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Medical Analysis Using the NHRC Tactical Medical Logistics (TML+) Planning Tool in Support of the Marine Corps Warfighting Laboratory (MCWL)

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Summary

Problem

The Marine Corps Warfighting Laboratory (MCWL) requested that the Naval Health Research Center conduct a feasibility study to determine the medical requirements during Ship to Objective Maneuvers (STOMs). STOM is a dynamic, fast-moving, and high-intensity event where a large number of injuries can be expected over a very short period of time as forces advance to various battlefield objectives. The challenge for the medical planner is to logistically support the event by facilitating the timely delivery of medical care and ensuring appropriate evacuation assets are available. The Marine Corps was interested in knowing how many casualties to expect and what types of injuries for which to plan. They also wanted to know the extent to which surgical capability ashore would save lives and what the evacuation requirements (ground/air) would be.

Objective

The primary objective of this study was to use the Tactical Medical Logistics (TML+) planning tool to provide the MCWL with the medical requirements for STOM by comparing alternate solutions for providing emergency surgical care in support of surface and vertical maneuver elements.

Approach

The approach was to use TML+ to conduct a study that would examine 4 alternatives: **Case A** – no Forward Resuscitative Surgery System (FRSS) ashore; **Case B** – 1 FRSS in support of the surface maneuver elements (SMEs) and 1 FRSS brought in with the vertical maneuver element (VME); **Case B'** – same as Case B, but with 2 FRSSs supporting the SME waves, and 1 FRSS still assigned to support the VME. FRSSs maneuvered in a leap-frog pattern to increase the availability of surgical care; **Case D** – a single FRSS moving with the SME, and no FRSS available to the VME. As the SME moves closer to the first objective, VME casualties may be routed to the SME FRSS. Additional capabilities were developed and incorporated in TML+ to accomplish the study.

Results

Data produced from TML+ indicated that when more FRSS units were deployed with the combat elements, more lives were saved because time to first surgery was reduced. About 14% more casualties survive when 2 or 3 FRSSs are available, simply because maneuver elements can reach an FRSS for stabilization about 1 hour quicker than they can get to the sea-based Casualty Receiving and Treatment Ship (CRTS).

Discussion and Conclusion

Simulation results of STOM scenarios provided useful information, such as how many and what types of injuries could be expected during STOM events and how many of these would be life-threatening. Based on these injuries, analyses showed whether demands on personnel, equipment, or supplies caused delays in patient treatment. Transportation issues for evacuating patients with both life-threatening and non-life-threatening injuries were closely studied as well, to determine how many ground and air transports would be needed for medical evacuation. Designating 2 to 3 MV22 aircraft was sufficient to transport casualties with life-threatening injuries.

Introduction

Background

The Marine Corps Warfighting Laboratory (MCWL) is developing and experimenting with capabilities related to Ship to Objective Maneuver (STOM). The initial medical planning done by MCWL indicates that some damage control surgical capability will be required in order to limit injury, disability, and mortality rates among casualties in a STOM scenario. MCWL proposed exploiting the well-developed medical modeling and simulation tools available at the Naval Health Research Center (NHRC), San Diego.

NHRC was tasked to conduct a study and publish a report that compares alternate solutions for emergency surgical care in support of surface and vertical maneuver elements (SMEs and VMEs) conducting STOM. Specifically, the NHRC model is the only one that provides unique, detailed output on combat casualties. Additionally, the NHRC model reflects empirical data from Operation Iraqi Freedom (OIF) and Operation Enduring Freedom (OEF) that are not available in other medical risk assessment models.

Both these attributes are crucial to the validity of the study, which examines 4 scenarios, discussed in greater detail below, for future emergency surgical support: **Case A,** which has no Forward Resuscitative Surgical System (FRSS) ashore; **Case B**, in which 1 FRSS travels with the SMEs and is available on a 6/4 hour up/down schedule and 1 FRSS is brought in with the VME; **Case B'** is the same as Case B, but with 2 FRSSs traveling with the SME waves and moving in a leap-frog pattern, while the VME FRSS is unchanged; and **Case D**, in which a single FRSS travels with the SME, and no FRSS is available to the VME.

Under Marine Corps Systems Command and the Bureau of Medicine and Surgery sponsorship, Teledyne Brown Engineering (TBE) and NHRC developed an emergency medical planning model called the Tactical Medical Logistics (TML+) planning tool, which supports medical mission planning by simulating results of scenarios based on empirical data and known underlying probability distributions of events. Because TML+ models casualty estimation, care providing, and patient evacuations for scenarios like STOM, in which the need for medical care can reach large numbers, NHRC employed this tool to complete the task outlined above.

In particular, TML+ results are based on:

- Historical casualty types (patient condition codes, or PCs) and occurrence rates based on a population at risk;
- A user-defined scenario encompassing mission requirements, and availability of medical treatment facilities (MTFs) and transportation assets;
- Standard medical capabilities available at each level of care (LOC)/MTF;
- Tasks, task durations, supplies (consumables and equipment), and personnel likely to be required for treating each type of injury; and
- Transportation assets and their properties, including capacity and speed.

To provide more realistic results, all aspects of the simulation are stochastic and based on data or known underlying distributions. Multiple replications of each scenario are executed, providing average output metrics for specified risk assessments.

The core of TML+ is a series of queues through which each casualty travels. After injury, a casualty is placed in a transport queue and picked up based on injury severity. Subsequent treatment is based on severity once casualties arrive at an MTF, and they then traverse a list of tasks associated with their PC (injury type) and current location (functional area, or FA) within that MTF. Each task performed may use medical providers, equipment, and consumable supplies. Limited resources mean some casualties will not receive immediate treatment.

TML+ records all aspects of treatment, including travel time, resources used, delays, casualty injury types, and reports them at the end of the simulation. Hundreds of metrics can be extracted and analyzed from these data. Additionally, to fulfill certain aspects of the study, NHRC and TBE modified functionality in TML+ to include the capacity to model time delays and actual trajectory of FRSS movement alongside troops, what we called the leap-frog scenario.

Methodology

To simulate the flow of patients in TML+, the user enters the length of the scenario, the mean numbers of wounded in action (WIA), disease and nonbattle injuries (DNBI) expected to occur, and builds a treatment network by selecting the types and locations of LOCs and the transportation assets expected to evacuate patients. With these inputs, TML+ uses stochastic processes to model patient arrivals, treatment, and outcomes as they flow from the point of injury (POI) through a network of care facilities. TML+ currently:

- generates a stream of patients occurring randomly in time and space among POIs,
- generates the specific PCs for each patient,
- prioritizes the treatment and evacuation of patients based on the severity of injuries,
- models mortality as killed in action and died of wounds (DOW) due to a delay in treatment,
- simulates patient flow through LOCs, including arrival times, wait times, and treatment times,
- models the routing and utilization of transportation assets, and
- generates dynamic reports in graph and tabular formats that show the status of the MTFs, patient disposition, and resource utilization.

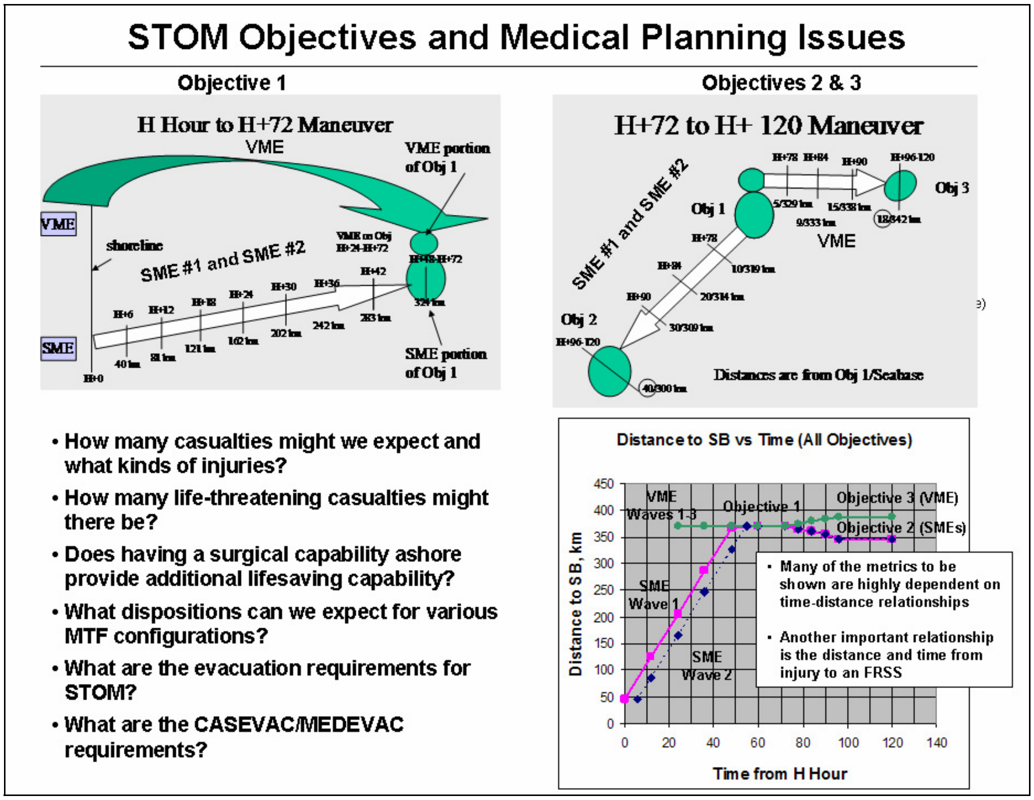
To successfully execute these functions, TML+ has a significant amount of underlying data that include over 400 PCs developed by the Defense Medical Standardization Board and NHRC; medical treatment tasks; task sequences; treatment times; consumable supplies and equipment; weight, cube, and cost of each supply item; DOW due to time; type, speed, and capacity of transportation assets; LOC and their respective FAs; number of personnel; and personnel skill sets. Treatment profiles describing the nature of the injury, anticipated patient signs and symptoms, and treatment tasks were constructed for each PC code. Supply assignments were made for each of the treatment tasks using a combination of technologically appropriate, triservice standardized consumables.[1,2] These requirements were then integrated into TML+ to evaluate the mission's operational risk and medical treatment requirements, with the ultimate end in mind to provide medical planners and providers the ability to investigate various courses of action, and determine readiness and capability in support of the warfighter.

Ship to Objective Maneuver (STOM)

The Navy-Marine Corps Combat Trauma Registry (N-MC CTR) provides a rich source of empirical data for NHRC's medical modeling tools, giving insight into how casualties proceed through the medical chain of evacuation, what treatment they receive, and a variety of other details. Of particular note is the fact that the N-MC CTR is capturing data from level 1 and 2 MTFs, a unique data set relevant to, among other things, the STOM mission modeling.[3]

Using these data, NHRC identified a pool of PCs with injury or illness requirements necessitating the type of clinical intervention or maintenance that falls within STOM mission parameters.

In order to model the STOM mission, TBE and NHRC built various scenarios of MTF networks connected by transportation assets. The MTFs included 1st Responders, FRSS units, and a sea-based surgical intervention capability. The patient distribution included those with both life-threatening (LT) and non-life-threatening (NLT) injuries and was based on OIF and OEF historical data. NHRC modeled treatment profiles based on lessons learned from historical events and medical subject matter expert inputs.



STOM Objectives and Medical Planning Issues

Objective 1

Objectives 2 & 3

- How many casualties might we expect and what kinds of injuries?
- How many life-threatening casualties might there be?
- Does having a surgical capability ashore provide additional lifesaving capability?
- What dispositions can we expect for various MTF configurations?
- What are the evacuation requirements for STOM?
- What are the CASEVAC/MEDEVAC requirements?

Distance to SB vs Time (All Objectives)

- Many of the metrics to be shown are highly dependent on time-distance relationships
- Another important relationship is the distance and time from injury to an FRSS

Figure 1. Issues and questions addressed in modeling STOM.

Some of the questions this inquiry sought to answer are presented in Figure 1. Additionally, we expanded on those questions to include the following as well:

- Which personnel, supplies, and equipment are the limiting factors on patient flow? How many lives might a particular MTF configuration save?
- What additional delays are incurred with increased casualty flow? What is the best STOM Concept of Operations (CONOPS) for FRSS(s)?
- Is the "up 6 hr/down 4 hr" schedule the most reasonable for a STOM-supported FRSS? How would 2 FRSSs operate together in a leap-frog approach?
- What is the composition of an FRSS in this context?
- How many air assets (designated/diverted) are required to move casualties to a sea-based MTF? What about availability issues of designated aircraft?
- How many ground assets are required to move casualties between facilities?

To begin to answer these questions, we explored how the various maneuver elements would proceed, as shown in Figure 1. The upper left graphic depicts the movement of 2 SMEs and 1 VME from the seabase (SB), situated 46 km from the shoreline, to the first objective. The VME flies directly to the objective, which lies 324 km from the shoreline, landing there at 24 hours into the operation. SMEs #1 and #2 proceed along the ground from shoreline to objective, arriving at 48 hours.

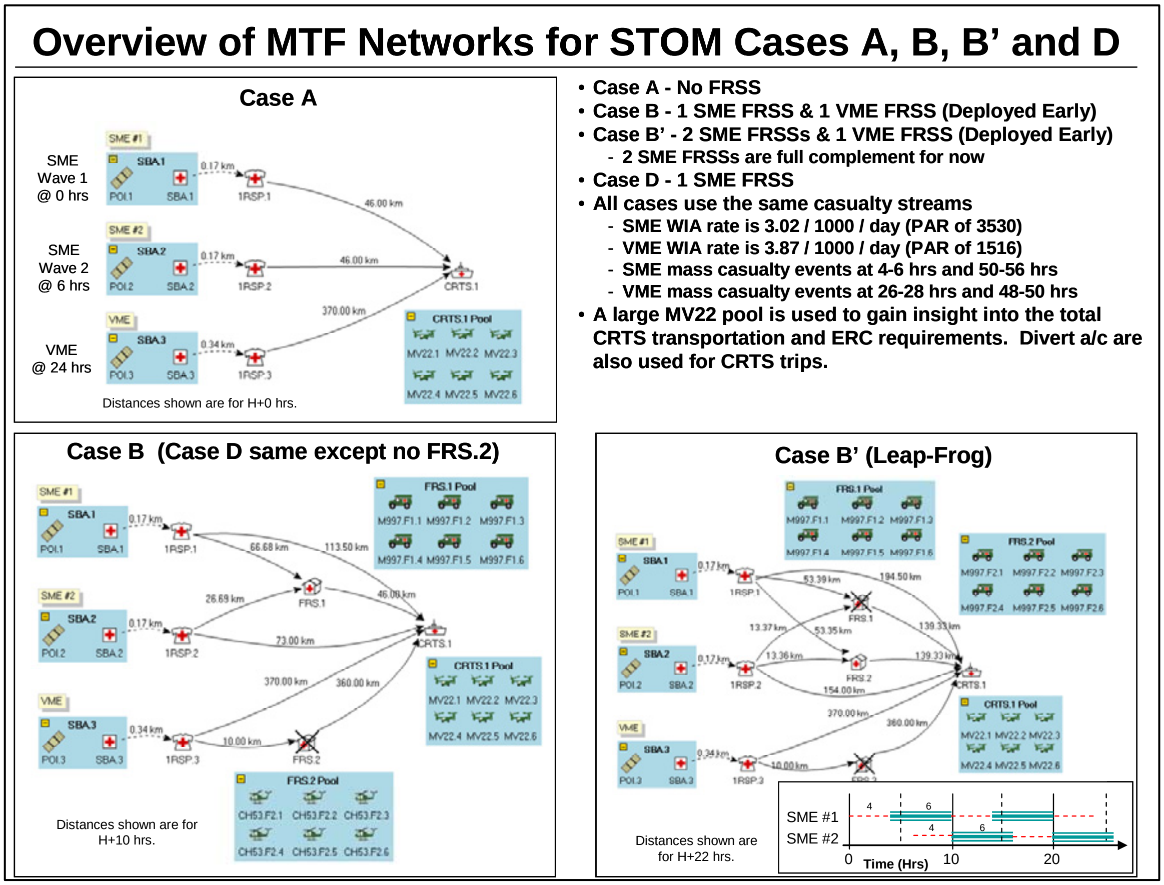
The upper right graphic details the movement to objectives 2 and 3 in a similar fashion. The VME moves to objective 3 (18 km from the 1st objective), arriving at 96 hours into the operation, while SMEs #1 and #2 move to objective 2 (40 km from the 1st objective) and also arrive at 96 hours. (Both graphics were provided by Bill Hoffman of MCWL and were the basis for constructing the STOM scenarios in TML+.)

The chart on the lower right of Figure 1 shows the distance of each wave (SME #1, SME #2, and VME) from the seabase over time. Note the upward slope on the left showing that the SME waves are progressing away from the sea base and toward the first objective. This chart shows one of the fundamental transportation issues associated with STOM, that of the increasing distance between the population at risk and the most advanced MTF (the sea base). At approximately time H+48 hours, both SMEs and the VME are located at the objective. After time H+72, the VME begins progressing toward objective 3, while the SMEs move toward objective 2.

Several assumptions were made for the STOM study to simplify the construction of the various scenarios, and TML+ itself has some limitations that may have an impact on results. For example, weather conditions do not limit operations in the model as they might in real time, equipment reliability is fixed at 1.0, re-supply is not modeled, and only "lift of opportunity" for transports to the seabase were modeled. It should also be noted that enroute care (ERC) modeling is limited to consumable usage, personnel attrition and skills degradation were not accounted for, designated transports are dispatched from the receiving LOC, and only WIA events are modeled; no DNBI were included. It is anticipated that several of these caveats will be addressed in a follow-on effort.

The Four Cases

Figure 2 shows the scenarios built in TML+ for the study. All cases include the common elements previously described, such as the SME movement toward the objective, VME landing at objective, and movement toward objectives 2 and 3. The difference is the placement (or existence) of FRSSs. Each case uses the same inputs, casualty streams based on historical rates for the population at risk (PAR), including 4 mass casualty events as provided by MCWL.



Overview of MTF Networks for STOM Cases A, B, B' and D

- **Case A - No FRSS**
- **Case B - 1 SME FRSS & 1 VME FRSS (Deployed Early)**
- **Case B' - 2 SME FRSSs & 1 VME FRSS (Deployed Early)**
  - **2 SME FRSSs are full complement for now**
- **Case D - 1 SME FRSS**
- **All cases use the same casualty streams**
  - **SME WIA rate is 3.02 / 1000 / day (PAR of 3530)**
  - **VME WIA rate is 3.87 / 1000 / day (PAR of 1516)**
  - **SME mass casualty events at 4-6 hrs and 50-56 hrs**
  - **VME mass casualty events at 26-28 hrs and 48-50 hrs**
- **A large MV22 pool is used to gain insight into the total CRTS transportation and ERC requirements. Divert a/c are also used for CRTS trips.**

Case A

Distances shown are for H+0 hrs.

Case B (Case D same except no FRS.2)

Distances shown are for H+10 hrs.

Case B' (Leap-Frog)

Distances shown are for H+22 hrs.

Figure 2. Overview of TML+ MTF laydowns for Cases A, B and B'.

The various FRSS cases are outlined here for quick reference, and then further elaborated below.

Case A – No FRSS ashore;
Case B – One FRSS travels with the SMEs and is available on a 6/4 hour up/down schedule (the 4 hours "down" include packing up, moving to a new location, and setting up again), and 1 FRSS is brought in with the VME;
Case B' – Same as Case B, but with 2 FRSSs traveling with the SME waves. FRSSs move in a leap-frog pattern to increase the availability of surgical care. The VME FRSS is unchanged;
Case D – A single FRSS travels with the SME, and no FRSS is available to the VME. As the SME moves closer to the first objective, VME patients may be routed to the SME FRSS.

MV22s and lift of opportunity aircraft are assumed for transport to the CRTS (seabase) and are assumed to be Medical Evacuation (MEDEVAC)-qualified, as are the divert aircraft for Casualty Evacuation (CASEVAC) patients. It is assumed that VME forces are employed with CH-53 helicopters that are available for airlift to an FRSS if the VME is deployed with one. Ground-based ambulances (M997s) are available to transport SME casualties to their respective FRSSs. (Adding air lift opportunity for movement to an SME FRSS is a proposed future effort.)

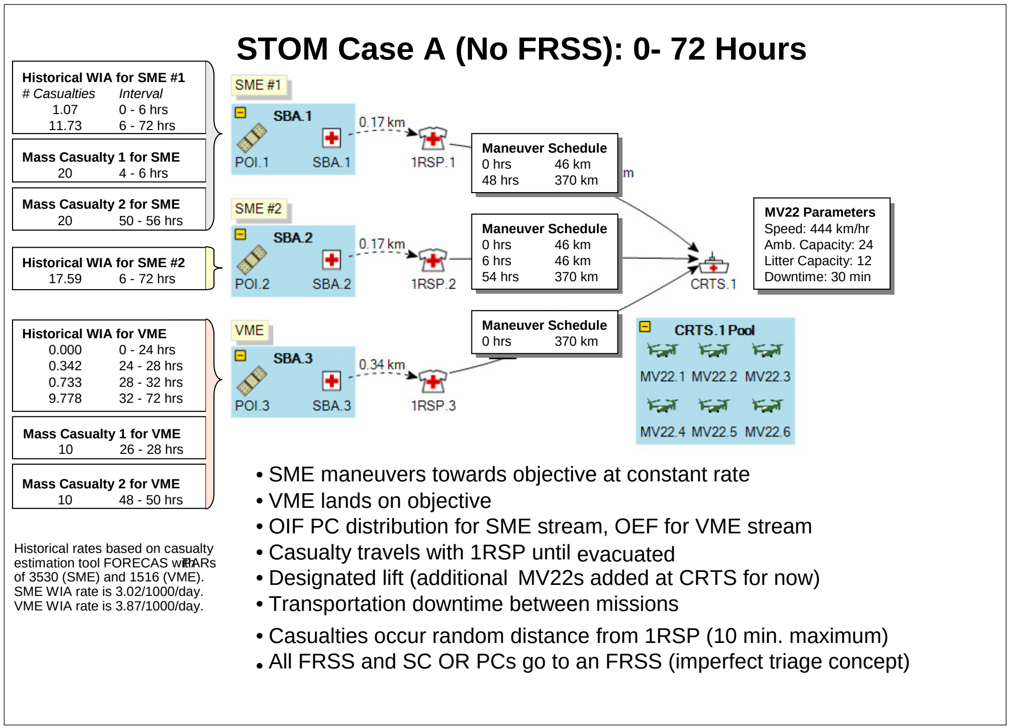
To study the requirements for MEDEVAC transportation, we assumed the MV22 inventory was unlimited (the current CONOPS assumes 2 MV22s). The requirements for ERC, with a description of the kinds and numbers of patients needing transportation from either the 1st Responders or the FRSSs to the CRTS, are described.

Case A

In Case A, there is no FRSS from 0-72 hours. Casualties occur at random distances (10 minutes maximum) from 1st Responders and travel with them until evacuated. There is a designated lift of opportunity, and additional MV22s are added at the CRTS that run at about 444 km/hr, carrying 24 with a litter capacity of 12. Transportation downtime of 30 minutes between missions is accounted for.

Because a 1st Responder cannot make a perfect determination regarding a casualty's injury severity, all surgical PCs were routed to an FRSS, constituting an imperfect triage concept. This means that though everyone initially goes to an FRSS for care, the less severely injured will, instead of going straight to the CRTS, wait in a queue for aircraft to take them to an FRSS. Depending on the injury, waiting is not always a preferable option, but because the FRSS is limited in the number of patients it can hold, this is the chain of evacuation protocol.

The patient stream distribution used for the SME was derived from OIF PCs (PAR=3530). The 2 SMEs move toward their objectives at a constant rate. The VME's patient stream distribution was derived from OEF (PAR=1516). The VME lands on its objective; its schedule is such that at 0 hours, it is at the 370-km mark; its 9 casualties occur mostly between the 32-72 hours. Between hours 4-6, there is a mass casualty event resulting in 20 additional injured personnel. Between hours 50-58, another mass casualty event occurs, and a second group of 20 casualties results.



STOM Case A (No FRSS): 0- 72 Hours

Historical WIA for SME #1	
# Casualties	*Interval*
1.07	0 - 6 hrs
11.73	6 - 72 hrs

Mass Casualty 1 for SME	
20	4 - 6 hrs

Mass Casualty 2 for SME	
20	50 - 56 hrs

Historical WIA for SME #2	
17.59	6 - 72 hrs

Historical WIA for VME	
0.000	0 - 24 hrs
0.342	24 - 28 hrs
0.733	28 - 32 hrs
9.778	32 - 72 hrs

Mass Casualty 1 for VME	
10	26 - 28 hrs

Mass Casualty 2 for VME	
10	48 - 50 hrs

Historical rates based on casualty estimation tool FORECAS with PARs of 3530 (SME) and 1516 (VME). SME WIA rate is 3.02/1000/day. VME WIA rate is 3.87/1000/day.

Maneuver Schedule	
0 hrs	46 km
48 hrs	370 km

Maneuver Schedule	
0 hrs	46 km
6 hrs	46 km
54 hrs	370 km

Maneuver Schedule	
0 hrs	370 km

MV22 Parameters
Speed: 444 km/hr
Amb. Capacity: 24
Litter Capacity: 12
Downtime: 30 min

- SME maneuvers towards objective at constant rate
- VME lands on objective
- OIF PC distribution for SME stream, OEF for VME stream
- Casualty travels with 1RSP until evacuated
- Designated lift (additional MV22s added at CRTS for now)
- Transportation downtime between missions
- Casualties occur random distance from 1RSP (10 min. maximum)
- All FRSS and SC OR PCs go to an FRSS (imperfect triage concept)

Figure 3. TML+ Case A laydown, showing positions for 1st Responders, FRSSs, the CRTS, transportation assets, and distances between them.

Case B

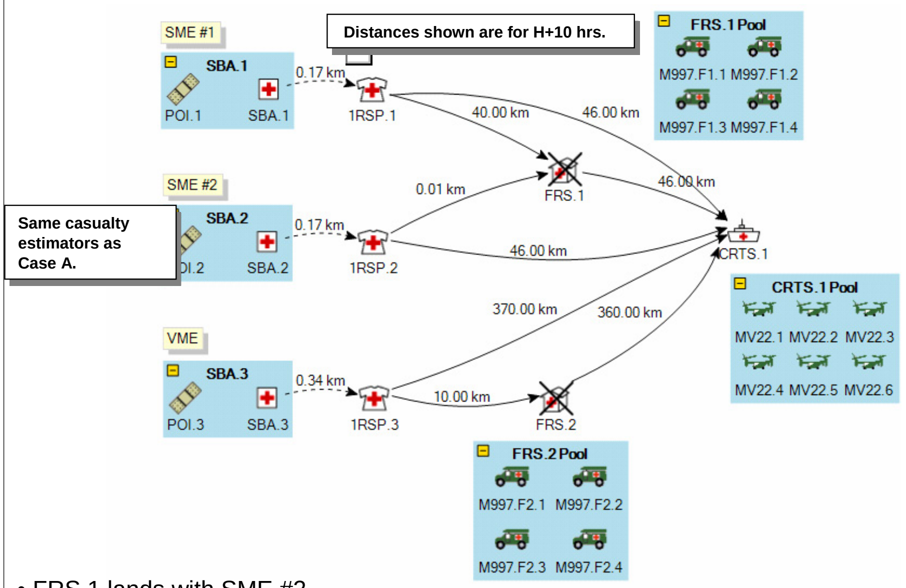
Case B includes 2 FRSSs, 1 traveling with an SME, and 1 with a VME from 0-72 hours. It uses the same casualty estimators as Case A.

The FRSS availability "Online vs. Offline" rule includes travel time and estimated treatment time, and a 4-hour breakdown, move, and setup time is assumed. FRS.1 lands with SME #2, remaining online for 6 hours at a time, e.g., between hours 10-16, 20-26, 30-36, etc., and then offline for the 4-hour intervals indicated.

FRS.2, because it is with the VME, is continuously online between 32-72 hours. Casualties occur at random distances from the 1st Responder (10 minutes maximum), and subsequently travel with the 1st Responder and the FRSS until evacuated. All surgical candidate PCs go to an

FRSS (again using the imperfect triage concept). The designated lift includes additional MV22s added to the CRTS.

STOM Case B with FRSSs: One with VME & One with SME 0-72 Hours



- FRS.1 lands with SME #2
- FRSS availability "Online vs. Offline" rule includes travel time and estimated treatment time
- Casualty travels with 1RSP & FRSS until evacuation
- Casualties occur random distance from 1RSP (10 min. max)
- All FRSS and SC OR PCs go to an FRSS (imperfect triage)
- Designated lift (additional MV-22s added at CRTS for now)

1RSP.1 to FRS.1 Maneuver Schedule

0 hrs	40 km
6	40
19.99	133
20	40
29.99	107
30	40
39.99	107
40	40
49.99	107
50	40
56	62
59.99	62
60	10

1RSP.2 to FRS.1 Maneuver Schedule

0 hrs	0 km
6	0
19.99	93
20	0
29.99	67
30	0
39.99	67
40	0
49.99	67
50	0
56	22
59.99	22
60	10

FRS.1 "Online"	FRS.2 "Online"
10 - 16 hrs	32 - 72 hrs
20 - 26 hrs	
30 - 36 hrs	
40 - 46 hrs	
50 - 56 hrs	
60 - 72 hrs	

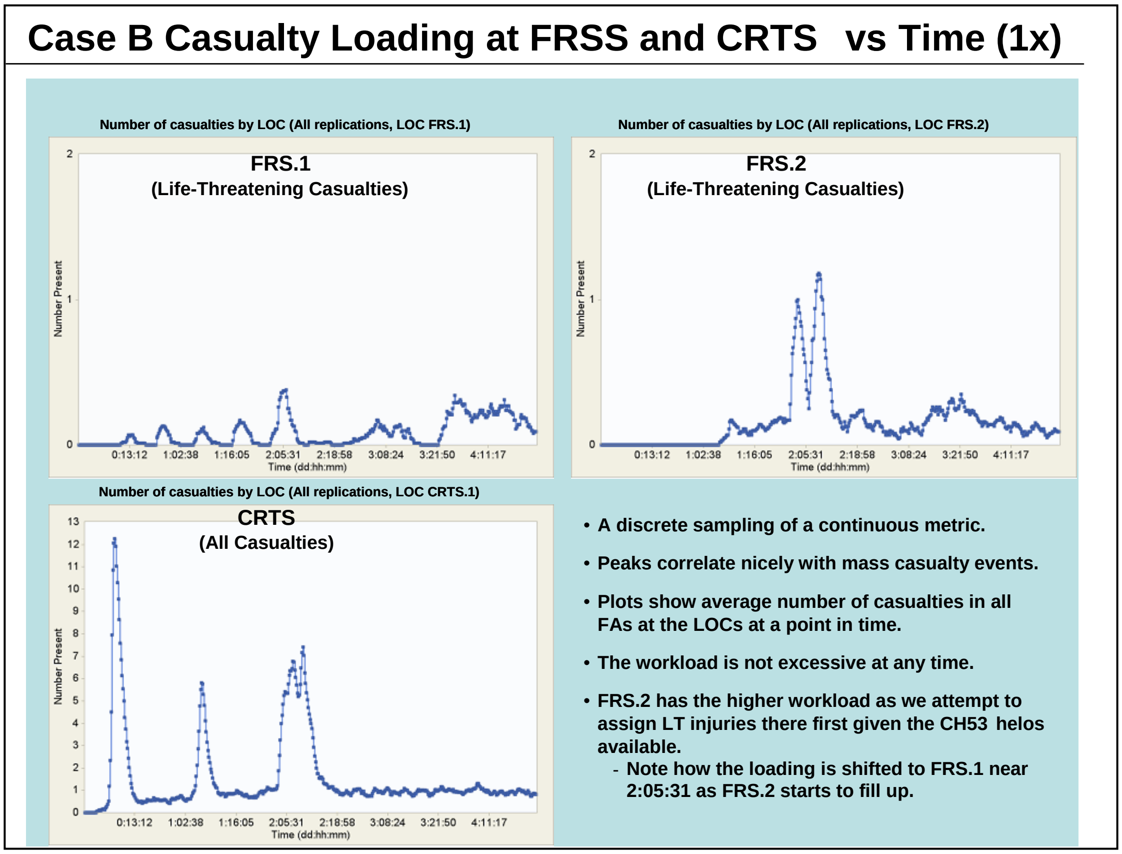
Assume breakdown, move, setup time of 4 hrs.

M997 Parameters
Speed: 88 km/hr
Amb. Capacity: 8
Litter Capacity: 4
Downtime: 10 min

Figure 4. Case B MTF and transportation laydown for the first 72 hours.

Figure 5 shows the average number of casualties in selected LOCs at any point in time, and the charts span the entire duration of the simulation. For instance, the highest peak on the lower left chart indicates that the CRTS is treating slightly more than 12 patients at around H+11 hours. The top two charts clearly show that FRS.1 and FRS.2 never have more than 2 people in them at once. In the upper left chart depicting FRS.1 it is easy to see how the small spikes correspond to the 6/4 hour up/down schedule FRS.1 follows. When FRS.1 is moving, packing, or unpacking, it cannot treat casualties, but as soon as it becomes available again, casualties flow in.

FRS.2, shown in the upper right chart, is associated with the VME and does not have an up/down schedule. Since it is always available, the flow of patients is more continuous. Note FRS.2 has two sharp peaks during the third and fourth mass casualty events. The first peak rapidly decreases as FRS.1 comes online and accepts casualties, then the casualty stream spikes again as FRS.1 goes offline and FRS.2 picks up the casualties again.



Case B Casualty Loading at FRSS and CRTS vs Time (1x)

- **A discrete sampling of a continuous metric.**
- **Peaks correlate nicely with mass casualty events.**
- **Plots show average number of casualties in all FAs at the LOCs at a point in time.**
- **The workload is not excessive at any time.**
- **FRS.2 has the higher workload as we attempt to assign LT injuries there first given the CH53 helos available.**
  - **Note how the loading is shifted to FRS.1 near 2:05:31 as FRS.2 starts to fill up.**

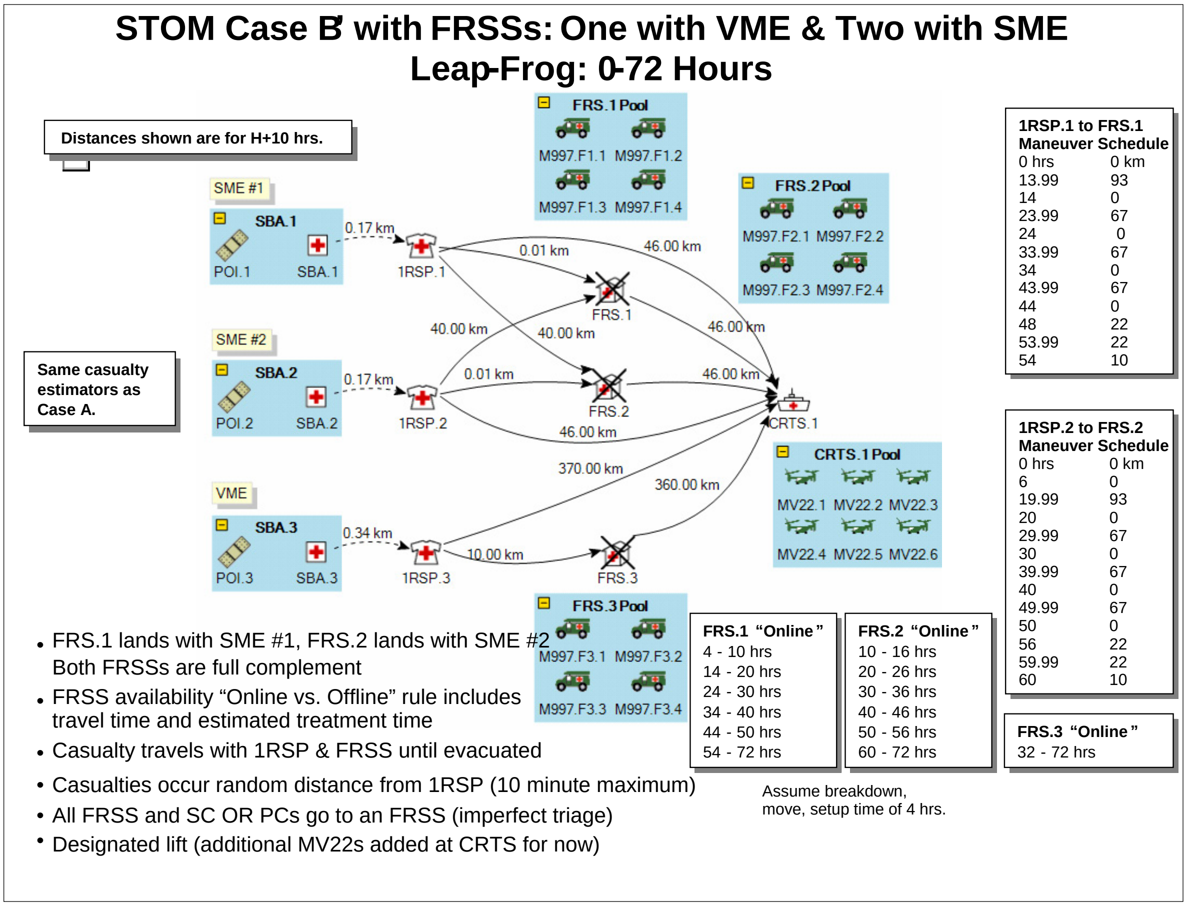
Figure 5. Charts showing Case B casualty loading workload.

The chart in the bottom left shows the relatively uniform and continuous stream of casualties entering the CRTS, with 3 distinct spikes corresponding to the 4 mass casualty events (events 3 and 4 are back to back).

Case B' (Leap-Frog Maneuver)

Case B' is the same as Case B with two important differences: it includes the addition of an FRSS to support SME #2 and it includes the leap-frog maneuver, which means the FRSSs move with the company, but alternate when each are up and running, so that an FRSS is always available to casualties. As in Case B, the availability "Online vs. Off-line" rule includes travel time and estimated treatment time; casualties occur at random distances from 1st Responders (10 minutes maximum), and travel with the 1st Responders and FRSSs until evacuated. All surgical candidate PCs go to the respective FRSSs (imperfect triage).

FRS.1 lands with SME #1, FRS.2 lands with SME #2. Designated lifts, MV22s are added at the CRTS.



STOM Case B' with FRSSs: One with VME & Two with SME Leap-Frog: 0-72 Hours

Distances shown are for H+10 hrs.

Same casualty estimators as Case A.

1RSP.1 to FRS.1 Maneuver Schedule

0 hrs	0 km
13.99	93
14	0
23.99	67
24	0
33.99	67
34	0
43.99	67
44	0
48	22
53.99	22
54	10

1RSP.2 to FRS.2 Maneuver Schedule

0 hrs	0 km
6	0
19.99	93
20	0
29.99	67
30	0
39.99	67
40	0
49.99	67
50	0
56	22
59.99	22
60	10

FRS.1 "Online"
4 - 10 hrs
14 - 20 hrs
24 - 30 hrs
34 - 40 hrs
44 - 50 hrs
54 - 72 hrs

FRS.2 "Online"
10 - 16 hrs
20 - 26 hrs
30 - 36 hrs
40 - 46 hrs
50 - 56 hrs
60 - 72 hrs

FRS.3 "Online"
32 - 72 hrs

Assume breakdown, move, setup time of 4 hrs.

- FRS.1 lands with SME #1, FRS.2 lands with SME #2 Both FRSSs are full complement
- FRSS availability "Online vs. Offline" rule includes travel time and estimated treatment time
- Casualty travels with 1RSP & FRSS until evacuated
- Casualties occur random distance from 1RSP (10 minute maximum)
- All FRSS and SC OR PCs go to an FRSS (imperfect triage)
- Designated lift (additional MV22s added at CRTS for now)

Figure 6. Case B' laydown showing Leap-Frog Maneuver.

Case D

In Case D, shown in Figure 7, FRS.1 lands with SME #1 and FRS.2 lands with SME#2 and both FRSSs are full complements. As with the other cases, the FRSS availability "Online vs. Off-line" rule includes travel time and estimated treatment time, and imperfect triage is utilized. Similar assumptions regarding FRSSs apply: the breakdown, move, and setup time is still 4 hours; casualties occur at random distances (10 minutes maximum) from 1st Responders and travel with them and the FRSSs until evacuated. As for designated lifts, sufficient MV22s are in place to handle all requests. Two designated MV22s handle LT patients from 1RSP.1, 1RSP.2, 1RSP.3, and FRS.1. A divert pool of MV22s handles NLT patients from 1RSP.1, 1RSP.2, and 1RSP.3.

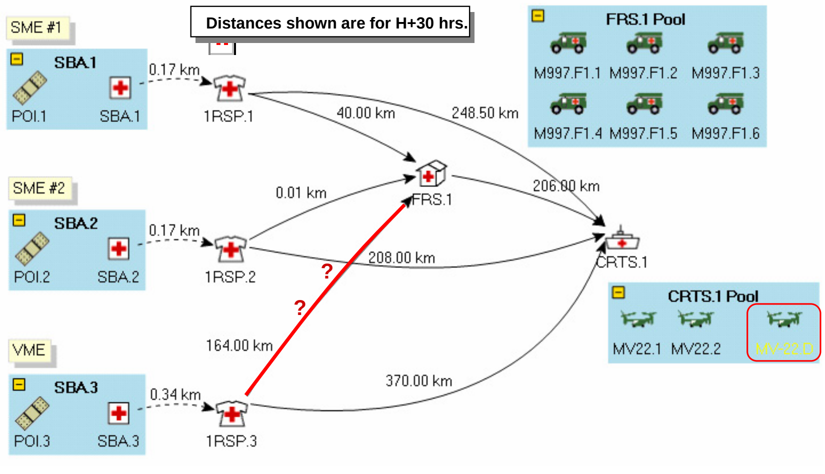
Some of the questions addressed were: Since ground travel to FRS.1 would be long, do we evacuate patients from 1RSP.3 only to the CRTS, bypassing any FRSS? If we evacuate to

FRS.1, which asset(s) would we use? In the TML+ system of queues, will LT patients "attempt" to evacuate to FRS.1 via M997 or divert aircraft? If an FRSS is unavailable, will LT patients evacuate to the CRTS via a designated MV22 and NLT patients using a divert MV22?

In this scenario, SME #1 and SME #2 combine at Objective 1 and move out together to Objective 2 at H+72. FRS.1 remains at Objective 1 until combined SMEs are 10 km away from Objective 2 at H+90. FRS.1 subsequently tears down, travels, and sets up (time 4 hrs), then is available from H+ 94 until H+120. FRS.1 treats only SME#1 and SME#2 patients.

The VME moves to Objective 3 at H+72. FRS.2 remains at Objective 1 and is available at all times, treating only VME patients.

STOM Case D: FRSS Lands with SME Only



1RSP.3 to FRS.1 Maneuver Schedule

24 hrs	230.6 km
29.9	230.6
30	164
39.9	164
40	97.3
49.9	97.3
50	30.6
59.9	30.6
60	10

Divert Aircraft Definition

MV22 Parameters
Speed: 444 km/hr
Amb. Capacity: 24
Litter Capacity: 12

Time from Request to Pickup Point

10%	30 min
20	45
20	60
20	75
10	90
10	105
10	120

- FRS.1 lands with SME #2 only
- Two designated MV 22s (handle *life-threatening (LT)* patients from 1RSP.1, 1RSP.2, 1RSP.3, and FRS.1)
- Divert pool of MV 22s (handle *non life-threatening (NLT)* patients from 1RSP.1, 1RSP.2, and 1RSP.3)

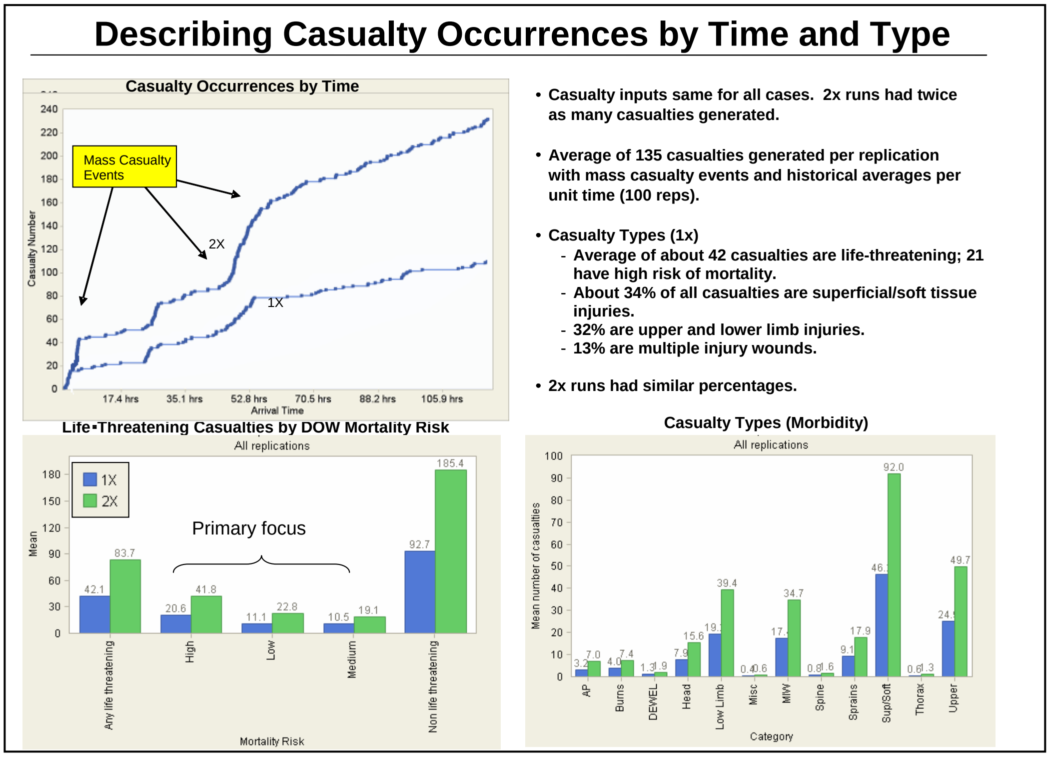
Figure 7. Case D MTF and transportation laydown.

Generating Twice as Many Casualties (2x)

Figure 8 shows the number and types of casualties generated in the scenarios. All cases had the same casualty input stream. To increase the load on the system, we also ran cases that generated twice as many casualties (2x), shown below in green.

The patient stream input for all 4cases is described:

1. An average of 129 casualties were generated by replication with mass casualty events and historical averages per unit time (25 replications);
2. Casualty types (1x) had an average of about 40 LT casualties, 21 of which had a high risk of mortality;
3. About 33% of all casualties were superficial and soft tissue injuries;
4. 33% were upper and lower limb injuries, 13% were multiple injury wounds; and
5. 2x runs had similar percentages.



Describing Casualty Occurrences by Time and Type

- **Casualty inputs same for all cases. 2x runs had twice as many casualties generated.**
- **Average of 135 casualties generated per replication with mass casualty events and historical averages per unit time (100 reps).**
- **Casualty Types (1x)**
  - **Average of about 42 casualties are life-threatening; 21 have high risk of mortality.**
  - **About 34% of all casualties are superficial/soft tissue injuries.**
  - **32% are upper and lower limb injuries.**
  - **13% are multiple injury wounds.**
- **2x runs had similar percentages.**

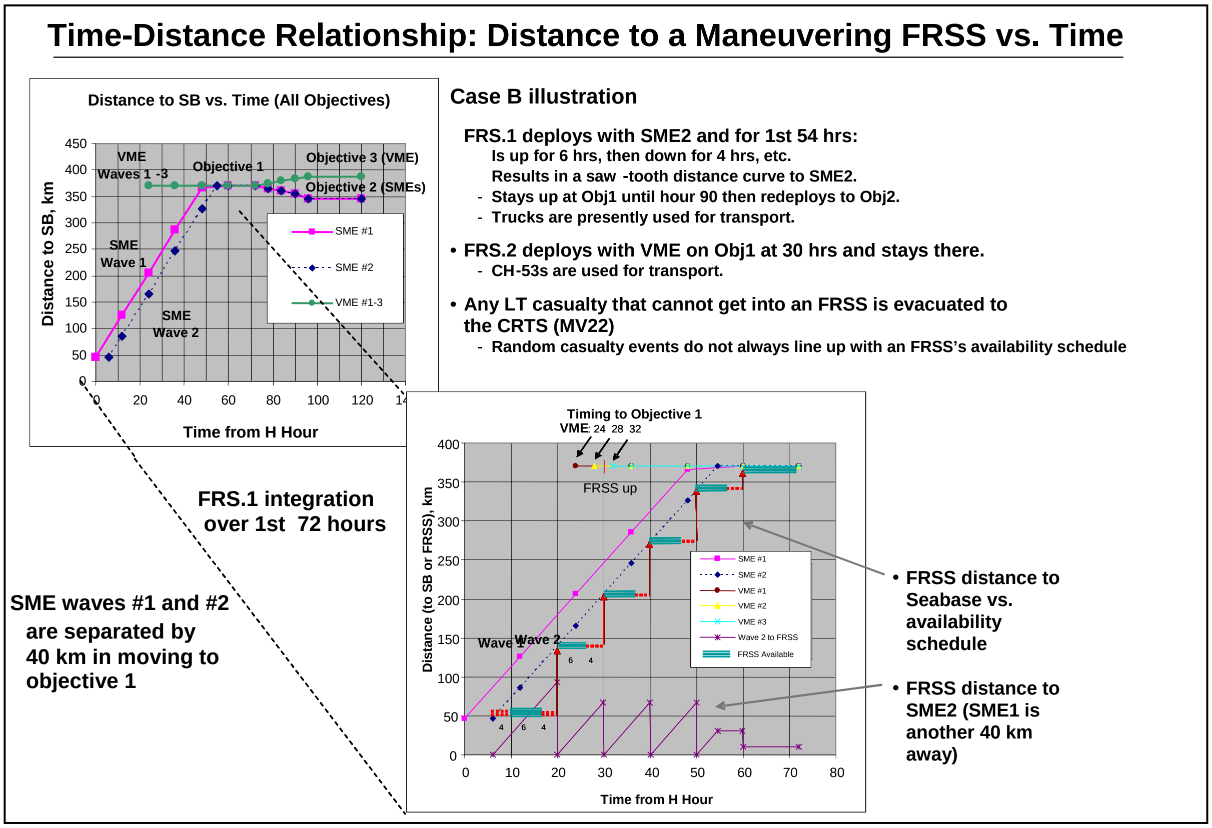
Figure 8. Casualty occurrences by time and type in 2x cases.

The chart in the upper left shows a cumulative count of casualties entering the system. Along the X-axis is the simulation time, and along the Y is the casualty number. The mass casualty events can be seen as the sharp upward slopes in the casualty stream. The third and fourth mass casualty events occur back to back, so they appear to be one very large mass casualty event starting at 48 hours and running through 56 hours.

On the bottom left, the generated casualties are shown based on their LT mortality risk. Only WIA casualties are included in the STOM runs, so approximately 190 PCs could be generated, of which about 75 are LT. This chart shows the STOM's primary focus—the LT PCs broken out by mortality risk; NLT PCs will not need treatment at an FRSS and will not die if they do not receive treatment for a prolonged period of time.

The chart on the bottom right shows a breakout of the types of injuries received. Superficial and soft tissue injuries are the most frequent, and are usually non-life-threatening. However, multiple injury wounds represent a significant percentage and often are life-threatening.

Figure 9 shows the FRSS movement with SME wave #2 for Case B. Since the FRSS cannot treat patients while moving, it moves to catch up with SME wave #2, then sets up and treats patients for 6 hours, during which time the SMEs are moving steadily away from the FRSS. After being active for 6 hours, the FRSS moves to the next location, and is down for 4 hours while it packs up, moves, and unpacks. This movement can be seen in the step-like line moving up the slope with SME wave #2. The thick blue lines on this step represent those times during which the FRSS is available to treat patients, while the dotted red sections are those when the FRSS is not available.



Time-Distance Relationship: Distance to a Maneuvering FRSS vs. Time

Case B illustration

FRS.1 deploys with SME2 and for 1st 54 hrs:
  - Is up for 6 hrs, then down for 4 hrs, etc.
  - Results in a saw -tooth distance curve to SME2.
  - Stays up at Obj1 until hour 90 then redeploys to Obj2.
  - Trucks are presently used for transport.
- **FRS.2 deploys with VME on Obj1 at 30 hrs and stays there.**
  - CH-53s are used for transport.
- **Any LT casualty that cannot get into an FRSS is evacuated to the CRTS (MV22)**
  - Random casualty events do not always line up with an FRSS's availability schedule

FRS.1 integration over 1st 72 hours

SME waves #1 and #2 are separated by 40 km in moving to objective 1

- **FRSS distance to Seabase vs. availability schedule**
- **FRSS distance to SME2 (SME1 is another 40 km away)**

Figure 9. Charts examining the time-distance relationship in Case B, which involves a maneuvering FRSS.

Along the bottom of this chart, there is also a purple saw-tooth line that corresponds to the distance from the FRSS to the SME wave #2. Note that as the SMEs move away from the FRSS, the distance to the FRSS increases along this line, then abruptly moves back to zero as the FRSS catches up with the SME and begins accepting casualties again. Also note that this line represents the distance to SME wave #2; casualties coming from SME wave #1 visit the same FRSS and have another 40 km distance to cover before they get to the FRSS.

LT injuries to casualties that occur at Objective 1 from either the SME or VME forces are sent to FRS.2 if possible, to take advantage of the CH-53 air lift capability.

The difficulty of a random casualty event lining up with the FRSS schedule is illustrated next in Figure 10, which shows that all LT casualties may not receive treatment at an FRSS, due to the

FRSS being offline, busy, or not able to complete a casualty's treatment before a scheduled shut down and move to a new location.

Figure 10 represents the time each casualty exits the 1st Responder for replication 8, in Case B. The LT casualties are noted by either killed in action (KIA), or a red, blue, or green arrow. The colored arrows denote the mortality risk rate of each LT casualty and indicate if the casualty received treatment at the FRSS or was evacuated to the CRTS and why.

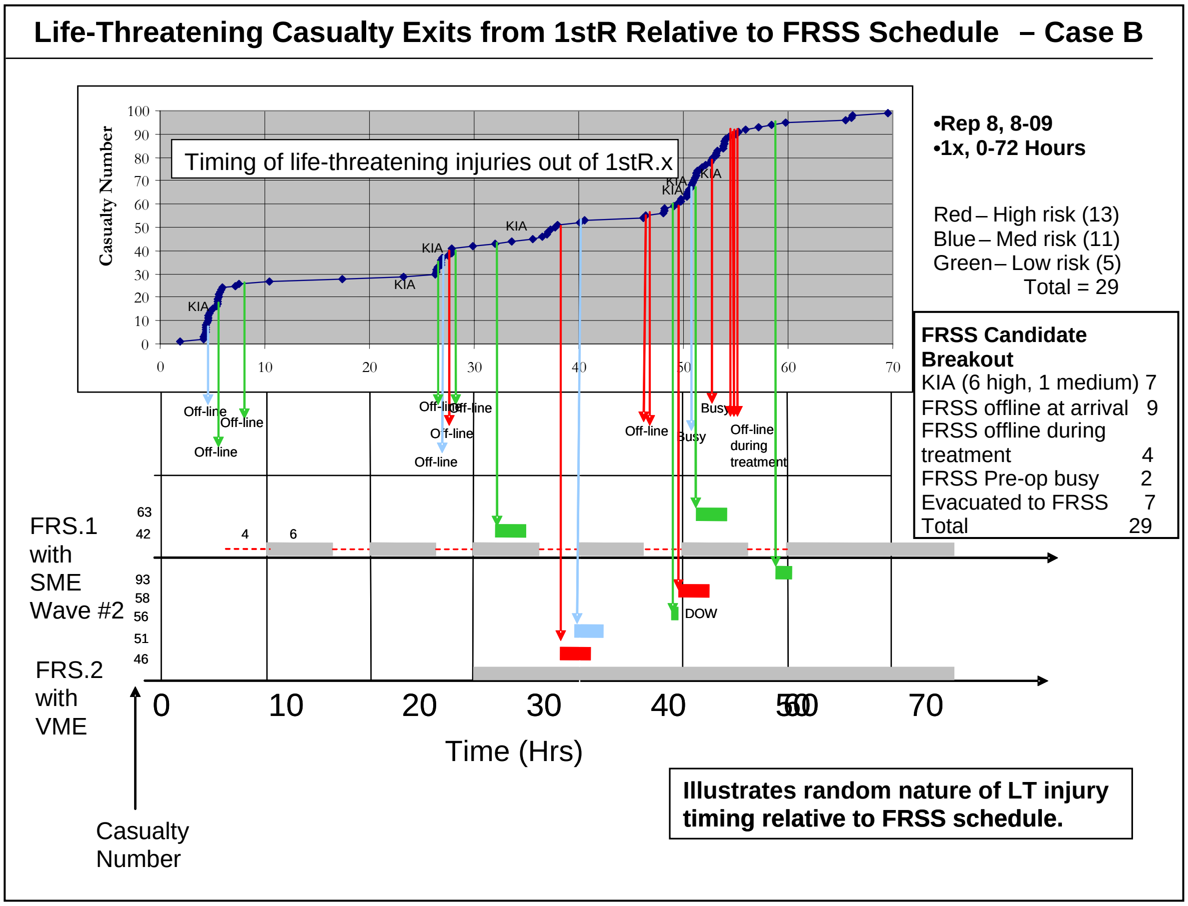


Figure 10. Case B, showing the random nature of injury timing to FRSS schedule.

The bottom section of Figure 10 is a schedule reflecting the hours that FRS.1 and FRS.2 are online versus offline. The solid gray bar is the time the FRSS is online; note the 6/4-up/down schedule. Note that the first three arrows show that three LT casualties occurred prior to arrival of either FRSS. These casualties were evacuated to the CRTS because the FRSS was offline. Notice that between time H+30 and H+40, 3 casualties were able to go to the FRSS for treatment. Other examples to note are between H+51 and H+52, when the FRSS is busy with other casualties and at H+54, when the FRSS is unable to treat 4 casualties before the scheduled downtime.

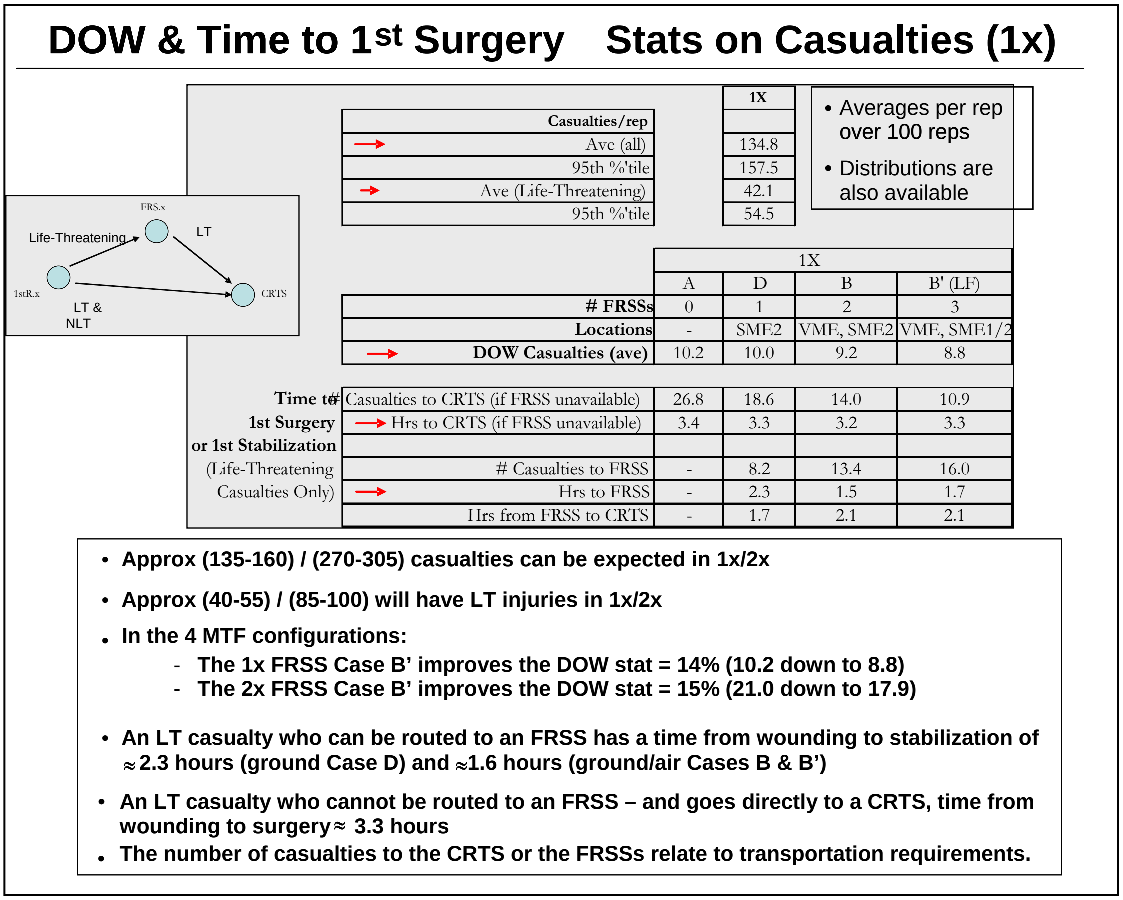
The chart illustrates the random nature of the LT injury timing relative to the FRSS schedule. It is also interesting to note what happened to the total of 29 LT injuries as indicated in the box on the right of the chart.

Results

Observations resulting from the STOM study and analysis:

- STOM can expect about 130 casualties with extremes up to 150 or so, about 1/3 of which will involve LT injuries.
- FRSSs do help save lives on the battlefield (about 14% for 2-3 FRSSs).
- Casualties can get to an FRSS for stabilization about 1 hour faster than to a CRTS.

Overall statistics on the simulation results and the DOW due-to-delay metric for each scenario are shown in Figure 11, as are results revealing how much time elapsed before a casualty first received surgery. A DOW event is defined in this study as a casualty who dies after leaving the 1st Responder.



DOW & Time to 1st Surgery Stats on Casualties (1x)

Casualties/rep	1X
→ Ave (all)	134.8
95th %'tile	157.5
→ Ave (Life-Threatening)	42.1
95th %'tile	54.5

- Averages per rep over 100 reps
- Distributions are also available

		1X			
		A	D	B	B' (LF)
	# FRSSs	0	1	2	3
	Locations	-	SME2	VME, SME2	VME, SME1/2
	→ DOW Casualties (ave)	10.2	10.0	9.2	8.8
Time to 1st Surgery or 1st Stabilization (Life-Threatening Casualties Only)	# Casualties to CRTS (if FRSS unavailable)	26.8	18.6	14.0	10.9
	→ Hrs to CRTS (if FRSS unavailable)	3.4	3.3	3.2	3.3
	# Casualties to FRSS	-	8.2	13.4	16.0
	→ Hrs to FRSS	-	2.3	1.5	1.7
	Hrs from FRSS to CRTS	-	1.7	2.1	2.1

- **Approx (135-160) / (270-305) casualties can be expected in 1x/2x**
- **Approx (40-55) / (85-100) will have LT injuries in 1x/2x**
- **In the 4 MTF configurations:**
    - **The 1x FRSS Case B' improves the DOW stat = 14% (10.2 down to 8.8)**
    - **The 2x FRSS Case B' improves the DOW stat = 15% (21.0 down to 17.9)**
- **An LT casualty who can be routed to an FRSS has a time from wounding to stabilization of ≈2.3 hours (ground Case D) and ≈1.6 hours (ground/air Cases B & B')**
- **An LT casualty who cannot be routed to an FRSS – and goes directly to a CRTS, time from wounding to surgery ≈ 3.3 hours**
- **The number of casualties to the CRTS or the FRSSs relate to transportation requirements.**

Figure 11. Overall statistics resulting from the STOM simulations.

As indicated at the top of Figure 11, an average of 134.8 casualties entered the system for each scenario, 42.1 of which were LT. The middle section of the chart shows the DOW metric, which depends on the average time from wounding to surgery; any delays (transportation, etc.) in getting to surgery increase the casualty's chance of death. Notice that DOW averages decrease in a reasonable direction across the scenarios (i.e., the more FRSSs, the fewer DOWs). A B' (the leap-frog) modified case without a VME FRSS was also run and showed that the additional FRSS saved an average of 0.8 lives (that is, B’ with the VME FRSS had 8.8 casualties after the 1st Responder, while B’ modified had 9.6).

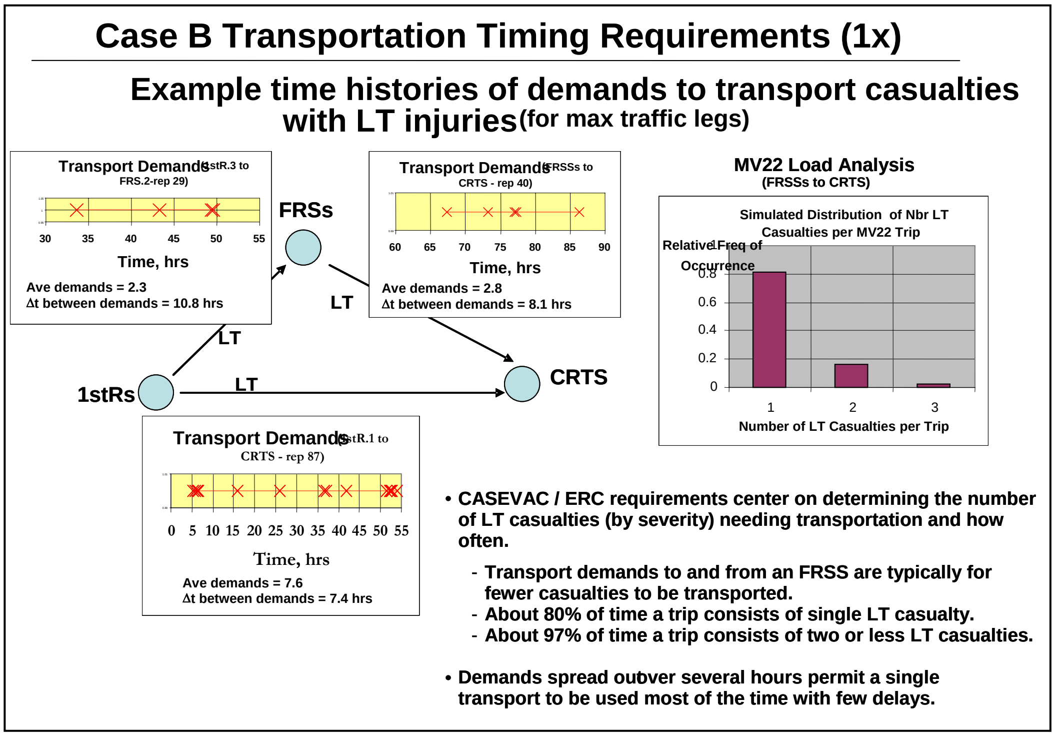
The lower portion of the chart shows the average time that elapsed before an LT casualty reached the CRTS for first surgery (if the FRSS were unavailable) versus the time that elapsed before the casualty reached the FRSS for first surgery (i.e., stabilization) for each scenario. Again, there is a correlation between the average DOWs, the number of FRSSs, and the time to first surgery. The time elapsed before the casualty receives surgery is reduced when there are more FRSSs represented in the scenario, resulting in fewer DOWs.

Some of the observations made concerning transportation include:

- 2-3 MV22s seem sufficient to transport casualties with LT injuries (Availability = 1.0 assumption for now)
- Use of high, medium, and low risk mortality categories could help prioritize MV22 use
- 12-15 flights for baseline case required
- Divert aircraft can be used to transport casualties with NLT injuries (about 30-35 flights for baseline case needed)
- Transportation from the point of injury to the FRSS became an issue, especially since the increasing distances between the SMEs and the FRSS could take a long time to traverse by truck. Additionally, the MV22s have a large capacity and were frequently utilized inefficiently, since the FRSS usually evacuated only a few patients at a time. These issues could be addressed by the use of vehicles better suited for the types of casualties they expect to receive.
- In these results, vehicles are always available, which in reality is not the case. A further exploration on the impact of mechanical failures could be valuable.

The visible reduction in hours to the FRSS for cases B and B’ (LF) is notable and is due to the use of VME helicopter assets transporting LT casualties to the FRSS for those cases, whereas in Case D, only ground vehicles were available.

The demands by time on transportation from the 1st Responder to the FRSS, from FRSS-to-CRTS, and from 1st Responder-to-CRTS for LT casualties are represented in Figure 12. The 1st Responder-to-FRSS leg shows that 2.3 demands occurred for transportation and were spread out over several hours. The FRSS-to-CRTS leg shows similar results, indicating that demands spread out over several hours permit a single transport to be used most of the time, with few delays. The 1st Responder-to-CRTS leg (when the FRSS is unavailable) shows a higher demand on transportation, but the time between demands is still several hours.



Case B Transportation Timing Requirements (1x)

Example time histories of demands to transport casualties with LT injuries (for max traffic legs)

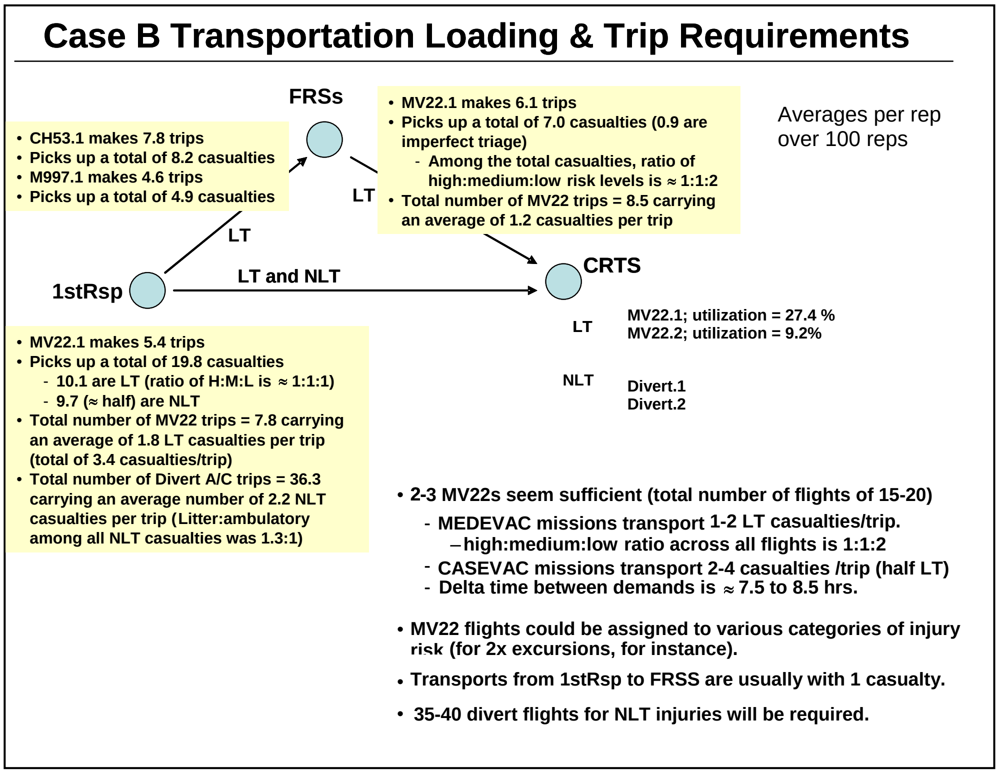
- **CASEVAC / ERC requirements center on determining the number of LT casualties (by severity) needing transportation and how often.**
  - **Transport demands to and from an FRSS are typically for fewer casualties to be transported.**
  - **About 80% of time a trip consists of single LT casualty.**
  - **About 97% of time a trip consists of two or less LT casualties.**
- **Demands spread out over several hours permit a single transport to be used most of the time with few delays.**

Figure 12. Transportation timing requirements for a 1x casualty stream using Case B.

The MV22 chart shows the number of casualties per MV22 trip going to either the FRSSs or the 1st Responders. About 80% of the trips consisted of only 1 casualty.

With this overview of transportation requirements for LT casualties, an analysis is presented that attempts to capture the ERC requirements both in terms of the number of MV22s needed and the composition of casualties needing transportation, categorized by mortality high, medium, or low risk. Definitions of mortality risk are as follows: high=probability of surviving past 1 hour with no treatment is less than 1/3; medium=probability of surviving past 1 hour with no treatment is 1/3 to 2/3; and low=probability of surviving past one hour with no treatment is more than 2/3.

There are three possible demands for transportation – 1st Responder-to-FRSS, FRSS-to-CRTS, and 1st Responder-to-CRTS (when the FRSS is unavailable). For each route, the average number of trips and the average number of casualties transported are given for each type of transport. The mix of LT risk categories are also given, if applicable.



Case B Transportation Loading & Trip Requirements

Averages per rep over 100 reps

- CH53.1 makes 7.8 trips
- Picks up a total of 8.2 casualties
- M997.1 makes 4.6 trips
- Picks up a total of 4.9 casualties

- MV22.1 makes 6.1 trips
- Picks up a total of 7.0 casualties (0.9 are imperfect triage)
  - Among the total casualties, ratio of high:medium:low risk levels is ≈ 1:1:2
- Total number of MV22 trips = 8.5 carrying an average of 1.2 casualties per trip

- MV22.1 makes 5.4 trips
- Picks up a total of 19.8 casualties
  - 10.1 are LT (ratio of H:M:L is ≈ 1:1:1)
  - 9.7 (≈ half) are NLT
- Total number of MV22 trips = 7.8 carrying an average of 1.8 LT casualties per trip (total of 3.4 casualties/trip)
- Total number of Divert A/C trips = 36.3 carrying an average number of 2.2 NLT casualties per trip (Litter:ambulatory among all NLT casualties was 1.3:1)

MV22.1; utilization = 27.4 %
MV22.2; utilization = 9.2%

Divert.1
Divert.2

- 2-3 MV22s seem sufficient (total number of flights of 15-20)
  - MEDEVAC missions transport 1-2 LT casualties/trip.
    - high:medium:low ratio across all flights is 1:1:2
  - CASEVAC missions transport 2-4 casualties /trip (half LT)
  - Delta time between demands is ≈ 7.5 to 8.5 hrs.
- MV22 flights could be assigned to various categories of injury risk (for 2x excursions, for instance).
- Transports from 1stRsp to FRSS are usually with 1 casualty.
- 35-40 divert flights for NLT injuries will be required.

Figure 13. Transportation loading and trip requirements for Case B.

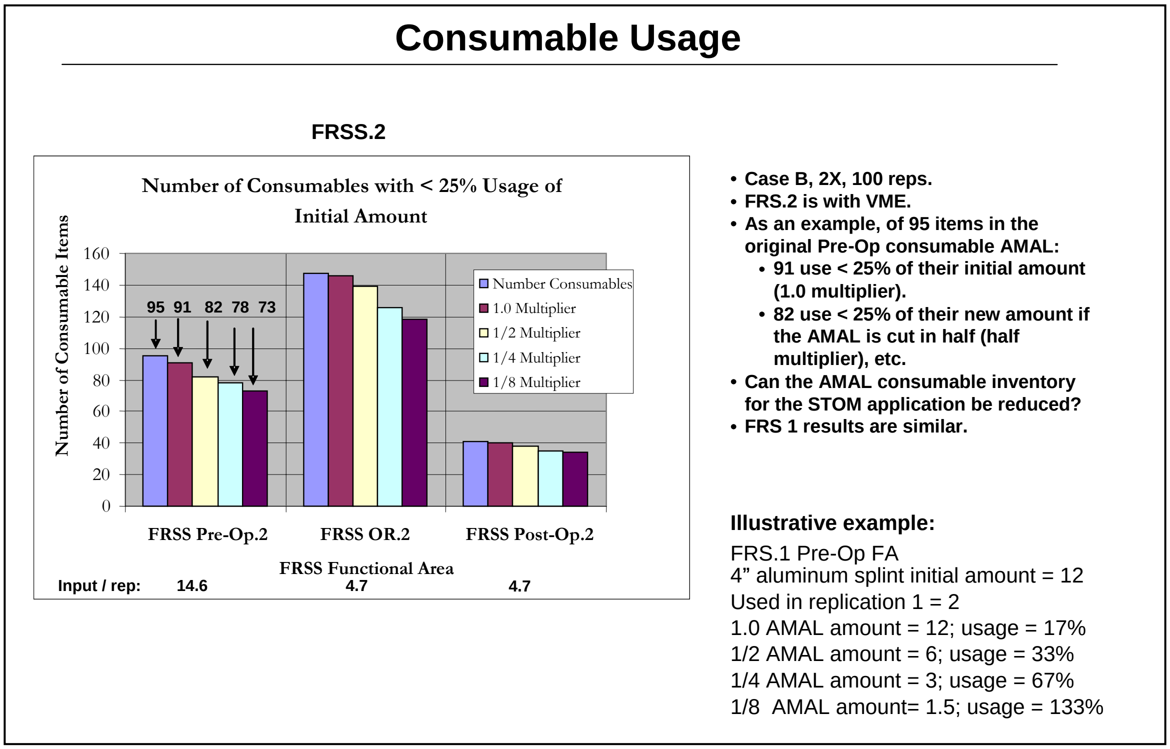
As shown in Figure 13, the route from 1st Responder to FRSS has two types of transports, CH53 and M997. For this example, CH53 transports LT casualties from the VME to the FRSS and the M997 is used to transport LT casualties from the SME to the FRSS. The CH53 made 7.8 trips and transported 8.2 casualties, indicating that the number of casualties per trip was rarely over 1. The same is true of the M997.

The route from the FRSS to the CRTS is serviced by MV22s that we assume are equipped to perform ERC. Again, the average number of casualties per trip was slightly over 1. For all casualties transported, the ratio of high to medium to low risk was 1:1:2. This mix could be useful if the MV22 pool was insufficient to handle all requirements for lift (i.e., maybe the MV22 would transport high and medium risk casualties while divert aircraft would handle low risk).

The route from 1st Responder to CRTS is serviced by MV22s for LT casualties, while divert aircraft are used to transport NLT casualties. However, NLT casualties may be transported by the MV22 if space and time allow. Note that MV22.1 (the most demanded transport) made 5.4 trips from the 1st Responder to the CRTS, transporting 19.8 casualties, almost half of which were LT casualties. About 35-40 divert flights will be required for those NLT casualties unable to take advantage of an MV22. Combined, the number of demands on MV22s for FRSS to CRTS and from 1st Responder to CRTS suggests that 2-3 MV22s seem sufficient. For scenarios with more casualties in which MV22s may not always be available, flights could be assigned to various injury categories to minimize trips.

Figure 14 illustrates that the FRSS is using only a fraction of its consumable supplies in the STOM scenario, even in the cases that have twice the expected number of casualties moving through the system. The blue bars show the total number of consumables for each FA in the

FRSS. The other bars represent the average number of consumables using less than 25% of their initial inventory. For instance, at FRSS Pre-Op.2, there were 95 different types of consumables, 91 of which were used less than 25% for the nominal Authorized Medical Allowance List (AMAL) inventory (multiplier of 1.0).



Consumable Usage

FRSS.2

- **Case B, 2X, 100 reps.**
- **FRS.2 is with VME.**
- **As an example, of 95 items in the original Pre-Op consumable AMAL:**
  - **91 use < 25% of their initial amount (1.0 multiplier).**
  - **82 use < 25% of their new amount if the AMAL is cut in half (half multiplier), etc.**
- **Can the AMAL consumable inventory for the STOM application be reduced?**
- **FRS 1 results are similar.**

Illustrative example:

FRS.1 Pre-Op FA
4” aluminum splint initial amount = 12
Used in replication 1 = 2
1.0 AMAL amount = 12; usage = 17%
1/2 AMAL amount = 6; usage = 33%
1/4 AMAL amount = 3; usage = 67%
1/8 AMAL amount= 1.5; usage = 133%

Figure 14. Chart showing consumable usage by FRSS Pre-Op, OR, and Post-Operation FAs.

The other bars represent consumable quantity multipliers, as illustrated in the text at the bottom right. Using FRSS Pre-Op.2 as an example again, at a 1/8 multiplier (meaning that the original AMAL package is cut by 1/8th) there were still 73 out of 95 types of consumables that were used less than 25% over the STOM scenario (Case B).

This indicates that an FRSS may be carrying many more consumable supplies than are necessary. While this is an area that warrants further study (especially on equipment usage at the FRSS), it stands to reason that if the FRSS supplies could be reduced, it may reduce the pack and unpack time, allowing the FRSS to be available for longer periods of time, which will be very important in a STOM scenario.

Conclusions concerning consumable usage from the model:

- Consumable package can probably be reduced for STOM application.
- FRSS CONOPS for STOM applications should be studied in more detail.
- A variation of the supplies and personnel included in the FRSS may be better suited to a STOM-type scenario. Specifically, a subset of the FRSS may be more efficient and still provide adequate treatment.

Discussion and Conclusion

The primary objective of this study was to provide the MCWL with the medical requirements for STOM, comparing alternate solutions for emergency surgical care in support of surface and heliborne forces. This involved evaluating STOM's operational risk and determining medical treatment and evacuation requirements for SME and VME casualties occurring in conjunction with MTFs like the FRSS, that are subject to periodic tear down and movement to stay close to the maneuver elements.

Simulation results of STOM scenarios provided useful information such as how many and what types of injuries could be expected during STOM events and how many of these would be life-threatening. Based on these injuries, analysis showed that demands on personnel, equipment, or supplies caused delays in patient treatment. Transportation issues for evacuating patients with both LT and NLT injuries were closely studied as well, to determine how many ground and air transports would be needed. The data produced from TML+ also indicated that more FRSS units helped save lives because time to first surgery was reduced.

The open architecture of the TML+ tool provided flexibility as the STOM analysis progressed. New modeling capabilities and functionality were incorporated into TML+, such as the ability of FRSS units to maneuver with the combat element, and the modeling of aircraft deck alert and return downtime.

Finally, the process of exploring and understanding the STOM CONOPS and developing those TML+ scenarios that best reflect it forced the developers and planners to consider new approaches to medical care delivery and casualty resuscitation, stabilization, and transport.

Future Work

Analysis of the TML+ results uncovered other areas of interest that could perhaps be explored to further understand the medical evacuation problems associated with a STOM operation. This is a list of those issues most deserving of further analysis.

- Timing of mass casualty events and FRSS availability have a great deal of impact on how many LT patients are seen at an FRSS. If it can be assumed that a mission planner might know when mass casualty events were likely to occur, it would make sense to be sure an FRSS is available at the same time.
- This scenario assumed the sea base could handle all casualties delivered to it, though in reality this might not be the case. The sea base could also be rendered inaccessible due to weather or the sea state, significantly increasing delays in patients getting to first surgery and highlighting the importance of having an FRSS in the field.
- The DOW algorithm needs to be tested and updated using patient data captured in the N-MC CTR, and long-term morbidity effects of various LOC interventions can be looked at in the future.

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14. ABSTRACT (maximum 200 words)

The primary objective of this study was to use the Tactical Medical Logistics (TML+) planning tool to provide the Marine Corps Warfighting Laboratory with the medical requirements for Ship to Objective Maneuver (STOM) by comparing alternate solutions for providing emergency surgical care in support of surface and vertical maneuver elements. Data produced from TML+ indicated that when more Forward Resuscitative Surgical System (FRSS) units were deployed with the combat elements, more lives were saved because time to first surgery was reduced. About 14% more casualties survive when 2 or 3 FRSSs are available, simply because maneuver elements can get to an FRSS for stabilization about 1 hour quicker than they can reach the seabased Casualty Receiving and Treatment Ship (CRTS). Simulation results of STOM scenarios provided useful information, such as how many and what types of injuries could be expected during STOM events and how many of these would be life-threatening. Based on these injuries, analyses showed whether demands on personnel, equipment, or supplies caused delays in patient treatment. Transportation issues for evacuating patients with both life threatening and non-life threatening injuries were closely studied as well, to determine how many ground and air transports would be needed for medical evacuation. Designating 2 to 3 MV22s was sufficient to transport casualties with life-threatening injuries.

15. SUBJECT TERMS
Ship to Objective Maneuver (STOM); medical requirements planning; emergency surgical care support; Tactical Medical Logistics (TML+) Planning Tool

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