WORCESTER POLYTECHNIC INSTITUTE

MASCAL MASCAL

[A system dynamics approach to a MASCAL]

Timothy Yee

[01 May 2010]

The ideas and beliefs reflected in this work are solely those of the author and are no way a reflection of the beliefs, ideas or policies of the authors mentioned, the Department of the Army, or the Department of Defense.

[This Interactive Qualifying Project uses a system dynamics approach to capture the hectic events of a MASCAL. Using data from past events, a model was built and simulations run to mimic a real world MASCAL and then used to examine where bottle necks affected patient survival. Policies were introduced to the model in an attempt to reduce these bottle necks. Based on those simulations a set of recommendations was made describing which of those policies worked best for a MASCAL.]

Table of Contents

1) INTRODUCTION: 4

A. Definitions: 5

1. Military Healthcare System (CHS) 5

2. MASCAL 5

3. Military MASCAL: 6

B. Previous Studies and Work Done on Mass Casualty Incidents 8

1. Non-System Dynamic 9

2. System Dynamic & Agent Based Modeling 9

3. System Dynamics 10

2) HISTORICAL DATA AND REFERENCE MODELS: 11

A. Historical data: 11

B. Reference Mode: 13

3) MODELING 15

A. Dynamic Hypothesis 15

C. Assumptions 16

D. Sectors 16

E. The Model 17

F. Policies and their limitations: 17

1. Increase in MEDEVAC units available 18

2. Advanced training for medical personnel 18

3. Decreased travel distance 19

4) SIMULATIONS AND POLICY TESTING RESULTS 20

A. Original Model: (default and overload models) 20

4. 0 Patient Model 20
5. 20 Patients Model 21
6. 60 Patient Model 22
G. Policies 24
1. Addition of more MEDEVAC units (more medevac model) 24
2. Advanced Traumatic Life Support Training (ATLS training) 25
3. Moving the MTF Closer (Closer MTF) 25
4. Overview: Best of the policies...26
5. Combination policy (combo) 27
5) RECOMMENDATIONS 28
A. Simulation Recommendations 28
B. Real World Recommendations 29
6) FURTHER TESTING AND CONCLUSION...30
7) DYNAMIC HYPOTHESIS...32
8) SECTORS:...33
9) EQUATIONS: 36
10) INDEX OF IMAGES..40
11) INDEX OF TERMS 41
12) BIBLIOGRAPHY..42

1) INTRODUCTION:

Modern medicine has improved by leaps and bounds over the past years, but there is still one thing that strains any healthcare system to the very limits. A Massive Casualty Incident, known as a MASCAL or MCI, is such an event. In the current time, with the Global War on Terror (GWOT) and numerous natural disasters, there has been a greater emphasis placed on training for an incident where there may be many casualties. But a MASCAL is nothing new; these types of incidents have taken place over generations, as a result of natural disasters or other catastrophic accidents. One of the most common places that have seen many MASCALS is on the battlefield.

Warfare always results in death. When battles are fought, the results are the living, the wounded and the dead. Many are wounded and killed on all sides of a conflict. Consider the siege of Vicksburg during the Civil War. There were approximately 8,000 killed or wounded total. (Headquarters, Department of the Army, 2008) With the many wounded there has always been a system in place to treat them. Basic first aid has always been given to those who were wounded, but the advanced life saving techniques have only been applied on the battle field more recently. These techniques include treating a MASCAL with a modern form of triage.

The purpose of this Interactive Qualifying Project is to use System Dynamics to model a Modern MCI with a focus on the combat healthcare system. The model will demonstrate the difficulties that are facing healthcare providers as they fight so save wounded soldiers and civilians. This model will take into account most of the major variables that affect a MCI, then look at where the bottle necks that clog the system are located. Finally, based on the simulations, introduce and test different policies meant to ease these bottle necks and allow for better treatment of those injured during the MCI. After testing, recommendations can be made based on the results from the introduction of those policies into the model.

This model was built primarily focusing on the military healthcare system but was done so using information gathered about the ways in which civilian and military healthcare providers handle a MASCAL. The data will look at the changes that have been made starting in the 1940s, World War II, and then progressing up to the modern time and the Current Operating Environment (COE); GWOT, Operation Iraqi Freedom (OIF) and Operation Enduring Freedom (OEF).

A. Definitions:

1. Military Healthcare System (CHS)

The military combat healthcare system (CHS) is broken into five echelons; the diagram can be seen in figure 1. Each is responsible for a different level of care and each has its own unique capability. Echelon I is at unit level, starting with three groups. Self-aid and Buddy aid (SABA) then Combat Life Savers (CLS) and finally Medics, they provide immediate care to the wounded. The next is a battalion or squadron aide station also known as a Military Treatment Facility (MFT), Echelon II, where patients are further stabilized prior to transport to the next level. Both Echelon I and II comprise of pre-hospital treatment (PHT) or care that is given prior to the casualties' arrival at a hospital. Echelon III comprises of the Combat Support Hospital (CSH), the first hospital that the casualty will be in. Echelon IV consist of general and field hospitals, normally found outside of the COE, the most notable being Landstuhl in Germany. The final Echelon is composed of stateside hospitals, Walter Reed or Brooke Stone as well as civilian hospitals. (Headquarters, Department of the Army, 2008)See figure 1 for a diagram of the Echelons.

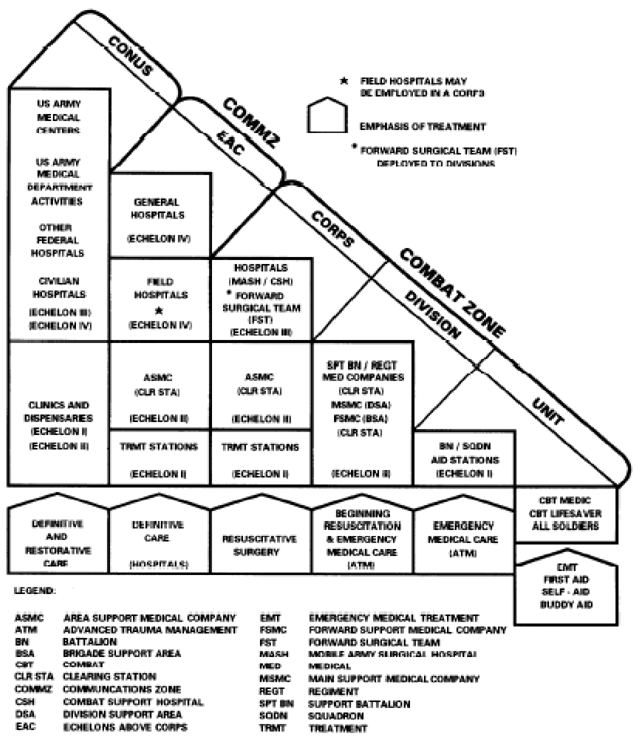


Figure 1 Echelons of the CHS

2. MASCAL

A MASCAL simply put is when there are many injured people, casualties, and the current healthcare system is overwhelmed. It is indiscriminant and strikes anyone, anywhere from a small town in the mid-west to a large metropolis such as downtown Tokyo. Wherever it happens, it can be the result of anything from the failure of a walk-way to the crash of a train. The end result is that the casualties need to be treated. As defined:

The term mass casualties means that a large number of casualties have been produced simultaneously or within a relatively short period of time. It also means that the number of patients requiring medical care exceeds the medical capability to provide treatment in a timely manner. (Headquarters, Department of the Army, 1994)

The MASCAL system can be broken into three major phases in the pre hospital setting. First, the incident and call for help, then triage and treatment, and finally transportation.

3. Military MASCAL:

Military MASCLs differ from civilian MASCALs in several ways. The most obvious is that they most often occur during war or tactical operations. The second are the types and extent of the injuries that are seen, more penetrating trauma than blunt trauma. The "golden hour," the first hour during which a trauma patient has the greatest chance to survive if they arrive at a MTF within that hour, that exists during most civilian traumas does not exist for many injuries seen on the battlefield, instead the golden hour only lasts for a few minutes at most. (Jadick, 2007) (Jadick, 2007) Military MASCALs still share the same beginnings, as any other with an incident, then triage and finally transportation.

The incident is the event that occurs that causes the casualties. There can be many things that cause casualties, on the battlefield. For the COE, the most common are from ambushes and explosive devices. Improvised Explosive Devices, Rocket Propelled Grenades and other forms of explosives, produce blast and fragmentation wounds as well as burns. They account for nearly seventy percent of all combat injuries since WWII. Most civilian traumatic injury is the result of blut force versus the penertrating trauma. (United States Army Medical Department, 2004)

Triage and treatment start once the first healthcare providers, the soldier medic, arrives at the scene and assumes command. Triage is a system used for categorizing and sorting casualties according to severity of their injuries and available resources. (United States Army Medical Department, 2004) Treatment is the aid provided to the casualties. During a combat mission, neither of these may not be possible while still engaged with enemy forces. The healthcare providers often CLS trained soldiers and the soldier medics are an intergrated into a unit and can be engaged by the enemy as well. The soldier medics are animportant part of the team as they are both soldier and medical providers. The first step for the soldier medic when someone is wounded is to return fire and not provide care. (United States Army Medical Department, 2004) Once the fighting has stopped, they can begin caring for the wounded. Triage and treatment must start when it is safe to the providers, or they risk becoming casualties as well. Treatment follows the doctrine of Tactical Combat Casualty Care (TCCC), due to the real possibility that the unit may be re-engaged by the enemy at any time. (United States Army Medical Department, 2004) The primary care consists of three major goals, stop any major bleeding, maintain an airway and ensure the casualty is adequtly breathing. SABA care consist of basic life-saving techniques outlined in TCCC, while CLS and medics will provide more advanced care such as intravenous fluids and advanced airways. Further advanced care will be provided at the next echelons at the battalion aid station and then at the CSH but the casualties must first get to these locations.

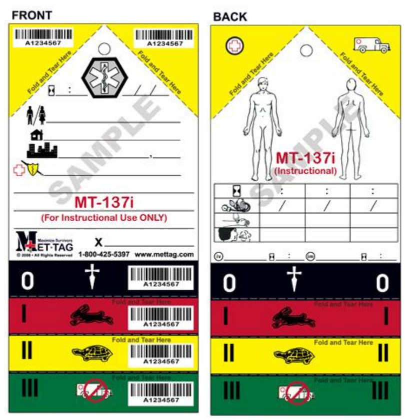


Figure 2 MASCAL Tag

The next major phase is transportation of the casualties, or what is known as Casualty evacuation/Medical evacuation (CASEVAC/MEDVAC). CASEVAC is the transportation of the casualties by any means while MEDVAC is the transportation of casualties by means of a dedicated medical vehicle. (Headquarters, Department of the Army, 2007)   Once casualties have been taken, healthcare providers begin to triage and treat while the leadership calls in for a MEDEVAC. The most common method is by a 9-line MEDVAC request. (United States Army Medical Department, 2004) This method puts into motion the needed resources to evacuate the casualties, and it also notifies the echelons above of the impending MASCAL. The casualties can be evacuated either by air or ground. Specialized aircraft like the UH-60Q as well as the M996/997, seen in figures 3 through 5, are specifically designed to transport casualties. Evacuation by air allows for a greater number of casualties to be moved and continuing care can be proved by the flight medic and is the preferred method. (Headquarters, Department of the Army, 2007)CASEVAC may often be required due to continuing hostile fire, relative distance or terrian. Once at the next level of care, the chances of the casualty surviving are greatly increased. Roughly ninty percent of casualties that arrive at echelon III care, survive. (United States Army Medical Department, 2004)

Figure 3 UH-60Q

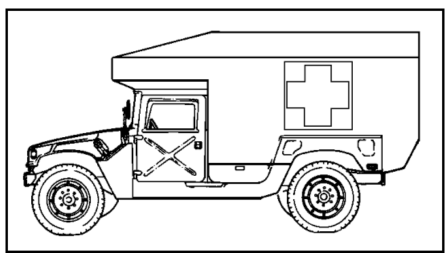


Figure 4 M997

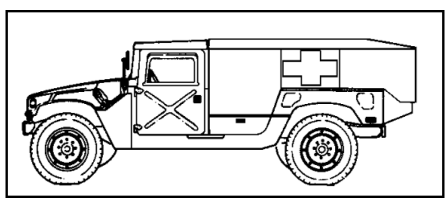


Figure 5 M996

B. Previous Studies and Work Done on Mass Casualty Incidents

System dynamics has been used to model many parts of the public safety system and the health care system. As of yet, there has been no single model, in system dynamics or with agent based modeling, that specifically addresses the MASCAL.

1. Non-System Dynamic

There have been many studies, experiments and simulations done on MASCALs. Each based off real life scenarios. For example a terrorist attack using explosives or a natural disaster that causes a large amount of trauma. Most of these studies have dealt with only specific parts of the larger event.

a) "Mass Casualty Triage Knowledge of Military Medical Personnel"

The article by Janousek, John T (Janousek, 1999), is the summary of a study conducted to see which medical professionals were better at triage. Triage is a key part of any MASCAL because it allows for the proper allocation of resources, the proper categorization of the wounded and the best transportation order of the wounded. Without it, treatment of the injured would be unorganized and ineffective. The study looked at all military healthcare providers, medics, nurses, physicians, surgeons, and physician assistants and gave each a written test in regards to handling a MASCAL. The overall scores results showed that physicians or surgeons were best at conducting the triage and were appointed the triage officer. It also stated that all healthcare providers should be trained to reacting to a MASCAL and how to effectively triage. Doing so would greatly aid the triage officer in making the decision as to who needed the proper medical help.

b) "Army Nurses' Knowledge Base for Determining Triage Categories in a Mass Casualty"

This is another study that looks at how Army nurses handle a triage. (Robison, 2002)Like the previous study, this one looks at the evaluation process where patients are triaged. This study looked specifically at nurses and presented different situations and also included real world observations. The study was conducted in theater with the 47th, 28th and the 21st CSH that were in Iraq during 2003. A worded test was given and the results arranged in a statistical manner. Overall most nurses scored well, the areas that suffered more during the test were in pediatrics and Nuclear, Biological and Chemical (NBC) situations.

2. System Dynamic & Agent Based Modeling

"Agent Based Casualty Care– A Medical Expert System for Modern Triage," (McGrath) is one study that takes advantage of agent based modeling. This model takes an in-depth look at Combat Casualty Care, now referred to as TCCC. In the simulation, each casualty was evaluated using this system, the medic along with higher levels of care are alerted to the status of the casualty. The major advantage to the system is that multiple casualties could be assessed at once using the system. This allowed for a reduced work load on the medical personal, not having to evaluate/triage each patient and would also allow for the most critical casualties to be treated first.

3. System Dynamics

In an attempt to solve the problems presented in this report, System Dynamics modeling will be used as a method of approach. *System Dynamics* is a unique subject that uses computer based modeling to predict possible outcomes of a system. This form of modeling can be applied to many areas of interest, ranging from economics to business and health care. The model represents a problem that a system faces. At first, it is modeled to show how the system would normally behave. The model is then modified using policies that will hopefully help the system from either collapsing or failing. As with anything that can be modeled, however, there will never be a model that is completely correct—all models are somewhat wrong, because reality is unpredictable.

The first step to modeling is the determining a reference mode. The reference mode is based on historical data or mental models that show how other systems' behave over time. The reference mode often reflects the problem as how the system will behave if left alone *then* the solution showing how the model should behave once new policies are implemented.

Once the reference mode has been completed, the next step is to build a *dynamic hypothesis*. The dynamic hypothesis represents the overall model. It shows which are the key factors to consider in the model, how each of the factors affect each other, the different flows between the factors and also the feedback loops within the system. A dynamic hypothesis is built showing the different connections between the factors. The factors are linked together with arrows and then positive and negative symbols showing the growth and decline that each factor has on the other. Using this overall diagram, the positive and negative feedback loops can be seen. Looking at all the factors, their connections and the feedback loops together, they serve as the basis for building the model.

Model construction takes into account all the factors mentioned in the dynamic hypothesis and several minor factors that are not included in the dynamic hypothesis. The factors are represented as *stocks* and the connections as *flows*. The stocks represent an amount of an item such as money, people, cars or any other measurable item. The flows represent the change in the stocks, both the inflow and the outflow. Examples of these flows might include birth rate, death rate, money saved or money spent. *Converters* are variables that allow the modeler to disaggregate the flow equations other major or minor factors that affect both stocks and flows. Combining all the stocks, flows and converters leaves the basic concept of the model. They are then given numerical values and relating equations to make the system work. Once all the parts have been added, the model is tested. When done correctly, the first model will create dynamic behavior similar to those represented by the reference mode. This offers an explanation for the problem that the system faces and how the system is threatened.

Once the first simulation runs, the model represents the problem that the system faces. The next step is to test different policies that may affect the model in such a way that it will stop the system from collapsing or failing. The policies that are tested are designed to have the system to behave in a certain, preferred manner. They can be represented as government regulations or as some sort of industry standard that will affect the system. Once these policies are written, the model is run again to demonstrate how the system behaves with the new policy in place. If the system responds well, then the policy that was implemented represents a possible solution. If the system does not respond well, then a new policy must me written and then retested. With multiple policies, the best one or combinations of the policies are implemented. These policies are put into effect and a game is created allowing users to change the parameters of the policy and seeing how the system behaves. As with all models, this too will be simply an aid to the human decision making process. The end model only represents a single outcome when there are many possibilities.

2) HISTORICAL DATA AND REFERENCE MODELS:

Making a modern MASCAL model will first require several steps before building the model. A collection of historical data is looked at to see what has been tried, where there have been advances in treatment and other factors, and where there have been successes and failures. The reference mode must be built to demonstrate how the key variables behave historically then how they behave after the implementation of a policy. Once those are done, the dynamic hypothesis and model can be built and tested.

A. Historical data:

History has shown that the overall key factor in many MASCALs is time. The further away a casualty is from advanced medical treatment, the more likely they are to die from their wounds. Casualties are the overall variable and are broken into four triage categories. The most immediate must be MEDEVACed as soon as possible or they risk becoming a fatality. Other categories must be MEDEVAC as well or they risk degrading from the original category.

Era	MEDEVAC Type	MEDEVAC Time to (care/advanced care)	Level of treatment (medics/MTF)	Rough Survival Percentage
WWI	Foot/Horse	Hours/Days	Basic first aid/Limited surgery capacity	30
WWII	Foot/Jeep	Minutes/Hours	Basic first aid/Limited surgery capacity	60
Korea	Jeep/Helicopter	Minutes/Hours	Basic first aid/full	70

			surgery capacity at MASH units	
Vietnam	Helicopter	Minutes/Minutes	Basic first aid/full surgery capacity at MASH units	80
Gulf War	Helicopters	Minutes/Minutes	Basic first aid/full surgery capacity at CSH units/Evacuations to advanced surgery as well	90
Global War on Terror	Helicopters	Minutes/Minutes	Advanced trauma care/fully surgery and lab testing available at MTF/Further evacuation for rehab and more advanced surgery	95-98

Figure 6 Table of MEDEVAC Capacity for major conflicts

Historical data organized into a table in figure 6, shows how time delays affected the survival rate among the casualties. Time delays are most common the result of transportation delays or the presence of the enemy.

In World War II, CASEVAC/MEDEVAC was done solely by ground or foot; this meant that the casualty might have to wait hours before reaching an aid station then even a longer wait to reach a field hospital. For even further treatment, the patient would have to wait weeks to reach a state side hospital because the only method of long distance transport was by sea (Headquarters, Department of the Army, 1994).

In the Korean War and Vietnam War, the introduction of the helicopter and the Dustoff, drastically reduced the time that a casualty had to travel before they reached a treatment facility. The development of the Mobil Army Surgical Hospital (MASH), also allowed for surgical units to be placed closer to the battlefield then in pervious wars allowing for a shorter trip in addition to the employment of helicopters. (Jadick, 2007)

In the COE, warfare has become more asymmetrical and rear medical units are no longer behind any lines as they would have been in a tradition conflict. Medical units are now being embedded with conventional war fighting units. This places healthcare providers the closest that they have ever been to the battlefield. The MASH has evolved into the CSH and as a mobile unit is capable of being sent to any remote location while being self sustainable (Headquarters, Department of the Army, 1994). Time delays have been further reduced as Dustoffs helicopters have advanced even more, flying faster, further and with the ability to carry more patients along with advanced medical gear. The 9-line MEDVAC request along with improved radios, streamline communication and help alert healthcare providers to incoming casualties and also advises them on the status of these casualties (Headquarters, Department of the Army, 2007). Advanced and basic life support training has helped front line healthcare providers' better treat the wounded further from a MTF. More advanced SABA training, for every soldier in the unit, has also helped in the treatment of casualties. Even with all new technology and advanced training, units still take casualties. Many will live and some will not.

B. Reference Mode:

The reference mode will show the most basic possibilities of the system. The stocks will be the four triage categories but a more simplified version of wounded, dead and treated. Wounded are the number of people who wounded and classified as Immediate. Treated will only include Pre Hospital Treatment (PHT) and they are considered stable for the time. The dead are the casualties who are expectant or are have died from wounds. Using the historical data as a guide, the first mode will show a MASCAL where there are no policies introduced. The next modes will be when a policy is introduced and the out is favorable and when the outcome is not. It is assumed that the beginning of the MASCAL takes place at time 0, so there is no sudden spike in the graph and there are initial values to some of the variables.

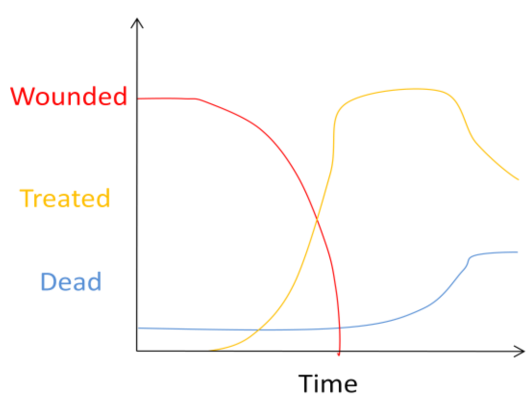


Figure 7 Reference Mode

The first mode shown in Figure 6 represents the system without any policies in place. Wounded, treated and dead are the stocks that are affected by time. The wounded are treated in a timely manner and become the treated. The problem comes up as time progresses, is that the casualties that are treated risk death due not being evacuated in time. Time delays can be the result of many facts as noted earlier, and travel time is noted as being the largest. These delays can often prove fatal to the casualties. While they are stable for the time being, there is the real possibility that their condition could degrade so rapidly that they die prior to arrival at a MTF. In a MASCAL, casualties maybe triaged and treated with little delay, but if they fail to be MEDEVAC they can lose their life. This mode reflects the need to address the issue of time delays to prevent loss of life.

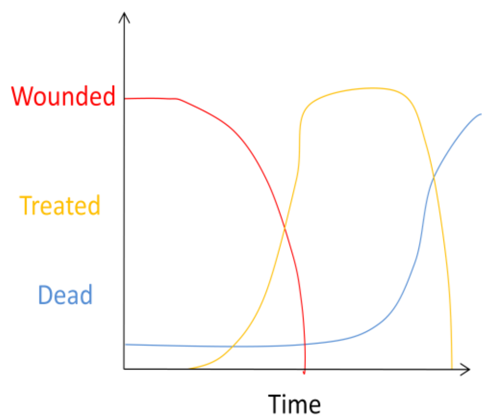


Figure 8 Undesired Results

The mode shown in Figure 7 reflects the worst case scenario after the introduction of a policy and is the result that is not wanted. The result is complete and utter failure of the CHS and shows that the introduced policy will produce undesired results. All casualties are treated but begin to die as time progress. The point reaches where all of the casualties have died as a result of this policy. This result is something that the model will try to avoid.

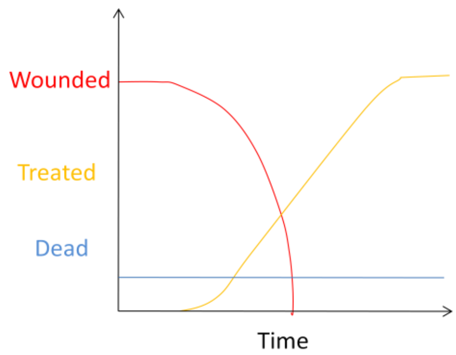


Figure 9 Desired Results

The final mode presented in Figure 8 shows the desired results. The introduced policy allows for the wounded to be treated and the treated casualties to be evacuated from the battlefield to a MTF where they can receive further care and stabilization. This prevents more casualties from becoming fatalities and keeps the number of dead low. If the results of a policy demonstrate this mode then the policy represents the desired outcome.

The reference mode demonstrates the principle bottle neck of the MASCAL system, time. Every action from time 0 has an affect on the survivability of the wounded. The initial triage and treatment of the wounded is done quickly and has a minimal time delay. Once the wounded arrive at a MTF, they have a high survival rate. Looking over the historical data shows that the single largest time delay is in MEDEVAC. Due to the limitations of the capacity of the MEDEVAC, the bottle neck occurs between getting the wounded out of the field and into a MTF. While advances have reduced this delay, it is still the single largest delay that has the greatest affect on the survival rate of the wounded.

3) MODELING

A. Dynamic Hypothesis

The dynamic hypothesis maps out the mental model created prior to the development of the model using Mystrategy software. Using this diagram, we highlight all the key variables in addition to the flows to and from these variables. We also look at how each of the key variables are inter dependent to another and how each will affect another. The key things to note from the dynamic hypothesis are the flow of wounded from one section to another, then the MEDEVAC variable and their time delays.

C. Assumptions

In a real world MASCAL there are many factors that affect the overall outcome. Many of these factors fall outside the realm of human control while others are easy to adjust. To regulate these factors some were assumed to be true or held constant. For the beginning model, these assumptions help control the model and focus it primarily on the flow of casualties. The assumptions are as follows:

- Security is fixed with no need for additional units/ armed escorts
- All MEDEVAC is done via Dustoff
- MEDEVAC platforms are standardized (UH-60Q)
- Weather has no effect on the performance or availability of MEDEVAC
- There are no CBNR (Chemical, Biological, Nuclear, Radioactive) threats
- All casualties are Coalition forces
- All units and MTF are fully stocked with all needed medical equipment
- There are no other events taking place during the MASCAL
- MEDEVAC units are co-located with the MTF
- Travel time to point of wounding from the MTF is 30 minutes, time on the ground is dependent on the number of wounded and travel time back is 30 minutes

D. Sectors

The model is broken into three sectors and several smaller sub-sectors. The large three are the MEDEVAC, Field and MTF sectors, with the minor sectors being Time Delays, Results, Testing variables and Patients. (see section 8 for full sector layouts)

The MEDEVAC sector deals with the flow of MEDEVAC units, it contains the stocks and flows of the helicopters. This includes when they are called on to missions, when they become available, their travel time and their capacity to handle patients. The Field sector, deals with the patients in the field. This includes the initial incident, their initial triage and then the time they wait for transportation. The final sector is the MTF, this is when the patients arrive at a MTF and they are either saved or lost based on the extent of their injuries and the time between the initial incident and when they arrive at the MTF. The minor sectors were added to help organize key variables, as well as the results so that they could be easily viewed and changed for testing.

E. The Model

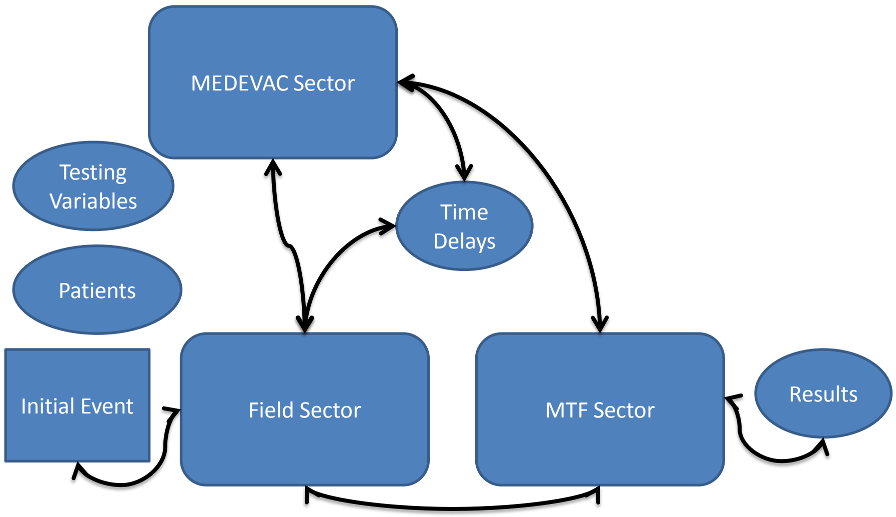


Figure 10 Sector View of Model

Figure 10 shows an over view of how the model was set up. It shows where the sectors are located as well as both the major and minor sectors and their relationship to one another. Please refer to section 8 for a complete overview of each sector as well as a larger model.

F. Policies and their limitations:

The golden hour represents the best chance for survival of a casualty. Getting the casualty off the battle field and to a MTF within this hour will significantly increase the chances of their survival. The following polices are based on written ideas of healthcare professionals as well as policies that would seem common sense. These policies either try to extend the golden hour or to get the casualty to a MTF within that golden hour. The tests that are run on the model will be done twice with each policy to show both sides of the policy, if implementing a certain policy actually helped or hindered the process. The final step will be a combination of the policies to address the question of whether the policies that worked alone, also work in unison. The limitations to these polices will also be discussed to show the positives as well as the negatives of the policy. These limitations are addressed here and should be noted that they are not included in the model due to the limitations of this software. It is important to be made aware of these limitations so a mental note can be made and understand why the model was tested using certain values.

1. Increase in MEDEVAC units available

For the original simulation the MEDEVAC unit was set with four helicopters. With the set value, the model could only handle four operations or a maximum number of twenty four casualties at any one time. This policy is based on the idea that putting more MEDEVAC units in the COA will allow for more casualties to be evacuated at the same time. The policy is straight forward and logical.

To run this policy the model will be adjusted to show two main variations. The first adjustment will be a decrease in the units available. The idea behind the first test reflects outside circumstances, maintained issues or other operations. This is designed to show what if there are fewer helicopters available to provide MEDEVAC and if the results are what are expected. This second adjustment will be an increase in the units available. The idea being an increase in the number of helicopters assigned to a unit or additional units that are able to assist the original unit. There is an added benefit of increased realism with this test, as the original values were assumed to be fixed. The completed testing of this policy will show whether an increase or decrease in the units available to conduct a MEDEVAC is beneficial or not to the model.

While at first glance, this may seem like the best option for reducing the MEDEVAC time, there are several other key factors that limit the viability of this option. When sending a MEDEVAC mission out, it will often require an armed escort. Sending more MEDEVACs out would require more escorts and this would burden and may harm other units, for example another unit may require air support from gunships but none are available due to the MEDEVAC mission. Another limitation is the landing space at the MTF. While they are located at a major base, the space may be limited to a certain number of helicopters at any one point. Having more helicopters in the air, both MEDEVAC and escorts would crowd the airspace, delay arrival time and increase the chance of accidents. These represent some of the limitations to this policy and how implementing it would require these to be overcome.

2. Advanced training for medical personnel

The lower levels in the CHS provide the most basic care the casualty can receive. Once they reach a MTF they begin to receive the more advanced care and their chances of survival greatly increase. The test in this policy is providing the advanced care that is traditionally found in a MTF, in the field at the point of wounding.

This policy will adjust the value of the converter Medical personal. The advance training that the medical personal receive, will act as a combat multiplier. The original value of Medical personal will remain the same, but a new converter will be introduced, ATLS training. In addition, a delay will also be added to the golden hour of the most severally wounded, reds. Depending on the training, the advanced training will act as a multiplier for Medical personal. The more advance training that they receive, the higher the multiplier will be. These tests will show if the more training that the medical personal receive, aides or hinders them in the speed and quality of their care. The key goal to this is to extend the golden hour for the wounded allowing for a better chance of survival should MEDEVAC be delayed or if the MTF is far away.

As with the MEDEVAC policy, there are also limitations to this policy. One major obstacle that this policy would face is training time. Units are required to undergo mandatory training before deployment often going over mission specific tasks. Medical skills are important but there may be times where the tasks of the unit will be given top priority and the medical task takes a second seat. That being said, the ATLS skills may not be taught. Another major drawback to ATLS is that there may not be enough time for providers or medics to use their skills. They could be constantly engaged by the enemy during the event and unable to provide care, so their ATLS skills would be of no use. Considering the limitations of this policy, these are minor factors that could be overcome.

3. Decreased travel distance

The largest area of delay that is represented in this model is the travel delay. Total time that it takes for an operation to come in, to be sent and to be completed has one of the largest effects on the survival of a casualty. Based on the experiences written by CDR Jadick (Jadick, 2007), deceasing the total time from point of wounding to advanced care at a MTF would greatly increase a casualty's survival chances. CDR Jadick acomplishes this by placing his BAS as close to the battle field as possible.

The policy testing done will reflect what was written by CDR Jadick as well as the opposite. The first test will show a increase in travel time. The point of wounding is far from a MTF and the total travel time is much greater than the original model. The converters that only affect travel time will all be increased, other delays will remain unchanged. Following this test, the travel times will be reduced. The point of wounding will be much closer to a MTF than in the previous test as well as the orginal model. The converters affecting the travel time will be changed while all others remain the same.

Like the two other policies, this policy also has it's limitations. Currently most MTF are located on instilation surrounded by other units that will support the medical unit. By moving the MTF away from the instilation means that they can provide advaced care to the patients in less time then before. But at the same time, the security for the MTF goes dramaticly down. The medics and the patients are now exposed to the enemy. This would mean additional units are required to help protect the MTF and its personal. Having the additional units protecting the MTF would mean a reduction in the higher unit's combat power. During a major operation, this may not be possible, as CDR Jadick (Jadick, 2007) wrote about, the needed security may not be avaliable. With the possibilty of lossing a MTF during a major operation, a commander may be reluctant to place that asset in such a location.

4) SIMULATIONS AND POLICY TESTING RESULTS

A. Original Model: (default and overload models)

The base model was tested using three initial values for patients and with all other variables set to the base values. The initial values for patients were; zero, twenty and then sixty. Initial value of zero was used as a check of the model to ensure that all part worked correctly. With zero patients, the model was supposed to have no changes at all. Then a twenty patient model would be to test the model with a small number of patients. This was designed to test the model under a normal situation and it was not intended to overload the model causing a crash of the model. With 60 patients, the model was supposed to be overloaded. The number of patients dying was supposed to increase and the number of surviving was supposed to decease. There would also be a noticeable increase in the time delays in that model as well. These are the initial settings for all the testing variables:

MEDEVAC units	MEDEVAC capacity	ATLS training	Distance to MTF	Distance to pt
4	24	1	30	30

Figure 11 Initial Values for policy variables

4. 0 Patient Model

The zero model set the patient number to zero where it remains for the entire simulation, figure 12 shows the results from the run. This was used to simulate equilibrium in the model where there are no changes throughout the simulation. The results showed that the model functions in correctly in this state. With zero patients, there are no deaths and no survivors.

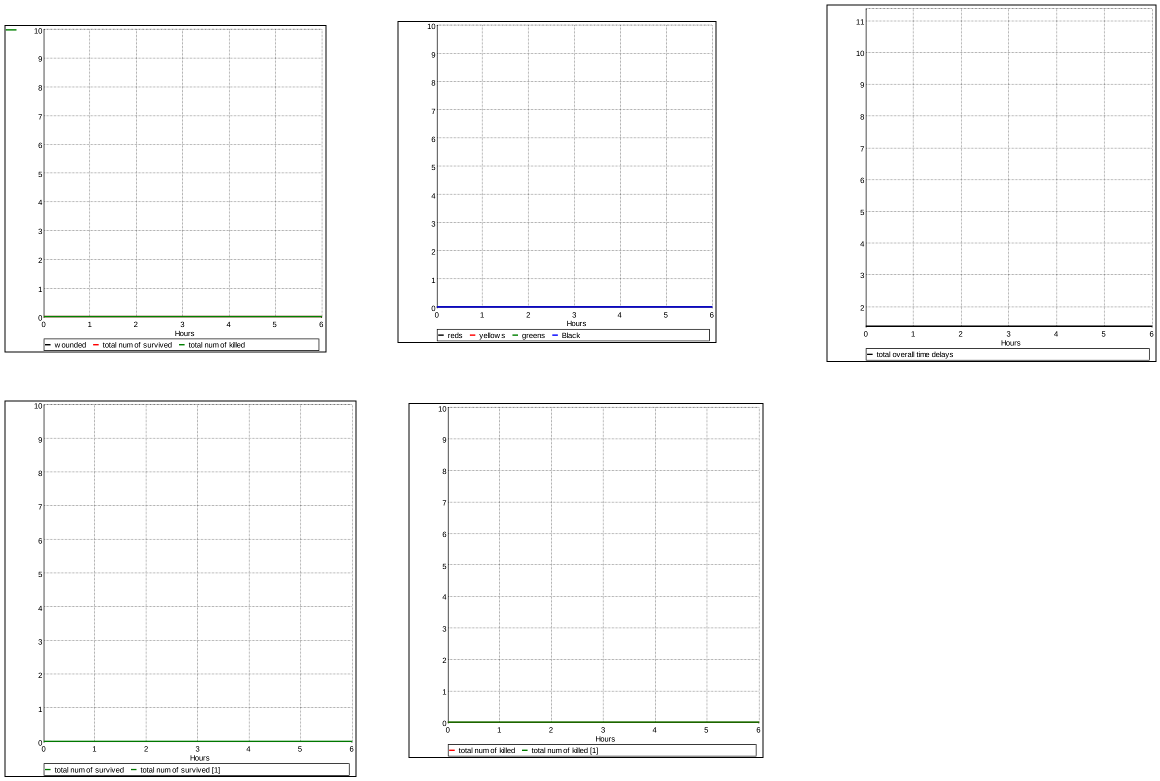


Figure 12 0 Model Results

Figure 12 shows how all the key result is with zero patients. All categories of patients, all time delays and the ratio between those that lived and died are at zero. Setting initial patients to zero has shown that the model behaves as expected with the given value. The next value entered would test the system, but would not cause it to collapse.

5. 20 Patients Model

The setting for this simulation was twenty patients. This would allow the model to run and simulate a small MASCAL, and check to see if the model ran the way it is supposed to with patients. Like the zero patient model, this value will not crash the model as the given number of patients is a number that the model should be able to handle.

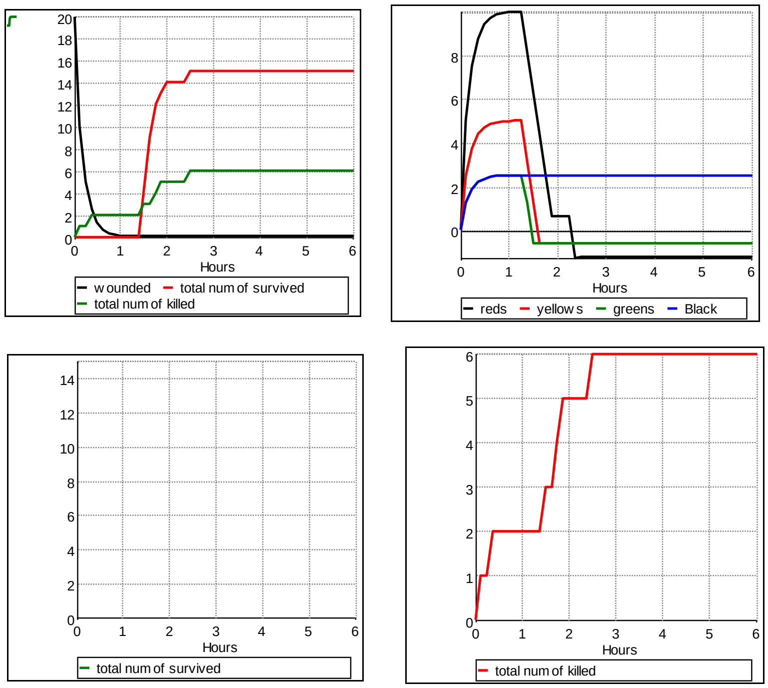


Figure 13 20 Patient Model

The results from running the twenty patient simulation show that the model behaves as expected when patients are introduced. Unlike the zero model, the graphs show that the model reaction to the new patient values. There are now wounded, so both survived and killed now have values. Given the initial number of patients is twenty; there are fourteen who survive and six who are killed. Refer to figures 13 and 14 for this run.

Total Wounded	Survived	Killed	Ratio killed to wounded
20	16	4	4 to 20

Figure 14 20 Patient Model Results

The initial results show that with the current system, no policies and not being over loaded, that one in four of the wounded died. This ratio is decent, but when it comes to saving lives a higher ratio is always better. Like the zero patient simulation, this was only a test to ensure that the model worked when there were patients. All parts of the model function as they should. The next step was to simulate an overload of the model by increased the number of patients.

6. <u>60 Patient Model</u>

This model is used to simulate when there are an overwhelming number of patients. The system is strained. While care is provided to all, the ratio of killed to survive is a lot worse. To make this simulation overload, the number of patients was increased to sixty, with the maximum transport capability of the system being, four helicopters with six patients each, twenty four patients total. As with both of the previous simulations, there are no policies in effect. The results are as follows in figure 15:

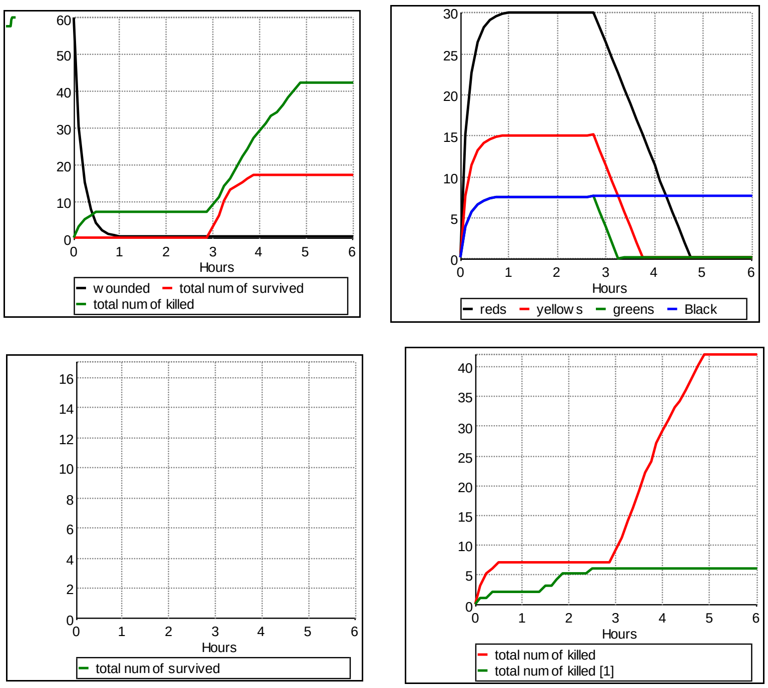


Figure 15 60 Patient Model

There is a substantial increase in the number of killed and a decrease in those who survive their wounds. The time delay also jumps as a result of the MEDEVAC sector being overwhelmed and the need for additional units to be called. The golden hour rule is in full effect and a majority of those, that are considered red, die from their wounds based on the current curve.

Total Wounded	Number Survived	Number Killed	Killed v. Wounded
60	18	42	42 of 60

Figure 16 60 Patient Model Results

With the patient number at sixty, the system becomes overloaded, especially in regards to the transportation of the wounded. Looking at figures 14 and 15 shows the difference between the first two runs of zero and twenty patients and this run. These results will be used as the values to compare new policies against. The new policies that were mentioned before will focus on the time delays and how to reduce them.

When comparing the sixty patient model to the reference modes mentioned before, there is a clear connection to the undesired results, figure 8 and this simulation. The first graph from figure 14 shows killed versus survived and is almost an exact match to the undesired results of figure 8. With the sixty patient model mimicking, the undesired reference mode, the next step is to introduce the policies and determine which of them will bring the model closer to the desired reference mode, seen in figure 9.

G. Policies

1. Addition of more MEDEVAC units (more medevac model)

The primary limiting factor causing an overload in the system is the number of MEDVEAC units available. The initial value is four helicopters, which amounts to a transport capacity of twenty four patients in total. When the there are more than twenty four patients, the request for additional MEDEVAC variable goes into effect. This solves the transportation issue, but adds an additional time delay, as it takes time for the request to be made and for those units to arrive at the location.

Knowing that the value of four helicopters is not enough to support a MACAL of more than twenty four patients, a policy is introduced to increase the helicopters available. The first change was to increase the number of helicopters by four, doubling its current capacity (now eight), then a further increase by eight, tripling the capacity (now at twelve). An additional change was to reduce the number of helicopters to test whether increasing the number actually helps. The simulations had sixty patients in each of the simulations. The results of the simulations are shown below in the simulation results section. Number, title, and refer to table.

Simulation	Wounded	Number of helicopters	Total helicopter Capacity	Number Survived	Number Killed	Killed vs. Wounded
1	60	4	24	17	43	43 of 60
2	60	8	48	17	43	43 of 60
3	60	12	96	26	34	32 of 60
4	60	2	12	17	43	43 of 60

Figure 17 MEDEVAC Policy Results

Overall the results from figure 17 show that forty three of the wounded died from their injuries in simulations 1 and 2. Doubling the number of helicopters did not have the desired effect in reducing the number killed; in fact there was no reduction in the number of those killed. The next simulation, the number of helicopters was tripled. In that simulation, there was a change in the number of wounded who died from their injuries. There is a decrease from forty three to thirty four who die from their wounds. This represents an increase of eleven to the number that survived. For comparison, simulation 4 reduced the number of helicopters to two and the number of those who died from their wounds returned to the previous levels. This policy is effective at reducing the number who die, however it is limited.

Increasing the number of helicopters had the desired results of reducing the number killed. The number of helicopters had to be tripled, not doubled in order for there to be a measurable difference. However, the decrease in deaths was not as significant as is desired. The reduction at most was eleven more survived. There was still a majority of patients dying.

2. Advanced Traumatic Life Support Training (ATLS training)

The ATLS training policy is a modifier that affects medics assigned to the unit. When the policy is in effect, the policy acts as a combat multiplier effectively doubling the number of medics in the unit. This policy reduces the time it takes for the wounded to be triaged and also extends the golden hour for the wounded that are triaged as red, by providing advanced life-saving care in the field. Without the policy, there is no multiplier and the number of medics remains fixed.

Three simulations were run, the first without modification, the second with a modifier of two and the third with a modifier of one-half. The first is the default, to which the two other simulations are compared. The second was tested to with the modifier of two which allowed the medics to be multiplied by two, signifying ATLS training. The third and final modifier was one-half which was used to show that having a smaller modifier would not result in the desired effect. Figure 18 shows the results from the three simulations.

Simulation	Wounded	ATLS modifier	Number Survived	Number Killed	Killed vs. Wounded
1	60	1	17	43	43 of 60
2	60	2	19	41	41 of 60
3	60	½	17	43	43 of 60

Figure 18 ATLS Training Policy Results

These results show that having ATLS training is a factor that can reduce the amount of patients who die from their injuries. The difference was marginal with a reduction of only two deaths, when compared to the previous policy that had a difference of eleven. With only a small difference between simulations, this policy appears to have a minimal effective at reducing deaths. However, the comparative cost is very low. The proper training to certify and equip medics can be done in a short period of time prior to the unit entering the COE or even after they have.

3. Moving the MTF Closer (Closer MTF)

The idea for this policy is based off the writings of CDR Jadick (Jadick, 2007). By moving the MTF closer the to the battlefield, advanced treatment, not traditionally available so close to the battlefield, can be provided. For this simulation there were four trial runs, all of them with different distances starting with the orignal, decreaseing two times than increasing the distance in the last simulation.

The first simulation is the default, with the original values for the variables set a distance of sixty miles to and from the MTF for this simulation and a total of sixty patients for this and all other simulations. The second and third simulation applied the policy; the distance to the MTF was halved to thirty miles, and then halved again so that the distance was fifteen miles. For the final simulation, the distance was doubled to a hundred and twenty miles to ensure that the policy works as intended. The results from the simulation are below in figure 18

Simulation	Wounded	Distance to MTF (miles)	Number Survived	Number Killed	Killed vs. Wounded
1	60	60	17	43	43 of 60
2	60	30	25	35	35 of 60
3	60	15	31	29	29 of 60
4	60	120	10	50	50 of 60

Figure 19 MTF Distance Policy Results

Like the two other policies there is a decrease in the number killed when compared to the default model. In figure 19, simulations 2 and 3 show an improvement over the default simulation. Reducing the distance traveled to thirty miles increased the amount who survived by eight for a total of twenty five. Reducing the distance even further to fifteen miles increased the amount who survived to fourteen and a total of thirty one, nearly double the amount that survived from the default case. Simulation 4 resulted in more deaths when the distance was increased, showing that this policy worked correctly. Out of the three policies, this one has provided the greatest increase in the amount of wounded who survived.

4. Overview: Best of the policies

Comparing all the simulations to the default model the best overall policy is the reduction in the distance between the battlefield and the MTF. The other two policies provided limited improvement over the default model, but not as drastic as in the third policy. Figure 20 below compares the best results from the three policies to the default model.

Policy	Wounded	Number Survived	Number Died	Dead vs. Wounded
Default	60	17	43	43 of 60

Increased MEDEVAC	60	26	34	34 of 60
ATLS Training	60	19	41	41 of 60
Decreased MTF Distance	60	31	29	29 of 60

Figure 20 Policies Best Results

A reduction in the distance between the battlefield and the MTF to fifteen miles reduced deaths by fourteen when compared to the default model and by five when compared to the next closet policy. This policy pushes the number of wounded who survived to just over 50%. While this policy is the best in the simulation, there is a great deal of limitations to this policy and real world limitations will restrict the actual benefit of this policy. Expanded testing is still needed to test whether this policy alone is actually the best one.

5. Combination policy (combo)

The last step to testing the different policies in the model is to see if any combinations of policies would have a greater affect than any of the individual policies in isolation. This was done by enabling the policies and setting the numbers that reflected the best results. The results from the simulations are shown below in figure 21.

Simulation	Wounded	Number Survived	Number Killed	Killed vs. Wounded
1	60	17	43	43 of 60
2	60	41	19	19 of 60
3	60	31	29	29 of 60

Figure 21 Combination Policy Results

From these simulations, the overall best resulted from implementing all three of the policies at once, simulation 2. By increasing MEDEVAC units to twelve, adding ATLS training and cutting the distance to the MTF to fifteen miles, there was a decrease in the number of deaths to only nineteen. While this was the best overall result, enabling all of the policies also means that all the limitations are present. Simulation 3 represented a more practical solution, by reducing certain parts of the policy. There were eight MEDEVAC units available and the distance was thirty miles instead of the fifteen for simulation 2. The results from simulation 3 show an improvement over the default simulation, but not as profound as in simulation 2.

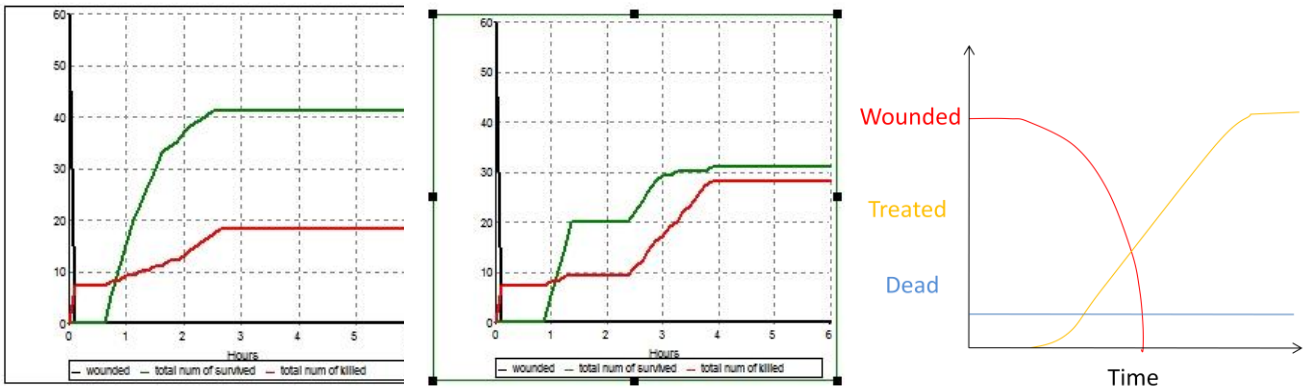


Figure 22 Combo Simulation 2 and 3 compared to Figure 9

Figure 22 compares the results from the two combination simulations to that of the desired reference mode seen back in figure 9. Simulation 2 results are the closest to that of the desired results. Neither simulation is an exact match to the desired outcome, but both simulation show a vast improvement over the results from the default model of sixty patients and the undesired outcome.

5) RECOMMENDATIONS

Before any recommendations are made, the limitations of this model must be accounted for. Considering that there are limitations to the policies and assumptions made, there were two recommendations, one for the model and one with more real-world application. By doing this, the recommendations can be better tailored to either the simulation or to possible real-world scenarios.

A. Simulation Recommendations

By looking at the results of all the simulations, it would be easy to say that combining all the policies into one is the best solution to the problem. When the three policies were in effect, there was the largest drop in the number of wounded killed. Based on those results, these are recommendations that should be followed to achieve the best results.

- Increase the number of MEDEVAC units to twelve, this allows for a total of seventy two patients to be transported by the MEDEVAC units. This number should be adjusted for the maximum expected number of wounded.

- Enable Advanced traumatic life support training for the unit's medics, allowing for the modifier to take effect.

- Reduce the distance to the MTF to at most fifteen miles and one half mile being ideal. With this set, the maximum travel distance is one mile.

From these recommendations, the simulation should show a vast improvement in the ratio of dead versus wounded. The above recommendations work in two important ways, they extend the golden hour and they reduce the time delays. By implementing these recommendations, the simulations will show a dramatic reduction in the number of wounded who are killed. With the policies in effect and the settings as noted above, the number killed will be reduced to only those that are killed from the initial event. These results would be closer to the desired reference model seen in figure 9 and are the results that are wanted.

B. Real World Recommendations

The above recommendations work well for the simulation; they would effectively reduce the number killed to only those who are killed from the initial event. However, those recommendations cannot be carried over to be applied in a practical or real world sense. The limitations and assumptions that were noted above greatly reduce the effect that these recommendations would actually have. While the effect may be damped, the simulation still mimics the real world so some recommendations can be considered.

- Increase in MEDEVAC units during anticipated large engagements. During normal operations staggered MEDVAC units to allow for overlapping coverage allowing for continuous coverage of an area during MEDVEAC missions.
- ATLS training for all medical personal in the unit as well as advanced medical training for non-medical personal in the unit. This should include CLS training for as many member of the unit as time and resources permit.
- Bring MTF closer to engagement areas only when anticipated large engagements are about to happen. Otherwise, the resources needed for such a move would be too great and the limited benefits during a low-intensity conflict may not justify the cost. Station lower level MTF more mobile and closer to where the war fighting units are located.

The results mentioned above have already been implemented to some extent in the real world. Looking at CDR Jadicks book, he implemented moving his aid station right to the front lines during the battle of Fallujah and as a result saved at least thirty more Marines then he would have if his aid station was in the rear. (Jadick, 2007) Over lapping MEDEVAC coverage is also in use by the military in the COE. It consists of not only Army but also Air Force, Navy and Marine units that are based at different locations though out the COE that fly MEDEVAC missions. (Headquarters, Department of the Army, 2007)

These recommendations take into account both the simulation results as well as the limitations of the model. Only looking at the simulation results will only provide recommendations to this particular model with limited application in the real world. But by taking the results from the simulations and looking at the limitations at the same time, there is a possibility that these recommendations can have some application in the real world.

6) FURTHER TESTING AND CONCLUSION

One of the first things that are taught about modeling and simulations is that all models are wrong. This model is no exception, as it too is wrong when compared to any real world event. To make this model run, there were many limitations set in place as well as many assumptions made. Those limitations and assumptions were important in keeping the model manageable and focused on the patient flow. Without placing these limitations, the model would be too large and too complex. While making the model easier to manage, these limitations of modeling also make the model less accurate in comparison to the real world. This model is not a game changer in the world of MASCALs, but it does demonstrate several key points.

What has been accomplished by building this model is the demonstration of the potential of using system dynamics to simulate the complex world of a MCI. While the model is far from perfect, it is a step in the right direction. This model was built specifically looking at patient flow. Further improvements can be made by other healthcare providers or public health specialist familiar with system dynamics. Other models should look into things like

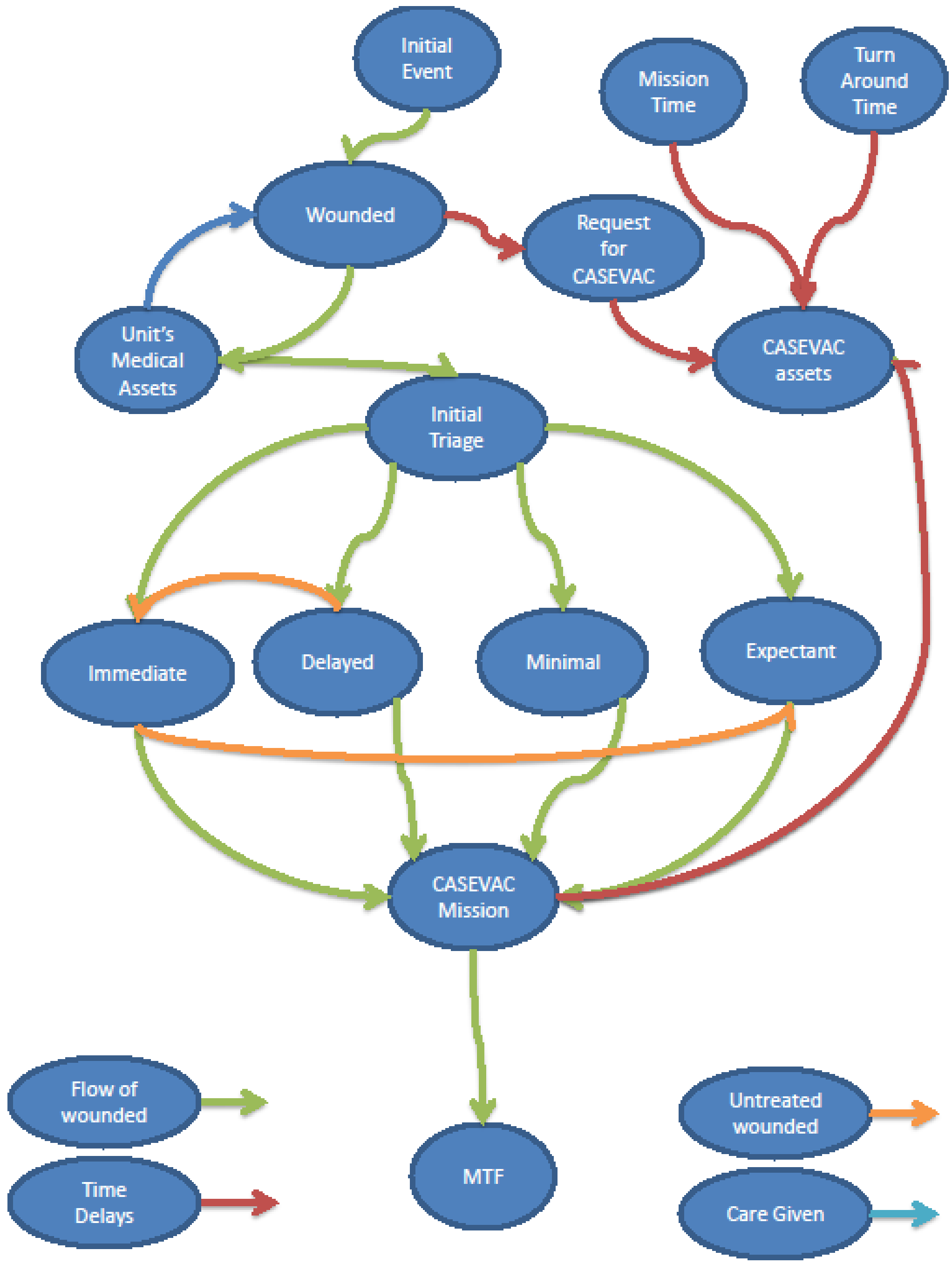
- The treatment provided throughout the MASCAL from CLS and medics to flight medics then to treatment at a MTF
- The medical supplies as a resource that becomes depleted as more and more casualties are treated.
- A more complex transportation sector that looks at both MEDEVAC and CASEVAC
- A more in depth look into communications on all levels

Combining the above parts into a single model would yield a model that could be used more effectively to model a MASCAL. There is a lot that can be done to improve this model through further testing and further development. By doing so, the model will have fewer assumptions and fewer limitations and be able to better simulate a real world MASCAL.

MASCALs will always be unpredictable and they will always push the CHS to it limits. There is nothing that can prevent them from happening once they happen there is no way to reverse what has happened. The only way to handle them is through training and preparation. Training must be done by all levels of providers as often as possible. This will best prepare all levels for such an event. Preparation is done in training and also through the acquisition of the proper equipment and supplies, the staging of equipment and supplies at strategic points, and also the proper allocation of MEDEVAC units. This model allows for some of the training and preparation to be done in a virtual world without expending time and resources.

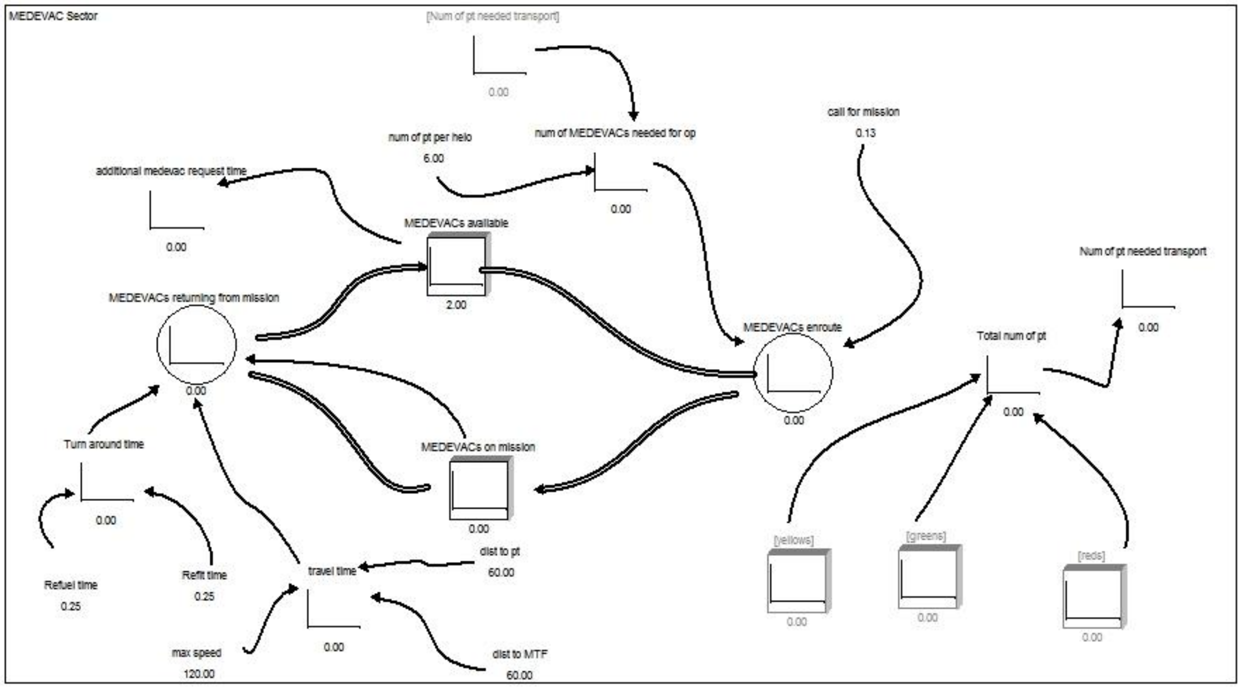
By using this model, different scenarios can be run though with different settings all while minimizing resources used. The limitations and assumptions reduce the realism of the model but this model allows for different variations to be run and all the outcomes looked it. There are a lot of improvements that can be made to this model and many more simulations and variables that can be changed to simulate an unlimited number of scenarios. Using system dynamics to model a MASCAL has drawbacks but should not be overlooked as a tool to help better prepare the CHS for not only MASCALs but other dynamic situations.

7) DYNAMIC HYPOTHESIS

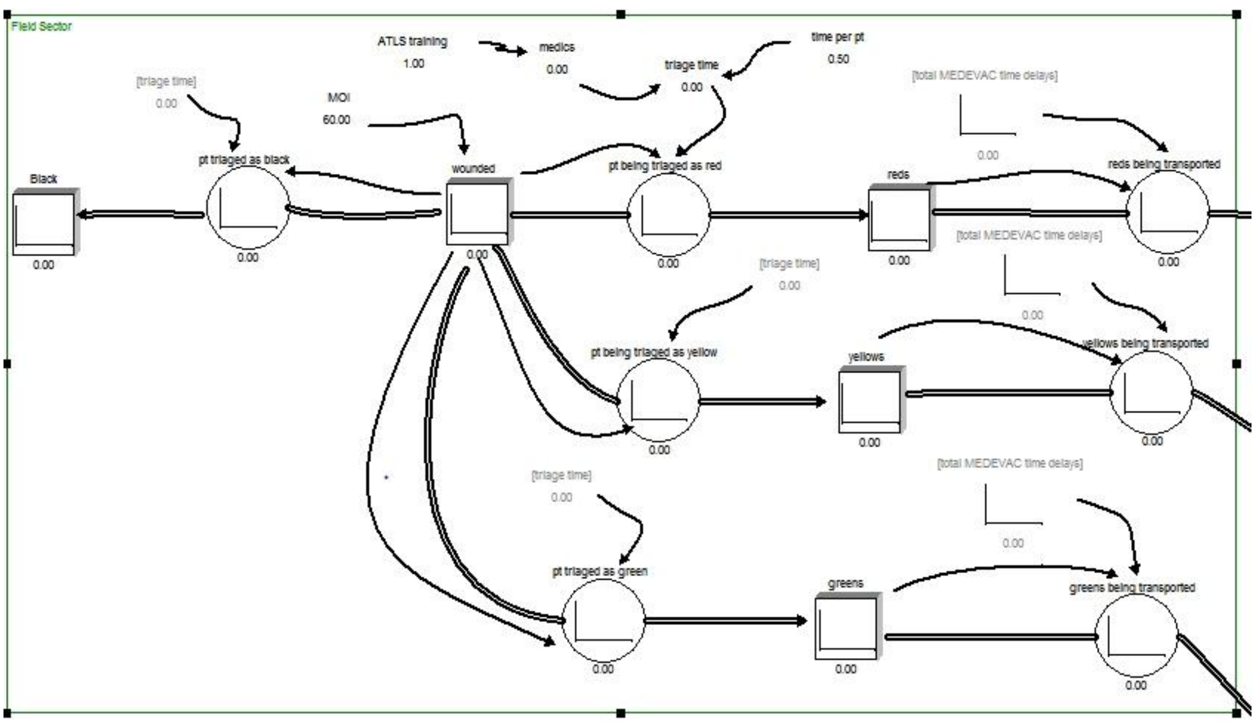


8) SECTORS:

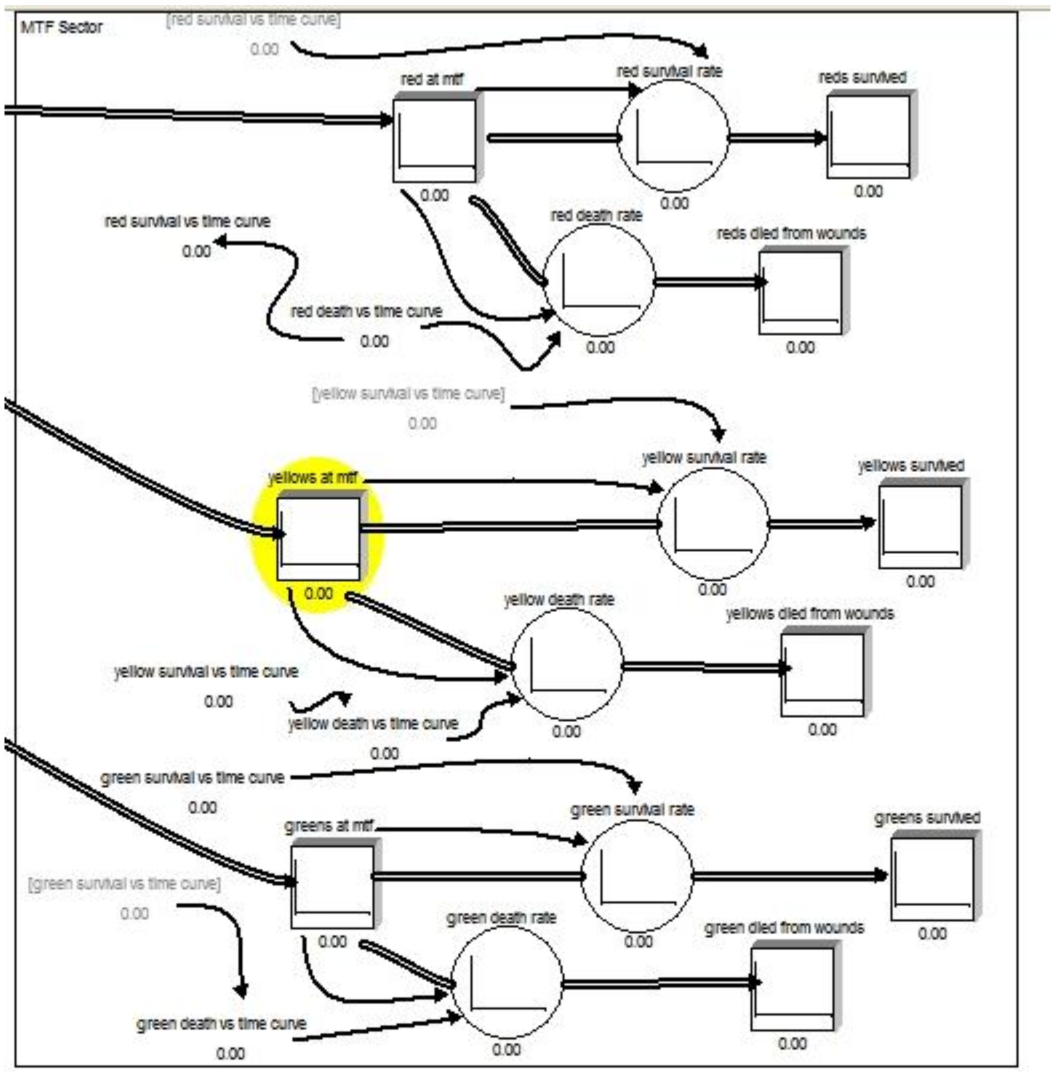
MEDEVAC Sector:



Field Sector:

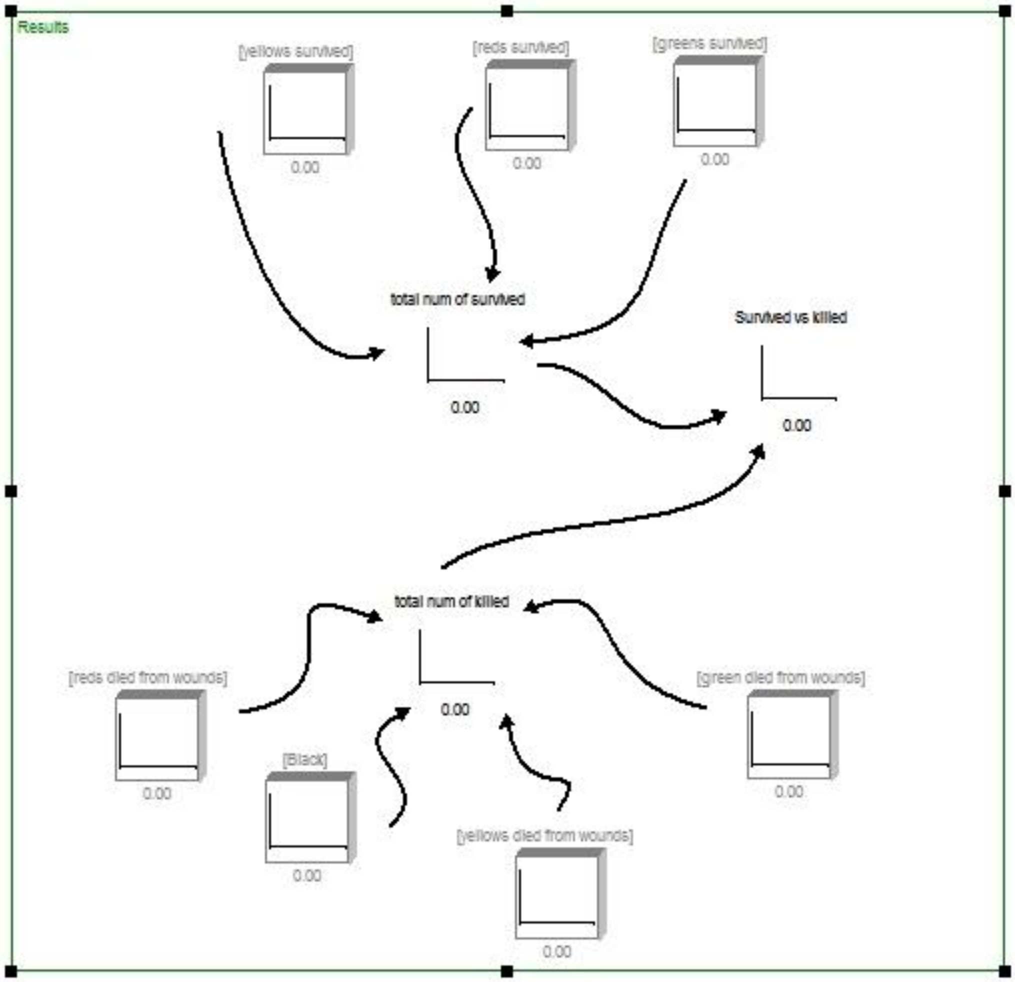


MTF Sector:

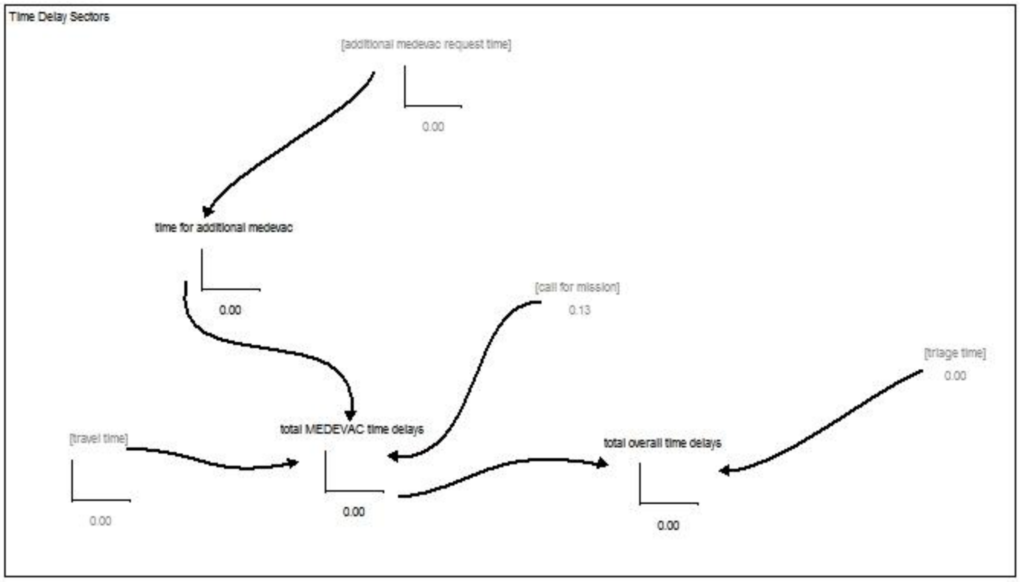


MTF Sector
[red survival vs time curve]
0.00
red at mtf
red survival rate
reds survived
0.00
0.00
0.00
red survival vs time curve
0.00
red death rate
reds died from wounds
red death vs time curve
0.00
0.00
0.00
[yellow survival vs time curve]
0.00
yellows at mtf
yellow survival rate
yellows survived
0.00
0.00
0.00
yellow death rate
yellows died from wounds
yellow survival vs time curve
0.00
yellow death vs time curve
0.00
0.00
0.00
green survival vs time curve
0.00
green survival rate
greens survived
greens at mtf
[green survival vs time curve]
0.00
0.00
green death rate
0.00
green died from wounds
0.00
green death vs time curve
0.00
0.00
0.00

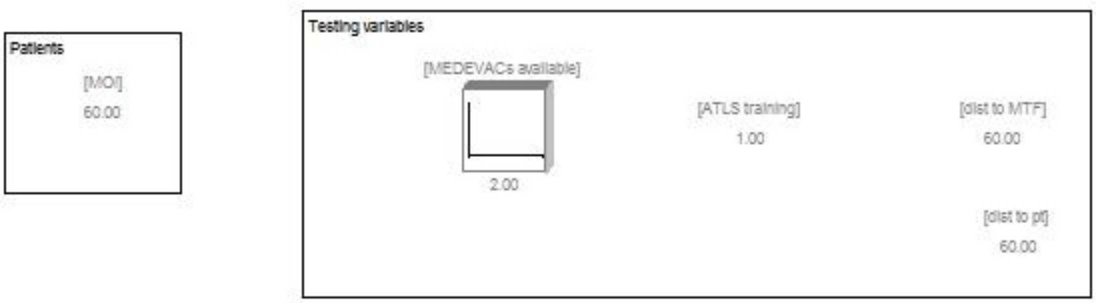
Results sector:



Time Delay Sector



Patients and Testing Variable Sectors



9) EQUATIONS:

Variable	Type	Units	Equation	Notes
additional medevac request time	Variable	hours	IF(MEDEVACs_available <0,1,0)	the call to supporting units for additional helicopters 1 for needed 0 for not needed
ATLS training	Constant		2	Advanced traumatic life support training offers a modifier that acts as a force multiplier allowing the medics to perform more life saving measures in the field. The initial value is 1, which is the default.
Black	Resource	pts	+ pt triaged as black * dt	pts who died from the initial event
call for mission	Constant	hours	.125	radio request for the MEDEVAC

dist to MTF	Constant	mile	30	
dist to pt	Constant	mile	30	
green death rate	Flow	pts/hours	greens_at_mtf * green_death_vs_time_curve / TIMESTEP	greens that are receiving treatment but will not survived their injuries
green death vs. time curve	Constant		1-green_survival_vs_time_curve	death curve based on the golden hour rule for reds, modified for greens
green died from wounds	Resource	pts	+ green death rate * dt	greens that have not survived their injuries
green survival rate	Flow	pts/hours	greens_at_mtf * green_survival_vs_time_curve / TIMESTEP	greens receiving treatment and will survive their injuries
green survival vs. time curve	Constant			survival curve based on the golden hour rule for reds, but modified for greens
greens	Resource	pts	+ pt triaged as green * dt - greens being transported * dt	Patients who have been identified as greens and are awaiting transport away from the field to a treatment center
greens at mtf	Resource	pts	- green death rate * dt - green survival rate * dt + greens being transported * dt	greens that have arrived at the mtf
greens being transported	Flow		IF(greens>0, DELAY(MIN(greens/ TIMESTEP , 15), total_MEDEVAC_time_delays),0)	pts that are being transported from the field to the mtf
greens survived	Resource	pts	+ green survival rate * dt	greens that have survived their injuries
max speed	Constant	miles per hour	120	max speed of the helicopters
MEDEVACs available	Resource	helicopters	init(8) ; - MEDEVACs enroute * dt + MEDEVACs returning from mission * dt	number of helicopters available
MEDEVACs enroute	Flow	helicopters/hours	IF(num_of_MEDEVACs_needed_for_op >0, DELAY((num_of_MEDEVACs_needed_for_op), call_for_mission , 0), 0)	MEDVACS enroute to pt
MEDEVACs on mission	Resource	helicopters	init(0) ; + MEDEVACs enroute * dt - MEDEVACs returning from mission * dt	helicopters on MEDEVAC mission
MEDEVACs	Flow	helicopters/hours	IF(MEDEVACs_on_mission	

returning from mission			>0, FLOOR(DELAY(MEDEVACs_on_mission, Turn_around_time + travel_time ,0)),0)	
medics	Constant		2* ATLS_training	The number of medics per unit
MOI	Constant	pts	60	The event that caused the injuries
num of MEDEVACs needed for op	Variable	helicopters	CEIL(Num_of_pt_needed_transport / num_of_pt_per_helo)	
Num of pt needed transport	Variable	pts	Total_num_of_pt	pts waiting for transport
num of pt per helo	Constant	pts	6	
pt being triaged as red	Flow	pt/hours	(.5* wounded)/triage_time	The patients who are being identified as Reds
pt being triaged as yellow	Flow	pts/hours	.25 *wounded / triage_time	The patients who are being identified as yellows
pt triaged as black	Flow	pts/hours	(.125* wounded) / triage_time	pts triaged as black
pt triaged as green	Flow	pts/hours	.125* wounded / triage_time	The patients who are being identified as greens
red at mtf	Resource	pts	+ reds being transported * dt - red survival rate * dt - red death rate * dt	reds that have arrived at the mtf
red death rate	Flow	pts/hours	red_death_vs_time_curve *red_at_mtf / TIMESTEP	reds that are receiving treatment but will not survived their injuries
red death vs. time curve	Constant			death curve based on the golden hour rule for reds
red survival rate	Flow	pts/hours	red_survival_vs_time_curve * red_at_mtf / TIMESTEP	reds receiving treatment and will survive their injuries
red survival vs. time curve	Constant		1- red_death_vs_time_curve	survival curve based on the golden hour rule for reds
reds	Resource	pts	init(0) ; + pt being triaged as red * dt - reds being transported * dt	pts who have been identified as red and are awaiting transport away from the field to a treatment center
reds being	Flow	pt/hours	IF(reds>0, DELAY(MIN(reds/	pts that are being transported from the field to the mtf

transported			TIMESTEP , 15), total_MEDEVAC_time_delays),0)	
reds died from wounds	Resource	pts	+ red death rate * dt	reds that have not survived their injuries
reds survived	Resource	pts	+ red survival rate * dt	reds that have survived their injuries
Refit time	Constant	hours	.25	time it takes to resupply the helicopter
Refuel time	Constant	hours	.25	time it takes to refuel the helicopter
Survived vs. killed	Variable	pts	DELAY((total_num_of_killed /total_num_of_survived), 1,0)	
time for additional medevac	Variable	hours	IF(additional_medevac_request_time =1, 1.5,0)	time it takes for additional medevac units to complete their mission
time per pt	Constant	hours	.5	the time it takes to check each patient
total MEDEVAC time delays	Variable	hours	travel_time + call_for_mission + time_for_additional_medevac	
total num of killed	Variable	pts	FLOOR(Black + reds_died_from_wounds + yellows_died_from_wounds + green_died_from_wounds)	
Total num of pt	Variable	pts	FLOOR(yellows + greens + reds)	total number of pt
total num of survived	Variable	pts	FLOOR(yellows_survived + reds_survived + greens_survived)	
total overall time delays	Variable	hours	total_MEDEVAC_time_delays + triage_time	
travel time	Variable	hours	(dist_to_pt + dist_to_MTF)/ max_speed	travel time from base to pt then to MTF
triage time	Constant	hours	time_per_pt / medics	the total time it takes to check a patient divided by the number of medics. The more medics the faster the triage can go
Turnaround time	Variable	hours	Refit_time + Refuel_time	time for complete refuel and refit
wounded	Resource	pt	init(MOI) ; - pt being triaged as red * dt - pt triaged as	the total number of wounded that have not been triaged

			black * dt - pt being triaged as yellow * dt - pt triaged as green * dt	
yellow death rate	Flow	pts/hours	yellows_at_mtf * yellow_death_vs_time_curve / TIMESTEP	yellows that are receiving treatment but will not survived their injuries
yellow death vs. time curve	Const ant		1- yellow_survival_vs_time_cur ve	death curve based on the golden hour rule for reds, modified for yellows
yellow survival rate	Flow	pts/hours	yellows_at_mtf * yellow_survival_vs_time_cur ve / TIMESTEP	yellows receiving treatment and will survive their injuries
yellow survival vs. time curve	Const ant			survival curve based on the golden hour rule for reds, but modified for yellows
yellows	Resou rce	pts	+ pt being triaged as yellow * dt - yellows being transported * dt	Patients who have been identified as yellows and are awaiting transport away from the field to a treatment center
yellows at mtf	Resou rce	pts	- yellow death rate * dt - yellow survival rate * dt + yellows being transported * dt	yellows that have arrived at the mtf
yellows being transport ed	Flow		IF(Yellows >0, DELAY(MIN(Yellows / TIMESTEP , 15), total_MEDEVAC_time_dela ys),0)	pts that are being transported from the field to the mtf
yellows died from wounds	Resou rce	pts	+ yellow death rate * dt	yellows that have not survived their injuries
yellows survived	Resou rce	pts	+ yellow survival rate * dt	yellows that have survived their injuries

10) INDEX OF IMAGES

Figure 1 Echelons of the CHS (Fix formatting) 5

Figure 2 MASCAL

Figure 3 UH-60Q.......... 8

Figure 4 M997 8

Figure 5 M996 8

Figure 6 Table of MEDEVAC Capacity for major conflicts 12
Figure 7 Reference Mode 13
Figure 8 Undesired Results 14
Figure 9 Desired Results 15
Figure 10 Initial Values for policy variables 20
Figure 11 0 Model Results 21
Figure 12 20 Patient Model 22
Figure 13 20 Patient Model Results 22
Figure 14 60 Patient Model 23
Figure 15 60 Patient Model Results 23
Figure 16 MEDEVAC Policy Results 24
Figure 17 ATLS Training Policy Results 25
Figure 18 MTF Distance Policy Results 26
Figure 19 Policies Best Results 27
Figure 20 Combination Policy Results 27

11) INDEX OF TERMS

CLS

Combat Life Saver, II-7, II-8, II-9

COE

Current Operating Enviroment, II-6, II-7, II-8

Converters, II-12

CSH

Combat Support Hospital, II-7, II-9, II-11, II-14, II-15

dynamic, II-12

dynamic hypothesis, II-12

feedback loops, II-12

flows, II-12

government, II-13

growth, II-12

GWOT

Global War On Terror, II-6

MASCAL, II-1, II-6, II-8, II-10, II-11

Mass Casualty, II-1, II-2, II-8, II-9, II-13, II-15, II-16, II-17, II-18, II-23, II-32, II-41

Medics, II-7

MFT

Military Treatment Facility, II-7

Model, II-12

OEF

Operation Enduring Freedom, II-6

OIF

Operation Iraqi Freedom, II-6

PHT

Pre Hospital Treatment, II-7

reference mode, II-12

SABA

Self-aid/Buddy-aid, II-7

stocks, II-12

12) BIBLIOGRAPHY

Headquarters, Department of the Army. (2008, Feburary 18). AR 40-3. *Medical, Dental and Veterinary Care* . Washington D.C: United States Army.

Headquarters, Department of the Army. (2007, May 8). FM 4-02.2. *Medical Evacuation* . Washington DC: United States Army.

Headquarters, Department of the Army. (1994, December 29). FM 8-10-14 . *Employment of the Combat Support Hospital* . Washington D.C: United States Army.

Headquarters, Department of the Army. (1994, September 9). FM 8-55. *Planning for Health Service Support* . Washington DC: United States Army.

Jadick, R. (2007). *On Call In Hell.* New York: NAL Caliber.

Janousek, J. T. (1999). “Mass Casualty Triage Knowledge of Military Medical Personnel”. *Military Medicine* .

McGrath, S. P. *Agent Based Casualty Care– A Medical Expert System for Modern Triage.* Hanover.

Robison, J. (2002). Army Nurses’ Knowledge Base for Determining Triage Categories in a Mass Casualty. *Military Medicine* .

United States Army Medical Department. (2004). Casualty Triage. *Combat Medic Advanced Skills* . Ft. Drum.

United States Army Medical Department. (2004). Point of Wounding. *Combat Medic Advanced Skills Training* . Ft. Drum.