The International Journal Of Engineering And Science (IJES)
|| Volume || 5 || Issue || 3 || Pages || PP -86-93|| 2016 ||
ISSN (e): 2319 – 1813 ISSN (p): 2319 – 1805

Engineering design approach in Marine Engineering: A bridge between Training Need Analysis (TNA) and Engineering Education

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ABSTRACT
This paper assesses the engineering design approach used in Marine engineering at Military Technological College (MTC), Oman and presents alternatives that bridges the gap between Training Need Analysis (TNA) and thesystem design approach to the curriculum. The Conceived, Design, Implement, and Operate (CDIO) concept was adopted for knowledge-induction and skills development in engineering graduates who would join the armed forces of Oman. The TNA department was tasked with the production of the required list that fulfills the needs of all military establishments under its umbrella. While developing marine engineering B. Eng. (Hons.) Program, with the core engineering modules and TNA non-credit modules, due weightage has been given to match the competencies required by the Royal Navy of Oman. The academic performance of students during last two years indicates that learning in a mixed-mode environment with the use of formative and summative assessment through Moodle can be successfully implemented in all engineering modules.

Keywords: *Engineering design approach; training needanalysis; pathways knowledge*

Date of Submission: 18 March 2016 Date of Accepted: 30 March 2016

I. Introduction

The traditional approach of educating engineers is to confine students to straight lecturing by an instructor and students passively absorb it. This mode of instruction can be effective for information that is aimed for short-term retention (Richard et al., 2000). Under this approach, it may take six to sevenyears to produce quality engineers with desired proficiency in methods of modern-age engineering practice. The future of engineering education largely depends on integration of fundamentals, practical, and real world engineering design and operations with quality management. It requires training in critical and creative thinking skills and problem-solving methods. It is important that engineering education prepare students to practice engineering through the creation of technology and in particular, to deal with the forces and materials of nature (Lyle & Albert, 2003). The check list of the Accreditation Board for Engineering and Technology (ABET) demands a strengthening of quality education in frontier areas of engineering and a reduction of the number of hours in the whole program for successful completion of the program in the other hand, years by an average student. On the other hand the wish-list of the public and corporate/private sector demands that their graduates must be conversant withreal-world problems, possess design skills and be capable of solving real world problems.

Published literature such as (ASEE, 1994; IEA, 1996) suggest that a major revision of national accreditation criteria be conducted in those countries that demand a shift from traditional learning to pathway specific learning with desired competencies. Therefore, their engineering programsshould demonstrate that graduates are able to achieve a set of specified learning outcomes.

The CDIOconcept (Bai et. al., 2013) is regarded as a new model for engineering education and has been successfully implemented in the universities of South East Asia. It could be used as a model-tool for engineering education in almost all disciplines (Bai et. al., 2013; Zhou et. al., 2010; & Wang, 2009); and could help in integration of the desired pathway-specificcompetencies within the program. This model helps students develop the ability of engineering application and enhance employability.

The Ministry of Defense (MOD), Oman recently conceptualized the idea of establishing a college that would fulfill the future needs of the services namely Royal Army of Oman (RAO), Royal Navy of Oman (RNO), and Royal Air Force of Oman (RAFO). The TNA department was taskedwith the production of the wish-list that fulfills the needs of all military establishments under its umbrella.

The purpose of this paper is to assess the systems design approach in Marine engineering and to present bridging the gap between TNA and program design at MTC established in 2013 at Muscat, Oman. The CDIO concept was adopted for knowledge-induction and skills development in engineering graduates who would join the armed forces of Oman.

II. Components of Engineering Education

It is widely known that main components of engineering are knowledge, skills, and attitude (Armando et. al., 2000). The knowledge relates to facts students know and concepts they understand; the skills correspond to the application of their knowledge such as analysis, design, evaluation, and teamwork; and the attitude orients the goals their skills and knowledge encompass. After graduation, most engineers perform mostly routine and repetitive tasks. The skills required in these tasks are acquired and developed by students by engaging in laboratory and workshop exercises, industry-assigned case studies or projects, and by participating in industrial placement work-study programs.

At present,practicing engineers face different circumstances than a quarter of a century or even ten years ago. It is expected that the circumstances in the future will be even more complex and challenging. Hence, enabling changes in engineering education are required to meet the challenges of the next century. In response to this, and in the context of integration with pathway specific learning an in-depth analysis of the main components of engineering is also required.

The volume and flow of information an engineer is subjected to today beincreasing more rapidly, and the curricula designed by academicians seems unable to cover it. A quarter of a century ago engineering graduates preferred to work in the industry of their discipline; now they are motivated to find employment in non-traditional engineering areas such as computer engineering, environmental engineering, software engineering, and risk and safety engineering. As a matter of fact, for today's students, the notion of working for one company for one's entire career is increasingly foreign, so students are demanding schooling in how to be self-employed. Typically at MTC, entrepreneurship knowledge has been integrated in all engineering modules that are taught within the school, but all students, no matter what their major, can access to those classes.Some researchers have proposed institutes offer multiple tracks for various areas of specialization through elective courses (Richard, 1997). The structuring a curriculum with multiple tracks is a challenging task, butviable. As we cannot teach everything to engineering students, another approach is to focus emphasis on providing students with a set of core science and engineering fundamentals for integration of knowledge across multiple tracks (Armando, 1993 &Prausnitz, 1998).

The skills may be divided into a number of categories such as problem solving, critical thinking, creative thinking, global thinking, integrative, interpersonal and team work, communication, self-assessment, management, and lifelong learning skills. From ABET's perspective for accreditation of engineering programs, engineering in the twenty-first Century first Century requires sucha curriculum that contains mathematics, science, and engineering, and that future graduates should be able to apply their knowledge, to design a system, analyze, interpret data, to function on multidisciplinary teams, identify, formulate, solve engineering problems, understand the ethical responsibility, communicate effectively, understand the impact of engineering in a global context, and understand modern engineering tools for engineering practice (Richard & Brent, 1999; ABET, 2008).

III. TNA and its relevance of course material

A training need is a shortage of skills or abilities, which could be reduced or eliminated by means of training and development. Training needs analysis identifies training needs at employee, departmental or organizational level in order to help the organization to perform effectively. The aim of training needs analysis is to ensure that training addresses existing problems, is tailored to organizational objectives, and is delivered in an effective and cost-efficient manner.

Training needs often appear at the organizational or activity level. An organization that decides to enhance its level of customer service as part of a corporate strategy knows that a programme of training and development is essential for its success.

Monitoring will indicate where gaps and problems exist. Active monitoring systems are essential to spot these and can make a valuable contribution to the process of collecting information on performance gaps and training needs. Variance analysis is one approach to monitoring. It translates neatly to the identification of training needs. Any major variance from the set goals triggers an investigation into why this happened and what the implications will be. The customer satisfaction surveys could measure any deviation from the targets.

Analyzing what the training needs are is a vital prerequisite for any effective training program. . Simply throwing training at individuals may miss priority needs, or even cover areas that are not essential. It is believed that this is a natural function of appraisal systems and is a key requirement for the award of Investors in People. Effective TNA involves systematic planning, analysis and coordination across the college, to ensure that organizational priorities are taken into account, that duplication of effort is avoided and economies of scale are achieved. All potential students should be included in the process, rather than rely on the subjective evaluation of TNA managers.

As part of the process for ensuring that the MTC becomes a "center of excellence", the college strategic plan integrated TNA to be conducted to ensure that it meets the requirements of the MOD. Effective training or development depends on knowing what is required for the individual, the department and the organization as a whole. With limited budgets and the need for cost-effective solutions, the college need to ensure that the resources invested in training are targeted at areas where training and employment is needed and a positive return on the investment is guaranteed. Effective TNA is particularly vital in today's changing workplace as new technologies and flexible working practices are becoming widespread, leading to corresponding changes in the skills and abilities needed.
While developing marine engineering B. Eng (Hons)Programme, with the core engineering modules and TNA modules, due weightage has been given to match the competencies required by the Royal Navy of Oman. These competencies have been weighed while keeping in mind the following aspects:

a. Maintenance level practiced in RNO.
b. Mission and objectives of MTC
c. Core engineering and TNA modules Vs-a-Vs Dip HE and B. Eng. curriculum
d. Advancements in Royal armed forces and their future needs.

The TNA competencies have been designed in the following order.

a. General competencies applicable to all pathways
b. Core competencies with definition of its elements and performance criteria, which were further divided into i) maintenance, ii) removal of installation, and iii) inspection, testing and troubleshooting.

The competencies common to all pathways are shown in table 1.

IV. Lifelong learning skills- a civilian and military requirement

It has been suggested that most students undergo a change from the dependent to the independent learner (Perry, 1968). Perry's model depicts that dependent learners are dualists (level 2). The dualist views every point as either right or wrong. It is their perception that all knowledge is known and available in the text books and can be obtained from teachers, and students should only absorb what they are told or demonstrated. With this notion they carry out all tasks and repeat it back. In the current century this view has changed, and it is the responsibility of the instructor to make the student realize that all knowledge is not known and different point of view may emerge if a variety of sources are referred to. Students must critically assess the authenticity of the source by themselves rather than taking it as black or white. This approach would push a student to the next level (level 4) of the Perry's model. Thereafter, while progressing to level 5 and 6 most students attain lifelong learning skills by the time they graduate (Fitch & Culver, 1984; Donald, 1994; Donald et. al., 1997). After graduation, while working with others engineers learn to recognize their strengths and weaknesses and learn a lot from other people's background and abilities if tasked with a common goal (Johnson et. al., 1999). As instructors, we have to equip students with lifelong learning skills that would assist them succeed in their post-graduate military career. In the military, integration of knowledge with lifelong learning skills is vital and has a wider application (Prausnitz, 1998; Longworth & Davies, 1996).

V. Integration of Engineering and TNA Courses

For structuring a curricula and courses for B. Eng. (Hons) program in Marine Engineering to meet the objectives of the competencieslist of the MOD, Oman, the integration of fundamentals and TNA application was made within courses in such a way that exhibits the appropriate balance. The order of courses was from fundamental to applications through deductive presentation and expository teaching. Another challenge was to incorporate courses to the main B. Eng. (Hons)program for five pathways namely Control Engineering, Radio/Radar Communication Engineering, Electrical Engineering, Mechanical Engineering, and Hull Engineering. This was achieved by integrating the TNA material to both main engineering courses and TNA courses (non-credit) so that the student can develop a practical and systematic understanding and way of thinking along pathway lines in their approach to problem-solving. This customization can be clearly seen in table 2of the program. There was no compromise on core engineering courses or the magnitude of its linkage with TNA and development of intended lifelong learning skills. The TNA modules listed in table 2 require training on board ship under naval base attachment. At MTC, housing of a decommissioned ship (shown in the picture) was accomplished for familiarization of equipment on board ship before conducting naval base attachment.

VI. Role of Laboratories

Engineering is a hands-on profession where learning is practiced (Lyle & Albert, 2003). The first engineering school in the United States, the U.S Military academy, West Point, New York, founded in 1802 was set up to produce and train military engineers was geared on a French curriculum (coupled with theory and practical). The civilian colleges and universities developed and followed the curricula that focused on application of science to live situations (RPI, 2001). The Industrial revolution forced the universities to develop the curricula that lay emphasis on laboratory instructionteaching students design and building plants. The accreditation of the B. Eng. program also requires well equipped engineering laboratories with online data acquisition system. The challenge of this century is to maintain quality as per accreditation criteria. During the last two decades, this challenge was compounded by the fact that a modern undergraduate laboratory requires complex laboratory equipment of higher cost, motivation of faculty/staff toward professional development in the use of equipment, and integration of the computer software with the equipment (Lyle & Albert, 2003). It is evident that the role of laboratories is linked with computers to provide practical experience to students in the areas of data acquisition, data reduction, design assistance, and simulations.

VII. Computer Based Training versus Real experimentation

The MTC has a requirement to equip its marine workshop with a variety of operational and decommissioned equipment/machinery. However, due to the exorbitant cost of this equipment, an alternate approach is being adopted to offset the high cost of the operational equipment. This is a hybrid approach where some of the hand skills will be achieved through decommissioned equipment and decommissioned ships being acquired separately. However to cover the fault diagnosis and various maintenance aspect, Computer-based Training based Training (CBTs) is proposed. The CBTs cover the operational features, underlying fundamental theories, risks/ hazards involved and mitigation measures, planned/ preventive maintenance and fault diagnosis, removal/ installation of components/sub components, inspections and tests of equipment and systems similar to those fitted on board RNO ships. These CBTs shall be capable of assessing a student's performance and progress. The CBTs focus on technical training as its key objective, hence major emphasis is placed on fault diagnosis and maintenance practices on the equipment. The CBTs are able to meet the following objectives:

a. To teach marine technicians and engineers on the operational aspects, theories involved, risks and safety measures, preventive and corrective maintenance.

b. To train marine technicians and officers on fault diagnosis
c. To familiarise the marine technicians and officers in their relevant specialist area before going on board the ship and attending to live operational and maintenance tasks
d. To prepare students in handling emergency situations and to respond suitably

e. To develop confidence in the students to operate, maintain, and up keep the equipment/machinery fitted onboard ships.
f. To familiarize the marine technicians and officers in their relevant specialist area before going onboard the ship.
g. To train in and prepare for routine and critical maintenance scenarios.
h. To reduce overall training time of students.
i. To reduce "accidents" on equipment and personnel.
j. To set-up, monitor and control exercises.
k. To evaluate and replay training scenarios.
l. To monitor the students' progress

The software is developed to simulate engineering processes such as laminar flow in pipes, heat transfer through materials, and electron flow in semiconductors (Kadlowec et al., 2002). Though the simulation experiments give students some idea of what they will encounter in an actual experiment (Hodge et al., 2001), it is agreed by researchers that these cannot completely replace the physical hands-on experiment. If the graduate engineers are expected to join the armed forces then it is extremely important to use a hybrid model approach where hand skills will be achieved through decommissioned equipment. The thirteen fundamental objectives of the physical hands-on on laboratories presented by Lyle (Lyle & Albert, 2003) makes an engineering student experimenter and help the student understand real world situations.

VIII. Multidisciplinary/cross disciplinary aspect of design projects

In the current situation, mechanical, electrical, or marine engineers could not afford to keep themselves classified as only a specific disciplinary engineers. Now they need to have some knowledge of other disciplines like electronics or biotechnology. For technological development there should be cooperation among engineers of separate disciplines to address problems that have no disciplinary boundaries. For this reason, the introduction of multidisciplinary/cross disciplinary design project modulesfor problem and project based learning within the curriculum serve as a working arsenal in building team work skills.

IX. Integration of academic and pathways knowledge

The training gap analysis (TGA) is an ongoing process of the TNA which consist of reviewing the current performance of training for each pathway and new competencies identified from the TNA. At MTC, the stages of the TGA has been (i) review of competencies by the subject specialists, (ii) its alignment to the academic syllabus. Integration of knowledge specific to each of the five pathways, namely, Control Engineering, Radio/Radar Communication Engineering, Electrical Engineering, Mechanical Engineering, and Hull Engineering was carefully made bythe mapping of TNA as shown in table 3. While developing instructions; a balance had to be made between material specific to pathway and specific to engineering. The project-based learning approach was adopted for pathway specific and problem-based learning for engineering specific knowledge. As project work is more directed to the application of knowledge, it is suitable to engineers who would join the military upon graduation. The first year program involves generic skill development common to all pathways. The second year of the program still includes some generic skill modules but a reasonable number of modules are marine engineering based. The third and fourth year modules require students to work on projects independently and identify their learning needs and find learning resources. The effectiveness of project-based learning is evaluated by Handy and Mills (Hendy &Hadgraft, 2002; Mills, 2002). The mixed-mode approach adopted at MTC serves as a bridge between Training Need Analysis (TNA) and Engineering Education. A modified assessment and feedback mechanism using formative and summative assessment through moodle can be successfully implemented in both core engineering and TNA modules.

X. Recommendation of Framework

Perry's model (Perry, 1968; Chapman, 1996; Richard, 1997; & Donald, 1993) and Kitchener's model(King & Kitchener, 1994) provides an academic framework for students to learn in a mixed-mode learning environment.

i) In a mixed-mode environment, the entering students can be placed in level 3 as an extension of level 2 (Dualism), where all knowledge is known and delivered by instructors.
ii) In a mixed-mode environment, level 4 (Multiplicity) would be cooperative learning where students start to resolve issues without examining alternatives.
iii) In a mixed-mode environment, level 5 (Transition) students would consider their answers as good as instructor's; and students are able to think critically.
iv) In a mixed-mode environment, level 6 (Relativism) would be able to choose the best solution of a problem and develop optimization skills. They only expectcorrective feedback from their instructors.

XI. Justification of Integration

The bridge between Training Need Analysis (TNA) and Engineering Education is akin to equipping students with critical skills, providing an environment for the application of these skills, extensive practice in the application of skills, and use of a modified assessment and feedback mechanism.

XII. Conclusion

The engineering design approach was successfully integrated with the TNA modules to each of the five pathways namely Control Engineering, Radio/Radar Communication Engineering, Electrical Engineering, Mechanical Engineering, and Hull Engineering in Marine engineering department at MTC, Muscat, Oman. This objective was successfully achieved by mapping of the TNA competencies along with accreditation requirements. While developing marine engineering B. Eng. (Hons.) Program, with the core engineering modules and TNA modules, due weightage has been given to match the competencies required by the Royal Navy of Oman. The CDIO concept was adopted for knowledge-induction and skills development in engineering graduates who would join the armed forces of Oman. The B.Eng. (Hons.) program of Marine Engineering The adoption of the mixed-mode and blended learning environment presents an alternative that bridges the gap between TNA and engineering design approach in engineering curriculum. In a mixed-mode environment use of formative and summative assessment through Moodle can be successfully implemented in all engineering modules.

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Table 1. TNA competencies common to L-5 TNA modules

S.No	Competencies	Code	TNA module codes; Level 5
1	Interpret OH&S practices in maintenance	101B	TNAC5010, 5020; TNAR5030, 5040; TNAL5050, 5060; TNAM5070, 5080; TNAH 5090, 5100
2	Plan and organise maintenance work activities	103B	TNAC5010, 5020; TNAR5030, 5040; TNAL5050, 5060; TNAM5070, 5080; TNAH5100
3	Apply quality standards applicable to maintenance processes	105C	TNAC5010, 5020; TNAR5030, 5040; TNAL5050, 5060; TNAM5070, 5080; TNAH 5090, 5100
4	Interpret and use maintenance manuals and specifications	107B	TNAC5010, 5020; TNAR5030, 5040; TNAL5050, 5060; TNAM5070, 5080; TNAH 5090, 5100
5	Complete maintenance documentation	108B	TNAC5010, 5020; TNAR5030, 5040; TNAL5050, 5060; TNAM5070, 5080; TNAH 5090, 5100
6	Perform basic hand skills, standard trade practices and fundamentals in maintenance	109B	TNAC5010, 5020; TNAR5030, 5040; TNAL5050, 5060; TNAM5070, 5080; TNAH5100
7	Plan and implement maintenance activities	112B	TNAC5010, 5020; TNAR5030, 5040; TNAL5050, 5060; TNAM5070, 5080; TNAH5100
8	Supervise maintenance activities and manage human resources in the workplace	113C	TNAC5010, 5020; TNAR5030, 5040; TNAL5050, 5060; TNAM5070, 5080; TNAH 5090, 5100
9	Conduct self in maintenance environment	118A	TNAC5010, 5020; TNAR5030, 5040; TNAL5050, 5060; TNAM5070, 5080; TNAH 5090, 5100
10	Participate in environmentally sustainable work practices	272B	TNAC5010, 5020; TNAR5030, 5040; TNAL5050, 5060; TNAM5070, 5080; TNAH5100

Example: for code 101B

	Knowledge		Skills
1	Interpret safe work practices	1	Selection of proper protective equipment
2	Interpret reporting procedures for work place hazards	2	Identification of emergency procedures
3	Interpret emergency procedures	3	Application of first aid and emergency procedures
4	Knowledge of regulatory and enterprise policies and procedures		
5	Knowledge of protective equipment		

Table. 2 B. Eng. Program structure with TNA modules.

[a] Common to all discipline; [b] common to relevant Engineering discipline; [c] Specific to Specialization; [d] Trade related skill development

	L3	L4	L5	L6
Found. Year	Year 1	Year 2	Year 3	Year 4
General Foundation Programme - MTC	Engineering Mathematics 1[a]	Engineering Mathematics 2[a]	Safety Engineering & Risk Management[a]	Engineering Management relevant to Engineering Discipline[b]
	Engineering Science[a]	Engineering Systems Design 2[a]	Interdisciplinary Group Design Projects[b]	Module related to Specific Specialization[c]
	Electrical Principles[a]	Energy and Environmental Engineering [a]	Module relevant to Engineering Discipline [b]	Module related to Specific Specialization[c]
	Materials & Hardware[a]	Module relevant to Engineering Discipline [b]	Module relevant to Engineering Discipline [b]	Module related to Specific Specialization[c]
	Engineering Systems Design 1[a]	Module relevant to Engineering Discipline [b]	Module related to Specific Specialization[c]	Module related to Specific Specialization[c]
	Introduction to relevant Engineering Discipline**	Module relevant to Engineering Discipline [b]	Module related to Specific Specialization[c]	Module related to Specific Specialization[c]

TNA	Engineering Workshop Practices[d]	Trade skills related to specific specialization [d]	Trade skills related to specific specialization[d]	Trade skills related to specific specialization[d]
	Introductory module related to applicable engineering trade [d]	Trade skills related to specific specialization[d]	Trade skills related to specific specialization[d]	Trade skills related to specific specialization[d]

Table. 3 TNA mapping for common and specific competencies for Control Engineering pathway

TRADE - MET(C): Marine Electrical Technician (Control)		Year 1 (L3)									Year 2 (L4)									Year 3 (L5)								
		UoP						TNA			UoP						TNA			UoP						TNA		
		Engineering Mathematics 1	Engineering Science	Electrical Principles	Materials & Hardware	Engineering Systems Design 1	Introduction to Electrical Engineering	Engineering Workshop Practices	Introduction to Marine Engineering	TNA Cumulative Score	Engineering Mathematics 2	Engineering Systems Design 2	Energy and Environmental Engineering	Computer Systems	Analogue and Digital Electronics	Data Communications	Electrical Technical Drawing and Electronic Design	Shipboard Organization & Weapon Systems	TNA Cumulative Score	Safety Engineering & Risk Management	Interdisciplinary Group Design Projects	Radar and Electronic Systems	Instrumentation and Control	Control System and Design	Data and Communication Networks	Shipboard Weapon Systems-1 (Tech. Descrip.)	Shipboard Weapons Systems-2 (Maintenance)	TNA Cumulative Score
Modules		MTCA 3001	MTCA 3002	MTCA 3003	MTCA 3004	MTCA 3005	MTCA 3006	TNA II 3010	TNA II 3020		MTCA 4001	MTCC 4002	MTCM 4003	MTCM 4005	MTCM 4009	MTCM 4010	TNAC 4010	TNAM 4020		MTCS 5001	MTCC 5003	MTCS 5006	MTCS 5005	MTCM 5034	MTCS 5037	TNAC 5010	TNAC5020	
Competencies		<25%		<50%		<75%		<100%			<25%		<50%		<75%					<25%		<50%		<75%				
Interpret OH&S practices in maintenance	101 B																											
Plan and organise maintenance work activities	103 B																											
Apply quality standards applicable to maintenance processes	105 C																											
Interpret and use maintenance manuals and specifications	107 B																											
Complete maintenance documentation	108 B																											
Perform basic hand skills, standard trade practices and fundamentals in maintenance	109 B																											
Plan and implement maintenance activities	112 B																											
Supervise maintenance activities and manage human resources in the workplace	113 C																											
Conduct self in maintenance environment	118 A																											
Participate in environmentally sustainable work practices	272 B																											
Perform Fire Fighting and Damage Control Techniquies	RN01																											
Maintain Combat Managment systems (CMS) and Fire Control System (FCS)	RN18																											
Maintain Above water weapons (AWW) systems (SSM), (SAM)	RN19																											
Maintain Gun Local Control systems	RN20																											
Maintain Navigation Aids	RN08																											
Remove and Install Combat Managment systems (CMS) and Fire Control System (FCS)	RN22																											
Remove and Install Above water weapons (AWW) systems (SSM), (SAM)	RN23																											
Remove and Install Gun Local Control systems	RN24																											
Remove and Install Navigation Aids	RN16																											
Inspect, Test and Troubleshoot Combat Managment systems (CMS) and Fire Control System (FCS)	RN26																											
Inspect, Test and Troubleshoot Above water weapons (AWW) systems (SSM), (SAM)	RN27																											
Inspect, Test and Troubleshoot Gun Local Control systems	RN28																											
Inspect, Test and Troubleshoot Navigation Aids	RN12																											
Configure and maintain control system networks	RN30																											
Maintain Electronic Warfare (EW) systems	RN31																											