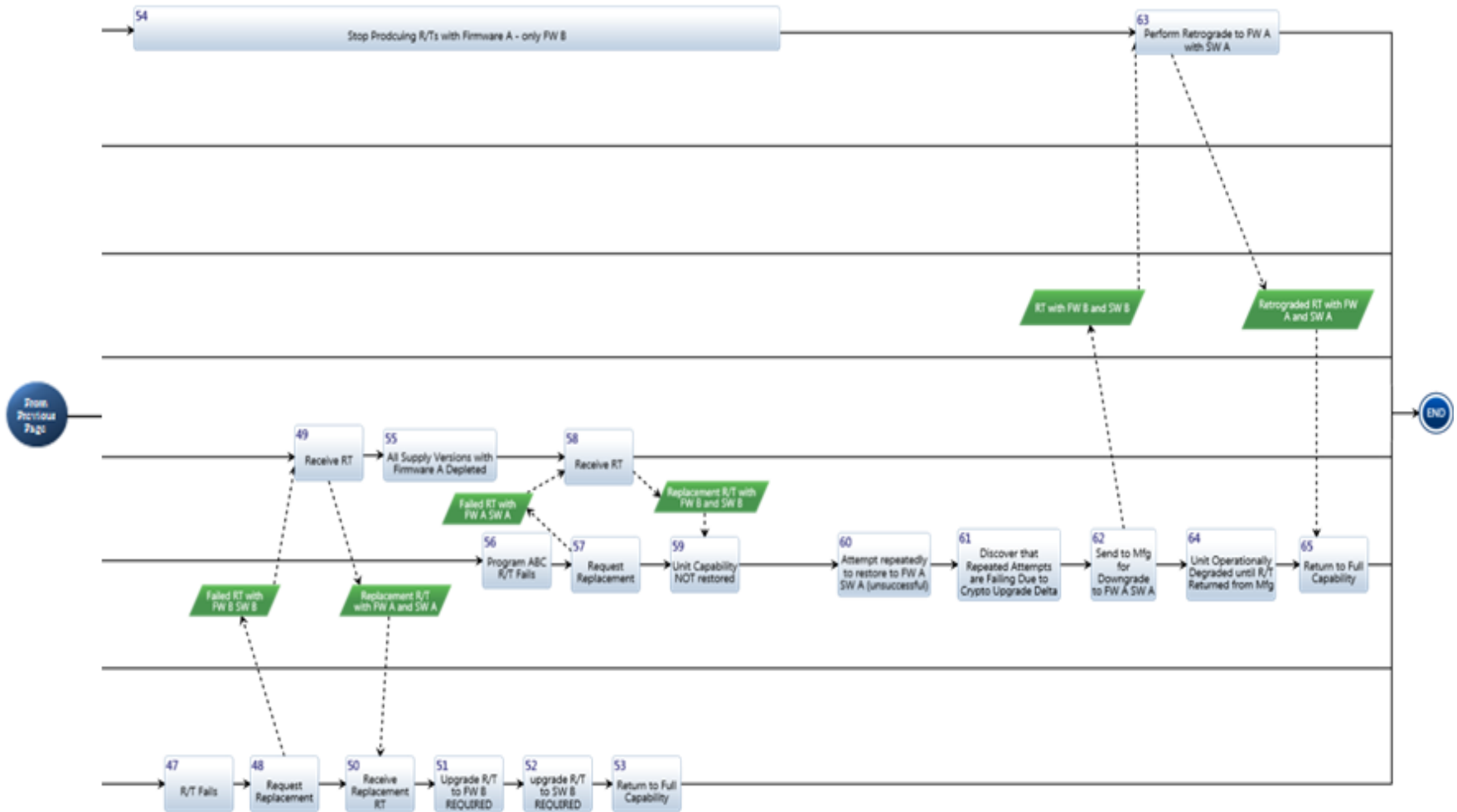


Figure 1. SDR CM Problem Definition (continued)



In Figure 1, the activity model begins with the action of the manufacturer producing a new R/T. The advertising of this new R/T attracts the attention of three programs: ABC, DEF, and GHI. These programs work independently to incorporate the new R/T into their systems to capitalize on its new inherent capabilities. How they go about this and how they handle additional releases of software and firmware varies depending on their missions. Eventually, this results in the manifestation of a problem in the field that requires the field Marine to ship his R/T to the manufacturer for a retrograde to a previous version.

Specifically, the problem becomes apparent when the replacement arrives from the supply warehouse. The replacement may have the exact same firmware and software as the R/T that was sent, as shown in blocks 14, 15, and 16. In this case, there is no problem: the using unit receives precisely what it sent originally. Sometimes, though, the replacement has different software, as shown in blocks 30–34. In this case, the radio maintenance Marines must gain access to the Internet to download and install the proper version. Still, other times, the replacement has different firmware and software, as shown in blocks 48–53. In this case, the situation can be remedied by having radio-maintenance Marines, who have been properly trained, download and install previous versions of firmware and software to conduct the retrograde themselves. The problem is no longer easily remedied when communications security (COMSEC) becomes involved, as shown in blocks 56–65. There are times when the COMSEC circuitry, firmware, or software gets modified from one firmware version to another. The COMSEC modifications cannot be undone by Marines in the field. When a radio maintenance Marine tries to change the firmware back to an older version they encounter much difficulty before learning that they must send off the R/T directly to the manufacturer. Only the manufacturer can perform the COMSEC mods and then retrograde the R/T to the desired versions.

Table 2, as an accompaniment to Figure 1, outlines the notional set of iterations whereby a Marine unit eventually sends an R/T back to the manufacturer to retrograde the firmware and software versions required for its respective system. In most cases, the Marine can download firmware or software from the manufacturer's website to return his R/T to the state he needs, but sometimes, COMSEC has been modified from one

firmware upgrade to another, and radio maintenance Marines are not permitted to modify COMSEC.

Table 2. SDR CM Problem Definition Explanation Table

Block	Lane	Label	Description
1	Manufacturer	Produce new R/T loaded with FW A and SW A	Radio manufacturers are constantly striving to improve their existing product line and/or to introduce new product lines that enhance the radio communication capabilities of their customers.
2	Program ABC	Acquire New R/T for R&D	Each program office seeking a capability offered by the new R/T (or any other capability upgrade) acquires one (either through purchase or on bailment) to assess the suitability of the product for its program.
3	Program DEF		
4	Program GHI		
5	Program ABC	Customize to Integrate with Platform	The product has many capabilities. Each program office may seek different capabilities, and each has different form & fit requirements as well.
6	Program DEF		
7	Program GHI		
8	Program ABC	Field System with R/T Integrated	Each program office fields its system in accordance with its approved acquisition objective (AAO). A case in which ABC, DEF, and GHI all field their systems to the same Operational Unit is entirely possible.
9	Program DEF		
10	Program GHI		
11	Operating Forces Unit #1	Receive R/T	The unit receives the fielded system with the R/T as a component.
12	Supply System	Receive R/T Spares from Program Offices	When programs field, they purchase spares that eventually make their way into the supply system.
13	Operating Forces Unit #1	R/T Fails	R/Ts can fail in the field due to normal operations or due to damage.
14	Operating Forces Unit #1	Request Replacement	The unit floats out the bad R/T and requests a replacement.
15	Supply System	Receive R/T	Supply issues unit a replacement from spares if available.
16	Operating Forces Unit #1	Return to Full Capability	The unit is now able to return to its full operational capability.

Block	Lane	Label	Description
17	Manufacturer	Produce New Software Module B	The radios are software-defined. Periodically, the manufacturer releases new software versions that provide additional capabilities.
18	Program ABC	Load SW Module B	Each program office seeking a capability offered by the new software acquires the software to assess the suitability of the product for its program.
19	Program DEF		
20	Program GHI		
21	Program ABC	Integration Attempt FAILS	For any number of reasons, the new software is not compatible with system ABC.
22	Program DEF	Customize to Integrate with Platform	The product has many capabilities. Each program office may seek different capabilities, and each has different form & fit requirements as well.
23	Program GHI		
24	Program ABC	Revert to SW Module A	Since the program was unable to integrate software B into its system, it reverts back to Module A and elects <i>not</i> to field.
25	Program DEF	Field System with R/T Integrated	Each program office fields its system in accordance with its AAO. The case wherein DEF and GHI field their systems to the same operational unit is entirely possible.
26	Program GHI		
27	Operating Forces Unit #2	Receive R/T	The unit receives the fielded system with the R/T as a component.
28	Supply System	Receive R/T Spares from Program Offices	When programs field, they purchase spares that eventually make their way into the supply system.
29	Operating Forces Unit #2	R/T Fails	R/Ts may fail in the field due to normal operations or damage.
30	Operating Forces Unit #2	Request Replacement	The unit floats out the bad R/T and requests a replacement.
31	Supply System	Receive R/T	Supply issues unit a replacement from spares if available.
32	Operating Forces Unit #2	Receive Replacement R/T	The unit receives the replacement system and attempts but cannot return to a fully operational capability because the replacement R/T from float is loaded with software A rather than software B.

Block	Lane	Label	Description
33	Operating Forces Unit #2	Upgrade R/T to SW B REQUIRED	Marines learn they must go to the manufacturer's website to download the newer version of software and install it onto their radios.
34	Operating Forces Unit #2	Return to Full Capability	The unit is now able to return to its full operational capability.
35	Manufacturer	Produce New Firmware Set B	Periodically, the manufacturer releases new firmware versions that provide additional capabilities such as the ability to use new/better/different waveforms.
36	Program ABC	Load FW Module B and Optimize SW with type A or type B	Each program office that seeks a capability offered by the new firmware acquires the firmware to assess the suitability of the product for its program.
37	Program DEF		
38	Program GHI		
39	Program ABC	Integration Attempt FAILS	For any number of reasons, the new firmware is not compatible with system ABC.
40	Program DEF	Customize to Integrate with Platform	The product may have many capabilities. Each program office may seek different capabilities, and each has different form & fit requirements as well.
41	Program GHI		
42	Program ABC	Revert to FW A and SW A	Since the program was unable to integrate firmware B into its system, it reverts back to firmware A with software A and does <i>not</i> field a new version of ABC.
43	Program DEF	Field System with R/T Integrated	Each program office fields its system in accordance with its AAO. The case wherein DEF and GHI field their systems to the same operational unit is entirely possible.
44	Program GHI		
45	Operating Forces Unit #3	Receive R/T	The unit receives the fielded system with the R/T as a component.
46	Supply System	Receive R/T Spares from Program Offices	When programs field, they purchase spares that eventually make their way into the supply system.
47	Operating Forces Unit #3	R/T Fails	R/Ts may fail in the field due to normal operations or damage.
48	Operating Forces Unit #3	Request Replacement	The unit floats out the bad R/T and requests a replacement.
49	Supply System	Receive R/T	Supply issues the unit a replacement from spares if available.

Block	Lane	Label	Description
50	Operating Forces Unit #3	Receive Replacement R/T	The unit receives the replacement system and attempts but cannot return to a fully operational capability because the replacement R/T from float is loaded with firmware A rather than firmware B.
51	Operating Forces Unit #3	Upgrade R/T to FW B REQUIRED	Marines learn they must go to the manufacturer's website to download the newer version of firmware and install it onto their radio.
52	Operating Forces Unit #3	Upgrade R/T to SW B REQUIRED	Marines learn they must go to the manufacturer's website to download the newer version of software and install it onto their radio.
53	Operating Forces Unit #3	Return to Full Capability	The unit is now able to return to its full operational capability.
54	Manufacturer	Stop Producing R/Ts with Firmware A - only FW B	For business reasons, the manufacturer eventually shuts down its production of older equipment to focus resources elsewhere.
55	Supply System	All Supply Versions with Firmware A Depleted	Eventually, the supply system spare R/Ts configured with firmware A become depleted.
56	Operating Forces Unit #1	Program ABC R/T Fails	R/Ts may fail in the field due to normal operations or damage.
57	Operating Forces Unit #1	Request Replacement	The unit floats out the bad R/T and requests a replacement.
58	Supply System	Receive R/T	Supply issues the unit a replacement from spares if available.
59	Operating Forces Unit #1	Unit Capability NOT restored	The unit needs an R/T configured with firmware A and software A, but supply has none available.
60	Operating Forces Unit #1	Attempt to restore to FW A SW A	COMSEC upgrades often accompany firmware upgrades. COMSEC retrogrades/upgrades are purposely <i>not</i> performed by Marines in the field.
61	Operating Forces Unit #1	Discover that Repeated Attempts are Failing Due to COMSEC Upgrade Delta	Eventually, Marines in the field discover that repeated attempts are failing due to incompatible COMSEC firmware versions.

Block	Lane	Label	Description
62	Operating Forces Unit #1	Send to Mfg for Downgrade to FW A SW A	The only option for Marines in the field is to send their R/Ts to the manufacturer for a retrograde to the older firmware and COMSEC versions.
63	Manufacturer	Perform retrograde to FW A with SW A	The manufacturer rebuilds the R/Ts with firmware A, software A, and the proper COMSEC.
64	Operating Forces Unit #1	Unit Operationally Degraded until R/T Returned from Mfg	The unit is not fully operationally capable until the R/Ts return from the manufacturer with firmware A and software A.
65	Operating Forces Unit #1	Return to Full Capability	The unit is now able to return to its full operational capability

Now that the problem has been mapped, the work of analyzing the problem statement model and determining some plausible solutions begins. This may include modifications to processes, procedures, and policy. Or, it may require the development of a materiel solution.

B. CONCEPT #1

1. Process Model

The following model, as shown in Figure 2, with its associated explanation shown in Table 3, outlines one approach for ensuring all R/Ts in the entire USMC supply system always use the same firmware and software uniformly, thereby making all R/Ts, regardless of the POR under which they were initially fielded, fully interchangeable. In this concept, the systems command (SYSCOM) commander orders all PORs that use the R/T to refrain from upgrading until every POR using that R/T has successfully integrated it into their respective platforms. This has the effect of stifling improvements in programs in the interest of preserving the interoperability among all programs that use a particular R/T.

Figure 2. Concept #1 Model

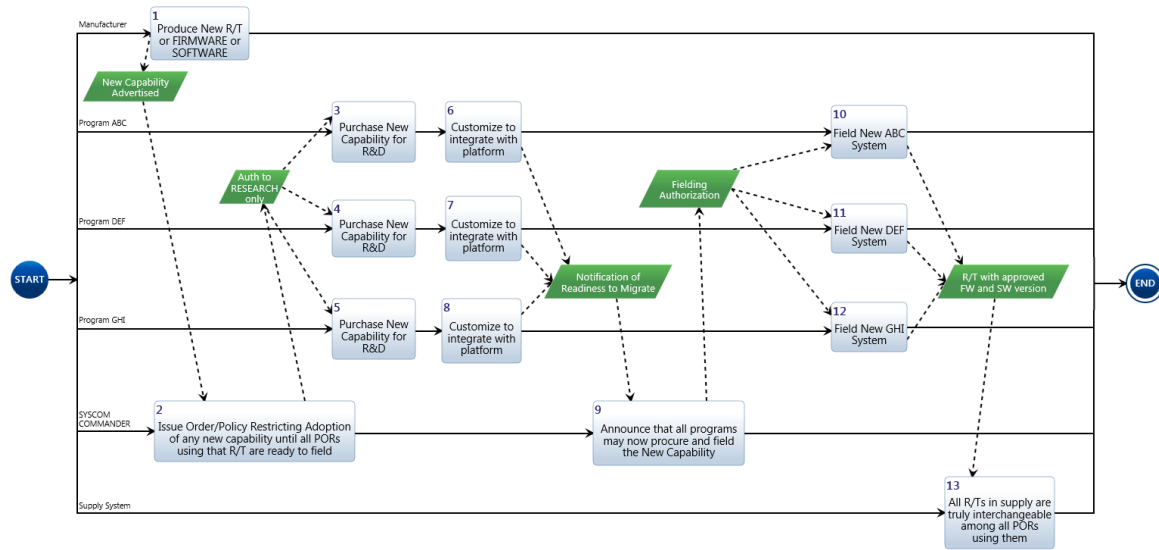


Table 3. Concept #1 Explanation Table

Block	Lane	Label	Description
1	Manufacturer	Produce New R/T or FIRMWARE or SOFTWARE Available	Radio manufacturers are constantly striving to improve their existing product line and/or to introduce new product lines that enhance the radio communication capabilities of their customers.
2	SYSCOM Commander	Issue Order/Policy Restricting Adoption of any new capability until all PORs using that R/T are ready to field	The Commanding General of MARCORSYSCOM issues policy that specifically prohibits any Programs of Record (POR) that could implement the new capability from doing so until ALL PORs that use the R/T for which the capability was built are capable of adapting the new capability into their POR.
3	Program ABC	Purchase New Capability for R&D	Each program office seeking a capability offered by the new R/T (or any other capability upgrade) acquires one (either through purchase or on bailment) to assess the suitability of the product for its program.
4	Program DEF		
5	Program GHI		
6	Program ABC	Customize to Integrate with Platform	The product has many capabilities. Each program office may seek different capabilities, and each has different form & fit requirements as well.
7	Program DEF		
8	Program GHI		

Block	Lane	Label	Description
9	SYSCOM Commander	Announce that all programs may now procure and field the New Capability	Now that all PORs have successfully integrated the new capability with their platform and have notified the appropriate authorities at SYSCOM, the CG issues the order to field the new capability.
10	Program ABC	Field New ABC System	Each Program Office will field their system in accordance with their AAO. The case where ABC, DEF, and GHI all field their system to the same Operational Unit is entirely possible.
11	Program DEF	Field New DEF System	
12	Program GHI	Field New GHI System	
13	Supply System	All R/Ts in supply are truly interchangeable among all PORs using them	Systems fielded include spares. Spare R/Ts from one POR are completely interchangeable with spare R/Ts from another POR.

As shown in Concept #1, Marine units that need the new improvement for one program must wait an indefinite period until all the other programs are ready to upgrade before they can appreciate the improvements on the battlefield. This reduces the autonomy of each individual program and is, therefore, a problematic yet plausible approach. This concept is heavily dependent on changes in processes and policies as opposed to the development of new technologies.

C. CONCEPT #2

1. Process, Procedure, and Policy Modification Models

The following model, as shown in Figure 3, with its associated explanation shown in Table 4, outlines another approach for ensuring all R/Ts in the entire USMC supply system always use the same firmware and software uniformly, thereby making all R/Ts, regardless of the POR under which they were initially fielded, fully interchangeable. The major difference between Concepts #1 and #2 is the involvement of a configuration control board (CCB) that assists the SYSCOM commander in determining when it would be operationally feasible for one (or more) systems to be forced to upgrade for the sake of uniformity even though that upgrade might result in a degradation of capability.

Figure 3. Concept #2 Model

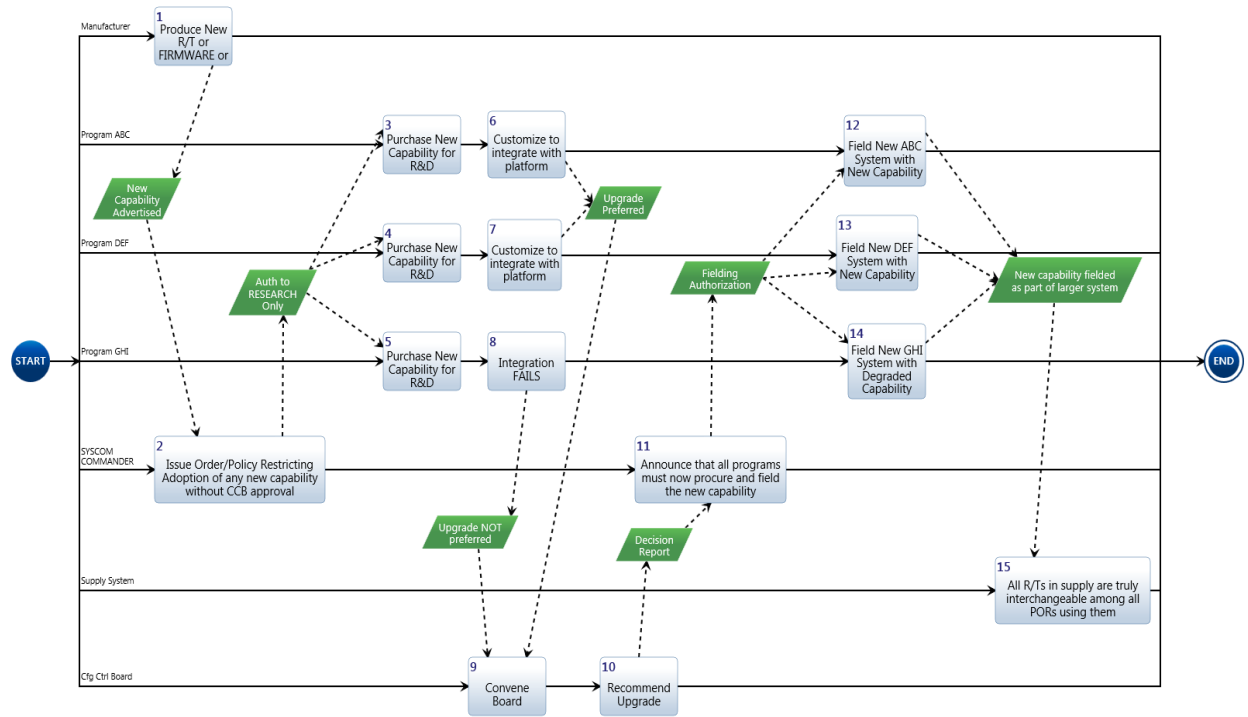


Table 4. Concept #2 Explanation Table

Block	Lane	Label	Description
1	Manufacturer	Produce New R/T or FIRMWARE or SOFTWARE	Radio manufacturers are constantly striving to improve their existing product line and/or to introduce new product lines that enhance the radio communication capabilities of their customers.
2	SYSKOM Commander	Issue Order/Policy Restricting Adoption of any new capability without CCB approval	The Commanding General of MARCORSYSKOM issues policy that specifically prohibits any Programs of Record (POR) that could implement the new capability from doing so until ALL PORs that use the R/T for which the capability was built are capable of adapting the new capability into their POR.
3	Program ABC	Purchase New Capability for R&D	Each program office seeking a capability offered by the new R/T (or any other capability upgrade) acquires one (either through purchase or on bailment) to assess the suitability of the product for its program.
4	Program DEF		
5	Program GHI		

Block	Lane	Label	Description
6	Program ABC	Customize to Integrate with Platform	The product has many capabilities. Each program office may seek different capabilities, and each has different form & fit requirements as well.
7	Program DEF		
8	Program GHI	Integration FAILS	For any number of reasons, the new capability is not compatible with system GHI. Program GHI therefore <i>does not</i> want the upgrade to happen. If it does, program GHI will not be fully capable until either a patch is produced that allows it to integrate the new capability or until the next new capability is produced that it CAN integrate into its platform.
9	CCB	Convene Board	At regular intervals (or as directed by CG MARCORSYSCOM), the CCB convenes to discuss new capabilities produced by the manufacturer and the feasibility of fielding the new capability to ALL R/Ts in the entire USMC inventory.
10	CCB	Recommend Upgrade	The overall benefit to the entire USMC of the new capability is decided to outweigh the fact that program GHI will temporarily have to operate in a degraded state, so the CCB decides to recommend to the SYSCOM Commander that the new capability be fielded to ALL PORs R/Ts.
11	SYSCOM Commander	Announce that all programs may now procure and field the New Capability	Now that all PORs have successfully integrated the new capability with their platform and have notified the appropriate authorities at SYSCOM, the CG issues the order to field the new capability.
12	Program ABC	Field New ABC System with New Capability	Each Program Office will field their system in accordance with their AAO. The case where ABC, DEF, and GHI all field their system to the same Operational Unit is entirely possible.
13	Program DEF	Field New DEF System with New Capability	
14	Program GHI	Field New GHI System with Degraded Capability	Since the decision of the CCB was made for ALL PORs to field the new capability to ensure uniformity amongst all the R/Ts in the arsenal, Program GHI has no choice but to field the new R/Ts to its POR systems even though the new fielding will result in a reduced capability.
15	Supply System	All R/Ts in supply are truly interchangeable among all PORs using them	Systems fielded include spares. Spare R/Ts from one POR are completely interchangeable with spare R/Ts from another POR.

As shown in Concept #2, Marine units that really need the new improvement for one program must wait an indefinite period until the CCB agrees to upgrade before they can appreciate the improvements on the battlefield. The CCB *could* determine that the upgrades benefiting one particular program in the field would so greatly improve the battle conditions for the Marines that the risk to other programs would be acceptable. This reduces the autonomy of each individual program and is therefore a problematic yet plausible approach. This concept is also heavily dependent on changes to processes and policies requiring no new technologies to be developed.

D. CONCEPT #3

1. Process and Materiel Solution Model

The following model, as shown in Figure 4, with its associated explanation shown in Table 5, outlines another approach altogether. Concept #3 does not ensure that all R/Ts in the entire USMC supply system are always using the same firmware and software uniformly, thereby making all R/Ts, regardless of the POR under which they were initially fielded, fully interchangeable. Instead, this concept employs a specialized testing agency with specialized equipment that rapidly runs through all possible permutations of R/T firmware, software, and waveforms. This provides a comprehensive assessment of the interoperability of all R/Ts in the USMC arsenal as it applies to any new capability. The following model assumes the results of such a hypothetical comprehensive assessment. The model shows how the hypothetical results indicate that this concept protects the POR that elects not to upgrade from having a negative interoperability effect.

Figure 4. Concept #3 Model

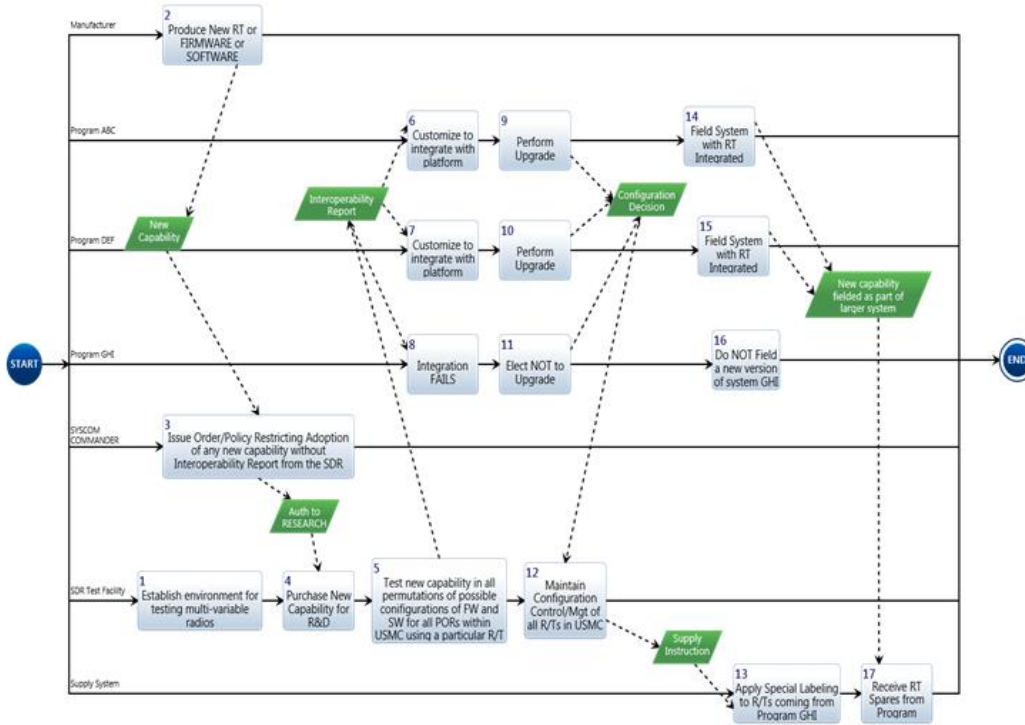


Table 5. Concept #3 Explanation Table

Block	Lane	Label	Description
1	SDR Testing Facility	Establish environment for testing multi-variable radio testing	The test facility requires a highly flexible/configurable environment where a great number of R/Ts can be arranged in a myriad of arrangements to ensure backward compatibility of any new capability and/or prevent a new capability from degrading other mission-critical capabilities.
2	Manufacturer	Produce New R/T or FIRMWARE or SOFTWARE	Radio manufacturers are constantly striving to improve their existing product line and/or introduce new product lines that enhance the radio communications capabilities of their customers.
3	SYSCOM Commander	Issue Order/Policy Restricting Adoption of any new capability without release from the SDR Test Facility	The Commanding General of MARCORSYSCOM issues policy that specifically prohibits any Programs of Record (POR) that could implement the new capability from doing so until the SDR Testing Facility completes its testing and analysis and provides its interoperability report.

Block	Lane	Label	Description
4	SDR Testing Facility	Purchase New Capability for R&D	The testing facility acquires the necessary amount of R/Ts with the new capability/R/T (either through purchase or on bailment) to assess the suitability of the product to ALL USMC PORs.
5	SDR Testing Facility	Test new capability in all permutations of possible configurations of FW and SW for all PORs within USMC using a particular R/T	Testing reveals that upgrading in any one USMC platform will <i>not</i> present any interoperability/compatibility issues with any other existing configurations of any existing USMC platform employing the R/T for which the new capability was designed. An ALL-OR-NOTHING situation does <i>not</i> apply for this particular new capability. Each POR can choose to upgrade or not to upgrade autonomously.
6	Program ABC	Customize to Integrate with Platform	The product would have many capabilities. Each Program office could be seeking different capabilities and each has different form & fit requirements as well.
7	Program DEF		
8	Program GHI	Integration FAILS	For any number of reasons, the new capability is not compatible with system GHI.
9	Program ABC	Perform Upgrade	Programs ABC and DEF desire the new capability and were able to successfully integrate it with their platforms, so ABC and DEF perform the upgrade (or direct that it be done by their Maintenance Marines).
10	Program DEF		
11	Program GHI	Elect NOT to Upgrade	Based on the interoperability report from the SDR Test Facility and on the inability to integrate the new capability into the GHI platform, Program GHI elects <i>not</i> to upgrade any of their Systems to incorporate the new capability offered.
12	SDR Testing Facility	Maintain Configuration Control/Mgt of all R/Ts in USMC arsenal	Since all R/Ts in the USMC will <i>not</i> be uniform/interchangeable but would most likely be treated as being uniform/interchangeable in the supply system, the SDR Test Facility would need to maintain configuration control of all R/Ts in the USMC arsenal so that it can assist units in obtaining appropriate replacements and/or so that it can assist the supply system in indicating (special labeling) certain spares accordingly.
13	Supply System	Apply Special Labeling to R/Ts coming from Program GHI	As directed by the SDR Test Facility (or some other appropriate authority) the supply system must set aside certain R/Ts from others and label them to indicate the firmware and software and any other special configuration information appropriate. (This could arguably be the responsibility of the program office.)

Block	Lane	Label	Description
14	Program ABC	Field System with R/T Integrated	Each Program Office will field their system in accordance with their Approved Acquisition Objective (AAO). The case where ABC, DEF, and GHI all field their system to the same Operational Unit is entirely possible.
15	Program DEF		
16	Program GHI	Do NOT Field a new version of system GHI	Since the new capability was not upgraded on any of their R/Ts in any of their systems, there is no need for the GHI program to release a new version.
17	Supply System	Receive R/T Spares from Program Offices	Systems fielded include spares. Spare R/Ts from one POR are completely interchangeable with spare R/Ts from another POR unless specially labeled otherwise.

As shown in Concept #3, Marine units that really need the new improvement for one program must wait a determinable time for the upgrade. The determinable time would be the time it takes the testing agency to run through the permutations. This process could all be automated so the permutations that cause issues could be reported in a relatively short amount of time (days instead of months). Once the permutations that cause interoperability issues are identified, the programs could individually make determinations based on risks to their programs. Programs would maintain their autonomy; however, programs choosing not to upgrade would be burdened with labeling their entire stock to differentiate their R/Ts from those that have been upgraded. This may be perceived as an unacceptable burden, but the solution remains a plausible approach.

2. Technologies

A new technology would be needed for Concept #3. Testing equipment would need to be developed capable of quickly running through all possible configuration permutations. Each permutation would be tested to see if the new capability works and if it does work, what interoperability issues are introduced. This system would then repeat this process until all possible permutations have been tested. The upper bound on the number of permutations will depend upon the number of R/Ts slated for upgrade and whether they are upgraded solely in regard to firmware or software, or both. Further complicating the permutations will be the number of different platforms into which the R/

T has been integrated. With the introduction of each variable, the number of permutations that would require checking grows exponentially. Then, this system would produce results indicating which permutations created issues. These results would serve as decision-grade information for those determining whether they should upgrade their programs' systems or remain on the current version until the next manufacturer's release.

E. CHAPTER SUMMARY

Concepts #1, #2, and #3 show approaches to solving the problem. The next chapter determines criteria for evaluating the concepts and analyzes each concept against those criteria. During the analysis, the concepts will score differently in one or more of the evaluation criteria. Comparing the evaluations, trade-offs begin to reveal themselves and are discussed at length in Chapter IV.

IV. ANALYSIS

From a holistic systems-engineering perspective of the problem, the radio communications priorities of each program of record (POR) certainly differ. For example, a Marine in the Operating Forces using a receiver/transmitter (R/T) for encrypted voice communications during a firefight focuses on securely conversing with fellow Marines. He might not be concerned with whether his R/T can use Link16 or Link22 tactical data links (TDL). Conversely, an F-22 pilot wants the digital exchanges—the TDLs—to work properly. Since each POR has a number of priorities that may significantly conflict with some or all of the other PORs, any trade studies require entirely different evaluation criteria for each POR. Simply put, there cannot be a one-size-fits-all solution. Therefore, a holistic approach sets aside the individual requirements of all PORs as understandably irreconcilable differences. Instead of exploring which solution concept is best for each of the PORs, we evaluate each of the concepts for its ability to provide customization while maintaining the ability for replacement R/Ts to meet the needs of all PORs. This chapter examines the configuration management (CM) of the United States Marine Corps (USMC)'s arsenal of software-defined radio (SDR) R/Ts. It identifies the functions, performance, and quality factors of this holistic system; decomposes those factors to the level necessary for high-fidelity analysis; and considers how the system fits into critical aspects of the USMC.

A. SYSTEM ANALYSIS

Chapter I set out to answer the following questions:

- How can the USMC maintain the flexibility necessary for program management offices and unit commanders to customize their radio sets without putting them at risk for interoperability issues?
- How can the USMC achieve configuration management of software-defined radios to ensure good battlefield communications?

Our analysis must emphasize how well each of the concepts, as outlined in Chapter III, addresses these questions. The analysis demonstrates the impact each of the

solutions—if fully implemented—would have on the USMC. Furthermore, the analysis assesses those factors by addressing each concept’s effect on doctrine, organization, training, materiel, leadership, personnel, facilities, and policy (DOTMLPF-P).

The Defense Acquisition University describes DOTmLPF as follows:

- Doctrine: the way we fight (e.g., emphasizing maneuver warfare, combined air-ground campaigns)
- Organization: how we organize to fight (e.g., divisions, air wings, Marine-Air Ground Task Forces)
- Training: how we prepare to fight tactically (basic training to advanced individual training, unit training, joint exercises).
- materiel: all the “stuff” necessary to equip our forces that DOES NOT require a new development effort (weapons, spares, test sets and such, that are “off the shelf” both commercially and within the government) [whereas Material with the capitalized M does require new development]
- Leadership and education: how we prepare our leaders to lead the fight (squad leader to 4-star general/admiral - professional development)
- Personnel: availability of qualified people for peacetime, wartime, and various contingency operations
- Facilities: real property, installations, and industrial facilities (e.g., government owned ammunition production facilities)
- Policy: DOD, interagency, or international policy that impacts the other seven non-materiel elements. (Defense Acquisition University 2016, para. 2)

B. EVALUATION CRITERIA

Based on the discussion in section A, the analysis criteria are as follows:

- How well will the solution concept maintain the flexibility necessary for program management offices and unit commanders to customize their radio sets?
- How well will the concept help the USMC achieve configuration management of software-defined radios to reduce the risk of interoperability issues?

- Doctrine: What new and revised operating procedures are required?
- Organization: What organizational changes are required in order to achieve success?
- Training: What needs to be taught in the formal schools? What needs to be taught in the field? When and how often should training occur?
- Materiel: What things need to be purchased? How often will they need to be updated/upgraded?
- Leadership: What do the USMC leaders need to know/do?
- Personnel: Will the concept require more Marines? More civilians?
- Facilities: Will the concept require more facilities?
- Policy: What new policy must be created? How will it be enforced?

C. ANALYSIS RESULTS

This section analyzes each of the solution concepts against the criteria outlined in Section C.

1. Solution Concept #1

- How well will Concept #1 maintain the flexibility necessary for program management offices and unit commanders to customize their radio sets?

Concept #1 is very rigid with regard to customizing radio sets. No radio system will receive any software or firmware updates until every single radio system in the entire Marine Corps has confirmed that the upgrade will not increase risk for the POR system in which it was implemented.

- How well will Concept #1 help the USMC achieve configuration management of software-defined radios to reduce the risk of interoperability issues?

Concept #1, if successfully implemented, would certainly reduce the risk of interoperability issues. Successfully implementing the concept would be the challenge. Keeping Marines from downloading and installing new advertised features would be difficult. Ten years ago, it would not have been, but in today's "update often" software environment, it is likely that

Marines would naturally upgrade without incessant firm reminders that upgrading is not allowed.

- Doctrine: What new and revised operating procedures are required?

Concept #1 would require revising oversight and op-check procedures that ensure any updates/upgrades performed without permission from the commander of Marine Corps Systems Command (MARCORSYSCOM) are identified prior to departure for any operation/exercise.

- Organization: What organization changes are required in order to achieve success?

Concept #1 would likely require additional oversight at multiple levels of operational force units as well as within the many programs of record that employ USMC radios in their designs.

- Training: What needs to be taught in the formal schools? What needs to be taught in the field? When and how often should training occur?

Concept #1 would require that curricula for Marine Corps military occupational specialty (MOS) training be modified to stress the importance of refraining from updating/upgrading to the latest version. Since many radios are involved, many curricula would need to be modified.

- Materiel: What things need to be purchased? How often will they need to be updated/upgraded?

Concept #1 would not require the development of any materiel solutions.

- Leadership: What do the USMC leaders need to know/do?

Concept #1 would require that leaders be educated regarding the risks. Additionally, leaders would need to provide additional oversight of the maintenance community.

- Personnel: Will the concept require more Marines? More civilians?

Concept #1 would not necessarily require additional manpower; however, the additional oversight could burden already strained resources to the point that success would require additional personnel.

- Facilities: Will the concept require more facilities?

Concept #1 would not require any additional facilities.

- Policy: What new policy must be created? How will it be enforced?

As mentioned in Chapter III, Concept #1 would require that an order be issued from the commander of Marine Corps Systems Command instructing to delay updates/upgrades until all programs are ready. Enforcement would be difficult.

2. **Solution Concept #2**

- How well will Concept #2 maintain the flexibility necessary for program management offices and unit commanders to customize their radio sets?

Concept #2 provides for very limited flexibility. When the configuration control board votes to upgrade to the newer capability, it is being more flexible. The CCB does this, however, at the detriment of programs unready to upgrade. Programs not ready to upgrade are then at an increased risk.

- How well will the concept help the USMC achieve configuration management of software-defined radios to reduce the risk of interoperability issues?

Concept #2, if successfully implemented, would certainly reduce the risk of interoperability issues. As with Concept #1, successfully implementing this concept would be the challenge. Keeping Marines from downloading and installing new advertised features would be difficult due to reasons previously stated.

- Doctrine: What new and revised operating procedures are required?

Concept #2 would require revising oversight and op-check procedures that ensure any updates/upgrades performed without permission from the commander of Marine Corps Systems Command (MARCORSYSCOM) are identified prior to departure for any operation/exercise.

- Organization: What organizational changes are required in order to achieve success?

Concept #2 would likely require additional oversight at multiple levels of operational force units as well as within the many programs of record that employ USMC radios in their designs.

- Training: What needs to be taught in the formal schools? What needs to be taught in the field? When and how often should training occur?

Concept #2 would require that curricula for Marine Corps military occupational specialty (MOS) training be modified to stress the importance of refraining from updating/upgrading to the latest version. Since many radios are involved, many curricula would need to be modified.

- Materiel: What things need to be purchased? How often will they need to be updated/upgraded?

Concept #2 would not require the development of any materiel solutions.

- Leadership: What do the USMC leaders need to know/do?

Concept #2 would require that leaders be educated regarding the risks. Additionally, leaders would need to provide additional oversight of the maintenance community.

- Personnel: Will the concept require more Marines? More civilians?

Concept #2 would not necessarily require additional manpower; however, the additional oversight could burden already strained resources to the point that success would require additional personnel.

- Facilities: Will the concept require more facilities?

Concept #2 would not require any additional facilities.

- Policy: What new policy must be created? How will it be enforced?

As mentioned in Chapter III, Concept #2 would require that an order be issued from the commander of Marine Corps Systems Command instructing all programs to delay updates/upgrades until approved by the CCB. Enforcement would be difficult.

3. Concept #3

- How well will the solution concept maintain the flexibility necessary for program management offices and unit commanders to customize their radio sets?

Concept #3 would allow units to update/upgrade their systems relatively frequently.

- How well will the concept help the USMC achieve configuration management of software-defined radios to reduce the risk of interoperability issues?

Concept #3 would not maintain complete uniformity of all R/Ts—of the same type—in the USMC arsenal. It would allow some Marine units to update/upgrade and keep others on older configurations, greatly complicating established processes.

- Doctrine: What new and revised operating procedures are required?

Concept #3 would require that new operating procedures be emplaced at all supply warehouses and program offices.

- Organization: What organization changes are required in order to achieve success?

Concept #3 would likely require that the structure of the testing organization be slightly modified to accommodate the increased workload.

- Training: What needs to be taught in the formal schools? What needs to be taught in the field? When and how often should training occur?

Concept #3 would require that engineers be trained on the radio permutation and testing system. Radio maintenance Marines would need to be trained to read the results of the testing organization to determine what updates/upgrades can happen safely. Supply Marines would need to be trained on variations in equipment and labeling procedures.

- Materiel: What things need to be purchased? How often will they need to be updated/upgraded?

Concept #3 would require the development of a materiel solution capable of performing the automated testing and permuting of software and firmware configurations across many different R/Ts in many different interoperability scenarios.

- Leadership: What do the USMC leaders need to know/do?

Concept #3 would require that for situational awareness, leaders are educated regarding the new process.

- Personnel: Will the concept require more Marines? More civilians?

Concept #3 potentially requires more Marines and/or more civilians at the designated testing agency.

- Facilities: Will the concept require more facilities?

Concept #3 may require more facilities at the designated testing agency.

- Policy: What new policy must be created? How will it be enforced?

Concept #3 would require that a new policy be created empowering the designated testing agency to examine all R/Ts and report issues. Policy forbidding updates/upgrades prior to the designated testing agency's determinations would also be necessary.

D. QUALITY FUNCTION DEPLOYMENT DIAGRAM

A quality function deployment diagram (QFD) is an excellent tool for comparing stakeholders' needs with other considerations. The QFD in Figure 5 is a graphical representation of the discussions in sections A through C of this chapter. Before creating a QFD, data was generated by assessing the three solution concepts viewed through the lenses of different stakeholder groups with the heaviest weight being assigned to the lens of a warfighter, and slightly lesser weights assigned to the lenses of the program managers, equipment maintainers, and supply system operators.

It is important to note that these are notional viewpoints based on over 25 years of experience working closely with Marines of the various roles. In the "Future Work" section of Chapter V, options for pursuing a more rigorous assessment will be discussed.

After scoring all 10 criteria viewing them through the four different lenses, the results were combined into Table 6, which shows how each criterion was valued when compared pair-wise against the other criteria.

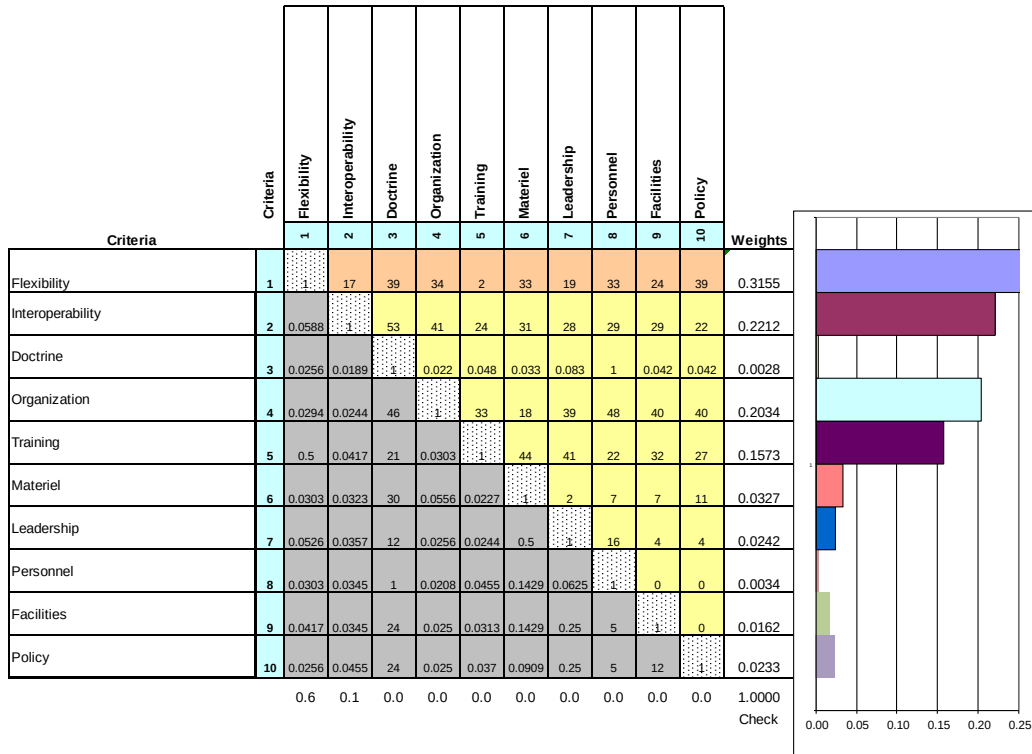
Table 6. Stakeholder Needs

Top Level System Requirements					
Flexibility	Versus	Interoperability	17	in favor of	Flexibility
Flexibility	Versus	Doctrine	39	in favor of	Flexibility
Flexibility	Versus	Organization	34	in favor of	Flexibility
Flexibility	Versus	Training	2	in favor of	Flexibility
Flexibility	Versus	Materiel	33	in favor of	Flexibility
Flexibility	Versus	Leadership	19	in favor of	Flexibility
Flexibility	Versus	Personnel	33	in favor of	Flexibility
Flexibility	Versus	Facilities	24	in favor of	Flexibility
Flexibility	Versus	Policy	39	in favor of	Flexibility
Interoperability	Versus	Doctrine	53	in favor of	Interoperability
Interoperability	Versus	Organization	41	in favor of	Interoperability
Interoperability	Versus	Training	24	in favor of	Interoperability
Interoperability	Versus	Materiel	31	in favor of	Interoperability
Interoperability	Versus	Leadership	28	in favor of	Interoperability
Interoperability	Versus	Personnel	29	in favor of	Interoperability
Interoperability	Versus	Facilities	29	in favor of	Interoperability
Interoperability	Versus	Policy	22	in favor of	Interoperability
Doctrine	Versus	Organization	46	in favor of	Organization
Doctrine	Versus	Training	21	in favor of	Training
Doctrine	Versus	Materiel	30	in favor of	Materiel
Doctrine	Versus	Leadership	12	in favor of	Leadership
Doctrine	Versus	Personnel	1	Neutral Against	Personnel
Doctrine	Versus	Facilities	24	in favor of	Facilities
Doctrine	Versus	Policy	24	in favor of	Policy
Organization	Versus	Training	33	in favor of	Organization
Organization	Versus	Materiel	18	in favor of	Organization
Organization	Versus	Leadership	39	in favor of	Organization
Organization	Versus	Personnel	48	in favor of	Organization
Organization	Versus	Facilities	40	in favor of	Organization
Organization	Versus	Policy	40	in favor of	Organization
Training	Versus	Materiel	44	in favor of	Training
Training	Versus	Leadership	41	in favor of	Training
Training	Versus	Personnel	22	in favor of	Training
Training	Versus	Facilities	32	in favor of	Training
Training	Versus	Policy	27	in favor of	Training
Materiel	Versus	Leadership	2	in favor of	Materiel
Materiel	Versus	Personnel	7	in favor of	Materiel
Materiel	Versus	Facilities	7	in favor of	Materiel
Materiel	Versus	Policy	11	in favor of	Materiel
Leadership	Versus	Personnel	16	in favor of	Leadership

Top Level System Requirements					
Leadership	Versus	Facilities	4	in favor of	Leadership
Leadership	Versus	Policy	4	in favor of	Leadership
Personnel	Versus	Facilities	5	in favor of	Facilities
Personnel	Versus	Policy	5	in favor of	Policy
Facilities	Versus	Policy	12	in favor of	Policy

Although the information in the table has value, it is difficult to ascertain quickly how best to make comparisons across the various solution concepts. The information, once graphed, is a little easier to decipher. In Figure 5, it becomes readily apparent that Flexibility, Interoperability, Organization, and Training are the most important, collectively, to the Marines. A high score in Organization indicates that it is important to the different Marine roles that no new organizations need to be created and no re-organizing of existing structures is required. Similarly, it is also important to the Marine roles that little or no new training should be required in order for the concept to be fully implemented. Short (one to two weeks) training is often considered to be acceptable, but beyond that the Marines tend to consider that level of training to be something that should be incorporated into the formal MOS training schools that Marines complete shortly after boot camp and infantry training.

Figure 5. Pairwise Comparison to Determine Weights



The pair-wise comparison allows for the assignment of weights. The flexibility, interoperability, organization, and training criteria received considerably higher weights than all the other criteria.

An implemented solution may have enduring effects. Figure 6 shows how each concept was scored regarding its effect on the criteria. If the solution concept increases the flexibility of a using unit to customize their equipment to meet their needs, then that solution concept would score between six and nine on the scale. Similarly, if the solution concept decreases the flexibility of a using unit to customize, the solution would score between one and four. If the solution concept would have no appreciable effect on the flexibility of a using unit, the solution concept would score a five. Each criterion was evaluated against each solution. The results are shown by the numbers ranging from one to nine inside the grid. Figure 6 also shows that there are long term effects that must also be considered. The long term effects are evaluated independently of the stakeholders

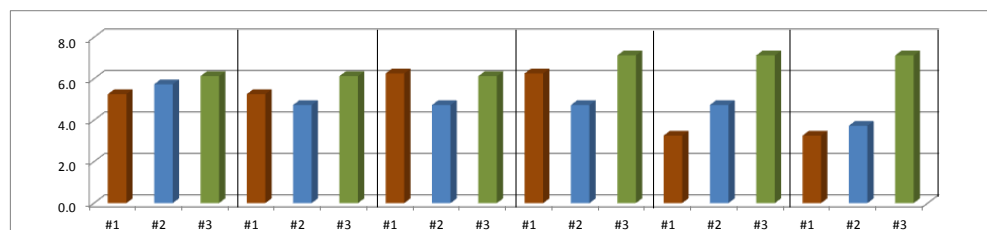
needs. There were six long-term effects considered (in blue). Solution concepts were considered against these potential long term effects and if they were assessed to have a strong negative impact, the solution concept was shaded red. Orange was chosen for a negative (but not a strong negative) impact, and pale yellow was selected to represent neutrality or a negligible impact. The columns that were determined to have a positive impact were shaded green.

Figure 6. Quality Function Deployment Diagram

		Long-term Effect																	
		Development Difficulty			New Supply Processes Req'd			Interchange-able Parts			New Maintenance Processes Req'd			Difficulty in enforcement of policy			General Officer Policy Required		
		#1	#2	#3	#1	#2	#3	#1	#2	#3	#1	#2	#3	#1	#2	#3	#1	#2	#3
Flexibility	0.3155	1	3	9	1	3	9	1	3	9	1	3	9	1	3	9	1	3	9
Interoperability	0.2212	2	4	9	2	4	9	2	4	9	2	4	9	2	4	9	2	4	9
Doctrine	0.0028	2	4	6	2	4	6	2	4	6	2	4	6	2	4	6	2	4	6
Organization	0.2034	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Training	0.1573	7	5	5	7	5	5	7	5	5	7	5	5	7	5	5	7	5	5
Materiel	0.0327	9	9	6	9	9	6	9	9	6	9	9	6	9	9	6	9	9	6
Leadership	0.0242	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Personnel	0.0034	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Facilities	0.0162	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Policy	0.0233	8	8	9	8	8	9	8	8	9	8	8	9	8	8	9	8	8	9
Check Sum	1.00																		

Note: The numbers in the grid above show the impact on the attributes on the left (1=worst; 9=best) and the colors are associated with the long-term effects at the top

Goal (Objective) Value	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
Threshold Value	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Performance	4.90	5.30	6.40	4.90	5.30	6.40	4.90	5.30	6.40	4.90	5.30	6.40	4.90	5.30	6.40	4.90	5.30	6.40	4.90
Weighted Performance	0.36	0.43	0.73	0.36	0.43	0.73	0.36	0.43	0.73	0.36	0.43	0.73	0.36	0.43	0.73	0.36	0.43	0.73	0.36
Long-Term Effect	0	0	-1	0	-1	-1	1	-1	-1	1	-1	0	-2	-1	0	-2	-2	0	
Weighted w/ Effect	5.3	5.7	6.1	5.3	4.7	6.1	6.3	4.7	6.1	6.3	4.7	7.1	3.3	4.7	7.1	3.3	3.7	7.1	



E. CHAPTER SUMMARY

Now that the concepts have been evaluated against a common set of evaluation criteria, the next step is to compare the results and make determinations about what

impacts those results may have on future decisions. In the next chapter, different potential viewpoints regarding the data are discussed. Then, conclusions are offered by proxy for each of those stakeholders concluding with a discussion regarding what future work on this subject might be worth further exploring.

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V. CONCLUSIONS

The results in Chapter IV may mean many different things to many different people depending on what role they play in the overall success of the United States Marine Corps (USMC). Trade-space considerations are incomplete without considering the needs of warfighters, program managers (PM), maintenance Marines, supply Marines, and their leadership. This final chapter reviews the results from Chapter IV different lenses, which represent the software-defined radio (SDR) stakeholders in the USMC. Then, conclusions are offered by proxy for each of the stakeholder groups.

A. THROUGH THE LENS OF WARFIGHTERS

Concepts #1 and #2 offer little for getting the new SDR features to the warfighter as quickly as possible. If anything, those concepts would likely be viewed by warfighters as delaying progress and/or unnecessarily embargoing new features for bureaucratic reasons. The leadership of warfighter units would likely value uniformity because it ensures interoperability within the area of responsibility. However, those who use and maintain the receivers/transmitters (R/T) used in radio or command-and-control systems would not likely appreciate the value this brings. Marines understand the value of moving forward together at a steady pace vice everyone moving disjoint on their own. This is how Marines operate. Marines move in formation at a speed acceptable to the whole team. If one Marine were to splinter-off alone, that one Marine would be at an increased risk. When it comes to the configuration of SDRs, however, they may continue to download software and firmware from the vendor to keep their radios as up-to-date as possible, firmly believing that in doing so, they are helping their unit.

Concept #3, however, brings the latest features to the field shortly after the manufacturer releases them, provided that most (or all) of the important permutations indicate no increased risks of interoperability issues for the warfighter. The burdens associated with Concept #3 seem to be localized to the designated testing facility and the supply system. Units at the tip of the spear would not likely notice the burdens. Based on

these assumptions, it is likely the warfighter community would prefer Concept #3 over the other options.

B. THROUGH THE LENS OF PROGRAM MANAGERS

PMs value their autonomy. They appreciate being able to make decisions regarding their programs unilaterally. Concepts #1 and #2 weaken the PM's independence by requiring that they coordinated their decisions with many other PMs prior to making a move to new versions of software or firmware.

Concept #3 provides the most flexibility for integration while minimizing interoperability risks, so it is highly likely that the program managers would prefer solution #3.

C. THROUGH THE LENS OF MAINTENANCE MARINES

For maintenance Marines, Concept #1 provides the least confusion. All radios in the supply system are always the same, and they always work as designed. The new features can wait.

Concept #2 may complicate matters for the maintenance Marines, however. When one or more programs are forced to upgrade to their own detriment in the interest of getting new capabilities to other—presumably higher-priority—programs, the operators may see the degraded service as a maintenance issue. Nevertheless, the maintenance Marines would not be authorized to fix their problem by retrograding their systems back to their last known good configuration. The operators would likely insist upon having the last known good configuration, while the maintenance Marines would point to the Maintenance Instruction showing that they are required to upgrade them. This could cause confusion at the unit level because ultimately, the Marine commander at the lowest level is empowered to make whatever decisions necessary to achieve mission accomplishment. It is entirely possible, that the Marine commander would instruct his maintenance personnel to perform the retrograde. If that were performed and the Crypto was modified in the last upgrade, such a decision could render the R/Ts incompatible with other units' R/Ts severely impacting interoperability.

Concept #3 would allow the maintenance Marines to update/upgrade some R/Ts while leaving others on older versions. This concept allows them more flexibility in providing their operators what they need but complicates the process of tracking R/Ts to radio systems and radio systems to programs of record (POR). Most R/Ts in the USMC today are equipped with onboard crypto. This places the radios into the Controlled Cryptographic Item (CCI) category. CCIs are not allowed to have labels affixed to them other than those approved by the National Security Agency (NSA) and emplaced by the manufacturer. With all R/Ts of the same model appearing the same, and no labeling allowed, the maintenance Marines would need to keep excellent records in order to ensure the correct versions of software and firmware are installed onto each R/T used in their unit.

D. THROUGH THE LENS OF SUPPLY MARINES

For supply Marines, Concept #1 may be preferred due to its simplicity and effectiveness, over Concept #2 which could result in some R/Ts not performing in some systems (at the cost of all the others). Many maintenance and supply warehouse hours may be wasted before maintenance Marines realize that the degradation is intentional. This situation would likely result in numerous unnecessary supply transactions. Many of the problems associated with Concepts #1 and #2 may be mitigated by the programs issuing maintenance and supply instructions whenever cases arise for which a program has to upgrade to its own detriment in the interest of the greater good. By issuing a maintenance instruction to all maintenance communities, it would allow the program office to explain the reasons for the upgrade, the likely results of conducting the upgrade, and why the consequences for completing the upgrade are necessary albeit undesirable. For the sake of a large number of other programs, they must be upgraded even though it negligibly impacts one program in a negative manner. Similarly, a supply instruction addresses the entire supply community providing specialized information and instruction pertaining to a change. Together, the maintenance and supply instructions might be successful in mitigating the risks associated with various programs upgrading while other programs do not.

From the supply Marine's perspective, Concept #3 is the worst solution because it introduces variability in the supply system that cannot be differentiated by traditional labeling (e.g., serial number, table of authorized material control numbers [TAMCN], or national stock numbers [NSN]). All R/Ts would have identical identifiers in the supply system, yet they would be functionally different due to the software and firmware configurations.

E. FINDINGS, RECOMMENDATIONS, AND FUTURE WORK

Evaluating each set of data viewed as different Marines performing different functions was at times daunting and one could easily question the validity of the approach. However, once all the results were tabulated and graphed, it was no surprise that the results indicated Marines prefer flexibility and interoperability over most other criteria. Also, it should come as no surprise that they do not want to restructure, reorganize, or train excessively to implement a solution concept either. These seem to be commonly held truths throughout the Corps: give me flexibility that allows me to customize to my environment, allow me to communicate with other units near me, and don't make me spend too much time training or organizing.

What was surprising however, was how large the gap was between the four heavily weighted criteria (Flexibility, Interoperability, Organization, and Training) and the nearest competitor, "avoiding the requirement for a materiel solution." The jump was from 15% for training all the way down to 3% for avoiding the need for a materiel solution. While going through the assessments, each, independently, seemed to have a much broader spectrum across the DOTMLPF-P, but when it was all combined, the differences emerged.

In the future, one might want to further flesh out the model. Surveys could be conducted at advanced staff schools where there would be a captive audience of Marines spanning the range of pertinent MOSs.

MCTSSA has already begun working on ways to permute different configurations through different radio systems using advanced computing and custom digital circuitry. It is also experimenting with automated test and retest (ATRT) functionality. Possible

future work could include developing a system similar to what would be needed in order to realize Solution Concept #3 using the permutation systems in conjunction with ATRT.

So, how can the United States Marine Corps (USMC) maintain the flexibility required to tailor equipment for unique missions without introducing interoperability issues? How can the USMC achieve configuration management of software-defined radios to ensure reliable battlefield communications? More work is certainly required to come to a definitive answer, but the three different solution concepts discussed in this thesis should bring attention to this matter and help people see some of the major considerations that must be discussed moving forward toward a viable solution.

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APPENDIX. DATA SHEETS

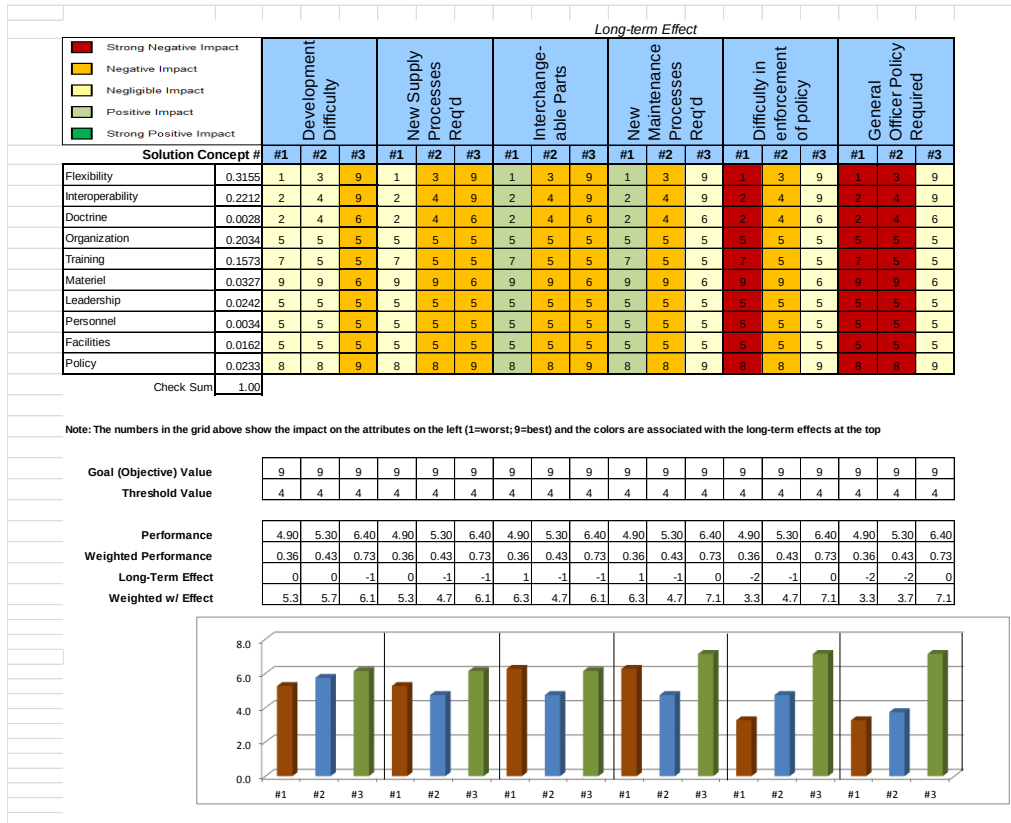
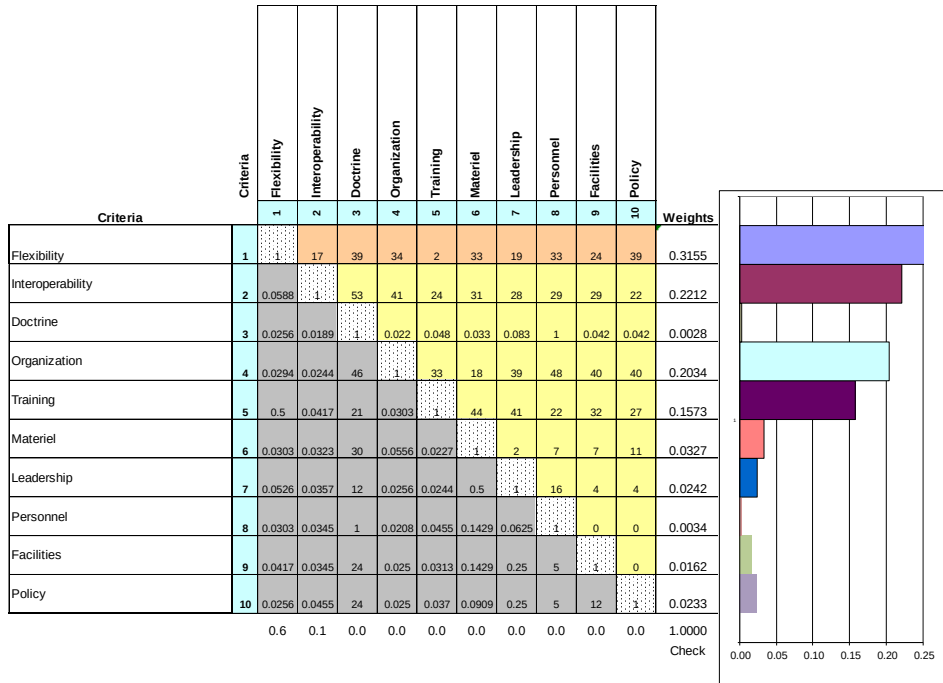
In this appendix, the data sheets used during the analysis phase of this thesis are made available for reference.

Warfighter: Req Rankings																		5 Warfighter weight																		Weighted Scores	
Top Level System Requirements																																					
Flexibility	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Interoperability	-8										-40								
Flexibility	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Doctrine	-9										-45								
Flexibility	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Organization	-9										-45								
Flexibility	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Training	-5										-25								
Flexibility	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Materiel	-9										-45								
Flexibility	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Leadership	-8										-40								
Flexibility	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Personnel	-6										-30								
Flexibility	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Facilities	-6										-30								
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Top Level System Requirements																																					
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Top Level System Requirements																																					
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Flexibility	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Personnel	-2	-4
Flexibility	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Facilities	4	8
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Organization	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Leadership	-2	-4
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Organization	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Facilities	-2	-4
Organization	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Policy	-2	-4
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Training	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Doctrine		
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Top Level System Requirements																				
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Materiel	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Personnel	2	4
Materiel	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Facilities	2	4
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Top Level System Requirements																				
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Leadership	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Doctrine		
Leadership	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Organization		
Leadership	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Training		
Leadership	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Materiel		
Leadership	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Leadership		
Leadership	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Personnel	-2	-4
Leadership	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Facilities	2	4
Leadership	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Policy	2	4
Top Level System Requirements																				
Personnel	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Interoperability		
Personnel	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Doctrine		
Personnel	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Organization		
Personnel	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Training		
Personnel	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Materiel		
Personnel	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Leadership		
Personnel	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Personnel		
Personnel	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Facilities	-2	-4
Personnel	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Policy	-2	-4
Top Level System Requirements																				
Facilities	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Interoperability		
Facilities	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Doctrine		
Facilities	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Organization		
Facilities	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Training		
Facilities	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Materiel		
Facilities	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Leadership		
Facilities	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Personnel		
Facilities	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Facilities		
Facilities	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Policy	1	2

	Supply: Req Rankings										2 Supply weight				Weighted Scores					
Top Level System Requirements																				
Flexibility	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Interoperability	1	2
Flexibility	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Doctrine	3	6
Flexibility	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Organization	3	6
Flexibility	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Training	3	6
Flexibility	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Materiel	3	6
Flexibility	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Leadership	3	6
Flexibility	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Personnel	5	10
Flexibility	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Facilities	5	10
Flexibility	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Policy	5	10
Top Level System Requirements																				
Interoperability	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Interoperability		
Interoperability	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Doctrine	5	10
Interoperability	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Organization	5	10
Interoperability	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Training	6	12
Interoperability	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Materiel	6	12
Interoperability	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Leadership	4	8
Interoperability	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Personnel	4	8
Interoperability	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Facilities	7	14
Interoperability	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Policy	7	14
Top Level System Requirements																				
Doctrine	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Interoperability		
Doctrine	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Doctrine		
Doctrine	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Organization	4	8
Doctrine	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Training	2	4
Doctrine	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Materiel	2	4
Doctrine	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Leadership	-3	-6
Doctrine	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Personnel	-3	-6
Doctrine	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Facilities	3	6
Doctrine	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Policy	3	6
Top Level System Requirements																				
Organization	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Interoperability		
Organization	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Doctrine		
Organization	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Organization		
Organization	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Training	-4	-8
Organization	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Materiel	-4	-8
Organization	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Leadership	-2	-4
Organization	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Personnel	-3	-6
Organization	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Facilities	-6	-12
Organization	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Policy	-6	-12
Top Level System Requirements																				
Training	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Interoperability		
Training	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Doctrine		
Training	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Organization		
Training	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Training		
Training	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Materiel	-3	-6
Training	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Leadership	-2	-4
Training	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Personnel	2	4
Training	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Facilities	4	8
Training	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Policy	4	8
Top Level System Requirements																				
Materiel	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Interoperability		
Materiel	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Doctrine		
Materiel	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Organization		
Materiel	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Training		
Materiel	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Materiel		
Materiel	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Leadership	3	6
Materiel	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Personnel	4	8
Materiel	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Facilities	5	10
Materiel	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Policy	6	12
Top Level System Requirements																				
Leadership	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Interoperability		
Leadership	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Doctrine		
Leadership	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Organization		
Leadership	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Training		
Leadership	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Materiel		
Leadership	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Leadership		
Leadership	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Personnel	2	4
Leadership	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Facilities	4	8
Leadership	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Policy	4	8
Top Level System Requirements																				
Personnel	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Interoperability		
Personnel	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Doctrine		
Personnel	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Organization		
Personnel	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Training		
Personnel	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Materiel		
Personnel	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Leadership		
Personnel	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Personnel		
Personnel	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Facilities	5	10
Personnel	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Policy	5	10
Top Level System Requirements																				
Facilities	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Interoperability		
Facilities	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Doctrine		
Facilities	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Organization		
Facilities	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Training		
Facilities	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Materiel		
Facilities	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Leadership		
Facilities	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Personnel		
Facilities	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Facilities		
Facilities	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Policy	1	2

Top Level System Requirements					
Flexibility	Versus	Interoperability	17	in favor of	Flexibility
Flexibility	Versus	Doctrine	39	in favor of	Flexibility
Flexibility	Versus	Organization	34	in favor of	Flexibility
Flexibility	Versus	Training	2	in favor of	Flexibility
Flexibility	Versus	Materiel	33	in favor of	Flexibility
Flexibility	Versus	Leadership	19	in favor of	Flexibility
Flexibility	Versus	Personnel	33	in favor of	Flexibility
Flexibility	Versus	Facilities	24	in favor of	Flexibility
Flexibility	Versus	Policy	39	in favor of	Flexibility
Interoperability	Versus	Doctrine	53	in favor of	Interoperability
Interoperability	Versus	Organization	41	in favor of	Interoperability
Interoperability	Versus	Training	24	in favor of	Interoperability
Interoperability	Versus	Materiel	31	in favor of	Interoperability
Interoperability	Versus	Leadership	28	in favor of	Interoperability
Interoperability	Versus	Personnel	29	in favor of	Interoperability
Interoperability	Versus	Facilities	29	in favor of	Interoperability
Interoperability	Versus	Policy	22	in favor of	Interoperability
Doctrine	Versus	Organization	46	in favor of	Organization
Doctrine	Versus	Training	21	in favor of	Training
Doctrine	Versus	Materiel	30	in favor of	Materiel
Doctrine	Versus	Leadership	12	in favor of	Leadership
Doctrine	Versus	Personnel	1	Neutral Against	Personnel
Doctrine	Versus	Facilities	24	in favor of	Facilities
Doctrine	Versus	Policy	24	in favor of	Policy
Organization	Versus	Training	33	in favor of	Organization
Organization	Versus	Materiel	18	in favor of	Organization
Organization	Versus	Leadership	39	in favor of	Organization
Organization	Versus	Personnel	48	in favor of	Organization
Organization	Versus	Facilities	40	in favor of	Organization
Organization	Versus	Policy	40	in favor of	Organization
Training	Versus	Materiel	44	in favor of	Training
Training	Versus	Leadership	41	in favor of	Training
Training	Versus	Personnel	22	in favor of	Training
Training	Versus	Facilities	32	in favor of	Training
Training	Versus	Policy	27	in favor of	Training
Materiel	Versus	Leadership	2	in favor of	Materiel
Materiel	Versus	Personnel	7	in favor of	Materiel
Materiel	Versus	Facilities	7	in favor of	Materiel
Materiel	Versus	Policy	11	in favor of	Materiel
Leadership	Versus	Personnel	16	in favor of	Leadership
Leadership	Versus	Facilities	4	in favor of	Leadership
Leadership	Versus	Policy	4	in favor of	Leadership
Personnel	Versus	Facilities	5	in favor of	Facilities
Personnel	Versus	Policy	5	in favor of	Policy
Facilities	Versus	Policy	12	in favor of	Policy



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