Ammunition Logistics Program
FARV PROJECTILE RESUPPLY EQUIPMENT
RAM ANALYSIS

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EXECUTIVE SUMMARY

The U.S. Army's Project Manager, Advanced Field Artillery System/Future Armored Resupply Vehicle (PM-AFAS/FARV) is sponsoring the development of technologies that can be applied to the resupply vehicle for the Advanced Field Artillery System. PM-AFAS/FARV has requested that Oak Ridge National Laboratory (ORNL) conduct an initial reliability, availability, and maintainability (RAM) assessment for the ammunition transfer arm, the automatic artillery processing, the passive storage, and the pick-and-place robot [Robotic Ammunition Transfer System (RATS)]. The U.S. Army Armament Research, Development, and Engineering Center at the Picatinny Arsenal, working with ORNL, supplied the RAM assessment of RATS. The Future Armored Resupply Vehicle (FARV) is undergoing preconceptual design (i.e., equipment system concepts have not yet been chosen for implementing required functions). PM-AFAS/FARV directed ORNL to base its RAM assessment on the current best technical approach, which was the FARV new-start chassis with the FARV mission module as specified in the July 9, 1993 Engineering Trade-off Analysis. A RAM assessment at this early stage of design is appropriate because (1) such studies can help in selecting a design and (2) the greatest gains in reliability can be achieved.

Reliability block diagrams were developed as part of the assessment and indicated that most equipment systems were in series; thus, when one component fails, the entire system fails. Where components were in parallel, the redundant components were combined to create a serial equipment configuration. This configuration greatly simplified the mathematics of the analysis. Further simplifications were made by using generic, best estimate failure rates from open literature and by assuming an exponential failure density distribution in the calculations. For this initial assessment, the input parameters incorporated in the calculations contain a high degree of uncertainty. Therefore, the information from this study is most beneficial in examining the reliability of one subsystem or component relative to another. This permits identification and ranking of reliability critical items which can provide an impetus for design changes and improvements in reliability. A study to establish the degree of data uncertainty and to propagate the uncertainty in failure rates throughout the calculations may be performed later.

The results of the mean time to failure (MTTF) calculations are summarized in Table 1. The range of uncertainty in MTTF is approximately a factor of three from the mean value. The range emphasizes that the results are preliminary and are based on a preconceptual design. The estimated MTTF for all four systems is about 1260 h with a range of 400 to 4000 h. The MTTF estimates are adjusted to reflect actual component operating time using the duty cycles defined in this report.

Mean time to repair (MTTR) estimates were chosen for all components in a coarse maintainability assessment. This value includes the time involved in removing the failed components and installing the new component; there is a great deal of uncertainty associated with this MTTR value. It is assumed that the replacement part and necessary tools are on hand. The time to diagnose the failed part is not included in the MTTR. It is also assumed that there is reasonable access to the failed component.

The study estimated the inherent total availability of the four systems to be 0.9991. This availability corresponds to a 0.019 failure per 24-h mission for the four systems. Inherent availability measures the characteristics of the equipment system itself and removes logistical

considerations such as the availability of spare parts and scheduled downtime. Logistics considerations will be included in later operational availability calculations.

Table 1. Summary of initial reliability assessment results

System	Estimate of MTTF (h)	Expected range of MTTF (h)
Artillery processing system	12,600	4000 to 38,000
Ammunition transfer arm	2110	700 to 6300
RATS	4360	1400 to 13,000
Passive storage	79,600	26,000 to 200,000
All resupply equipment (combined)	1260	400 to 4000

In addition, this work estimated mean time between essential unscheduled maintenance demand (EUMD), essential functional failure (EFF), and system abort (SA) to provide information for the FARV Material Developers Analysis. See Sect. 7 for additional information. These parameters are given in Table 2 and are used in reliability and maintainability scoring.

Table 2. Reliability scoring parameters

System	Mean time (1000 h)		
	EUMD	EFF	SA
Ammunition processing system ^a	12.6	14.2	38
Ammunition transfer arm ^a	2.1	2.8	6
Passive storage ^a	79.6	195.4	743
RATS ^b	1.1	1.5	3

^aDuty cycles incorporated in the calculations

^bDuty cycles not incorporated in the calculations

The potential for reliability improvement was evaluated; this analysis estimates that an embedded prognostics capability can detect at least 50% of electromechanical component wear prior to failure. For additional information, see Sect. 4.4. Replacing these components between missions can improve mission reliability (i.e., increase MTTF) by approximately 28%. If both embedded diagnostics and high-reliability components are used, the reliability can be improved by approximately 49%. This significantly increases the number of successful missions before failure from 52 to 78.

A failure modes and effects analysis was conducted using a team meeting approach. An interdisciplinary (mechanical, electrical, and nuclear) group of engineers met with system design engineers and probed the effects of various failures and how to improve reliability. RAM

engineers provided the expertise required to perform the RAM analysis and asked key "what if" questions. This report provides recommendations for specific design improvements. Principal recommendations are as follows:

1. Consider reducing the operational demands on RATS. Currently all ammunition handling operations must use the RATS robot. One alternative is to use a conveyor system instead of the RATS robot to move ammunition rounds from process station 1 to process station 2.
2. For the automated ammunition processing system, different end-effector handling fixtures are required for the two operations performed in station 1. Consider providing a universal end effector which performs both operations and provides redundancy.
3. Consider providing a breakaway connection between the docking port and the AFAS vehicle so that movement by either vehicle during transloading will not damage the arm.

1. INTRODUCTION

The U.S. Army's Project Manager, Advanced Field Artillery System/Future Armored Resupply Vehicle (PM-AFAS/FARV), located at the Armament Research, Development, and Engineering Center (ARDEC) at the Picatinny Arsenal, is sponsoring the development of technologies that can be applied to the resupply vehicle for the Advanced Field Artillery System (AFAS). Oak Ridge National Laboratory (ORNL) is responsible for two major development efforts in support of PM-AFAS/FARV: the Modular Artillery Ammunition Delivery System (MAADS) and the Advanced Integrated Robotics Rearm System (AIRRS). The development of these systems began in FY 1993; an interim demonstration is scheduled for July 1994, and a final technology demonstration is scheduled for September 1995. ORNL is a U.S. Department of Energy (DOE) facility, and this work is performed for PM-AFAS/FARV under an interagency agreement between ARDEC and DOE.

The MAADS project is developing and demonstrating technology for artillery ammunition handling and delivery using active modular storage concepts. The AIRRS project is developing concepts for process handling using advanced robotics and passive storage of artillery ammunition. MAADS and AIRRS development are both in the conceptual design stage. A number of equipment options are being examined for each project to achieve various functions. The final recommended designs for MAADS and AIRRS have not yet been chosen.

Reliability, availability, and maintainability (RAM) is an important consideration in the development of any new technological system. The objectives of the ORNL RAM activity are to (1) assist PM-AFAS/FARV in understanding RAM-critical issues for the best technical approach (BTA) concepts and systems developed by MAADS and AIRRS and (2) recommend technology for reliability improvement. Early RAM assessments are cursory and are conducted at a high system design level because of the tentative nature of the design at the conceptual stage. However, early RAM assessments are perhaps the most useful because it is at these early stages that the greatest increases in reliability might be achieved. These early analyses identify failure-prone equipment and systems which require further development efforts or redesign.

ORNL has conducted an initial cursory RAM assessment of those design options in MAADS and AIRRS that are present in the BTA for the Future Armored Resupply Vehicle (FARV) as it existed in July 1993. The assessment calculated the preliminary mean time to failure (MTTF) and mean time to repair (MTTR) for the systems examined. A preliminary critical equipment items list has been established, and the potential for reliability growth is addressed. A failure modes and effects analysis (FMEA) has also been conducted at a cursory level for each component.

2. SYSTEM DESCRIPTIONS AND PHASES OF OPERATION

2.1 SYSTEM DESCRIPTION

The BTA for the FARV projectile resupply equipment consists of the ammunition transfer arm, the pick-and-place robot [Robotic Ammunition Transfer System (RATS)], the passive storage cells, and the horizontal automatic ammunition processing. These systems are described in this section. For this study, the BTA was based on the Engineering Trade-off Analysis on July 9, 1993, and was determined to be the FARV mission module on the new-start chassis.

2.1.1 Ammunition Transfer Arm

The ammunition transfer arm is a three-joint, 6-D.F. hollow robotic arm which houses conveyor systems for transferring the artillery rounds to and from the FARV. The ammunition transfer arm can be retracted/extended along tracks located inside the vehicle (see Fig. 1). When not in use, the arm is housed inside the vehicle to simplify vehicle motion and to offer a more discrete vehicle profile. The first two joints, the shoulder and the elbow, consist of dual gimbal rings which allow rotation about the two axes perpendicular to the long axis of the arm. The shoulder pitch motion is performed by a single electric motor-driven linear actuator; gas springs are used as counter weights at the shoulder joint. The shoulder yaw motion is also accomplished with a single electric motor-driven linear actuator. The two elbow rotations (pitch and yaw) are each performed by a single linear actuator, similar to but smaller than those required to rotate the shoulder. The third joint, the wrist, is equipped with two linear actuators—one to allow the wrist to rotate about the long axis of the arm and one to allow an 18-in. extension at the end of the arm.

The arm houses three conveyor systems for transferring the artillery rounds into and out of the FARV. The conveyor systems transfer the rounds from inside the vehicle to the shoulder, from the shoulder to the elbow, and from the elbow to the end of the arm. The first two conveyor sections consist of two belts which form a "V" to cradle the artillery round (see Fig. 2). The V-belt configuration is driven via a single motor with a dual drive train which consists of right angle gear reducers, universal joints, pulley systems, and bearings. The third conveyor system is a single belt capable of extending 18 in. along with the wrist joint. Retractable side guides are used to guide the round through this section of the arm.

The docking port is located at the end of the ammunition transfer arm and serves to align with and lock onto the AFAS. Docking can be accomplished by telerobotics; in addition, the system will be equipped with computer-aided docking capabilities. The docking system requires motor-driven docking latches, an intervehicle communication connection, a pair of externally mounted cameras, as well as ultrasonic and close-range proximity sensors. The computer-aided docking will also require an internally mounted camera, an additional central processing unit (CPU), and software. The telerobotic system includes video monitors, joysticks, buttons, and switches.

The controls system for the ammunition transfer system includes a modular CPU control board, dc/dc converters, and a 24-Vdc regulator. Tachometers and encoders on the various motors provide feedback to the CPU and to the motor amplifiers. The system is powered by a dc power supply.

Fig. 1. Ammunition transfer arm.

2.1.2 RATS Pick-and-Place Robot

The RATS device is a 4-D.F. pick-and-place robot with an ammunition transfer head, a head rotator, a load elevator, and a system translator. The report, *Robotic Ammunition Transfer System (RATS) Reliability, Availability, Maintainability (RAM) and Failure Modes, Effects, and Criticality Analysis (FMECA)*, by D. S. Nielsen, B. J. Laidig, and S. H. Figueroa, provides a more detailed description and analysis of the design.

2.1.3 Passive Storage Cells

The passive storage system consists of cylindrical cans stacked in an array. Each can is equipped with three spring-loaded latches for locking the artillery round into place.

2.1.4 Horizontal Automatic Ammunition Processing

Processing is accomplished in two horizontal stations. In station 1, the lifting eye is removed and the artillery is fuzed; in station 2, the fuzed round is weighed and marked (see Fig. 3). The rounds are placed in the stations by RATS. Each station is equipped with mechanical stops; latches are not required to hold the artillery round in the stations.

Station 1 houses a lifting lug remover head and a fuzing head, each mounted on machine slides. The lifting lug remover has 2 translational D.F. and 1 rotational D.F., and the lifting lug remover head is equipped with a slot for engaging the lifting lug. The fuzing mechanism has 2

translational and 2 rotational D.F., and the fuze head has a spring-loaded end effector to grip the fuze. The fuzes are manually loaded into a serpentine conveyor which consists of a motor-driven chain and sprocket assembly. The control system for station 1 includes a modular CPU control board, dc/dc converters, and a 24-Vdc regulator. Torque sensors and encoders on the various motors provide feedback to the CPU and to the motor controllers. The system is powered by a dc power supply.

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Fig. 2. V-belt conveyor system for ammunition transfer arm.

Fig. 3. Horizontal two-station automated processing.

Station 2 consists of a scale assembly mounted on a motorized jack which lifts the scale and the round above the station floor. Marking is accomplished by raising the round on wheels and rotating it about a fixed laser printer assembly. The station 2 control system has components similar to those for station 1.

2.2 PHASES OF OPERATION

The projectile resupply functions of the FARV consist of (1) uploading artillery rounds via the ammunition transfer arm, (2) transferring the rounds from the arm to process station 1 via RATS, (3) removing the lifting lugs and fuzing the rounds in process station 1, (4) transferring the rounds from process station 1 to process station 2 via RATS, (5) weighing and marking the rounds in process station 2 (6) transferring the rounds from process station 2 to storage via RATS, (7) docking the ammunition transfer arm with an AFAS using both telerobotics and computer-aided docking, (8) transferring the rounds from storage to the ammunition transfer arm via RATS, and (9) rearming an AFAS via the ammunition transfer arm.

2.2.1 Uploading

The uploading operation requires a soldier to feed artillery rounds into the ammunition transfer arm. The upload operation must be accomplished within a 65-min time frame. Each round is placed on the single-belt conveyor at the docking port end of the arm. All the arm conveyor belts will operate continuously during the uploading operation. Intermittent operation is required from the retraction/extension system, which moves the arm into and out of the FARV, the ammunition transfer arm door, and the docking port door. These systems must operate prior to and following the uploading operation. The operation of the ammunition transfer arm joints, the docking port latches, the computer-aided docking, and telerobotic docking capabilities are not

required for the uploading operation. A brace is needed at the docking port end of the arm to stabilize and support the extended arm during uploading.

2.2.2 Handling

All of the transfer operations are accomplished by the RATS device: moving rounds into and out of the ammunition transfer arm, moving rounds into and out of each of the two process stations, and moving rounds into and out of the passive storage cells. The RATS components must operate intermittently during these operations.

2.2.3 Processing

The processing operations consist of removing the artillery lifting lug, fuzing, weighing, and marking the round. The first two operations, performed in process station 1, require intermittent operation of the lifting lug remover head, the fuzing head, the machine slides, and the fuze storage serpentine conveyor system. The second two operations, performed in process station 2, require intermittent operation of the scale, the jack, the round printer, the round lifter, and the round rotator.

2.2.4 Storing

The storage operation requires that the three spring-loaded latches operate continuously to hold a round in the storage cell. The latches must operate while the FARV travels at speeds and over terrain as stipulated in the FARV Operational Requirements Document.

2.2.5 Rearming

The rearming operation requires that the ammunition transfer arm be docked with an AFAS and that the artillery rounds be transferred through the arm to the AFAS. FARV-to-AFAS docking is accomplished by computer control and computer-aided manipulation of the transfer arm. The vision system, the man-machine interface system, and the joint actuators must operate intermittently in order to successfully dock the two vehicles. Once the docking is accomplished, the docking latches engage and provide added support to maintain the arm configuration effected by the joint actuators. The joint actuators, the gas springs, and the docking latches must support the weight and maintain the configuration of the ammunition transfer arm during the rearming operation. The rounds (60 rounds maximum) will be transferred via the three sets of conveyor belts located inside the arm. These conveyor belts must operate continuously during the rearming operation. Intermittent operation is required from the retraction/extension system, which moves the arm into and out of the FARV, the ammunition transfer arm door, and the docking port door. These systems must operate before and after rearming. The rearming operation, including docking and undocking, will be performed within a 12-min time frame.

3. METHODOLOGY AND ASSUMPTIONS

3.1 RELIABILITY

The primary assumptions in this initial analysis are that (1) components, subsystems, and systems are in series and (2) the lifetimes of the components are independent exponentials. Serial operation implies that failure of one component results in failure of the system. Wherever components are in parallel (such as the array of compartments in passive storage), redundant capabilities are combined until a serial component configuration is obtained.

An exponential failure density distribution means that the component failure rates are constant with time. Thus, the i^{th} component is assumed to have the constant failure rate λ_i . The up-time distribution for a subsystem, j , or a series of n components can be shown to be exponential with the parameter

$$\lambda_j = \sum_{i=1}^n \pi_i \lambda_i , \quad (\text{Eq. 1})$$

where π_i is the environmental factor for the i^{th} component. This factor allows the failure rates to be adjusted to reflect the operating environment. For this preliminary analysis, an environmental factor of 1.0 was used.

The probability of a component surviving, P_{si} , over a time interval, t , becomes

$$P_{si} = e^{-(\lambda_i)t} , \quad (\text{Eq. 2})$$

where d is the duty cycle factor, defined as the ratio of operating time to mission time. The duty cycle factor allows the distribution to be adjusted to reflect actual component operating time. When a component has a failure rate during nonoperation, the following equation is used:

$$P_{si} = e^{-[\lambda_{1i}td_i + \lambda_{2i}t(1-d_i)]} . \quad (\text{Eq. 3})$$

Here λ_{1i} and λ_{2i} are the failure rates during operation and nonoperation for component i respectively. This analysis assumes that nonoperating component failures are negligible. In addition, the constant failure rate assumption implies that when a failed system becomes operational again, it is considered to be as good as new.

For exponential failure density distributions, the MTTF is the reciprocal of the failure rate:

$$\text{MTTF}_i = \frac{1}{\lambda_i} . \quad (\text{Eq. 4})$$

MTTF and mean time between failures (MTBF) are approximately the same when the repair time is small compared to the operating time.

3.2 MAINTAINABILITY

The probability that the subsystem j failure is a consequence of the failure of component i is

$$\alpha_j = \frac{\lambda_i}{\sum_{i=1}^n \lambda_i} . \quad (\text{Eq. 5})$$

The MTTR of subsystem j becomes

$$(\text{MTTR})_j = \frac{1}{\lambda_j} \sum_{i=1}^n \lambda_i (\text{MTTR})_i . \quad (\text{Eq. 6})$$

A similar equation applies for systems.

3.3 AVAILABILITY

The unavailability of a component, $\bar{a}_i$, is approximated by

$$\bar{a}_i \approx \lambda_i (\text{MTTR})_i , \quad (\text{Eq. 7})$$

where high systems availability and short repair times are assumed. The unavailability of subsystem $\bar{A}_j$ is

$$\bar{A}_j = \sum_{i=1}^n \bar{a}_i . \quad (\text{Eq. 8})$$

The textbook definition of inherent availability, a_i , is

$$a_i = \frac{MTTF_i}{MTTF_i + MTTR_i} \quad (\text{Eq. 9})$$

Substituting the estimates for MTTF and MTTR of the component population into this formula yields an estimate for component availability, similarly for subsystems and systems. This formula is accurate regardless of the underlying population distribution.

This study calculated inherent availabilities, which are true measures of the performance capability of the equipment system. Inherent unavailability, $\bar{a}_i$, is defined as

$$a_i = 1.0 - \bar{a}_i \quad (\text{Eq. 10})$$

All logistics questions (e.g., scheduled downtimes and the availability of spare parts) have been neglected for this initial analysis. Operational availability will be calculated at a later date.

Understanding or interpreting a value of availability is sometimes difficult. It is often expressed as a number only slightly less than 1.0. A much more informative parameter is the expected number of failures (ENF). The equation for the expected number of failures is

$$ENF_i = \lambda_i a_i t \quad (\text{Eq. 11})$$

where a_i is the availability of component i and t is the duration of the mission.

3.4 ASSUMPTIONS

The preliminary nature of this design required simpler RAM calculations. Many of these simplifications have been mentioned in the previous sections as the equations were introduced. It is important to present all simplifications and assumptions associated with this analysis. Ideally, the mathematical models would be time dependent, the failure rates would have failure distributions, factors would be utilized to account for environmental stress, and the propagation of these uncertainties would be analyzed. However, the conceptual design of the FARV is at too early a phase and the time constraints are too tight to permit more sophisticated analyses at this time. An analysis of the uncertainties in the present failure rate data and the propagation of these uncertainties in calculations will be performed later.

The assumed serial nature of components, subsystem, and system operation, however, is appropriate at this early phase of conceptual design (i.e., if a single component fails, the whole system fails). RAM assessments such as this serve to identify critical components which fail often, or whose failure has a high impact on mission success. It is these critical components which should have redundant capabilities. To decide *a priori* to have selected redundant components may result in unnecessary redundancy and added cost.

The assumption of exponentiality of component lifetimes which result in constant failure rates is mathematically convenient and appropriate due to the insufficient information about actual failure rates. In addition many components, especially electronic types, exhibit failure rates which are approximately constant. Many more components whose failure times do not follow

exponential distributions have failure rates that follow the famous bathtub-shaped curve. First, the failure rate declines because of the infant mortality period. Thereafter, the failure rate remains relatively constant over a long period of time (the useful lifetime of the component). Finally the component failure rate increases, and the component is said to be in the wear-out phase. Typically the component would be replaced prior to wearout to avoid frequent system failure. Embedded component diagnostics or prognostics capabilities help determine when wearout is occurring and predict the component end of life. Thus in long-term reliability engineering problems, little error should be incurred if high failure rates during infant mortality and wearout are ignored and the failure rate is assumed to be the average failure rate over the ordinary service life. Infant mortality and wear-out failures were ignored in this study. Considering the very conceptual nature of the design and other factors such as variation in equipment quality, environmental stress, and use, we believe that extreme precision in failure rate distribution and exact failure rate development is inappropriate.

The generic failure rates should be modified by an environmental factor to account for the operating environment of the FARV. The duty cycle factor should be applied to the time variable; however, since different components and subsystems have different duty factors, it was mathematically convenient (and equivalent) to apply the duty cycle factor to failure rates and perform all calculations in real calendar time.

The major uncertainties in the failure rate data are due to the preliminary nature of the component lists. In this phase of the project, the component lists are based on conceptual design ideas for the technology demonstrators. Therefore, the information from this study is most beneficial in examining the relative reliability of one subsystem or component to another. This permits identification and ranking of reliability critical items which can provide an impetus for design changes and improvements in reliability. As the FARV design matures, increasingly accurate information will be obtained from either vendors or testing programs. In addition, we assumed that (1) 130 storage positions would be available initially and that operation would continue with up to 10 failures, (2) the software failure rate was negligible, (3) welds and structural steel failures were negligible, and (4) failures due to human error were negligible.

4. RELIABILITY ASSESSMENT

4.1 FAILURE MODES AND EFFECTS ANALYSIS

The FMEA is performed to identify all significant component failure modes and the effects of failure on the operation of the system. It is an interactive process of a systematic nature, proceeding item by item through the systems, from lower levels through the higher levels of assembly to assess failure consequences. Failure modes are obtained from field data or hypothetical failure modes derived from design analyses, reliability prediction activities, and experience relative to the manner in which components might fail. The failure modes are analytically deduced for each component, and the effects are evaluated and noted, including the severity and expected frequency (or probability) of occurrence.

Prior to conducting the FMEA, a list of components for each subsystem had to be generated. This reliability assessment was unusual in that a substantial amount of the time was spent defining the systems to be analyzed. Due to the conceptual nature of the design, no engineering drawings existed for the systems. Two systems, the ammunition transfer arm and RATS, were based on the Future Armor Rearm System and the Light Armament Module respectively. There was substantial experience for these similar systems, but no conceptual drawings were available for the FARV resupply systems. At the start of the assessment, a variety of concepts were being evaluated for the Automatic Ammunition Processing System; Concept IV-B in the AIRRS Concept Selection Package was defined as the BTA for the processing system. Consequently, no component parts lists existed at the start of this RAM assessment for any of the subsystems examined in this study. A major accomplishment of this RAM assessment was developing the parts lists (see Appendix A), which were obtained during interviews with system designers. As the study progressed, conceptual drawings, such as those shown in Sect. 2., became available. These drawings greatly aided in understanding the components and the functioning of each subsystem.

Developing the FMEA was a joint effort linking design engineering and reliability engineering. The FMEA tables were completed based on team meetings with system designers and an interdisciplinary group of engineers. In the meetings, system designers provided detailed knowledge of the design of the subsystem, its function, and how it copes with component failure. The interviewing team, comprised of staff from many disciplines (e.g., mechanical, electrical, and nuclear engineering), asked pertinent questions of designers. RAM engineers provided the knowledge and expertise required to perform the RAM analysis and asked key "what if" questions, probing for failure modes and mechanisms. The results of these meetings provided a more thorough probing than could be done by either engineer alone plus a greater transfer of knowledge and perspective across the normal disciplinary boundaries. In concluding discussions, a consensus was reached and FMEA tables were completed. A complete listing of these tables is given in Appendix B.

Key results of the FMEA were recommendations for reliability improvements that arose from team meetings with design engineers. These recommendations are listed for each subsystem in the following subsections.

4.1.1 Ammunition Transfer Arm

1. Consider providing a breakaway connection between the FARV and the AFAS so that movement of either vehicle during transloading will not damage the ammunition transfer arm.
2. Consider incorporating a manual backup for transferring artillery rounds and retracting the arm (or make provisions for vehicle movement when the arm fails while extended).
3. Consider providing embedded prognostics for motors to enable a prediction of the time of associated component failure. This would prevent many modes of failure and increase system reliability.

4.1.2 Automated Ammunition Processing System

1. Consider designing a universal end effector to perform the two operations in station 1 so that one can provide backup for the other.
2. The RATS device is a nodal point through which all ammunition handling operations pass. Consider using a conveyor belt to move rounds between stations, thus relieving some of the operational responsibilities of RATS.
3. The lifting plug (eye bolt) drops to the floor of the FARV after it has been disconnected. Consider devising a mechanism to collect and dispose of these without human intervention.
4. The accuracy of the round-weighing device (one part in ten thousand) seems very tight. This is weighing to within 1/100 lb for a 100-lb round. Is this necessary? How can this accuracy be assured? Consider calibrating the weighing scale each time ammunition is processed.
5. Access to RATS and the processing area is needed both for maintenance and to allow room for a manual backup in the event of a system failure.
6. Consider providing embedded prognostics for motors to predict the time of associated component failure. This would prevent many modes of failure and increase system reliability.

4.1.3 Passive Storage System

For this study, we assumed that the storage cells had no sensors; all required sensors were to be located on the RATS device.

4.2 RELIABILITY BLOCK DIAGRAMS

The reliability block diagram for the FARV projectile supply equipment BTA is shown in Fig. 4. The diagram shows the phases of operation and the system or subsystems required for each phase. The subsystems and RATS operate in series; the storage has some redundancy. Series operations are expected at this conceptual phase. One of the benefits of performing an early RAM analysis is to identify critical systems and subsystems and to determine where redundancy is needed.

Fig. 4. Reliability block diagram for FARV projectile supply equipment.

Figure 4 also highlights the recurrent use of RATS, which serves as the interface between the upload, process, store, and rearm operations. The ammunition transfer arm also performs the dual functions of uploading and rearming. However, not all the arm subsystems are needed to perform the upload operation.

4.3 CALCULATIONS

The code RAMCAL1 was used to calculate subsystem MTTF, MTTR, expected number of failures per mission, and inherent availability. The calculations were based on the logic diagrams, mathematical models, failure rate data, and duty cycle factors. A detailed listing of calculation inputs and results are given in Appendix D.

4.3.1 Mission Profile

A simplified mission profile was provided by ARDEC. From this information, system duty factors were calculated for use in the reliability assessment. The mission length was defined to be 24 h (1 d). A 65-min time frame was given for uploading ammunition at the logistics resupply, and there are 2.2 uploads/d for a total of 143 min/d (2.38 h/d). Processing is assumed to be performed concurrently with uploading; thus, processing is also estimated to require 143 min/d. The time to arm the AFAS is 10 min/rearm, and there are 20.4 rearms/d, for a total of 204 min/d. The ammunition transfer arm is required for both uploading and AFAS arming, thus, its total operating time is 347 min/d (5.78 h/d). Likewise, RATS is operated during both uploading and rearming, so its total operating time is also 347 min/d. The passive storage system is used 24 h/d. Table 3 lists the daily operating time and the duty cycle factor for each system. The duty cycle factor represents the percentage of time in a 24-h period in which the system is anticipated to operate.

Table 3. System duty cycles

System	Operation (min/d)	Duty cycle factors
Ammunition transfer arm	347	0.241
Artillery processing	143	0.100
Passive storage	1440	1.000
Robotic ammunition transfer	347	0.241

4.3.2 Failure Rate Data

Generic failure rate data sources were used in this study, and a listing of these sources is given in the References section. The source of each component's failure rate is given in Appendix D. Whenever possible, the *Nonelectric Parts Reliability Data*, NPRD-91, was used for mechanical components. It is the primary reference for the RAM assessment of the RATS subsystem performed by ARDEC. ORNL and ARDEC made a considerable effort to use a common reliability data base to promote consistency in comparing the performance of various subsystems. The *IEEE Guide to the Collection and Presentation of Electrical, Electronic, Sensing*

Component, and Mechanical Equipment Reliability, ANSI/IEEE Std 500-1984, was the primary data base for electrical and electronic components. The *Offshore Reliability Data Handbook* was used for some special components (e.g., CPUs and I/O cards).

4.3.3 Reliability Predictions

Reliability prediction is the quantitative assessment of a system. In this study the prediction is obtained through a bottom-up approach: RAM is determined at the lowest level, and the analysis proceeds through intermediate levels until the total system is reviewed.

The estimates of the MTTF for the artillery processing system, the ammunition transfer arm, and the passive storage is based on analysis by ORNL (see Appendix C). The estimate for the robotic ammunition transfer system is based on analyses by ARDEC (see Sect. 2.1.2).

The results are summarized in Table 4. Of the four systems examined, the ammunition transfer arm had the highest expected number of failures and the passive storage system had the lowest expected number of failures. The expected number of failures for the projectile resupply system during a 24-h mission is 0.019. This translates to one failure per 52.6 missions.

Table 4. Summary of detailed RAM calculations

System	Applied failure rate (1E-6 h)	Expected number of failures in 24 h
Ammunition transfer arm	469.65	0.0113
Artillery processing	78.69	0.0019
Passive storage	12.56	0.0003
Robotic ammunition transfer	229.19	0.0055
Total	790.09	0.0190

4.3.4 Critical Items

Critical items are those items whose failure could significantly affect the ability of a component system to perform its function effectively. The critical items list identifies all components that perform critical functions, are reliability sensitive, have long procurement times and limited life, are high cost, etc. In this study, a reliability critical items list was developed based on the component and subsystem calculations given in Appendix D. This list ranks failure rates from highest to lowest values.

Tables 5, 6, and 7 show components with the ten highest failure rates for the ammunition transfer systems, the artillery processing system, and RATS respectively. These components contribute most to system unreliability. The primary contributors to unreliability for the artillery processing system are linear actuators, rotary actuators, and CPU boards, which contribute 25%, 15%, and 13% respectively to the total failure rate. The top contributors to failure rate for the ammunition transfer arm are electromechanical brakes, cameras, and linear actuators, which contribute 21%, 21%, and 18% respectively to the total failure rate.

In addition to ranking components from highest to lowest failure rate, high failure rate components are listed by group. Three equipment groups were defined for the artillery processing and ammunition transfer arm systems. The electromechanical group includes the actuators, drive assembly, motors, and electromechanical brakes. The electrical/electronic group includes the

electronics, electrical cables/connectors, sensors, switches, and cameras. The mechanical group includes gimbal rings, conveyors, seals, bearings, latches, and other mechanical components. Table 8 summarizes the failure rate and percent contribution for the artillery processing system and ammunition transfer arm for each of the three categories.

Table 5. Ranking of components with the ten highest failure rates in the ammunition transfer arm

Component	Failure rate 1E-6 (h)	Number of parts	Duty cycle	Applied failure rate 1E-6 (h)	Expected number of failures (1/24 h)
Brake (electrical/mechanical)	41.43	10	0.241	99.85	0.0024
Camera	135.46	3	0.241	97.94	0.0024
Linear actuator assembly	40.29	9	0.241	87.39	0.0021
Drive assembly	40.29	3	0.241	29.13	0.0007
Gas spring	12.48	6	0.241	18.04	0.0004
Switches (mechanical)	5.16	14	0.241	17.41	0.0004
Cable (electrical)	0.86	79	0.241	16.37	0.0004
Sensor (position)	2.83	24	0.241	16.37	0.0004
CPU control board	51.00	1	0.241	12.29	0.0003
Wheel/roller bearing	3.29	10	0.241	7.93	0.0002

Table 8 shows that for the artillery processing system, the electrical/electronic group contributes 51.78% and the electromechanical group contributes 45.74% of the failure rate for the system. The mechanical group contributes 2.48%. For the ammunition transfer arm, the electrical/electronic group contributes 40.9% and the electromechanical group contributes 47.74% of the failure rate for the system. The mechanical group contributes 11.36%.

4.4 POTENTIAL FOR RELIABILITY GROWTH

Reliability growth is the improvement in a reliability parameter (e.g., MTTR) over a period of time due to changes in the product design or manufacturing process. Initial equipment system prototypes have unforeseen reliability deficiencies. Developmental testing identifies design problems, allowing reliability improvements. Detailed calculations of reliability growth involve models which require experimental data as input (e.g., "An Improved Methodology for Reliability Growth Projections," Larry H. Crow, June 1992, Doc. No. AMSAA TR No. 357). The sponsors of the work reported in this document asked that the potential for reliability growth be addressed, even though the designs being assessed are at a conceptual phase and no hardware for testing exists.

Reliability can be improved by using (1) embedded prognostics/diagnostics to detect and remove degraded components (between missions) prior to failing, (2) high-reliability

components, and (3) redundancy (primarily limited to controls for the ammunition transfer arm, artillery processing, and RATS).

Table 6. Ranking of components with the ten highest failure rates in the artillery processing system

Component	Failure rate 1E-6 (h)	Number of parts	Duty cycle	Applied failure rate 1E-6 (h)	Expected number of failures (1/24 h)
Linear actuator assembly	40.29	5	0.1	20.15	0.0005
Rotary actuator assembly	29.55	4	0.1	11.82	0.0003
CPU control board	51.00	2	0.1	10.20	0.0002
Digital output channel cards	8.20	6	0.1	4.92	0.0001
Switches (mechanical)	5.16	9	0.1	4.64	0.0001
Printer assembly (ink jet)	41.34	1	0.1	4.13	0.0001
Drive assembly	40.29	1	0.1	4.03	0.0001
Cable (electrical)	0.86	43	0.1	3.70	0.0001
Sensor (position)	2.83	7	0.1	1.98	0.0000
d/a converter	8.20	2	0.1	1.64	0.0000

Table 7. Ranking of components with the ten highest failure rates in RATS

Component	Failure rate 1E-6 (h)	Number of parts	Duty cycle	Applied failure rate 1E-6 (h)	Expected number of failures (1/24 h)
Brake (electrical/mechanical)	41.43	4	0.241	39.94	0.0010
Coupling (gear shaft)	27.43	4	0.241	26.44	0.0006
Sensor (solid state)	13.16	8	0.241	25.37	0.0006
Transducer (ultrasonic)	80.14	1	0.241	19.31	0.0005
Bearing (linear ball)	3.98	16	0.241	15.33	0.0004
Cables (electrical)	0.34	153	0.241	12.54	0.0003
CPU control boards	51.00	1	0.241	12.29	0.0003
Connectors	0.15	306	0.241	11.06	0.0003
Switch (limit)	39.89	1	0.241	9.61	0.0002
Resolver (synchro)	9.71	4	0.241	9.36	0.0002

Table 8. Contribution to unreliability by equipment type

Component group type	Artillery processing system		Ammunition transfer arm		Robotic ammunition transfer	
	Applied failure rate contribution	Percent contribution to failure rate	Applied failure rate contribution	Percent contribution to failure rate	Applied failure rate contribution	Percent contribution to failure rate
Electromechanical	35.996	45.74	224.198	47.74	83.64	36.49
Electrical/electronic	40.748	51.78	192.072	40.90	115.64	50.46
Mechanical	1.946	2.48	53.38	11.36	29.91	13.05
Total	78.69	100.0	469.65	100.0	229.19	100.0

Prognostics can improve the reliability and availability characteristics of the resupply systems by detecting components that are in a degraded state prior to failing, thus allowing the replacement of the degraded components between missions. Prognostics/diagnostics techniques have the greatest potential for application to electromechanical components such as linear actuators, rotary actuators, and the conveyor drive components. Devices with electrical motors driving a mechanical drive train are excellent candidates for prognostics because as the mechanical drive components degrade (bearings, gears, etc.), different power levels are required to drive the components. There is the potential for built-in prognostics to detect the majority of electromechanical defects at a degraded state prior to failure. In this analysis, we estimate that at least 50% of the electromechanical defects in the ammunition transfer arm, artillery processing, and RATS can be detected with embedded prognostics. With prognostics there is a knowledge base (i.e., learning process) which will increase with experience to allow the user to detect and correct an ever greater percentage of the problems. The prognostics community has enjoyed a great deal of success in the aircraft industry, where safety and availability are a high priority. The nuclear industry is incorporating this technology to obtain licensing approval to operate aged equipment (i.e., plant life extension).

Table 9 summarizes the potential benefit if 50% of the electromechanical components are detected at a degraded state and replaced between missions. Reducing the expected failure rate of the four systems from 790.09 to 618.17 failures per million hours is a significant improvement. The MTTF increases from 1265 to 1617 h for a 352-h (27%) improvement. Applying prognostics to key electromechanical components can improve the availability of the system.

Table 9. Potential benefit of prognostics

System	Expected applied failure rate without prognostics 1E-6 (h)	Expected applied failure rate with prognostics 1E-6 (h)	Improvement in applied failure rate 1E-6 (h)
Ammunition transfer arm	469.65	357.55	112.14
Artillery processing	78.69	60.69	18.0
Passive storage	12.56	12.56	0
Robotic ammunition transfer	229.19	187.37	41.82
Total	790.09	618.17	171.96

The use of high-reliability components and the selected use of redundancy (e.g., redundant CPU control for the ammunition transfer arm) could lower the failure rates for the system significantly. There is potential to reduce the failure rates of the electronic/electrical equipment by at least 25%. There is also potential for the combined effects of (1) selected use of prognostics on the electromechanical hardware, (2) use of high-reliability components, and (3) use of redundancy (as needed) for CPU control hardware to increase the MTTF for the four systems from the 1260 h to the 2000- to 3000-h range. In order to achieve this MTTF, a well structured reliability improvement program will be required. Table 10 describes the potential reliability improvement by system, and Table 11 gives the improvement in terms of expected number of failures per thousand missions.

Table 10. Potential reduced failure rates with a reliability improvement program

System	Expected applied failure rate with prognostics and high-reliability parts [1E-6 (h)]
Ammunition transfer arm	309.532
Artillery processing	50.503
Passive storage	12.56
Robotic ammunition transfer	158.46
Total	531.055

Table 11. Potential reduced expected number of failures with a reliability improvement program

Case	Expected number of failures per 1000 missions
Base case	19.0
With prognostics	14.8
With prognostics and high-reliability parts	12.7

5. MAINTAINABILITY ASSESSMENT

Maintainability analysis provides the design and operational bases for ensuring that all required maintenance actions are complete and efficient and that they do not degrade the reliability and availability characteristics of the system. From analysis, (1) maintenance information is developed for identifying limited life items whose characteristics are incompatible with design life requirements, (2) establishing spares for provisioning, (3) schedules and procedures are established to accomplish the preventive maintenance tasks at regular intervals, and (4) maximum times are established for completing maintenance actions. Maintenance considerations allow (1) simple item repair or replacement, (2) on-line diagnostics and repair, whenever possible, and (3) actions to be performed within existing capabilities of personnel and equipment.

There are a number of elements of downtime associated with every failure. These elements must be estimated to develop a total downtime for each failure. These elements are (1) fault detection time, (2) fault diagnosis, (3) preparation time (including acquiring a replacement part), (4) the actual correction time (repair or replacement of the failed part), and (5) verification that the fault was corrected and returned to design criteria conditions. Often only the correction time is estimated, but the other elements of downtime may constitute the majority of the downtime. A fault may exist for some time before it is detected. For example, the ammunition round weighing scale in station 2 of the FARV may lose its calibration, and it may be some time before the fault is detected. Often several parts are replaced before the failure is properly diagnosed. Preparation time includes acquiring a spare part but may also include any special training such as operation manual review. Correction time is usually simply the removal of the failed component and installation of a replacement part. After the repair is made, the component must be tested to ensure that the system is operating within design limits.

This study assumes zero detection time. That is, the time interval between a failure occurring and the realization that a failure has occurred resulting in mission abort is assumed zero. This study assumes a short diagnosis time. However, we believe that substantial time might be spent troubleshooting failures (i.e., diagnosing the root cause of component failure). An embedded diagnostics capability would enable a quick identification of many causes of failure.

The preparation time component of total downtime is also assumed to be short. It is too early in the conceptual design to reasonably estimate the logistics requirements (e.g., needed spare parts and their storage location). Like diagnosis time, preparation time (e.g., acquiring a replacement part) could be significant.

This study estimates only the active correction, or replacement time. Replacement time, not repair time, is estimated. This assumes that the FARV makes extensive use of modular components which can be easily removed as a unit. One concern in estimating replacement time is defining the accessibility of the maintenance worker to the spare part. Many components are "buried" deep inside the vehicle. A failed component may be located behind other components, all of which may have to be removed to obtain access to the failed part. It is too early in the FARV design to have a layout, or footprint, of equipment location. Accessibility to failed components always requires careful design. Therefore, we assume that the FARV is equipped with side and top hatches for easy access whenever needed. This study also assumes zero repair verification time.

6. AVAILABILITY

The availability of a system or equipment is the probability that it is operating satisfactorily at any point in time when used under stated conditions. Availability is a widely used term both in industry and in the military. Availability may be stated in terms applicable to specifications (design) or operational use. Availability is defined in Sect. 3 as the operating time (MTTF) divided by operating time plus active repair time (MTTR). This definition is for inherent availability because it is for active downtime, not total downtime. Total downtime would include time spent in acquiring spare parts, scheduled maintenance, etc.

Inherent availability, A_i , is one of the parameters calculated by the RAMCAL1 computer code. The unavailability of the system and the calculated expected number of failures per mission are summarized in Table 12. The total availability of the four systems is 0.9991.

Table 12. Summary of inherent availabilities

System	Unavailability (1E-6)	Expected number of failures per 24-h mission
Ammunition transfer arm	605.28	0.0113
Automatic artillery processing	79.18	0.0019
Passive storage	12.76	0.0003
Robotic ammunition transfer	239.91	0.0055
Total	937.13	0.0190

7. PARAMETERS FOR SCORING CRITERIA

The basis for the reliability and maintainability scoring process is failure definition and scoring criteria. These definitions and criteria are used during reliability and maintainability testing to determine the classification and chargeable element of incidents. Gathering this information during testing enables a data base to be generated which can be used to project operational reliability and maintainability values, to estimate operational effectiveness, and to determine contractual compliance, etc. During testing, incidents are identified that impact the minimum operational tasks that the FARV must be capable of performing to accomplish its mission profile. The underlying cause of each incident is assigned to one of several sources: hardware, software, operator (crew), manuals, support equipment, accident, etc.

In this analytical work, the severity and frequency of incidents charged to hardware failure are estimated. The impact of failure of each component in each system examined was evaluated. The question was asked: Would failure of the component cause the system to be unable to perform any of its mission essential functions at the minimum accepted level? If the answer was yes, the incident was scored as a system abort (SA), essential function failure (EFF), essential unscheduled maintenance demand (EUMD), or nonessential unscheduled maintenance demand (NUMD). These parameters are defined as follows:

NUMD failure	Incident which requires any unscheduled maintenance that could have been deferred indefinitely or until the next scheduled maintenance service without impacting the system's essential functions, causing danger to the crew, or causing essential potential damage to the system. When an NUMD occurs, the system can still perform all essential functions.
EUMD failure	System is still capable of transferring munitions at a high rate of speed; however, if maintenance were deferred to the next scheduled maintenance demand, it might evolve into an EFF.
EFF	Failure which would cause the system to operate in a significantly degraded state (low rate of speed) such that corrective action would be implemented at first opportunity.
SA failure	The system cannot transfer munitions.

NUMD failures were not evaluated in this initial RAM evaluation because of their low consequence characteristics.

The frequency of incidents is derived from component failure rates. The modes of component failure were established, and the severity (i.e., EUMD, EFF, or SA) of each failure mode was evaluated. Failure mode ratios, which sum to a value of one for each component, were generated. Component incremental frequencies of EUMD, EFF, and SA were then calculated by multiplying the failure mode ratios by the total component failure rate. Total EUMD frequency is defined as the sum of incremental EUMD, EFF, and SA frequencies. Total EFF frequency is defined as the sum of incremental EFF and SA frequencies. Since all components are in series in

this initial RAM assessment, component frequencies are summed to give system EUMD, EFF, and SA values. The mean time between EUMD, EFF, and SA is the reciprocal of the total frequencies (i.e., failure rates) per equation (see Sect. 3). The work sheet for these calculations is given in Appendix D. Final calculated parameter values are given in Table 2 in the Executive Summary.

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APPENDIX A
SUBSYSTEM COMPONENT LISTS

AMMUNITION TRANSFER ARM

AUTOMATIC AMMUNITION PROCESSING SYSTEM

APPENDIX B

FMEA

The criticality column contains "tbd," which indicates that a criticality value was not calculated.

Block number	Design element	Failure mode/cause	Failure effects	Method of detection	Compensating provisions	Criticality	Remarks
1.4	Ammunition transfer arm						
1.4.1	Retraction/extension subgroup						
1.4.1.1	Linear actuator	Open motor winding due to a short circuit condition or due to a latent manufacturing defect. Bearing wear and binding due to use.	The motor would be inoperable. The FARS's ammo transfer arm would not be able to extend to or retract from AFAS.	There would be no motor current.	None	tbd.	None.
	Linear actuator	Wear of the mechanical components due to usage and aging. Gear wear in the gearbox, wear of screw system components, and bearing wear are the most likely candidates for wear. Fasteners could loosen due to vibration.	Mechanical binding could prevent the arm from extending or retracting.	Motor current increase.	None.	tbd.	None.
1.4.1.2	Motor brake	Premature braking due to open solenoid coil, loss of power, or loose part. Failure to break due to spring failure.	The motor would be inoperable. The arm would not be able to extend or retract.	Motor current.	None.	tbd.	None.

Block number	Design element	Failure mode/cause	Failure effects	Method of detection	Compensating provisions	Criticality	Remarks
1.4.1.3	Wheel/lap-erected roller bearing	Failure to rotate freely due to roller bearing wear or failure and bent or deformed shaft.	Wear or deformation could introduce a slight vibration into the arm and shorten the arm's life. Failure of bearing or shaft could prevent the arm from retracting or extending.	Possible higher motor current.	None.	ibid.	None
1.4.1.4	Switch, over-travel	Loss of output or erroneous output due to failed internal part or out adjustment arm.	Failure of the over-travel switch could result in the arm damaging itself due to over-travel. The arm would not be able to extend or retract.	Unknown.	None.	ibid.	None.
1.4.1.5	Sensor, position	Failure of internal part due to aging or the service environment.	Loss of the position signal would prevent the arm from extending or retracting.	Position signal to CPU.	None.	ibid.	None.
1.4.1.6	Door gasket.	Failure to provide an airtight seal for the vehicle door.	Crew could be exposed to NBC agents.	Unknown.	None.	ibid.	Action required.
1.4.1.7	Cable, electrical.	An open conductor or short in the cable due to mishandling or bending.	Loss of power to motor resulting in the arm being out of service.	Motor current.	None.	ibid.	None.
1.4.1.8	Connector, electrical.	Faulty connector due to mishandling, vibration or material defect.	Loss of power to motor resulting in the arm being out of service.	Motor current.	None.	ibid.	None.

Block number	Design element	Failure mode/cause	Failure effects	Method of detection	Compensating provisions	Criticality	Remarks
1.4.2	Shoulder subgroup						
1.4.2.1	Linear actuator	Open motor winding due to a short circuit condition or due to a latent manufacturing defect. Bearing wear and binding due to use.	The motor would be inoperable. This joint would be inoperable resulting in loss of one degree of freedom (dof). The effect of losing one dof on the FARS vehicle ranges from degraded operation of the arm to aborted mission.	There would be no motor current.	None	tbd.	None.
	Linear actuator	Wear of the mechanical components due to usage and aging. Gear wear in the gearbox, wear of screw system components, and bearing wear are the most likely candidates for wear. Fasteners could loosen due to vibration.	Mechanical binding could prevent the arm from moving resulting in the loss of one dof.	Motor current increase.	None.	tbd.	None.
1.4.2.2	Motor brake	Premature braking due to open solenoid coil, loss of power, or loose part. Failure to break due to spring failure.	The motor would be inoperable. This joint would be inoperable resulting in loss of one degree of freedom (dof). The effect of losing one dof is assumed to prevent docking to AFAS.	Motor current.	None.	tbd.	None.

Project: FARV
System: Ammunition transfer arm

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Block number	Design element	Failure mode/cause	Failure effects	Method of detection	Compensating provisions	Criticality	Remarks
1.4.2.3	Gimbal/ring	Wear or failure of the mechanical component due to usage, lack of lubrication, or defective materials.	The effect on the arm ranges from slower movement of the joint to loss of movement. The effect on the FARS vehicle ranges from degraded operation to loss of ability to transfer rounds.	Motor current.	None.	tbd.	None.
1.4.2.3.1	Shaft	Deformation due to usage or abuse, material defects, or aging.	The effect on the arm ranges from slower movement of the joint to loss of movement. The effect on the FARS vehicle ranges from degraded operation to loss of ability to transfer rounds.	Motor current.	None.	tbd.	None.
1.4.2.3.2	Bearing, spherical	Wear or failure due to usage, loss of lubricant or service environment (i.e. particulates in lubricant).	The effect on the arm ranges from slower movement of the joint to loss of movement. The effect on the FARS vehicle ranges from degraded operation to loss of ability to transfer rounds.	Motor current.	None.	tbd.	
1.4.2.4	Gas spring	Seal failure results in loss of gas. Spring fails results in loss of counter balancing force.	The gas spring would be degraded or lose ability to provide counter balancing force.	Motor current.	Other 3 gas springs would compensate for the loss of one.	tbd.	None.
1.4.2.5	Seal, rubber boot	Loss of rubber boot integrity due to aging, the service environment or service abuse.	The crew could be exposed to NBC agents.	Unknown.	None.	tbd.	Action required.

Block number	Design element	Failure mode/cause	Failure effects	Method of detection	Compensating provisions	Criticality	Remarks
1.4.2.6	Switch, over-travel	Loss of output or erroneous output due to failed internal part or out adjustment arm.	Failure of the over-travel switch could result in the arm damaging itself due to over-travel. The arm would lose the motion of this joint.	Unknown.	None.	tbd.	None.
1.4.2.7	Sensor, position	Failure of internal part due to aging or the service environment.	Loss of the position signal would result in loss of joint movement. The effect on the FARS vehicle is loss of ability to dock to AFAS.	Position signal to CPU.	None.	tbd.	None.
1.4.2.8	Cable, electrical.	An open conductor or short in the cable due to mishandling or bending.	Loss of power to motor resulting in the arm being out of service.	Motor current.	None.	tbd.	None.
1.4.2.9	Connector, electrical	Faulty connector due to handling, vibration, or material defect.	Loss of power to motor resulting in arm being out of service.	Motor current.	None.	tbd.	None.
1.4.3	Elbow subgroup						
1.4.3.1	Linear actuator	Open motor winding due to a short circuit condition or due to a latent manufacturing defect. Bearing wear and binding due to use.	The motor would be inoperable. The FARS's arm would not be able to move this joint.	There would be no motor current.	None.	tbd.	None.

Block number	Design element	Failure mode/cause	Failure effects	Method of detection	Compensating provisions	Criticality	Remarks
	Linear actuator	Wear of the mechanical components due to usage and aging. Gear wear in the gearbox, wear of screw system components, and bearing wear are the most likely candidates for wear. Fasteners could loosen due to vibration.	Mechanical binding could prevent the arm from moving this joint.	Motor current increase.	None.	tbd.	None.
1.4.3.2	Motor brake	Premature braking due to open solenoid coil, loss of power, or loose part. Failure to break due to spring failure.	The motor would be inoperable. The arm would not be able to move this joint.	Motor current.	None.	tbd.	None.
1.4.3.3	Gimbal/ring	Wear or fracture of the mechanical component due to usage, the service environment or defective materials.	The effect on the arm ranges from slower movement of the joint to loss of movement. The effect on the FARS vehicle ranges from degraded operation to loss of ability to transfer rounds.	Motor current.	None.	tbd.	None.
1.4.3.3.1	Shaft	Deformation due to usage or abuse, material defects, or aging.	The effect on the arm ranges from slower movement of the joint to loss of movement. The effect on the FARS vehicle ranges from degraded operation to loss of ability to transfer rounds.	Motor current.	None.	tbd.	None.

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Block number	Design element	Failure mode/cause	Failure effects	Method of detection	Compensating provisions	Criticality	Remarks
1.4.3.3.2	Bearing, spherical	Wear or failure due to usage, loss of lubricant or service environment (i.e. particulates in lubricant).	The effect on the arm ranges from slower movement of the joint to loss of movement. The effect on the FARS vehicle ranges from degraded operation to loss of ability to transfer rounds.	Motor current.	None.	tbd.	
1.4.3.4	Gas spring	Seal failure results in loss of gas. Spring fails results in loss of counter balance force.	The gas spring would be degraded or lose ability to provide counter balancing force.	Motor current.	None.	tbd.	None.
1.4.3.5	Seal, rubber boot	Loss of rubber boot integrity due to aging, the service environment or service abuse.	The crew could be exposed to NBC agents.	Unknown.	None.	tbd.	Action required.
1.4.3.6	Switch, over-travel	Loss of output or erroneous output due to failed internal part or out adjustment arm.	Failure of the over-travel switch could result in the arm damaging itself due to over-travel. The arm would lose the motion of this joint.	Unknown.	None.	tbd.	None.
1.4.3.7	Sensor, position	Failure of internal part due to aging or the service environment.	Loss of the position signal would result in loss of joint movement. The effect on the FARS vehicle is loss of ability to dock to AFAS.	Position signal to CPU.	None.	tbd.	None.
1.4.3.8	Cable, electrical.	An open conductor or short in the cable due to mishandling or bending.	Loss of power to motor resulting in the arm being out of service.	Motor current.	None.		None

Block number	Design element	Failure mode/cause	Failure effects	Method of detection	Compensating provisions	Criticality	Remarks
1.4.3.9	Connector, electrical	Faulty connector due to handling, vibration, or material defect.	Loss of power to motor resulting in arm being out of service.	Motor current.	None.	tbd.	None.
1.4.4	Conveyor/delivery subgroup						
1.4.4.1	Drive assembly	Open motor winding due to a short circuit condition or due to a latent manufacturing defect. Bearing wear and binding due to use.	The motor would be inoperable. The FARS's conveyor delivery group would not be able to transfer rounds.	There would be no motor current.	None	tbd.	None.
	Drive assembly	Wear of the mechanical components due to usage and aging. Gear wear in the gearbox, wear of universal joints, and bearing wear are the most likely candidates for wear. Timing belts could break. Fasteners could loosen due to vibration.	Mechanical binding could prevent the conveyor from transferring rounds.	Motor current increase.	None.	tbd.	None.
1.4.4.2	Motor brake	Premature braking due to open solenoid coil, loss of power, or loose part. Failure to break due to spring failure.	The motor would be inoperable. The conveyor would not be operational.	Motor current.	None.	tbd.	None.

Block number	Design element	Failure mode/cause	Failure effects	Method of detection	Compensating provisions	Criticality	Remarks
1.4.4.3	Drive roller	Wear or fatigue due to use or material defects.	Degraded or loss of ability to operate the conveyor. Loss of ability to transfer rounds to the AFAS.	Position sensor or motor current.	None.	tbd.	None.
1.4.4.4	Toothed roller	Wear due to usage or fracture due to abuse, material defects, or aging.	The effect on the conveyor ranges from slower movement to loss of movement. The effect on the FARS vehicle ranges from degraded operation to loss of ability to transfer rounds.	Motor current.	None.	tbd.	None.
1.4.4.5	Sliding block	Wear due to usage or defective material.	Potential for conveyor belt not to be supported properly by sliding block. The effect on the FARS vehicle ranges from degraded operation to loss of ability to transfer rounds.	Unknown.	None.	tbd.	None.
1.4.4.6	Conveyor belt	Wear of the nylon surface due to usage. Failure of steel belt due to aging, manufacturing defect or handling abuse.	The effect on the FARS vehicle ranges from degraded operation to loss of ability to transfer rounds.	Unknown.	None.	tbd.	None.
1.4.4.7	Sensor, position	Failure of internal part due to aging or the service environment.	Loss of the position signal would result in loss of conveyor movement. The effect on the FARS vehicle is loss of ability to transfer rounds.	Position signal to CPU.	None.	tbd.	None.

Block number	Design element	Failure mode/cause	Failure effects	Method of detection	Compensating provisions	Criticality	Remarks
1.4.4.8	Cable, electrical.	An open conductor or short in the cable due to mishandling or bending.	Loss of power to motor resulting in the conveyor being out of service.	Motor current.	None.		None
1.4.4.9	Connector, electrical	Faulty connector due to handling, vibration, or material defect.	Loss of power to motor resulting in conveyor being out of service.	Motor current.	None.	tbd.	None.
1.4.5	Wrist subgroup						
1.4.5.1	Linear actuator	Open motor winding due to a short circuit condition or due to a latent manufacturing defect. Bearing wear and binding due to use.	The motor would be inoperable. The FARS's wrist would not be able to extend to or retract from AFAS. The effect of losing one dof on the FARS vehicle ranges is assumed to be loss of ability to dock with the AFAS.	There would be no motor current.	None	tbd.	None.
	Linear actuator	Wear of the mechanical components due to usage and aging. Gear wear in the gearbox, wear of screw system components, and bearing wear are the most likely candidates for wear. Fasteners could loosen due to vibration.	Mechanical binding could prevent the wrist from extending or retracting. The effect of losing one dof on the FARS vehicle is loss of ability to dock with AFAS.	Motor current increase.	None.	tbd.	None.

Block number	Design element	Failure mode/cause	Failure effects	Method of detection	Compensating provisions	Criticality	Remarks
1.4.5.2	Rotary actuator	Open motor winding due to a short circuit condition or due to a latent manufacturing defect. Bearing wear and binding due to use.	The motor would be inoperable. The FARS's wrist would not be able to rotate. The effect of losing one dof on the FARS vehicle is loss of ability to dock with AFAS.	There would be no motor current.	None	tbd.	None.
	Rotary actuator	Wear of the mechanical components due to usage and aging. Gear wear in the gearbox, bearing and seal wear are the most likely candidates for wear. Fasteners could loosen due to vibration.	Mechanical binding could prevent the wrist from rotating. The effect of losing one dof on the FARS vehicle is loss of ability to dock with AFAS.	Motor current increase.	None.	tbd.	None.
1.4.5.3	Motor brake	Premature braking due to open solenoid coil, loss of power, or loose part. Failure to break due to spring failure.	The motor would be inoperable. The wrist would not be operational. The effect of losing one dof on the FARS vehicle is loss of ability to dock with AFAS.	Motor current.	None.	tbd.	None.
1.4.5.4	Bearing assembly	Wear or binding of bearings due to use, lack of lubrication and the service environment.	Loss or degraded ability for the wrist to rotate. The effect of losing one dof on the FARS vehicle is loss of ability to dock with AFAS.	Motor current.	None.	tbd.	None.

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Block number	Design element	Failure mode/cause	Failure effects	Method of detection	Compensating provisions	Criticality	Remarks
1.4.5.5	Switch, over-travel	Loss of output or erroneous output due to failed internal part or out adjustment arm.	Failure of the over-travel switch could result in the arm damaging itself due to over-travel. The arm would lose the motion of this joint. The effect of losing one dof on the FARS vehicle is loss of ability to dock with AFAS.	Unknown.	None.	tbd.	None.
1.4.5.6	Sensor, position	Failure of internal part due to aging or the service environment.	Loss of the position signal would result in loss of joint movement. The effect of losing one dof on the FARS vehicle is loss of ability to dock with AFAS.	Position signal to CPU.	None.	tbd.	None.
1.4.5.7	Seal, rubber boot	Loss of rubber boot integrity due to aging, the service environment or service abuse.	The crew could be exposed to NBC agents.	Unknown.	None.	tbd.	Action required.
1.4.5.8	Cable, electrical.	An open conductor or short in the cable due to mishandling or bending.	Loss of power to motor resulting in the arm being out of service.	Motor current.	None.		None
1.4.5.9	Connector, electrical	Faulty connector due to handling, vibration, or material defect.	Loss of power to motor resulting in arm being out of service.	Motor current.	None.	tbd.	None.
1.4.6	Extension conveyor subsystem						

Block number	Design element	Failure mode/cause	Failure effects	Method of detection	Compensating provisions	Criticality	Remarks
1.4.6.1	Drive assembly	Open motor winding due to a short circuit condition or due to a latent manufacturing defect. Bearing wear and binding due to use.	The motor would be inoperable. The FARV's conveyor delivery group would not be able to transfer rounds.	There would be no motor current.	None	tbd.	None.
	Drive assembly	Wear of the mechanical components due to usage and aging. Gear wear in the gearbox, wear of universal joints, and bearing wear are the most likely candidates for wear. Timing belts could break. Fasteners could loosen due to vibration.	Mechanical binding could prevent the conveyor from transferring rounds.	Motor current increase.	None.	tbd.	None.
1.4.6.2	Motor brake	Premature braking due to open solenoid coil, loss of power, or loose part. Failure to break due to spring failure.	The motor would be inoperable. The conveyor would not be operational.	Motor current.	None.	tbd.	None.
1.4.6.3	Drive roller	Wear or fatigue due to use or material defects.	Degraded or loss of ability to operate the conveyor. Loss of ability to transfer rounds to the AFAS.	Position sensor or motor current.	None.	tbd.	None.

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Block number	Design element	Failure mode/cause	Failure effects	Method of detection	Compensating provisions	Criticality	Remarks
1.4.6.4	Toothed roller	Wear due to usage or fracture due to abuse, material defects, or aging.	The effect on the conveyor ranges from slower movement to loss of movement. The effect on the FARS vehicle ranges from degraded operation to loss of ability to transfer rounds.	Motor current.	None.	tbd.	None.
1.4.6.5	Sliding block	Wear due to usage or defective material.	Potential for conveyor belt not to be supported properly by sliding block. The effect on the FARS vehicle ranges from degraded operation to loss of ability to transfer rounds.	Unknown.	None.	tbd.	None.
1.4.6.6	Side guide	Wear or binding of bearings due to use, lack of lubrication and the service environment.	Loss or degraded ability to guide round through the extension conveyor subsystem.	Motor current.	None.	tbd.	None.
1.4.6.7	Back-flexing chain.	Chain breaks due to aging effects, defective materials, or service abuse.	Loss of ability to move side guide and guide rounds.	Motor current.	None.	tbd.	None.
1.4.6.8	Take-up assembly	Failure of the spring due to aging, defective materials, or service abuse.	Loss of ability to take-up excess chain.	Unknown.	None.	tbd.	None.

Block number	Design element	Failure mode/cause	Failure effects	Method of detection	Compensating provisions	Criticality	Remarks
1.4.6.9	Conveyor belt	Wear of the nylon surface due to usage. Failure of steel belt due to aging, manufacturing defect or handling abuse.	The effect on the FARS vehicle ranges from degraded operation to loss of ability to transfer rounds.	Unknown.	None.	tbd.	None.
1.4.6.10	Sensor, position	Failure of internal part due to aging or the service environment.	Loss of the position signal would result in loss of joint movement. The effect on the FARS vehicle is loss of ability to dock with AFAS ranges from degraded operation to loss of ability to transfer rounds.	Position signal to CPU.	None.	tbd.	None.
1.4.6.11	Cable, electrical.	An open conductor or short in the cable due to mishandling or bending.	Loss of power to motor resulting in the conveyor being out of service.	Motor current.	None.	tbd.	None.
1.4.6.12	Connector, electrical	Faulty connector due to handling, vibration, or material defect.	Loss of power to motor resulting in conveyor being out of service.	Motor current.	None.	tbd.	None.
1.4.7	Docking port						
1.4.7.1	Latch motor	Open motor winding due to a short circuit condition or due to a latent manufacturing defect. Bearing wear and binding due to use.	The motor would be inoperable. Degraded or loss of ability to dock and undock with the AFAS. Degraded or loss of ability to transfer rounds.	There would be no motor current.	None.	tbd.	None.

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Block number	Design element	Failure mode/cause	Failure effects	Method of detection	Compensating provisions	Criticality	Remarks
1.4.7.2	Docking latch/cam	Wear, deformation, or fatigue due to usage, the service environment, or defective material.	Degraded or loss of ability to dock and undock with the AFAS. Degraded or loss of ability to transfer rounds.	Latching motor current.	None.		
1.4.7.3	Communications port	Failure of transfer information or faulty transfer due to component failure due to service environment or defective materials.	Failure to transfer information from the AFAS to the FARS. This could prevent the transfer of ammunition.	Unknown	None	tbd	None.
1.4.7.4	Camera	Loss of output or distorted output due to component failure.	Loss of output or degraded output would degrade or prevent docking.	Unknown	None	tbd	None
1.4.7.5	Linear actuator	Open motor winding due to a short circuit condition or due to a latent manufacturing defect. Bearing wear and binding due to use.	The motor would be inoperable. The FARS would not be able to open or close the docking door or position the camera.	There would be no motor current.	None	tbd.	None.

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Block number	Design element	Failure mode/cause	Failure effects	Method of detection	Compensating provisions	Criticality	Remarks
	Linear actuator	Wear of the mechanical components due to usage and aging. Gear wear in the gearbox, wear of screw system components, and bearing wear are the most likely candidates for wear. Fasteners could loosen due to vibration.	Mechanical binding could prevent the dock door from being opened or closed. This would prevent rounds from being transferred.	Motor current increase.	None.	tbd.	None.
1.4.7.6	Sensor, position	Failure of internal part due to aging or the service environment.	Loss of the position signal would result in loss of linear actuator movement. The effect on the FARS vehicle is to loss of ability to transfer rounds.	Position signal to CPU.	None.	tbd.	None.
1.4.7.7	Door gasket.	Failure to provide an air tight seal for the docking port door.	Crew could be exposed to NBC agents.	Unknown.	None.	tbd.	Action required.
1.4.7.8	Cable, electrical.	An open conductor or short in the cable due to mishandling or bending.	Loss of power to motor resulting in the arm being out of service.	Motor current.	None.	tbd.	None
1.4.7.9	Connector, electrical	Faulty connector due to handling, vibration, or material defect.	Loss of power to motor resulting in arm being out of service.	Motor current.	None.	tbd.	None.
1.4.8	Control subsystem						

Block number	Design element	Failure mode/cause	Failure effects	Method of detection	Compensating provisions	Criticality	Remarks
1.4.8.1	CPU control board	Circuit failure due to electrical and thermal stresses.	The effect on the FARS vehicle ranges from degraded operation to loss of ability to transfer rounds.	Central CPU.	None.	tbd.	None.
1.4.8.2	Digital input cards	Erroneous or failure to process input signal.	The effect on the FARS vehicle ranges from degraded operation to loss of ability to transfer rounds.	CPU.	None.	tbd.	None.
1.4.8.3	Digital output cards	Erroneous or failure to process output signal.	The effect on the FARS vehicle ranges from degraded operation to loss of ability to transfer rounds.	CPU.	None.	tbd.	None.
1.4.8.4	DVA converter	Erroneous or fails to convert DVA signal.	The effect on the FARS vehicle ranges from degraded operation to loss of ability to transfer rounds.	CPU	None.	tbd.	None.
1.4.8.5	A/D converter	Erroneous or fails to convert A/D signal.	The effect on the FARS vehicle ranges from degraded operation to loss of ability to transfer rounds.	CPU	None.	tbd.	None.
1.4.8.6	Motor amplifiers	Loss of output or out of specification output signal.	The effect on the FARS vehicle ranges from degraded operation to loss of ability to transfer rounds.	CPU.	None.	tbd.	None.

Block number	Design element	Failure mode/cause	Failure effects	Method of detection	Compensating provisions	Criticality	Remarks
1.4.8.7	DC/DC converter	Loss of output or out-of-spec output.	The effect on the FARS vehicle ranges from degraded operation to loss of ability to transfer rounds.	CPU.	None.	tbd.	None.
1.4.8.8	Regulator, 24 volt. supplies, single phase	Loss of output or out-of-spec output.	The effect on the FARS vehicle ranges from degraded operation to loss of ability to transfer rounds.	CPU.	None.	tbd.	None.
1.4.8.9	Camera	Loss of output or distorted output due to component failure.	Loss of output or degraded output would degrade or prevent docking.				
1.4.8.10	Encoder/Digital card	Erroneous or failure to process input signal.	Loss of ability to detect location of device being controlled. The effect on the FARS vehicle ranges from degraded operation to loss of ability to transfer rounds.	CPU.	None.	tbd.	None.
1.4.8.11	Monitor	Component failure result in loss of monitor.	Loss of output or degraded output would degrade or prevent docking.	Visual.	None.	tbd.	None.
1.4.8.12	Joystick	Component failure due to aging or service abuse.	Loss of ability to manually control FARV hardware.	Visual.	None.	tbd.	None.

Project: FARV
System: Artillery processing system

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Block number	Design element	Failure mode/cause	Failure effects	Method of detection	Compensating provisions	Criticality	Remarks
1.5	Artillery processing system						
1.5.1	Lifting eye removal station 1						
1.5.1.1	Rotary actuator	Open motor winding due to a short circuit condition or due to a latent manufacturing defect. Bearing wear and binding due to use.	The motor would be inoperable. The lift eye could not be removed. The station would not be able to process a round.	There would be no motor current.	None	tbd.	None.
	Rotary actuator	Wear of the mechanical components due to usage and aging. Gear wear in the gearbox, bearing and seal wear are the most likely candidates for wear. Fasteners could loosen due to vibration.	Mechanical binding could prevent the actuator from rotating. The effect of losing this dof is the loss of ability to remove the lifting eye and process a round.	Motor current increase.	None.	tbd.	None.
1.5.1.2	Linear actuator	Open motor winding due to a short circuit condition or due to a latent manufacturing defect. Bearing wear and binding due to use.	The motor would be inoperable. Station 1 would be inoperable due to the loss in ability to position a round. The artillery processing system would be inoperable.	There would be no motor current.	None	tbd.	None.

Block number	Design element	Failure mode/cause	Failure effects	Method of detection	Compensating provisions	Criticality	Remarks
	Linear actuator	Wear of the mechanical components due to usage and aging. Gear wear in the gearbox, wear of screw system components, and bearing wear are the most likely candidates for wear. Fasteners could loosen due to vibration.	Mechanical binding could prevent the linear actuator from moving resulting in the loss in ability to position a round. The artillery processing system would be inoperable.	Motor current increase.	None.	tbd.	None.
1.5.1.3	End effector, spring loaded	Wear of end effector slot due to usage or spring failure due usage.	The end effector would not be able to grip the lifting eye so the station would not be able to remove the lift eye or process a round.	Visual.	None.	tbd.	None.
1.5.1.4	Sensor, position	Failure of internal part due to aging or the service environment.	Loss of the position signal would result in loss of ability to locate round. The effect on the FARS vehicle is loss of process.	Position signal to CPU.	None.	tbd.	None.
1.5.1.5	Sensor, force	Failure of internal part due to aging or the service environment.	Loss of the force signal would result in loss of ability to detect force being exerted to remove lifting eye. The effect on the FARS vehicle is loss of process.	Force sensor signal to CPU.	None.	tbd.	None.

Block number	Design element	Failure mode/cause	Failure effects	Method of detection	Compensating provisions	Criticality	Remarks
15.1.6	Mechanical switch (over-travel)	Loss of output or erroneous output due to failed internal part or out adjustment arm.	Failure of the over-travel switch could result in station one damaging itself due to over-travel. The effect on the FARV vehicle is loss of process.	Unknown.	None.	ibid.	None.
15.1.7	Cable, electrical.	An open conductor or short in the cable due to mishandling or bending.	Loss of power to motor resulting in station one being out of service.	Motor current.	None.	ibid.	None.
15.1.8	Connector, electrical.	Faulty connector due to handling, vibration, or material defect.	Loss of power to motor resulting in station one being out of service.	Motor current.	None.	ibid.	None.
15.2	Fuzing station one						
15.2.1	Rotary actuator	Open motor winding due to a short circuit condition or due to a latent manufacturing defect. Bearing wear and binding due to use.	The motor would be inoperable. The fuse could not be installed due to inability to rotate. The station would not be able to process a round.	There would be no motor current.	None	ibid.	None.
	Rotary actuator	Wear of the mechanical components due to usage and aging. Gear wear in the gearbox, bearing and seal wear are the most likely candidates for wear. Fasteners could loosen due to vibration.	Mechanical binding could prevent the actuator from rotating. The effect of losing this dot is the loss of ability to install the fuse and process a round.	Motor current increase.	None.	ibid.	None.

Block number	Design element	Failure mode/cause	Failure effects	Method of detection	Compensating provisions	Criticality	Remarks
1.5.2.2	Linear actuator	Open motor winding due to a short circuit condition or due to a latent manufacturing defect. Bearing wear and binding due to use.	The motor would be inoperable. Station 1 would be inoperable due to the loss in ability to position a round. The artillery processing system would be inoperable.	There would be no motor current.	None	tbd.	None.
	Linear actuator	Wear of the mechanical components due to usage and aging. Gear wear in the gearbox, wear of screw system components, and bearing wear are the most likely candidates for wear. Fasteners could loosen due to vibration.	Mechanical binding could prevent the linear actuator from moving resulting in the loss in ability to position a round. The artillery processing system would be inoperable.	Motor current increase.	None.	tbd.	None.
1.5.2.3	End effector, spring loaded	Wear of end effector due to usage or spring failure due usage.	The end effector would not be able to grip the fuze so the station would not be able to install the fuze or process a round.	Visual.	None.	tbd.	None.
1.5.2.4	Gimbal/ring	Wear or failure of the mechanical component due to usage, lack of lubrication, or defective materials.	The effect on station one ranges from slower movement of the joint to loss of movement. The effect on the FARS vehicle ranges from degraded operation to loss of ability to process rounds.	Motor current.	None.	tbd.	None.

Block number	Design element	Failure mode/cause	Failure effects	Method of detection	Compensating provisions	Criticality	Remarks
1.5.2.5	Sensor, position	Failure of internal part due to aging or the service environment.	Loss of the position signal would result in loss of ability to locate round (i.e. different lengths). The effect on the FARS vehicle is loss of processing.	Position signal to CPU.	None.	tbd.	None.
1.5.2.6	Sensor, torque	Failure of internal part due to aging or the service environment.	Loss of the torque signal would result in loss of ability to detect force being exerted to install a fuze. The effect on the FARS vehicle is loss of processing.	Torque sensor signal to CPU.	None.	tbd.	None.
1.5.2.7	Mechanical switch (over-travel)	Loss of output or erroneous output due to failed internal part or out adjustment arm.	Failure of the over-travel switch could result in station one damaging itself due to over-travel. The effect on the FARS vehicle is loss of process.	Unknown.	None.	tbd.	None.
1.5.2.8	Cable, electrical.	An open conductor or short in the cable due to mishandling or bending.	Loss of power to motor resulting in station one being out of service.	Motor current.	None.	tbd.	None.
1.5.2.9	Connector, electrical	Faulty connector due to handling, vibration, or material defect.	Loss of power to motor resulting in station one being out of service.	Motor current.	None.	tbd.	None.
1.5.3	Fuze storage						

Block number	Design element	Failure mode/cause	Failure effects	Method of detection	Compensating provisions	Criticality	Remarks
1.5.3.1	Drive assembly	Open motor winding due to a short circuit condition or due to a latent manufacturing defect. Bearing wear and binding due to use.	The motor would be inoperable. The FARS's fuze storage conveyor would not be able to transfer fuzes.	There would be no motor current.	None	tbd.	None.
	Drive assembly	Wear of the mechanical components due to usage and aging. Gear wear in the gearbox, wear of universal joints, and bearing wear are the most likely candidates for wear. Timing belts could break. Fasteners could loosen due to vibration.	Mechanical binding could prevent the conveyor from transferring fuzes.	Motor current increase.	None.	tbd.	None.
1.5.3.2	Sensor, position	Failure of internal part due to aging or the service environment.	Loss of the position signal would result in loss of ability to locate fuzes (i.e. different lengths). The effect on the FARS vehicle is loss of processing.	Position signal to CPU.	None.	tbd.	None.
1.5.3.3	Cable, electrical.	An open conductor or short in the cable due to mishandling or bending.	Loss of power to motor resulting in station one fuze storage being out of service.	Motor current.	None.	tbd.	None.
1.5.3.4	Connector, electrical	Faulty connector due to handling, vibration, or material defect.	Loss of power to motor resulting in station one fuze storage being out of service.	Motor current.	None.	tbd.	None.

Block number	Design element	Failure mode/cause	Failure effects	Method of detection	Compensating provisions	Criticality	Remarks
1.5.4	Controls-station one						
1.5.4.1	CPU control board	Circuit failure due to electrical and thermal stresses.	The effect on the FARS vehicle ranges from degraded operation to loss of ability to process rounds.	Central CPU.	None.	tbd.	None.
1.5.4.2	Digital input cards	Erroneous or failure to process input signal.	The effect on the FARS vehicle ranges from degraded operation to loss of ability to process rounds.	CPU.	None.	tbd.	None.
1.5.4.3	Digital output cards	Erroneous or failure to process output signal.	The effect on the FARS vehicle ranges from degraded operation to loss of ability to process rounds.	CPU.	None.	tbd.	None.
1.5.4.4	D/A converter	Erroneous or fails to converter D/A signal.	The effect on the FARS vehicle ranges from degraded operation to loss of ability to process rounds.	CPU	None.	tbd.	None.
1.5.4.5	A/D converter	Erroneous or fails to converter A/D signal.	The effect on the FARS vehicle ranges from degraded operation to loss of ability to process rounds.	CPU	None.	tbd.	None.
1.5.4.6	Motor amplifiers	Loss of output or out of specification output signal.	The effect on the FARS vehicle ranges from degraded operation to loss of ability to process rounds.	CPU.	None.	tbd.	None.

Block number	Design element	Failure mode/cause	Failure effects	Method of detection	Compensating provisions	Criticality	Remarks
1.5.4.7	DCDC converter	Loss of output or out-of-spec output.	The effect on the FARS vehicle ranges from degraded operation to loss of ability to process rounds.	CPU.	None.	tbd.	None.
1.5.4.8	Regulator, 24 volt. supplies, single phase	Loss of output or out-of-spec output.	The effect on the FARS vehicle ranges from degraded operation to loss of ability to process rounds.	CPU.	None.	tbd.	None.
1.5.4.9	Encoder/Digital card	Erroneous or failure to process input signal.	Loss of ability to detect location of device being controlled. The effect on the FARS vehicle ranges from degraded operation to loss of ability to process rounds.	CPU.	None.	tbd.	None.
1.5.5	Weighing subsystem-station two						
1.5.5.1	Electrical scale assembly.	Loss of output or out-of-spec output.	The effect on the FARS vehicle ranges from degraded operation to loss of ability to process rounds.	CPU.	None.	tbd.	None.

Block number	Design element	Failure mode/cause	Failure effects	Method of detection	Compensating provisions	Criticality	Remarks
1.5.5.2	Linear actuator	Open motor winding due to a short circuit condition or due to a latent manufacturing defect. Bearing wear and binding due to use.	The motor would be inoperable. Station 1 would be inoperable due to the loss in ability to weigh a round. The artillery processing system would be inoperable.	There would be no motor current.	None	td.	None.
	Linear actuator	Wear of the mechanical components due to usage and aging. Gear wear in the gearbox, wear of screw system components, and bearing wear are the most likely candidates for wear. Fasteners could loosen due to vibration.	Mechanical binding could prevent the linear actuator from moving resulting in the loss in ability to position a round. The artillery processing system would be inoperable.	Motor current increase.	None.	td.	None.
1.5.5.3	Level meter assembly	Loss of output or erroneous output	The effect on the FARS vehicle ranges from degraded operation to loss of ability to process rounds.	Unknown.	None.	td.	None.
1.5.5.4	Sensor, position	Failure of internal part due to aging or the service environment.	Loss of the position signal would result in loss of ability to locate rounds. The effect on the FARS vehicle is loss of weighing.	Position signal to CPU.	None.	td.	None.

Block number	Design element	Failure mode/cause	Failure effects	Method of detection	Compensating provisions	Criticality	Remarks
1.5.5.5	Mechanical switch (over-travel)	Loss of output or erroneous output due to failed internal part or out adjustment arm.	Failure of the over-travel switch could result in weighing station actuator damaging itself due to over-travel. The effect on the FARS vehicle is loss of process.	Unknown.	None.	tbd.	None.
1.5.5.6	Cable, electrical.	An open conductor or short in the cable due to mishandling or bending.	Loss of power to motor resulting in weighing station being out of service.	Motor current.	None.	tbd.	None
1.5.5.7	Connector, electrical	Faulty connector due to handling, vibration, or material defect.	Loss of power to motor resulting in the weighing station being out of service.	Motor current.	None.	tbd.	None.
1.5.6	Marking subsystem						
1.5.6.1	Printer assembly, inkjet	Loss of ability to mark due to printer failure (i.e. head) due to use or service abuse or poor quality marking.	Loss of ability to mark and process rounds.	Unknown.	None.	tbd.	None.
	Printer assembly, inkjet	Round mark at wrong location due to being mispositioned or mismarked due to human error (i.e. data entry error).	Loss or degraded ability to process rounds.	Unknown.	None.	tbd.	None.

Block number	Design element	Failure mode/cause	Failure effects	Method of detection	Compensating provisions	Criticality	Remarks
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1.5.6.2	Linear actuator	Open motor winding due to a short circuit condition or due to a latent manufacturing defect. Bearing wear and binding due to use.	The motor would be inoperable. Station two would be inoperative due to the loss in ability to lift a round for marking. The artillery processing system would be inoperable.	There would be no motor current.	None	ibid.	None.
	Linear actuator	Wear of the mechanical components due to usage and aging. Gear wear in the gearbox, wear of screw system components, and bearing wear are the most likely candidates for wear. Fasteners could loosen due to vibration.	Mechanical binding could prevent the linear actuator from moving resulting in the loss in ability to position a round for marking. The artillery processing system would be inoperable.	Motor current increase.	None.	ibid.	None.
1.5.6.3	Rotary actuator	Open motor winding due to a short circuit condition or due to a latent manufacturing defect. Bearing wear and binding due to use.	The motor would be inoperable. Loss of ability to rotate a round for marking. The station would not be able to process a round.	There would be no motor current.	None	ibid.	None.

Block number	Design element	Failure mode/cause	Failure effects	Method of detection	Compensating provisions	Criticality	Remarks
1.5.6.4	Rotary actuator	Wear of the mechanical components due to usage and aging. Gear wear in the gearbox, bearing and seal wear are the most likely candidates for wear. Fasteners could loosen due to vibration.	Mechanical binding could prevent the actuator from rotating. The effect of losing this dot is the loss of ability to mark a round (i.e. rotation) and process a round.	Motor current increase.	None.	ibid.	None.
1.5.6.5	Cable, electrical, Connector, electrical,	An open conductor or short in the cable due to mishandling or bending. Faulty connector due to handling, vibration, or material defect.	Loss of power to motors resulting in station two being out of service.	Motor current.	None.	ibid.	None.
1.5.7	Controls-station two						
1.5.4.1	CPU control board	Circuit failure due to electrical and thermal stresses.	The effect on the FARS vehicle ranges from degraded operation to loss of ability to process rounds.	Central CPU.	None.	ibid.	None.
1.5.4.2	Digital input cards	Erroneous or failure to process input signal.	The effect on the FARS vehicle ranges from degraded operation to loss of ability to process rounds.	CPU.	None.	ibid.	None.

Block number	Design element	Failure mode/cause	Failure effects	Method of detection	Compensating provisions	Criticality	Remarks
1.5.4.3	Digital output cards	Erroneous or failure to process output signal.	The effect on the FARS vehicle ranges from degraded operation to loss of ability to process rounds.	CPU.	None.	tbd.	None.
1.5.4.4	D/A converter	Erroneous or fails to converter D/A signal.	The effect on the FARS vehicle ranges from degraded operation to loss of ability to process rounds.	CPU	None.	tbd.	None.
1.5.4.5	A/D converter	Erroneous or fails to converter A/D signal.	The effect on the FARS vehicle ranges from degraded operation to loss of ability to process rounds.	CPU	None.	tbd.	None.
1.5.4.6	Motor amplifiers	Loss of output or out of specification output signal.	The effect on the FARS vehicle ranges from degraded operation to loss of ability to process rounds.	CPU.	None.	tbd.	None.
1.5.4.7	DC/DC converter	Loss of output or out-of-spec output.	The effect on the FARS vehicle ranges from degraded operation to loss of ability to process rounds.	CPU.	None.	tbd.	None.
1.5.4.8	Regulator, 24 volt. supplies, single phase	Loss of output or out-of-spec output.	The effect on the FARS vehicle ranges from degraded operation to loss of ability to process rounds.	CPU.	None.	tbd.	None.

Project: FARV
System: Artillery processing system

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Block number	Design element	Failure mode/cause	Failure effects	Method of detection	Compensating provisions	Criticality	Remarks
1.5.4.9	Encoder/Digital card	Erroneous or failure to process input signal.	Loss of ability to detect location of device being controlled. The effect on the FARS vehicle ranges from degraded operation to loss of ability to process rounds.	CPU.	None.	tbd.	None.

Project: FARV
System: Passive storage system

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Block number	Design element	Failure mode/cause	Failure effects	Method of detection	Compensating provisions	Criticality	Remarks
1.6	Passive storage system.						
1.6.1	Storage cells						
1.6.1.1	Spring loaded latch	Wear, deformation, or fatigue of the pin or latch due to usage, the service environment or defective materials.	Loss of ability to remove or store a round in a storage position. The FARS can continue its mission with some storage positions out of service but this does result in some loss of capability.	Failure of RATS to insert or remove round.	Partial redundancy in number of storage positions.	tbid.	None.
	Spring loaded latch	Deformation or fatigue of the spring due to usage or defective materials.	Loss of the ability to store a round in a storage position. The FARS can continue its mission with some storage positions out of service but this does result in some loss of capability.	Failure of RATS to load a round.	Partial redundancy in number of storage positions.	tbid.	None.
1.6.1.2	Storage tubes	Wear due to long-term use or defective materials.	Degraded ability to place and retrieve a round from a storage position. The FARS can continue its mission with some storage positions out of service but this does result in some loss of capability.	Failure of RATS to load a round.	Partial redundancy in number of storage positions.	tbid.	None.

Project: FARV
System: Passive storage system

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Block number	Design element	Failure mode/cause	Failure effects	Method of detection	Compensating provisions	Criticality	Remarks
1.6.1.3	Fasteners	Loose due to vibration or fatigue due to usage or defective materials.	Degraded ability to place and retrieve a round from a storage position. The FARS can continue its mission with some storage positions out of service but this does result in some loss of capability.	Failure of RATS to load a round.	Partial redundancy in number of storage positions.	tbd.	None.

APPENDIX C
DETAILED RAM CALCULATIONS

SUBSYSTEM RAM CALCULATIONS

BLOCK SYSTEM:

BLOCK NUMBER	SYSTEM:	FAILURE RATE (1E-6 H)	REF. FAILURE RATE	ENVIRON. FACTOR	NUMBER OF PARTS	DUTY CYCLE	APPL. FAILURE RATE (1E-6 H)	MTTR (H)	UNAVAIL- ABILITY (1E-6 H)	EXPECTED NUMBER OF FAILURES (1/24 H)
1.4	AMMO TRANSFER ARM									
	PART									
1.4.1	RETRACTION/EXTENSION SUBSYS.									
1.4.1.1	LINEAR ACTUATOR ASSY.	40.29	1	1	2	0.241	19.42	2.0	38.84	0.0005
1.4.1.2	BRAKE, ELECTROMECHANICAL	41.43	1	1	1	0.241	9.98	1.0	9.98	0.0002
1.4.1.3	WHEEL/ROLLER BEARING	3.29	1	1	10	0.241	7.93	1.0	7.93	0.0002
1.4.1.4	SWITCHES, MECHANICAL	5.16	1	1	4	0.241	4.98	0.5	2.49	0.0001
1.4.1.5	SENSOR, POSITION	2.83	2	1	2	0.241	1.36	0.5	0.68	0.0000
1.4.1.6	GASKET, DOOR	0.73	1	1	2	0.241	0.35	1.0	0.35	0.0000
1.4.1.7	CABLE, ELECTRICAL	1.01	2	1	11	0.241	2.68	1.0	2.68	0.0001
1.4.2	SHOULDER (JOINT 1) SUBSYSTEM									
1.4.2.1	LINEAR ACTUATOR ASSY.	40.29	1	1	2	0.241	19.42	2.0	38.84	0.0005
1.4.2.2	BRAKE, ELECTROMECHANICAL	41.43	1	1	2	0.241	19.97	1.0	19.97	0.0005
1.4.2.3	GIMBAL/RING ASSY.	7.83	3	1	2	0.241	3.77	4.0	15.10	0.0001
1.4.2.4	GAS SPRING	12.48	1	1	4	0.241	12.03	1.0	12.03	0.0003
1.4.2.5	SEAL, RUBBER BOOT	3.99	1	1	1	0.241	0.96	1.0	0.96	0.0000
1.4.2.6	SWITCHES, MECHANICAL	5.16	1	1	4	0.241	4.98	0.5	2.49	0.0001
1.4.2.7	SENSOR, POSITION	2.83	2	1	2	0.241	1.36	0.5	0.68	0.0000
1.4.2.8	CABLE, ELECTRICAL	1.01	2	1	12	0.241	2.92	1.0	2.92	0.0001
1.4.3	ELBOW SUBSYSTEM									
1.4.3.1	LINEAR ACTUATOR ASSY.	40.29	1	1	2	0.241	19.42	2.0	38.84	0.0005
1.4.3.2	BRAKE, ELECTROMECHANICAL	41.43	1	1	2	0.241	19.97	1.0	19.97	0.0005
1.4.3.3	GIMBAL/RING	7.83	3	1	2	0.241	3.77	4.0	15.10	0.0001
1.4.3.4	GAS SPRING	12.48	1	1	2	0.241	6.01	1.0	6.01	0.0001
1.4.3.5	SEAL, RUBBER BOOT	3.99	1	1	1	0.241	0.96	1.0	0.96	0.0000
1.4.3.6	SWITCHES, MECHANICAL	5.16	1	1	2	0.241	2.49	0.5	1.24	0.0001
1.4.3.7	SENSOR, POSITION	2.83	2	1	2	0.241	1.36	0.5	0.68	0.0000
1.4.3.8	CABLE, ELECTRICAL	1.01	2	1	12	0.241	2.92	1.0	2.92	0.0001
1.4.4	CONVEYOR/DELIVERY SUBSYSTEM									
1.4.4.1	DRIVE ASSY.	40.29	1	1	2	0.241	19.42	2.0	38.84	0.0005
1.4.4.2	BRAKE, ELECTROMECHANICAL	41.43	1	1	2	0.241	19.97	1.0	19.97	0.0005
1.4.4.3	ROLLER AND PIN	1.00	8	1	2	0.241	0.48	2.0	0.96	0.0000
1.4.4.4	ROLLER, TOOTHED	1.00	8	1	4	0.241	0.96	2.0	1.93	0.0000
1.4.4.5	SLIDING BLOCK	0.10	*	1	2	0.241	0.05	4.0	0.19	0.0000
1.4.4.6	BELT, CONVEYOR	2.96	1	1	4	0.241	2.85	2.0	5.70	0.0001
1.4.4.7	SENSOR, POSITION	2.83	2	1	2	0.241	1.36	0.5	0.68	0.0000
1.4.4.8	CABLE, ELECTRICAL	1.01	2	1	7	0.241	1.70	1.0	1.70	0.0000

1.4.5	WRIST SUBSYSTEM								
1.4.5.1	LINEAR ACTUATOR ASSY.	40.29	1	1	1	0.241	9.71	2.0	19.42 0.0002
1.4.5.2	ROTARY ACTUATOR ASSY.	29.55	1	1	1	0.241	7.12	2.0	14.24 0.0002
1.4.5.3	BRAKE, ELECTROMECHANICAL	41.43	1	1	2	0.241	19.97	1.0	19.97 0.0005
1.4.5.4	BEARING	3.11	1	1	4	0.241	3.00	4.0	12.00 0.0001
1.4.5.5	SWITCHES, MECHANICAL	5.16	1	1	4	0.241	4.98	0.5	2.49 0.0001
1.4.5.6	SENSOR, POSITION	2.83	2	1	2	0.241	1.36	0.5	0.68 0.0000
1.4.5.7	SEAL, RUBBER BOOT	3.99	1	1	1	0.241	0.96	1.0	0.96 0.0000
1.4.5.8	CABLE, ELECTRICAL	1.01	2	1	12	0.241	2.92	1.0	2.92 0.0001
1.4.6	EXTENSION CONVEYOR SUBSYSTEM								
1.4.6.1	DRIVE ASSY.	40.29	1	1	1	0.241	9.71	2.0	19.42 0.0002
1.4.6.2	BRAKE, ELECTROMECHANICAL	41.43	1	1	1	0.241	9.98	1.0	9.98 0.0002
1.4.6.3	ROLLER AND PIN	1.00	8	1	2	0.241	0.48	2.0	0.96 0.0000
1.4.6.4	ROLLER, TOOTHED	1.00	8	1	2	0.241	0.48	2.0	0.96 0.0000
1.4.6.5	SLIDING BLOCK	0.10	*	1	1	0.241	0.02	4.0	0.10 0.0000
1.4.6.6	SIDEGUIDE	3.29	1	1	2	0.241	1.59	4.0	6.34 0.0000
1.4.6.7	CHAIN, BACKFLEXING	8.86	1	1	2	0.241	4.27	4.0	17.08 0.0001
1.4.6.8	TAKE-UP ASSY.	2.65	1	1	2	0.241	1.28	4.0	5.11 0.0000
1.4.6.9	BELT, CONVEYOR	2.96	1	1	1	0.241	0.71	2.0	1.42 0.0000
1.4.6.10	SENSOR, POSITION	2.83	2	1	4	0.241	2.73	0.5	1.36 0.0001
1.4.6.11	CABLE, ELECTRICAL	1.01	2	1	7	0.241	1.70	1.0	1.70 0.0000
1.4.7	DOCKING PORT								
1.4.7.1	MOTORS	0.98	1	1	3	0.241	0.71	1.0	0.71 0.0000
1.4.7.2	LATCH/CAM	4.09	1	1	3	0.241	2.96	1.0	2.96 0.0001
1.4.7.3	COMM PORT	3.43	2	1	1	0.241	0.83	1.5	1.24 0.0000
1.4.7.4	CAMERA	135.46	1	1	1	0.241	32.65	1.2	39.17 0.0008
1.4.7.5	LINEAR ACTUATOR ASSY.	40.29	1	1	2	0.241	19.42	1.0	19.42 0.0005
1.4.7.6	SENSOR, POSITION	2.83	2	1	10	0.241	6.82	0.5	3.41 0.0002
1.4.7.7	GASKET, DOOR	0.73	1	1	2	0.241	0.35	1.0	0.35 0.0000
1.4.7.8	CABLE, ELECTRICAL	1.01	2	1	18	0.241	4.38	1.0	4.38 0.0001

1.4.8	CONTROL SUBSYSTEM												
1.4.8.1	CPU CONTROL BOARDS	51.00	5	1	1	0.241	12.29	0.5	6.15	0.0003			
1.4.8.2	DIGITAL INPUT CHAN. CARD	0.83	5	1	3	0.241	0.60	0.5	0.30	0.0000			
1.4.8.3	DIGITAL OUTPUT CHAN. CARD	8.20	5	1	3	0.241	5.93	0.5	2.96	0.0001			
1.4.8.4	D/A CONVERTER	8.20	5	1	1	0.241	1.98	0.5	0.99	0.0000			
1.4.8.5	A/D CONVERTER	8.20	5	1	1	0.241	1.98	0.5	0.99	0.0000			
1.4.8.6	MOTOR AMP/CONTROLLER	0.38	2	1	11	0.241	1.01	0.5	0.50	0.0000			
1.4.8.7	DC/DC CONVERTER	3.82	2	1	1	0.241	0.92	0.5	0.46	0.0000			
1.4.8.8	REGULATOR, 24 VOLT	3.00	1	1	1	0.241	0.72	0.5	0.36	0.0000			
1.4.8.9	CAMERA	135.46	1	1	2	0.241	65.29	1.0	65.29	0.0016			
1.4.8.10	ENCODER/DIGITAL CARD	8.20	5	1	4	0.241	7.90	0.5	3.95	0.0002			
1.4.8.11	MONITOR	7.18	1	1	1	0.241	1.73	1.0	1.73	0.0000			
1.4.8.12	JOYSTICK	3.30	1	1	3	0.241	2.39	0.5	1.19	0.0001			
											469.65	605.28	0.0113

SUBSYSTEM PARAMETERS

EXPECTED NUMBER OF FAILURES IN 24 HOURS=	0.0113
MEAN TIME TO FAILURE =	2129.23
MEAN TIME TO REPAIR =	1.3
AVAILABILITY =	0.9994

SUBSYSTEM RAM CALCULATIONS

BLOCK NUMBER	SYSTEM:	FAILURE RATE (1E-6 H)	REF. FAILURE RATE	ENVIRON. FACTOR	NUMBER OF PARTS	DUTY CYCLE	APPL. FAILURE RATE (1E-6 H)	MTTR (H)	UNAVAIL- ABILITY (1E-6 H)	EXPECTED NUMBER OF FAILURES (1/24 H)
1.5	ARTILLERY PROCESSING SYSTEM									
	PART									
1.5.1	LIFTING EYE REMOVAL-STATION 1									
1.5.1.1	ROTARY ACTUATOR ASSY.	29.55	1	1	1	0.1	2.96	1.0	2.96	0.0001
1.5.1.2	LINEAR ACTUATOR ASSY.	40.29	1	1	2	0.1	8.06	1.0	8.06	0.0002
1.5.1.3	END EFFECTOR, SPRING LOADED	5.15	1	1	1	0.1	0.52	1.0	0.52	0.0000
1.5.1.3	SENSOR, POSITION	2.83	2	1	2	0.1	0.57	0.5	0.28	0.0000
1.5.1.4	SENSOR, FORCE	2.83	2	1	1	0.1	0.28	0.5	0.14	0.0000
1.5.1.5	SWITCH, MECHANICAL	5.16	1	1	4	0.1	2.06	0.5	1.03	0.0000
1.5.1.6	CABLE, ELECTRICAL	1.01	2	1	9	0.1	0.91	1.0	0.91	0.0000
1.5.2	FUZZING-STATION 1									
1.5.2.1	ROTARY ACTUATOR ASSY.	29.55	1	1	2	0.1	5.91	1.0	5.91	0.0001
1.5.2.2	LINEAR ACTUATOR ASSY.	40.29	1	1	1	0.1	4.03	1.0	4.03	0.0001
1.5.2.3	END EFFECTOR, SPRING LOADED	5.15	1	1	1	0.1	0.52	1.0	0.52	0.0000
1.5.2.4	GIMBAL/RING ASSY.	7.83	3	1	2	0.1	1.57	1.0	1.57	0.0000
1.5.2.5	SENSOR, POSITION	2.83	2	1	3	0.1	0.85	0.5	0.42	0.0000
1.5.2.6	SWITCH, MECHANICAL	5.16	1	1	3	0.1	1.55	0.5	0.77	0.0000
1.5.2.7	SENSOR, TORQUE	2.83	2	1	1	0.1	0.28	0.5	0.14	0.0000
1.5.2.8	CABLE, ELECTRICAL	1.01	2	1	15	0.1	1.52	1.0	1.51	0.0000
1.5.3	FUZE STORAGE									
1.5.3.1	DRIVE ASSEMBLY	40.29	1	1	1	0.1	4.03	2.0	8.06	0.0001
1.5.3.2	SENSOR, POSITION	2.83	2	1	1	0.1	0.28	0.5	0.14	0.0000
1.5.3.3	CABLE, ELECTRICAL	1.01	2	1	3	0.1	0.30	1.0	0.30	0.0000
1.5.4	CONTROLS-STATION 1									
1.5.4.1	CPU BOARD	51.00	5	1	1	0.1	5.10	0.5	2.55	0.0001
1.5.4.2	DIGITAL INPUT CHAN. CARDS	0.83	5	1	3	0.1	0.25	0.5	0.12	0.0000
1.5.4.3	DIGITAL OUTPUT CHAN. CARDS	8.20	5	1	3	0.1	2.46	0.5	1.23	0.0001
1.5.4.4	D/A CONVERTER	8.20	5	1	1	0.1	0.82	0.5	0.41	0.0000
1.5.4.5	A/D CONVERTER	8.20	5	1	1	0.1	0.82	0.5	0.41	0.0000
1.5.4.6	MOTOR AMPLIFIER/CONTROLLER	0.38	2	1	7	0.1	0.27	0.5	0.13	0.0000
1.5.4.7	DC/DC CONVERTER	3.82	2	1	1	0.1	0.38	0.5	0.19	0.0000
1.5.4.8	REGULATOR, 24 VOLTS	3.00	1	1	1	0.1	0.30	0.5	0.15	0.0000
1.5.4.9	ENCODER/DIGITAL CARD	8.20	5	1	1	0.1	0.82	0.5	0.41	0.0000

1.5.5	WEIGHING SUBSYSTEM-STATION 2									
1.5.5.1	ELECTRICAL SCALE ASSY.	10.00	*	1	1	0.1	1.00	3.0	3.00	0.0000
1.5.5.2	LINEAR ACTUATOR ASSY.	40.29	1	1	1	0.1	4.03	1.0	4.03	0.0001
1.5.5.3	LEVEL METER, ELECTRIC	5.00	*	1	2	0.1	1.00	2.0	2.00	0.0000
1.5.5.4	SENSOR, POSITION	2.83	2	1	1	0.1	0.28	0.5	0.14	0.0000
1.5.5.5	SWITCH, MECHANICAL	5.16	1	1	2	0.1	1.03	0.5	0.52	0.0000
1.5.5.6	CABLE, ELECTRICAL	1.01	2	1	10	0.1	1.01	1.0	1.01	0.0000
1.5.6	MARKING SUBSYSTEM									
1.5.6.1	PRINTER ASSY, INKJET	41.34	1	1	1	0.1	4.13	3.0	12.40	0.0001
1.5.6.2	LINEAR ACTUATOR ASSY.	40.29	1	1	1	0.1	4.03	1.0	4.03	0.0001
1.5.6.3	ROTARY ACTUATOR ASSY.	29.55	1	1	1	0.1	2.96	1.0	2.96	0.0001
1.5.6.4	CABLE, ELECTRICAL	1.01	2	1	6	0.1	0.61	1.0	0.61	0.0000
1.5.7	CONTROLS-STATION 2									
1.5.7.1	CPU BOARD	51.00	5	1	1	0.1	5.10	0.5	2.55	0.0001
1.5.7.2	DIGITAL INPUT CHAN. CARDS	0.83	5	1	3	0.1	0.25	0.5	0.12	0.0000
1.5.7.3	DIGITAL OUTPUT CHAN. CARDS	8.20	5	1	3	0.1	2.46	0.5	1.23	0.0001
1.5.7.4	D/A CONVERTER	8.20	5	1	1	0.1	0.82	0.5	0.41	0.0000
1.5.7.5	A/D CONVERTER	8.20	5	1	1	0.1	0.82	0.5	0.41	0.0000
1.5.7.6	MOTOR AMPLIFIER/CONTROLLER	0.38	2	1	7	0.1	0.27	0.5	0.13	0.0000
1.5.7.7	DC/DC CONVERTER	3.82	2	1	1	0.1	0.38	0.5	0.19	0.0000
1.5.7.8	REGULATOR, 24 VOLTS	3.00	1	1	1	0.1	0.30	0.5	0.15	0.0000
1.5.7.9	ENCODER/DIGITAL CARD	8.20	5	1	1	0.1	0.82	0.5	0.41	0.0000
									78.69	79.18 0.0019

SUBSYSTEM PARAMETERS

EXPECTED NUMBER OF FAILURES IN 24 HOURS=	0.0019
MEAN TIME TO FAILURE =	12707.46
MEAN TIME TO REPAIR =	1.0
AVAILABILITY =	0.9999

SUBSYSTEM RAM CALCULATIONS

BLOCK NUMBER	SYSTEM:	FAILURE RATE (1E-6 H)	REF. FAILURE RATE	ENVIRON. FACTOR	NUMBER OF PARTS	DUTY CYCLE	APPL. FAILURE RATE (1E-6 H)	MTTR (H)	UNAVAIL- ABILITY (1E-6 H)	EXPECTED NUMBER OF FAILURES (1/24 H)
1.6	PASSIVE STORAGE									
	PART									
1.6.1	STORAGE CELLS									
1.6.1.1	SPRING LOADED LATCHES	12.26	1	1	1	1.0	12.26	1.0	12.26	0.0003
1.6.1.2	TUBES, STORAGE	0.10	*	1	1	1.0	0.10	4.0	0.40	0.0000
1.6.1.3	FASTENERS	0.02	8	1	10	1.0	0.20	0.5	0.10	0.0000

12.56

12.76 0.0003

SUBSYSTEM PARAMETERS

EXPECTED NUMBER OF FAILURES IN 24 HOURS= 0.0003
 MEAN TIME BETWEEN FAILURES = 79592.49
 MEAN TIME TO REPAIR = 1.0
 AVAILABILITY = 1.0000

SUBSYSTEM RAM CALCULATIONS

BLOCK NUMBER	SYSTEM:	FAILURE RATE (1E-6 H)	REF. FAILURE RATE	ENVIRON. FACTOR	NUMBER OF PARTS	DUTY CYCLE	APPL. FAILURE RATE (1E-6 H)	MTTR (H)	UNAVAIL-ABILITY (1E-6 H)	EXPECTED NUMBER OF FAILURES (1/24 H)
1.	ROBOTIC AMMUNITION TRANSFER SYSTEM (RATS)									
	PART									
	TRANSFER HEAD SUBSYSTEM									
1.1.1	MOTOR, AC SERVO	0.98	1	1	1	0.241	0.24	1.6	0.38	0.0000
1.1.2	SERVO DRIVE/CONTROLLER	7.97	1	1	1	0.241	1.92	1.2	2.30	0.0000
1.1.3	RESOLVER, SYNCHRO	9.71	1	1	1	0.241	2.34	1.0	2.34	0.0001
1.1.4	BRAKE, ELECTROMECHANICAL	41.43	1	1	1	0.241	9.98	0.8	7.99	0.0002
1.1.5	GEARCASE, MOTOR, LO-RATIO	0.88	1	1	1	0.241	0.21	1.6	0.34	0.0000
1.1.6	CHAIN, PRECISION TIMING	8.86	1	1	1	0.241	2.13	0.8	1.71	0.0001
1.1.7	GEAR, SPUR	3.22	1	1	2	0.241	1.55	0.8	1.24	0.0000
1.1.8	GEARSHAFT, SPUR	0.20	1	1	2	0.241	0.09	1.2	0.11	0.0000
1.1.9	BEARING, BALL	1.60	1	1	2	0.241	0.77	1.2	0.93	0.0000
1.1.10	BEARING, LINEAR, BALL	3.98	1	1	4	0.241	3.83	1.6	6.13	0.0001
1.1.11	RAILS, CYLINDRICAL, STEEL	0.15	1	1	2	0.241	0.07	1.8	0.13	0.0000
1.1.12	LATCH ASSY	5.54	1	1	2	0.241	2.67	1.6	4.27	0.0001
1.1.13	CAM ASSEMBLY	5.69	1	1	2	0.241	2.74	1.2	3.29	0.0001
1.1.14	SWITCH, LIMIT	39.89	1	1	1	0.241	9.61	0.4	3.85	0.0002
1.1.15	SENSOR, SOLID STATE	13.16	1	1	2	0.241	6.34	0.4	2.54	0.0002
1.1.16	TRANSDUCER, ULTRASONIC	80.14	1	1	1	0.241	19.31	0.4	7.73	0.0005
	TRANSFER HEAD ROTATOR SUBSYSTEM									
1.2.1	MOTOR, AC SERVO	0.98	1	1	1	0.241	0.24	1.6	0.38	0.0000
1.2.2	SERVO DRIVE/CONTROLLER	7.97	1	1	1	0.241	1.92	1.2	2.30	0.0000
1.2.3	RESOLVER, SYNCHRO	9.71	1	1	1	0.241	2.34	1.0	2.34	0.0001
1.2.4	BRAKE, ELECTROMECHANICAL	41.43	1	1	1	0.241	9.98	0.8	7.99	0.0002
1.2.5	GEARCASE, MOTOR, LO-RATIO	0.88	1	1	1	0.241	0.21	1.6	0.34	0.0000
1.2.6	GEAR, (RING)	4.55	1	1	1	0.241	1.10	1.2	1.31	0.0000
1.2.7	GEAR, (PINION)	4.55	1	1	1	0.241	1.10	0.8	0.88	0.0000
1.2.8	GEARSHAFT, PINION	0.62	1	1	1	0.241	0.15	1.2	0.18	0.0000
1.2.9	BEARING, ROLLER	3.29	1	1	1	0.241	0.79	1.2	0.95	0.0000
1.2.10	BEARING, ROLLER	3.29	1	1	2	0.241	1.59	1.8	2.85	0.0000
1.2.11	SENSOR, SOLID STATE	13.16	1	1	2	0.241	6.34	0.4	2.54	0.0002
	TRANSFER HEAD ELEVATOR SUBSYSTEM									
1.3.1	MOTOR, AC SERVO	0.98	1	1	1	0.241	0.24	1.6	0.38	0.0000
1.3.2	SERVO DRIVE/CONTROLLER	7.97	1	1	1	0.241	1.92	1.2	2.30	0.0000
1.3.3	RESOLVER, SYNCHRO	9.71	1	1	1	0.241	2.34	1.0	2.34	0.0001
1.3.4	BRAKE, ELECTROMECHANICAL	41.43	1	1	1	0.241	9.98	0.8	7.99	0.0002
1.3.5	GEARCASE, MOTOR, LO-RATIO	0.88	1	1	1	0.241	0.21	1.6	0.34	0.0000
1.3.6	CHAIN, PRECISION TIMING	8.86	1	1	2	0.241	4.27	0.8	3.42	0.0001
1.3.7	GEAR, SPUR	3.22	1	1	2	0.241	1.55	0.8	1.24	0.0000
1.3.8	GEARSHAFT, SPUR	0.20	1	1	1	0.241	0.05	1.2	0.06	0.0000
1.3.9	BEARING, BALL	1.60	1	1	2	0.241	0.77	1.2	0.93	0.0000
1.3.10	BEARING, LINEAR, BALL	3.98	1	1	4	0.241	3.83	1.6	6.13	0.0001
1.3.11	RAILS, CYLINDRICAL, STEEL	0.15	1	1	2	0.241	0.07	1.8	0.13	0.0000
1.3.12	COUNTER, WEIGHT	0.00	1	1	2	0.241	0.00	0.4	0.00	0.0000
1.3.13	SENSORS, SOLID STATE	13.16	1	1	2	0.241	6.34	0.4	2.54	0.0002

TRANSVERSE SUBSYSTEM										
1.4.1	MOTOR, AC SERVO	0.98	1	1	1	0.241	0.24	1.6	0.38	0.0000
1.4.2	SERVO DRIVE/CONTROLLER	7.97	1	1	1	0.241	1.92	1.2	2.30	0.0000
1.4.3	RESOLVER, SYNCHRO	9.71	1	1	1	0.241	2.34	1.0	2.34	0.0001
1.4.4	BRAKE, ELECTROMECHANICAL	41.43	1	1	1	0.241	9.98	0.8	7.99	0.0002
1.4.5	GEARCASE, MOTOR, LO-RATIO	0.88	1	1	2	0.241	0.42	1.6	0.68	0.0000
1.4.6	GEAR, RACK	1.76	1	1	4	0.241	1.69	0.8	1.35	0.0000
1.4.7	GEAR, (PINION)	4.55	1	1	4	0.241	4.38	0.8	3.51	0.0001
1.4.8	GEARSHAFT, PINION	0.62	1	1	4	0.241	0.60	1.2	0.72	0.0000
1.4.9	COUPLING, GEARSHAFT, FLEXIBLE	27.43	1	1	4	0.241	26.44	0.8	21.15	0.0006
1.4.10	BEARING, BALL	1.60	1	1	4	0.241	1.54	1.2	1.85	0.0000
1.4.11	BEARING, LINEAR, BALL	3.98	1	1	8	0.241	7.66	1.6	12.26	0.0002
1.4.12	RAILS, CYLINDRICAL, STEEL	0.15	1	1	4	0.241	0.14	1.8	0.26	0.0000
1.4.13	SENSORS, SOLID STATE	13.16	1	1	2	0.241	6.34	0.4	2.54	0.0002
CONTROL SUBSYSTEM										
1.5.1	CPU CONTROL BOARDS	51.00	5	1	1	0.241	12.29	3.0	36.87	0.0003
1.5.2	DIGITAL INPUT CARDS	3.72	5	1	3	0.241	2.69	2.0	5.38	0.0001
1.5.3	DIGITAL OUTPUT CARDS	5.64	5	1	3	0.241	4.08	2.0	8.16	0.0001
1.5.4	DC/DC CONVERTER	3.83	2	1	1	0.241	0.92	1.0	0.92	0.0000
1.5.5	REGULATOR, 24 VOLTS	3.00	1	1	1	0.241	0.72	1.0	0.72	0.0000
1.5.6	CABLES, ELECTRICAL (20 FT LENGTH)	0.34	5	1	153	0.241	12.54	1.5	18.80	0.0003
1.5.7	CONNECTORS	0.15	5	1	306	0.241	11.06	1.5	16.59	0.0003

229.19

239.91 0.0055

SUBSYSTEM PARAMETERS

EXPECTED NUMBER OF FAILURES IN 24 HOURS=	0.0055
MEAN TIME TO FAILURE =	4363.22
MEAN TIME TO REPAIR =	1.0
AVAILABILITY =	0.9998

APPENDIX D
SCORING CRITERIA CALCULATIONS

SUBSYSTEM RAM CALCULATIONS

BLOCK NUMBER	SYSTEM:	FAILURE RATE (1E-6 H)	NUMBER OF PARTS	DUTY CYCLE	APPL. FAILURE RATE (1E-6 H)	FAILURE MODE RATIO			REDUCED FAILURE RATE		
						EUMD	EFF	SA	EUMD	EFF	SA
1.4	AMMO TRANSFER ARM										
	PART SUMMARY										
1	BRAKE, ELECTROMECHANICAL	41.43	10	0.241	99.85	0.10	0.20	0.70	9.98	19.97	69.89
2	CAMERA	135.46	3	0.241	97.94	0.40	0.60	0.00	39.17	58.76	0.00
3	LINEAR ACTUATOR ASSY.	40.29	9	0.241	87.39	0.10	0.50	0.40	8.74	43.70	34.96
4	DRIVE ASSY.	40.29	3	0.241	29.13	0.40	0.30	0.30	11.65	8.74	8.74
5	GAS SPRING	12.48	6	0.241	18.04	0.30	0.40	0.30	5.41	7.22	5.41
6	SWITCHES, MECHANICAL	5.16	14	0.241	17.41	0.40	0.30	0.30	6.97	5.22	5.22
7	CABLE, ELECTRICAL	1.01	79	0.241	19.23	0.30	0.30	0.40	5.77	5.77	7.69
8	SENSOR, POSITION	2.83	24	0.241	16.37	0.40	0.40	0.20	6.55	6.55	3.27
9	CPU CONTROL BOARDS	51.00	1	0.241	12.29	0.00	0.30	0.70	0.00	3.69	8.60
10	WHEEL/ROLLER BEARING	3.29	10	0.241	7.93	0.50	0.20	0.30	3.96	1.59	2.38
11	ENCODER/DIGITAL CARD	8.20	4	0.241	7.90	0.00	0.30	0.70	0.00	2.37	5.53
12	GIMBAL/RING ASSY.	7.83	4	0.241	7.55	0.10	0.50	0.40	0.75	3.77	3.02
13	ROTARY ACTUATOR ASSY.	29.55	1	0.241	7.12	0.10	0.50	0.40	0.71	3.56	2.85
14	DIGITAL OUTPUT CHAN. CARD	8.20	3	0.241	5.93	0.00	0.30	0.70	0.00	1.78	4.15
15	CHAIN, BACKFLEXING	8.86	2	0.241	4.27	0.50	0.20	0.30	2.13	0.85	1.28
16	BELT, CONVEYOR	2.96	5	0.241	3.56	0.20	0.30	0.50	0.71	1.07	1.78
17	BEARING	3.11	4	0.241	3.00	0.20	0.30	0.50	0.60	0.90	1.50
18	LATCH/CAM	4.09	3	0.241	2.96	0.40	0.30	0.30	1.18	0.89	0.89
19	SEAL, RUBBER BOOT	3.99	3	0.241	2.88	0.50	0.20	0.30	1.44	0.58	0.86
20	JOYSTICK	3.30	3	0.241	2.39	0.20	0.40	0.40	0.48	0.95	0.95
21	D/A CONVERTER	8.20	1	0.241	1.98	0.00	0.30	0.70	0.00	0.59	1.38
22	A/D CONVERTER	8.20	1	0.241	1.98	0.00	0.30	0.70	0.00	0.59	1.38
23	MONITOR	7.18	1	0.241	1.73	0.40	0.60	0.00	0.69	1.04	0.00
24	SIDEGUIDE	3.29	2	0.241	1.59	0.50	0.20	0.30	0.79	0.32	0.48
25	ROLLER, TOOTHED	1.00	6	0.241	1.45	0.10	0.50	0.40	0.14	0.72	0.58
26	TAKE-UP ASSY.	2.65	2	0.241	1.28	0.50	0.20	0.30	0.64	0.26	0.38
27	MOTOR AMP/CONTROLLER	0.38	11	0.241	1.01	0.10	0.50	0.40	0.10	0.50	0.40
28	ROLLER AND PIN	1.00	4	0.241	0.96	0.10	0.50	0.40	0.10	0.48	0.39
29	DC/DC CONVERTER	3.82	1	0.241	0.92	0.00	0.30	0.70	0.00	0.28	0.64
30	COMM PORT	3.43	1	0.241	0.83	0.40	0.40	0.20	0.33	0.33	0.17
31	REGULATOR, 24 VOLT	3.00	1	0.241	0.72	0.00	0.30	0.70	0.00	0.22	0.51
32	MOTORS	0.98	3	0.241	0.71	0.10	0.50	0.40	0.07	0.35	0.28
33	GASKET, DOOR	0.73	4	0.241	0.71	0.70	0.20	0.10	0.50	0.14	0.07
34	DIGITAL INPUT CHAN. CARD	0.83	3	0.241	0.60	0.00	0.30	0.70	0.00	0.18	0.42
35	SLIDING BLOCK	0.10	3	0.241	0.07	0.70	0.20	0.10			
						469.65			109.58	183.92	176.07

SUBSYSTEM PARAMETERS

	FAILURE RATE (1E-6)	MTTF (H)
EUMD =	469.58	2130
EFF =	360.00	2778
SA =	176.07	5679

SUBSYSTEM RAM CALCULATIONS

BLOCK SYSTEM:

BLOCK NUMBER	SYSTEM:	FAILURE RATE (1E-6 H)	NUMBER OF PARTS	DUTY CYCLE	APPL. FAILURE RATE (1E-6 H)	FAILURE MODE RATIO			REDUCED FAILURE RATE		
						EUMD	EFF	SA	EUMD	EFF	SA
1.5	ARTILLERY PROCESSING SYSTEM										
	PART										
	SUMMARY OF PARTS										
1	LINEAR ACTUATOR ASSY.	40.29	5	0.1	20.15	0.10	0.50	0.40	2.01	10.07	8.06
2	ROTARY ACTUATOR ASSY.	29.55	4	0.1	11.82	0.10	0.50	0.40	1.18	5.91	4.73
3	CPU BOARD	51.00	2	0.1	10.20	0.00	0.70	0.30	0.00	7.14	3.06
4	DIGITAL OUTPUT CHAN. CARDS	8.20	6	0.1	4.92	0.00	0.70	0.30	0.00	3.44	1.48
5	SWITCH, MECHANICAL	5.16	9	0.1	4.64	0.40	0.30	0.30	1.86	1.39	1.39
6	PRINTER ASSY, INKJET	41.34	1	0.1	4.13	0.00	0.70	0.30	0.00	2.89	1.24
7	DRIVE ASSEMBLY	40.29	1	0.1	4.03	0.20	0.50	0.30	0.81	2.01	1.21
8	CABLE, ELECTRICAL	1.01	43	0.1	4.34	0.30	0.40	0.30	1.30	1.74	1.30
9	SENSOR, POSITION	2.83	7	0.1	1.98	0.40	0.40	0.20	0.79	0.79	0.40
10	D/A CONVERTER	8.20	2	0.1	1.64	0.00	0.70	0.30	0.00	1.15	0.49
11	A/D CONVERTER	8.20	2	0.1	1.64	0.00	0.70	0.30	0.00	1.15	0.49
12	ENCODER/DIGITAL CARD	8.20	2	0.1	1.64	0.00	0.70	0.30	0.00	1.15	0.49
13	GIMBAL/RING ASSY.	7.83	2	0.1	1.57	0.50	0.50	0.20	0.78	0.78	0.31
14	END EFFECTOR, SPRING LOADED	5.15	2	0.1	1.03	0.30	0.50	0.20	0.31	0.52	0.21
15	ELECTRICAL SCALE ASSY.	10.00	1	0.1	1.00	0.00	0.70	0.30	0.00	0.70	0.30
16	LEVEL METER, ELECTRIC	5.00	2	0.1	1.00	0.00	0.70	0.30	0.00	0.70	0.30
17	DC/DC CONVERTER	3.82	2	0.1	0.76	0.00	0.70	0.30	0.00	0.53	0.23
18	REGULATOR, 24 VOLTS	3.00	2	0.1	0.60	0.00	0.70	0.30	0.00	0.42	0.18
19	SENSOR, FORCE	2.83	2	0.1	0.57	0.00	0.70	0.30	0.00	0.40	0.17
20	MOTOR AMPLIFIER/CONTROLLER	0.38	14	0.1	0.53	0.00	0.70	0.30	0.00	0.37	0.16
21	DIGITAL INPUT CHAN. CARDS	0.83	6	0.1	0.50	0.00	0.70	0.30	0.00	0.35	0.15
						78.69			9.05	43.61	26.35

SUBSYSTEM PARAMETERS

	FAILURE RATE (1E-6)	MTTF (H)
EUMD =	79.01	12657
EFF =	69.96	14294
SA =	26.35	37955

SUBSYSTEM RAM CALCULATIONS

BLOCK NUMBER	SYSTEM:	FAILURE RATE (1E-6 H)	NUMBER OF PARTS	DUTY CYCLE	APPL. FAILURE RATE (1E-6 H)	FAILURE MODE RATIO			REDUCED FAILURE RATE		
						EUMD	EFF	SA	EUMD	EFF	SA
1.6	PASSIVE STORAGE										
	PART										
1.6.1	STORAGE CELLS										
1.6.1.1	SPRING LOADED LATCHES	12.26	1	1.0	12.26	0.60	0.30	0.10	7.36	3.68	1.23
1.6.1.2	TUBES, STORAGE	0.10	1	1.0	0.10	0.30	0.30	0.40	0.03	0.03	0.04
1.6.1.3	FASTENERS	0.02	10	1.0	0.20	0.30	0.30	0.40	0.06	0.06	0.08
						12.56			7.45	3.77	1.35

SUBSYSTEM PARAMETERS

	FAILURE RATE (1E-6)	MTTF (H)
EUMD =	12.56	79592
EFF =	5.12	195480
SA =	1.35	742721

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