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AN INSTRUCTIONAL DESIGN REFERENCE MISSION: TACTICAL DISC CLEARANCE SYSTEM

by

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ABSTRACT

This instructional guide provides learners with an example operational context for use in the specification, design, testing and analysis of a Tactical Disc Clearance System (TDCS), a fictitious system concept to address the problem of identifying and clearing hazardous objects from a designated area. A notional customer has provided expectations for the TDCS in the form of a Design Reference Mission (DRM). A DRM establishes an operational context, descriptions of the environment and situations in which solution concepts are expected to operate, an operational narrative of expected behavior including a sequence of operational activities and interactions between systems in an environment, and sample measures for establishing goals for mission success. This instructional DRM also provides an example of how to separate short and long term goals for prototype and production ready systems, respectively. This DRM is intended to serve as an underpinning for lessons in decision making using Model Based Systems Engineering (MBSE) analyses, including behavioral logic testing with simulation, resource utilization analysis, cost analysis, and analysis of alternative candidate operational and solution architectures to satisfy high level mission success requirements.

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List of Acronyms and Abbreviations

DRM	Design Reference Mission
IED	Improvised Explosive Device
LOE	Limited Objective Experiment
MBSE	Model Based Systems Engineering
NPS	Naval Postgraduate School
OPSIT	Operational Situation
POE	Projected Operating Environment
QFD	Quality Function Deployment
TD	Tactical Disc
TDCS	Tactical Disc Clearance System
TDDS	Tactical Disc Detection System

CHAPTER 1:
Introduction

The objective of this guide is to provide an example operational context for a fictitious system called the Tactical Disc Clearance System (TDCS), intended for use by students in an academic setting learning skills related to systems engineering or product development. Taking the time to frame a problem well is the first and most critical step in successful system architecture and design. For students new to the process, this guide contains an initial specification for an example real-world problem of hazardous object clearance. The remaining sections of Chapters I, II, and III constitute an instructional outline containing example content for a Design Reference Mission (DRM). This DRM, however, is no pristine academic ideal – rather, it contains a few flaws, ambiguities, omissions, and possibly some inconsistencies to simulate early drafts of real world documents of this sort. The deliberately seeded errors allow the students to practice developing their skills in exposing and addressing these issues through interactions with a notional "customer" (their instructor or project advisor) via systematic application of engineering reasoning [1]. For more background about design reference missions in general, see reference [2].

1.1 DRM Objective

The TDCS DRM establishes an operational context for area clearance missions, including descriptions of the problem, the environment, and different situations in which solution concepts are expected to operate. An operational narrative containing enough detail to generate multiple operational scenario variants is provided as a sequence of operational activities and interactions among systems, subsystems, and objects in the environment. Finally, the DRM provides sample measures for establishing goals for mission success. This DRM is intended to support decision-making processes that rely on Model Based Systems Engineering (MBSE) analyses such as automated architecture view and event trace generation and inspection, behavioral logic testing with simulation, resource utilization analysis, cost analysis, and analysis of alternative candidate operational and solution architectures to satisfy high level mission success requirements. Specific use case examples are provided for working out a high-level architecture design, against which detailed designs belonging to different candidate solutions may be tested and compared.

The DRM is structured with placeholders for both short- and long-term objectives to allow for system prototyping. The short-term objectives are those that are relevant in the academic setting so that a prototype design may be implemented that is analogous to, but less complicated than, a system that would be deployable in a real operational environment.

This approach of separating near- and far-term objectives parallels the real world, where proof of concept demonstrations often precede full scale implementation.

1.2 Mission Background

Hazardous objects continue to be a serious threat to military forces and to civilian populations. Examples of hazardous objects include landmines, Improvised Explosive Devices (IEDs), and biological, chemical and radiological devices. There are many related problem areas in countering the use of these hazards, including route clearance and area clearance. Because of the need for operational expediency, route clearance has received a great deal of relative attention, while area clearance, though important, has been comparatively neglected. The problem addressed herein is that of area clearance.

1.3 Operational Concept

To start to deal with this problem, the customer has conducted a concept development project, which has just been completed and from which a specific operational concept was selected. The selected operational concept calls for a Tactical Disc Clearance System (TDCS) that consists of both human operators and a technological unmanned system. The human operators comprise an operations team that deploys to a mission area and uses an unmanned system called the Tactical Disc Detection System (TDDS) to locate hazardous objects called Tactical Discs (TDs). The customer is interested in identifying a solution concept for the unmanned system (the TDDS), and developing and testing a prototype in a Limited Objective Experiment (LOE) before making a recommendation on the acquisition of a full-scale system. The operational concept is depicted in the Operational View-1 (OV-1) diagram in Figure 1.1, and the characteristics corresponding to both the prototype system and its intended full-scale, production ready system is depicted in Table 1.1.

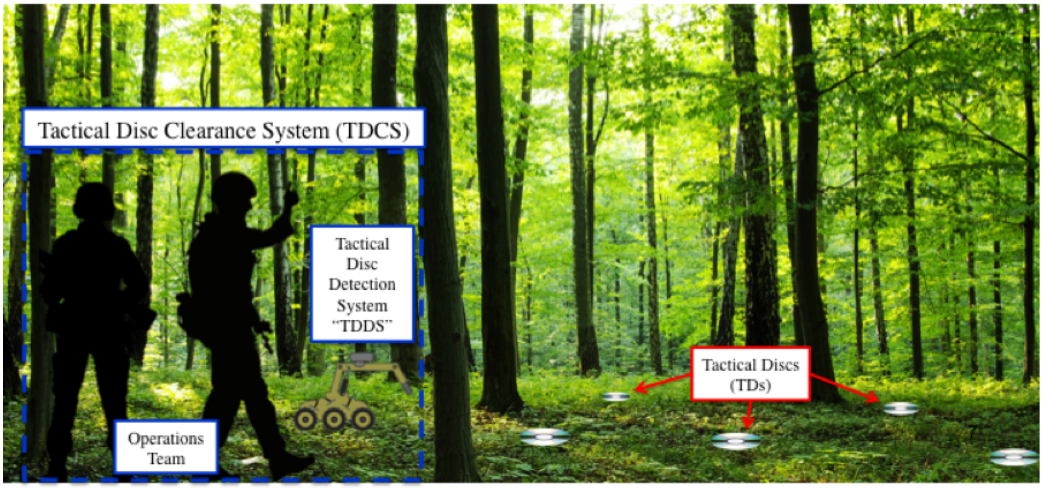


Figure 1.1. OV-1 Operational Concept for the TDCS. An operations team deploys to a mission area and uses an unmanned system, the TDDS, to locate hazardous objects called TDs.

Table 1.1. Near- and Far-Term Concept Characteristics

Characteristic	Prototype (LOE)	Production Ready System
Physical Environment	Climate-controlled indoor environment	Indoor and outdoor environments, wind, sun, temperature extremes, precipitation
Surface Terrain	Interior flooring (carpeted or hard-surface areas of classrooms, offices, etc.)	Interior flooring and exterior ground surfaces, concrete, asphalt, soil, foliage, grass, and sand
Obstacle Avoidance / Traversal	Simulated obstacles that must be avoided or pushed out of the way	Actual obstacles that must be avoided or pushed out of the way
Objects to be Cleared	Simulated hazardous objects called tactical discs (TDs) – compact discs (CDs) with the recording surface facing up	Actual hazardous objects (landmines, IEDs, biological / chemical / radiological devices)
Autonomy	Limited; a human operator manually removes each TD upon its discovery by the system	Full; removal of hazardous object requires no human intervention

1.4 Limited Objective Experiment (LOE)

For the near-term prototype demonstration (LOE), the mine clearance area is square, four feet on each side, and bordered on each side by a strip or surface (tape, paint, carpet, or other material) of contrasting color. It may simply be a white paper or cloth resting on a dark carpet or floor. The purpose is to have a light-level contrast that allows a prototype system to sense the edge of the mine clearance area and also to differentiate between the simulated hazardous objects (TDs) and LOE surface area. The number of TDs can vary between 0 and 100 and TDs may be placed arbitrarily in the area, as determined by the test director (the instructor). During testing, no operations team member will physically contact the clearance area or handle more than one TD at a time. At any time, the operations team leader may declare the TDCS as not available and abort the test. Two baseline LOE configurations are provided for DRM analysis: Nearby Area Clearance and Remote Area Clearance. The first increment delivers a prototype system that is placed by the operations team directly into the area to be cleared. The second increment delivers a prototype that is able autonomously to navigate to a remote area to be cleared, and able to clear obstacles blocking the ingress/egress route. Other increments or different configurations may be separately provided as seen fit by the test director.

1.4.1 Nearby Area Clearance

At the commencement of the mission, an operator picks up the TDDS and drops it on the Start Point – just inside the area to be cleared, as illustrated in Figure 1.2. The system begins a search for TDs. As the TDDS identifies each TD, it stops and alerts the operator, an operations team member removes the TD to a controlled storage facility adjacent to the area being cleared, and the mission continues until as many TDs as possible are found. When the unmanned system has detected all possible TDs, the mission is complete. Test elapsed time is the time between TDDS departure from its start point and the storage of the final TD in the controlled storage facility. The clock starts when the TDDS powers on, and stops when the last TD has been stored in the controlled storage facility.

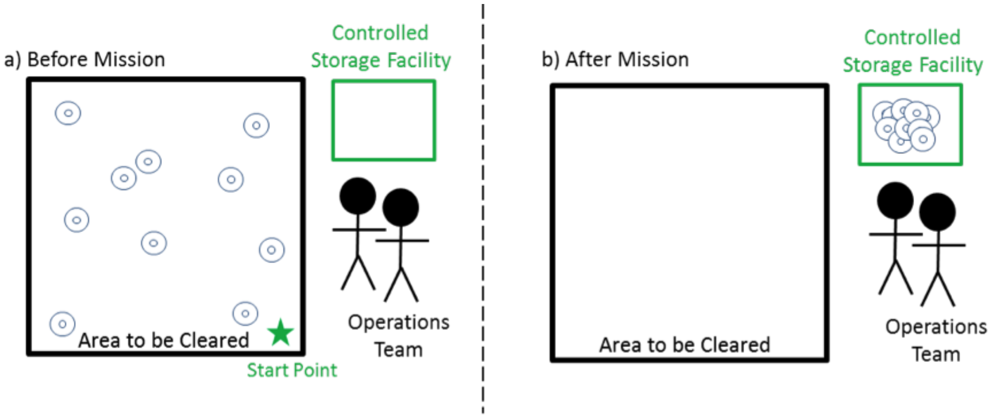


Figure 1.2. Nearby Area Clearance LOE test configuration for the TDCS, before mission start (a) and after mission complete (b).

1.4.2 Remote Area Clearance

At the commencement of the mission, an operator picks up the TDDS and drops it on its test start point – the point of deployment shown in Figure 1.3. The system ingresses to the area to be cleared, clearing any obstacles from its path, then begins a search for TDs, avoiding any additional obstacles it encounters inside the clearance area. As the TDDS identifies each TD, it alerts the operator and waits, an operations team member removes the TD to a controlled storage facility adjacent to the area being cleared, and the mission continues until as many TDs as possible are found. When the unmanned system has detected all possible TDs, it egresses back to the point of return. Test elapsed time is the time between the TDDS's departure from the point of deployment and its return to the point of deployment. The clock starts when the TDDS enters the path and stops when the TDDS exits the path.

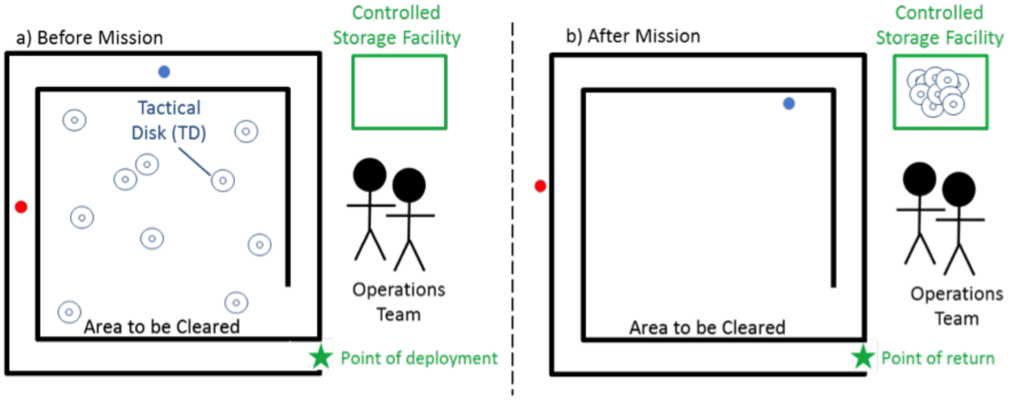


Figure 1.3. Remote Area Clearance LOE test configuration for the TDCS, before mission start (a) and after mission complete (b).

CHAPTER 2:
Projected Operating Environment

The Projected Operating Environment (POE) is the environment in which the TDCS is expected to operate. This section provides details that describe the environmental conditions (Table 2.1), types of locations, and threats to which the TDCS will be subject. The POE establishes a context within which interactions among components of the TDCS and between those components their environment may be modeled to produce measurable outcomes for use in making physical architecture decisions about solution alternatives.

Table 2.1. Near- and Far-Term Concept Characteristics

Condition	**Prototype**	**Production Ready System**
Temperature	50 °F to 90 °F	-50 °F to 130 °F
Pressure	60 to 110 kPa	40 to 110 kPa
Precipitation	None	Light to heavy rain, sleet, snow
Wind	None	Wind gusts up to 40 mph
Ambient light	Operates in the presence of natural and artificial light sources	Operates in the presence or absence of natural and artificial light sources
Electromagnetic fields	Operates in the presence of active appliances typically found in home and offices, such as wireless devices and microwave ovens	Operates in the presence of multiple electromagnetic emissions across a range of radio frequency spectra

The remainder of this chapter will focus on the near term TDCS prototype specifications for the LOE. A typical office space, such as that depicted in Figure 2.1, serves as a baseline reference for the testing environment. These example locations provide ample floor space to lay out the LOE configuration assigned by the test director.

Figure 2.1. Example environments suitable for operating the TDCS prototype: a small office (left) and a conference room (right), each having sufficient floor space that can be cleared for laying down the test configuration.

2.1 Threat Details

2.1.1 Assumed Threat Environment

Threats to the success of area clearance missions in a prototype testing environment may include poor environmental conditions, interference from other humans or animals in the vicinity, and moving or stationary physical obstacles.

2.1.2 Assumed Threat General Conditions

Assumed threat conditions that apply to the prototype environment are:

Power conditions:

- 0-1 power outages during the TDCS prototype operation

Lighting conditions:

- moderate (barely enough light to capture a video of the test) to excellent (expected lighting levels for an indoor home or office environment) during the TDCS prototype operation

2.1.3 Threat Assumptions

Assumptions about the presence of potential threats include:

- possible nearby animals, such as cats and dogs, that may accidentally or deliberately disrupt the TDCS prototype during its operation

- possible nearby humans that may accidentally or deliberately disrupt the TDCS prototype during its operation
- possible moving or stationary obstacles in the path of the TDDS

2.1.4 Threat Characterization

Threats that are present in the environment may be moving or stationary.

Moving obstacles:

- 0-2 spherical obstacles rolled onto a collision course with the TDDS
- 0-2 domestic cats that have taken an interest in the TDDS
- 0-2 domestic dogs that have taken an interest in the TDDS
- 0-2 neutral humans that have taken an interest in the TDDS

Stationary Obstacles:

- 0-4 obstacles that cannot be traversed by the TDDS
- 0-4 obstacles that can be traversed or moved by the TDDS

CHAPTER 3:
Mission and Measures

This chapter contains a description of the possible mission variants and the associated measures of success.

3.1 Mission Success Requirements

In order for the mission to be considered successful, the following high-level requirements must be met by the TDCS.

- The TDCS shall correctly identify TDs and borders.
- The TDCS shall complete its mission in the minimum time.
- The TDCS shall execute the design reference mission without experiencing a disabling state or malfunction.

3.2 Mission Definition

This section defines the environmental conditions for the LOE missions, and provides narratives of the missions themselves. Other mission variants, different environmental assumptions, or additional instructions may be provided by the test director as deemed necessary for a successful LOE.

The following three Operational Situations (OPSITs) have been approved for use at the TDCS LOE. An OPSIT is a description of POE variables that define the selected environmental conditions for a mission.

3.2.1 Office Environment OPSIT

The TDCS design reference mission is tested by a team of students in the office workplace of one of the team members. The office has an ambient room temperature of between 65°F and 75°F. The test is being conducted indoors and so there is no wind or precipitation. Ambient light is sufficient for capturing a clear video of the test, as shot with a typical camera phone, laptop with a built in camera, or a video camera. There are no power outages while the design reference mission is being conducted and no interference from wayward humans or their pets.

3.2.2 Home Environment OPSIT

The TDCS design reference mission is tested by a team of students in the home of one of the team members. The home has an ambient room temperature of between 65°F and 75°F. The test is being conducted indoors, so there is no wind or precipitation. Ambient light is sufficient for capturing a clear video of the test, as shot with a typical camera phone, laptop with a built in camera, or a video camera. There are no power outages while the design reference mission is being conducted and no interference from wayward humans or their pets.

3.2.3 Outdoor Environment OPSIT

The TDCS design reference mission is tested by a team of students outdoors. The outdoor area has a temperature of between 30°F and 90°F. There is no precipitation, but some wind gusts up to 15 mph may be present. Ambient light is sufficient for capturing a clear video of the test, as shot with a typical camera phone, laptop with a built in camera, or a video camera. There are no power outages while the design reference mission is being conducted and no interference from wayward humans or wildlife.

3.3 Mission Execution

A mission consists of multiple operational activities, and its execution typically involves multiple operational nodes (a.k.a. actors, performers, or assets) concurrently conducting a variety of assigned operational tasks (specific, measurable activities). The product of the mission execution analysis is a narrative sequence that details the activities to be assigned to the nodes in order to complete a mission. The activities and actors are herein described as independent of solution as possible to allow the mission execution sequences to serve as a baseline for comparing multiple alternative solution concepts.

Each of the following narratives describes a reference mission for each TDCS prototype increment. Each narrative is broken into phases for ease of comprehension. Decision logic is incorporated into the narrative to show possible alternate paths that could occur during mission execution as the various nodes perform actions and make decisions. The sequenced steps conclude with numerical suffixes to facilitate mapping of the narrative to other models. General rules are denoted separately at the end of each narrative. A nominal mission is defined as one that does not invoke any of the alternatives provided for in the general rules. The LOE goal is to execute nominal missions only (having no failure modes).

3.3.1 Nearby Area Clearance Mission Narrative

The following mission narrative for nearby area clearance has been divided into phases.

Drop Test Phase

- The Operations Team collects environmental measurements from the TDCS Environment. If the measurements are within the OPSIT parameters, the Operations Team decides to conduct a mission; otherwise the Operations Team scrubs the mission and proceeds no further.
- The Operations Team supplies the TDDS with stored energy.
- The Operations Team drops the TDDS from a height of 1" to its start point.
- The Operations Team powers up the TDDS.
- The TDDS reports its mission readiness status to the Operations Team.
- If the TDDS is ready to conduct a mission, the Operations Team commands the TDDS to start the mission.

Search Phase

- The TDDS commences a search for the simulated hazardous objects (TDs).
- For each TD it detects, the TDDS stops and alerts the Operations Team before resuming its search for additional TDs.
- As each TD is detected, the Operations Team removes the detected TD to a Controlled Storage Facility.
- When all TDs have been discovered, the Operations Team powers down the TDDS, without entering the clearance area.

General Rules

- At any point in the mission, if the TDDS crosses a border, or experiences a condition or system failure rendering it unable to complete the mission, the Operations Team aborts the mission, collects the TDDS, and conducts unscheduled maintenance.
- If the TDDS becomes inoperative and unable to return on its own to the edge of the clearance area, the Operations Team may enter the area to retrieve it (constitutes a safety violation.)

3.3.2 Example Instances of the Nearby Area Mission Narrative

The nearby area mission narrative provides for different possible variants of the mission. The Conduct Mission section below lists example use case outcomes for these instances by phase. Additional example use cases are given for maintenance.

Conduct Mission

1. Drop Test Phase: Measures Outside of OPSIT Parameters
2. Drop Test Phase: TDDS Fails Readiness Check
3. Drop Test Phase: TDDS Is Mission Ready

4. Search Phase: TDDS Fails to Detect Area Clearance Border
5. Search Phase: Detect Zero TDs
6. Search Phase: Detect One TD
7. Search Phase: Detect Three TDs
8. Search Phase: Detect Ten TDs
9. Search Phase: Detect One Hundred TDs

Conduct Maintenance

1. Undergo Scheduled Maintenance
2. Undergo Unscheduled Maintenance
3. Program System Behavior

3.3.3 Remote Area Clearance Mission Narrative

The following mission narrative for remote area clearance has been divided into phases.

Drop Test Phase

- The Operations Team collects environmental measurements from the TDCS Environment. If the measurements are within the OPSIT parameters, the Operations Team decides to conduct a mission; otherwise the Operations Team scrubs the mission and proceeds no further.
- The Operations Team supplies the TDDS with stored energy.
- The Operations Team drops the TDDS from a height of 1” to its point of deployment.
- The Operations Team powers up the TDDS.
- The TDDS reports its mission readiness status to the Operations Team.
- If the TDDS is ready to conduct a mission, the Operations Team commands the TDDS to start the mission.

Ingress Phase

- The TDDS begins its ingress along the route connecting the point of deployment and the area to be cleared, staying within the left and right borders of the route.
- The TDDS detects the first stationary obstacle, stops, then pushes it out of the way continuing forward.
- The TDDS collides with a moving obstacle and proceeds without stopping.
- The TDDS detects the second stationary obstacle, stops, then pushes it out of the way continuing forward to the end of the ingress route.

Search Phase

- The TDDS commences a search for the simulated hazardous objects (TDs).
- For each TD it detects, the TDDS stops and alerts the Operations Team before resuming its search for additional TDs.
- As each TD is detected, the Operations Team removes the detected TD to a Controlled Storage Facility.
- When all TDs have been discovered, the Operations Team commands the TDDS to egress to the point of return.

Egress Phase

- The TDDS begins its egress along the route connecting the area to be cleared to the point of deployment, staying within the left and right borders.
- The TDDS detects the end of the egress route, then stops.
- The Operations Team powers down the TDDS.
- The Operations Team removes the depleted energy store from the TDDS.

General Rules

- At any point in the mission, if the TDDS crosses a border, or experiences a condition or system failure rendering it unable to complete the mission, the Operations Team aborts the mission, collects the TDDS, and conducts unscheduled maintenance.
- If the TDDS becomes inoperative and unable to return on its own to the edge of the clearance area, the Operations Team may enter the area to retrieve it (constitutes a safety violation.)

3.3.4 Example Instances of the Remote Area Mission Narrative

The remote area mission narrative provides for different possible variants of the mission. The Conduct Mission section below lists example use case outcomes for these instances by phase. Additional example use cases are given for maintenance.

Conduct Mission

1. Drop Test Phase: Measures Outside of OPSIT Parameters
2. Drop Test Phase: TDDS Fails Readiness Check
3. Drop Test Phase: TDDS Is Mission Ready
4. Ingress Phase: Fail to Detect Ingress Border
5. Ingress Phase: Fail to Detect the 1st Stationary Obstacle
6. Ingress Phase: Malfunction after Moving Obstacle Collision
7. Ingress Phase: Fail to Detect the 2nd Stationary Obstacle
8. Ingress Phase: Successfully Navigate to Area to be Cleared

9. Search Phase: Detect Zero TDs
10. Search Phase: Detect One TD
11. Search Phase: Detect Three TDs
12. Search Phase: Detect Ten TDs
13. Search Phase: Detect One Hundred TDs
14. Egress Phase: Fail to Detect Egress Border
15. Egress Phase: Fail to Detect End of Route
16. Egress Phase: Successfully Navigate to Point of Deployment

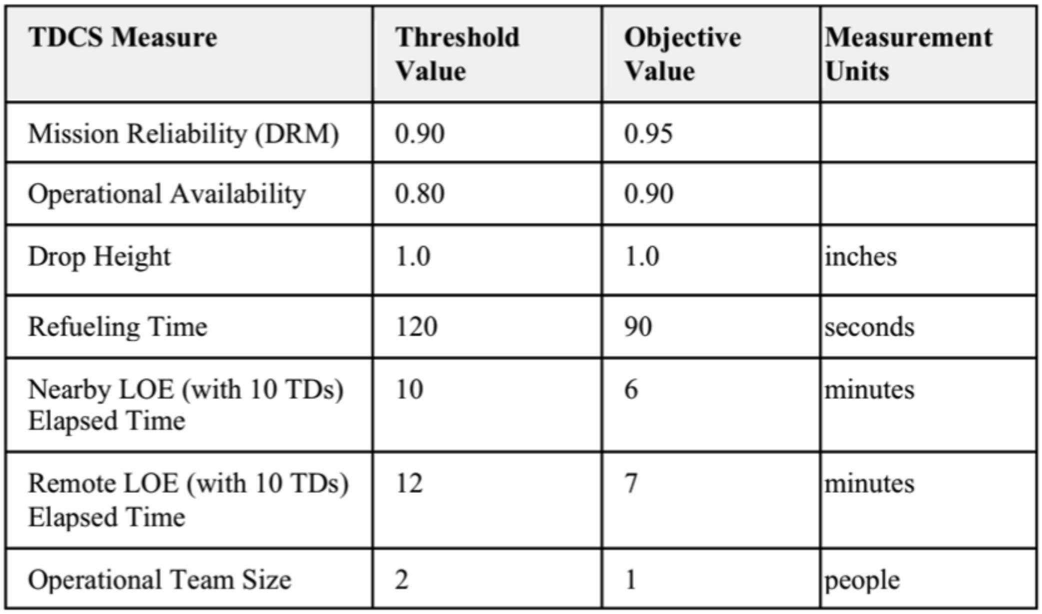
Conduct Maintenance

1. Undergo Scheduled Maintenance
2. Undergo Unscheduled Maintenance
3. Program System Behavior

3.4 Measures

Having provided the operational background and expectations for a prototype system under design, this section provides specific threshold and objective measures for use in assessing system capabilities in the context of the above reference mission. To provide quantitative results and recommendations, measures must be defined to assess the effectiveness and performance of different possible solution concepts in meeting the mission success requirements. There may be many solution concepts capable of meeting the mission success requirements, but these may have different degrees of suitability as perceived by the stakeholders. To assist with ordering possible solutions from most to least preferable, stakeholder interviews and requirements elicitation methods are employed to gather the important system characteristics that can be used to discriminate the suitability of each solution in executing this mission. For the purposes of this DRM, the top ranking system characteristics for the prototype demonstration system are summarized in Table 3.1.

Table 3.1. TDCS Top Ranking System Characteristics



TDCS Measure	**Threshold Value**	**Objective Value**	**Measurement Units**
Mission Reliability (DRM)	0.90	0.95	
Operational Availability	0.80	0.90	
Drop Height	1.0	1.0	inches
Refueling Time	120	90	seconds
Nearby LOE (with 10 TDs) Elapsed Time	10	6	minutes
Remote LOE (with 10 TDs) Elapsed Time	12	7	minutes
Operational Team Size	2	1	people

Each potential solution may also be evaluated for estimated lifecycle cost. For example, the estimated cost of development, production, fielding, operation, maintenance, and disposal may be computed based on: 1) the cost of prototype system components, assuming that, at any one time, 10 TDCSs will be in inventory between 2018 and 2038, 2) that a TDCS will be in operational use 10% of the time after fielding, 3) that the planned life of a TDDS is five years, and 4) that personnel costs are accrued only for TDCS-related activities (e.g., operations, maintenance, training). The prototype data may be used in the calculations to establish and document the methodology for lifecycle cost estimation to be later used on the production ready system. Other concerns that rank high in importance with the stakeholders include:

- interoperability
- safety
- security
- sustainability
- maintainability
- ease of use
- adaptability for employment in multiple OPSITs

The TDCS measures in Table 3.1 are quantitative, and all directly measureable. The stakeholders have not provided details, however, on how the example suitability characteristics listed above are to be measured, but they have qualitative expectations for them. A method such as Quality Function Deployment (QFD) [3] may be used to select and map high level suitability characteristics that do not have a direct observable measure or mathematical computation to measures that do have these properties, for a more formal definition of each characteristic that can be negotiated with stakeholders.

3.5 Summary of DRM Analysis Objectives

This DRM outlined an operational context for an area clearance mission conducted by increments 1 and 2 of the TDCS. Specific use case examples were provided for developing a high level architecture design, against which detailed designs for different candidate solutions may be tested and compared for their satisfaction of a set of mission success requirements:

- The TDCS shall correctly identify TDs and borders.
- The TDCS shall complete its mission in the minimum time.
- The TDCS shall execute the design reference mission without experiencing a disabling state or malfunction.

References [4] [5] [6] contain representative MBSE analyses based on a DRM and are recommended as further reading for understanding how a DRM can be used to support structured and systematic architectural analysis.

The DRM has established:

- an operational context, description(s) of the environment and situations in which a system under design is expected to operate,
- an operational narrative containing enough detail to generate multiple operational scenario variants,
- a sequence of operational activities and interactions between the system and other systems in its environment, and
- measures for establishing goals for mission success.

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