Hex Size In JTLS

Ellen Roland
Bernie Wisthoff
Edward Kelleher
ROLANDS & ASSOCIATES Corporation

1.0 Introduction

The Joint Theater Level Simulation (JTLS) is an interactive, computer-based, multi-sided wargaming system that includes land, sea, air, intelligence, and logistics functions. To accomplish this task, JTLS simulates the interactions of air, land, and naval forces on a terrain board. The terrain board is conceptually equivalent to placing a hexagonal overlay on a map and reducing all the map data within each hex into a small set of codes. This methodology produces a very efficient representation of large terrain areas, but can cause concern due to the lack of terrain detail. Generally it is agreed that the smaller the hex size, the better the terrain representation. This concept then leads to the natural question, "How small can the JTLS hex size be made?"

The purpose of this paper it to provide the information needed so a JTLS user organization can attempt to answer this question and make decisions concerning hex size in their JTLS databases. Selecting a hex size affects the manner in which the JTLS model operates and the efficiency with which it operates. Section 2.0 of this paper concentrates on describing the principal model algorithms that are closely tied to the terrain's selected hex size. Section 3.0 addresses the processing concerns due to small hex sizes. This paper does not go into algorithm details. For more information on JTLS algorithms the user is referred to the *JTLS Analyst Guide*. Enclosure 1 provides a list of the many modeling concerns that, while not as important as others, are affected by hex size.

Many of the potential problems would be most likely to be encountered in a database where there had been a functioning database and the hex size was changed radically, or where the physical size of the units represented was significantly mismatched to the size of the hexes.

2.0 Model Impact

The purpose of this section is to outline the model algorithms that are closely tied to the hex size and should be strongly considered when making the hex size decision.

2.1 Lanchestrian Combat

The most important impact, by far, is the fact that Lanchestrian combat can only occur between units that are in the same hex or adjacent hexes. Lanchestrian attrition, as the primary force-on-force combat algorithm in JTLS, must properly represent all feasible and realistic combat between forces. Specifically, the user must consider the combat range of all direct fire weapon systems that are being played. Consider the situation in Figure 1.

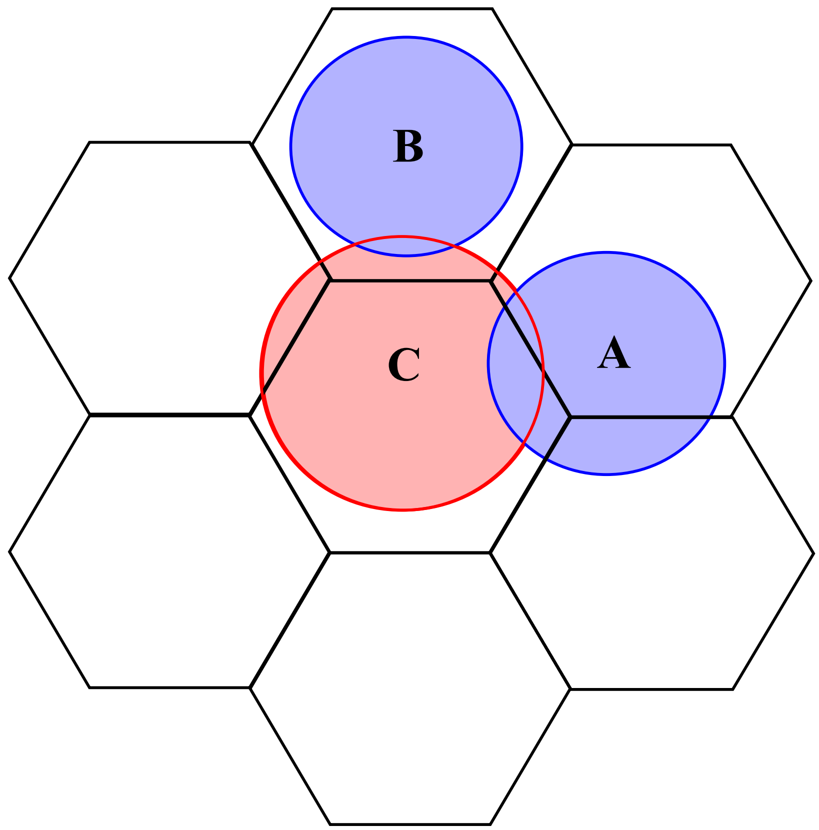

FIGURE 1. Direct Fire Range Affects On Lanchestrian Attrition - Large Hex Size

Assume that Units A and B are on the Blue side and based on their unit radius and range of their direct fire weapon systems, they can fight anything in the Blue circles. Similarly Unit C belongs to the Red side and based on its unit radius and combat system range, it can fight anything covered by the Red circle. As shown in Figure 1, the direct combat system range circles overlap; therefore, Unit A, B, and C would be conducting Lanchestrian attrition in JTLS if the units had Rules of Engagement (ROE) that permitted them to fight.

Now consider Figure 2 in which the hex size has been cut in half. As shown, only the non-colored hexes are considered when determining which units could possibly be in combat with Unit C. Neither Unit A nor Unit B are in a hex adjacent to Unit C; therefore, there is no combat in this situation.

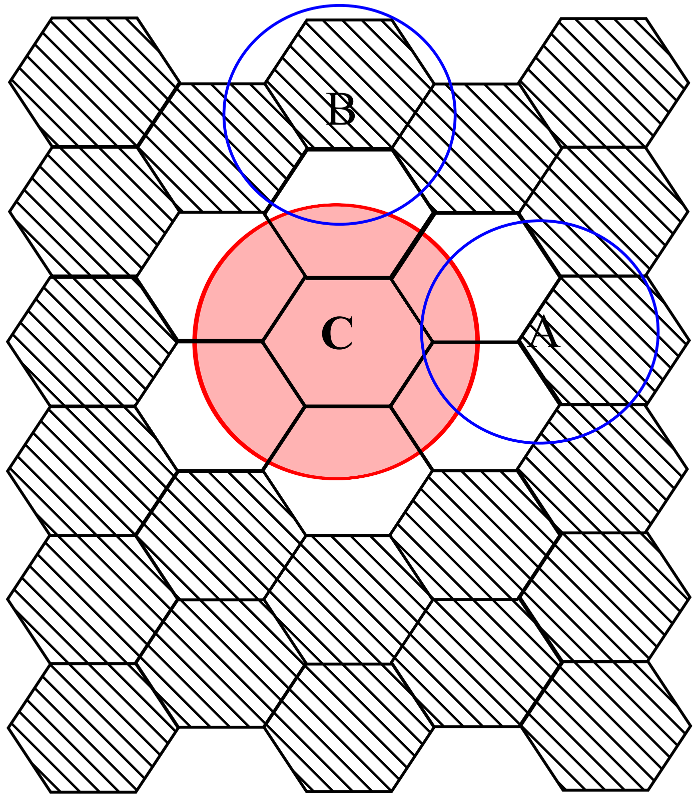

FIGURE 2. Direct Fire Range Affects On Lanchestrian Attrition - Small Hex Size

Specifically ordered artillery fire missions are not limited to impacting in a hex adjacent to the firing unit. For example, if a user specifically orders a unit to fire its artillery at a location or detected unit and the ammunition to be fired has the needed range, the order is executed. Even though the user can input orders to specifically fire artillery missions outside of the adjacent hex, any unused indirect fire combat system capability is assumed to fire as part of the indirect fire portion of the Lanchestrian combat algorithm. This means that even indirect fire combat systems, which generally have longer ranges than the direct fire systems, must be in an adjacent hex for them to be considered as part of the force-on-force attrition algorithm.

As long as weapon systems are continuing to improve and the range over which they are effective continues to grow, users must be very aware of the adjacent hex limitations for Lanchestrian combat within JTLS when selecting a hex size for the terrain representation.

2.2 HRU Combat

When a High Resolution Unit (HRU) determines whether it has the capability to attack another Aggregate Resolution Unit (ARU) or target, the model only allows the HRU to check in its current hex and the six surround adjacent hexes. If the hex size is too small, the HRU is not given credit for being able to attack an object over fairly long distances.

2.3 Unit Radius

When you select a hex size, you need to also consider the desired unit size for the units being represented in the scenario. It is inappropriate to use a small hex size and large units. In JTLS a unit is generally considered to be located in the hex in which the center of the unit is found. If the unit radius is extremely large compared to the hex size, then the unit would in reality “overflow” into one or more adjacent hexes.

For the most part, this “overflow” is not considered in JTLS when determining damage or other effects, such as chemical or nuclear radiation. Consider the situation in Figure 3. An area effects weapon lands in the hex, and damages items within the area shown in Red. When creating a list of units that can possibly be affected by the area weapon, only the impact hex and the six adjacent hexes are scanned for possible units. Unit A would not make the list and damage would not be assessed against the unit.

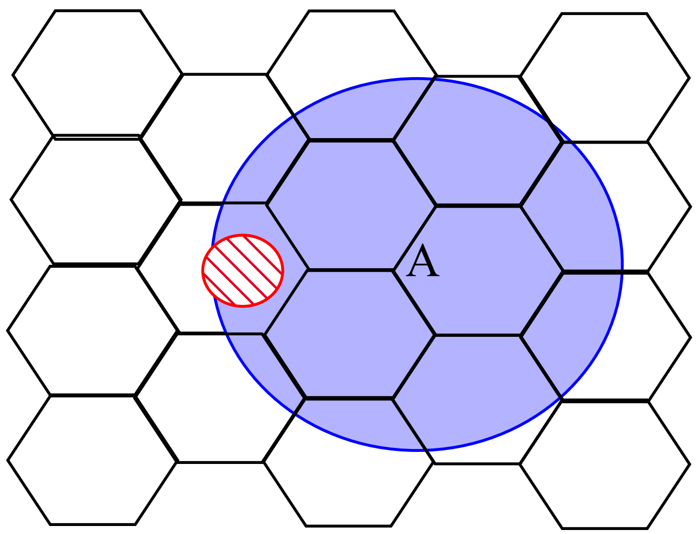

FIGURE 3. Large Unit Size Compared To Hex Size

If hex sizes are too small compared to the average unit’s radius, this situation could lead to undesirable results.

2.4 Unit Movement

In a similar vein, unit movement is also affected by an inconsistency between hex size and unit size. In JTLS a unit entering a hex adjacent to (or containing) an enemy unit must stop and “fight” its way past the enemy unit. This rule can lead to undesirable results if the hex size is too small compared to the unit size. Consider the example shown in Figure 4. The enemy Unit B, following a path depicted by the red line, has no trouble moving past Unit A. Given the current algorithms in JTLS, the unit movement logic would not become aware of the existence of Unit A as Unit B moved from hex to hex.

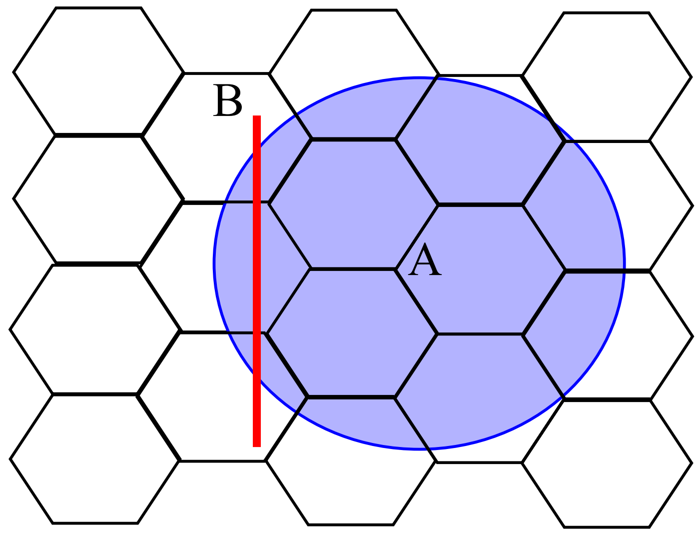

FIGURE 4. Unit Movement Problems With Inconsistent Hex Size and Unit Size

2.5 Next Firing Position

In JTLS it is possible to set up standard operating procedures for units that include automatic orders for an artillery unit to change its firing position after the completion of a series of fire missions. The logic used by JTLS only considers the firing unit's current hex and six adjacent hexes when selecting a new location. This means that the maximum distance that a unit can automatically move when selecting a new firing position is 2.0 * the hex size. If the hex size is small, the maximum distance that a unit can automatically move after firing is also small and will impact the ease with which the unit can be found and hit by the enemy.

2.6 Composite Unit Collocation

Typical JTLS Airbases are large composite units that consist of supplies, aircraft shelters, communication facilities, runways, and several squadrons with their own targets. By definition all of these objects must be located in the same hex. If the hex size is too small, the objects that belong to the composite unit may be placed unrealistically close to one another. This makes the composite object easier to attack and kill.

2.7 Looking For Colocated Supplies

When a unit needs supplies, such as an airbase or squadron looking for fuel or weapons for a planned mission, the unit first determines if it has any of the needed supplies. If the unit does not have the supplies, it is allowed to search in its current hex and the six surrounding hexes for a source of the supplies. Any own side supply dump or other unit that is within COLOCATED DISTANCE can be a source of the needed supplies. In JTLS it is assumed that any supplies found within this database parameter value of

COLOCATED.DISTANCE can be made instantaneously available to the unit needing the supplies. Consider the example in Figure 5. Unit A is looking for supplies. Based on the COLOCATED DISTANCE criteria, Unit A is allowed to acquire supplies anywhere in the shaded circle, but the model will not recognize the supply dump labeled B as a possible source, because B is not in one of the seven hexes searched for supplies.

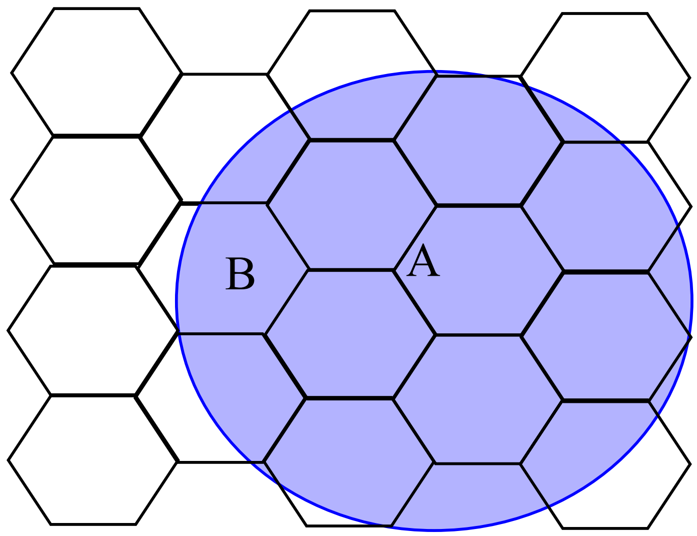

FIGURE 5. Colocated Supply Search

2.8 Distributing Supplies

When a unit receives more supplies that it can store or it decides to move and must leave some supplies behind because of a lack of carry capacity, the unit attempts to distribute the supplies to other units in the area. The unit only looks in its current hex and the six surrounding hexes for units capable of receiving the supplies. If no units are found, the supplies are placed on the ground in an open supply storage area target. The smaller the hex size, the less likely a unit will be found to accept the supplies.

2.9 Unit Reporting

When a Surface-to-Surface Missile (SSM) starts to prepare to fire or actually fires a missile, all units in the area are given a chance to detect the event and report the event to their assigned intel function workstation. Unit detections are not the only source by which these SSM events can be detected, but they do comprise one of several detection options. When the size of the hex is reduced the number of units that are given a chance to detect the event is potentially reduced.

Similarly, units in the area are allowed to report the takeoff of an air mission from a base. Unlike the SSM report, the model assumes that the “area” in this circumstance is the same hex in which the aircraft took off. Still, the concept is the same. If the hex size is reduced, the number of units that will be allowed an opportunity to report the air mission takeoff event will potentially be reduced.

2.10 Amphibious Pickup / Dropoff Location

Units participating in an amphibious assault using amphibious boats or Over The Shore capability, must be placed in a hex adjacent to a water hex. If the hex size is small this means that the units are placed close to shore when the first wave lands, and they will not be able to move away from that hex location until the entire assault of the unit is complete. This is not a problem when considering the hex sizes normally used for JTLS databases. For a typical JTLS database, a unit can be as much as 7.5 Kilometers (KM) away from the shore even though portions of the unit are still being off-loaded as part of the assault. If the hex size is reduced to 3 KM (for example), the maximum distance allowed between the shore and the unit's center of mass will be 3 KM and the unit will not be able to move forward to meet the enemy until the assault is complete.

Similarly unit participating in an amphibious pickup must be located in a hex adjacent to the water for the pickup to be accomplished. If hex sizes are small this means that the unit must be move closer to the shore for the pickup to take place.

2.11 Airlift Pickup Strategy

In JTLS, the model attempts to determine whether an airlift is lifting the unit out of combat or lifting the unit into combat. This determination must be made to insure that the combat systems are loaded at the proper time. If a unit is being airlifted out of combat, the model attempts to leave the combat systems on the ground as long as possible to help protect the loading of the aircraft. On the other hand, if the airlift is lifting a unit into combat the combat systems are loaded first so they will be offloaded first and the unit can help protect the area while the remaining aircraft offload the other portions of the unit.

In order to make this determination, the model checks the pickup location and all surrounding hexes and the dropoff location and all surrounding hexes for enemy units. If hex size is too small, the model may incorrectly determine what is being accomplished. This may result in the wrong load strategy for the air movement of the unit,

2.12 Probability Of Detection For Air Missions

Air missions move from hex-to-hex in JTLS. Each time the mission moves, the model determines whether the mission has been detected. This is done by drawing a uniformly distributed random variate and comparing it against the probability of detection for the air mission by the covering sensor. This means that the probability of detection value for a sensor really means the probability that the sensor can detect the mission within the time period the it takes aircraft to fly through one hex. For example, assume that the probability of detection held by a sensor for an aircraft is 0.3 or 30%. Each time the air mission moves the mission can be detected by the sensor. After the first move there is a 30% chance the mission was detected. After the second move there is a 51% chance it is detected. (1.0 -

(1.0-0.3) ** 2). After the third move there is 65.7% change it is detected. If the hex size is 7.5 KM, then after the air mission travels 22.5 KM within the sensor's coverage area there is a 65.7% chance the mission will be detected. On the other hand, if the hex size is only 3 KM, there will be a 65.7% chance that the mission will be detected within the first 9 KM of coverage. This means if there is a reduction in the size of the hex in a JTLS terrain database, the database developer must review and properly adjust all of the probability of detection data that exists in the database to keep the final detection results equivalent.

2.13 Probability Of Engage For Air Defense

Similarly, air missions are subject to be engaged by air defense sites each time the mission moves into a new hex. If an air defense radar is not on an IADS network, it is allowed to fire on the air mission based on a uniformly distributed random variate compared to the data parameter Probability of Engage. Using the same logic described in Section 2.12, the database developer would need to review and adjust the probability that the air defense site can engage the air mission when the hex size is reduced. Other aspects of air defense firing such as reload time, and number of feasible shots is not affected by the hex size. The hex size is considered in the remainder of the algorithm.

2.14 Convoy Attrition

In JTLS convoys are allowed to be attacked by enemy ground units in hexes adjacent to the convoy, as well as by enemy ground units that move into hexes that contain convoys. If hex sizes are reduced, it is expected that the number of ground unit kills on convoys would be reduced.

3.0 Simulation Processing Impact

Besides the modeling assumption problems discussed in Section 2.0, there are several processing concerns with reducing the size of the JTLS hex size. These concerns are discussed in this section.

3.1 Number of Hex Effect Structures

Consider again the terrain representation shown in Figure 1 and Figure 2. These two diagram represent approximately the same area but Figure 2 is using a hex size that is approximately one half of the hex size shown in Figure 1. Figure 1 only needs seven hexes to cover the area, but Figure 2 needs at least 28 hexes to represent the same area.

When sensors are placed on the game board, a portion of memory is reserved to hold a structure known as a hex tag and the hex tag is placed in a linked list owned by the hex. This hex tag indicates what sensor is covering the hex and the distance the hex is from the sensor. By computing and saving this information, model processing time is reduced, because the model can quickly determine which objects affects the hex and the distance the object is from the hex. The model is capable of running faster.

These hex tags are known to be one of the major components of the memory requirements needed by a JTLS scenario. In fact, many times, the actual range of long range sensors, such as those found on the E3 Airborne Warning and Control System (AWACS) aircraft and the U2 aircraft, have been reduced to eliminate some of the memory requirements. Decreasing the size of the JTLS terrain hex will exponentially increase the number of needed hex tags for a given scenario. If you decrease the hex size by one half, you can expect much more that twice the memory requirements for the execution of the game. Given a small enough hex size, this could become unmanageable if faster than real time speeds are desired.

3.2 Number Air Mission Moves

Not only will memory requirements increase, but also the number of events that need to be processed will increase. Specifically, a reduction of the hex size by one half will result in twice as many air mission movement events to be executed. Given a large air scenario, this could also lead to the inability to maintain faster than real time game speeds.

4.0 Minor Areas of Concern for Hex Size

The following areas are of minor concern when looking at the hex size within a JTLS database.

4.1 Air Concerns

- Air-to-Air engagements are possible each time the interceptor or interceptee enter a new hex. If the aircraft have air-to-air weapons within range and pass an Attain Firing Position Probability check, then weapons are fired. Smaller hexes may result in more air-to-air weapons being fired or in their being fired at a different time. Adjust the Attain Firing Position Probability data as the hex size is adjusted.
- The Aircraft Continue Engage Multiplier is checked each time the interceptor or interceptee enter a new hex within range of expected enemy weapons. Smaller hexes cause the mission to check more often which will cause the mission to break off the intercept more frequently, unless the probability is 1.0
- The ACP Distance Lose Air Track is effectively a number of hexes measure. Aircraft movement is always center hex to center hex. At 7.5 km hex size a detected mission must be detected again within the next three hexes for an ACP Distance Lose Air Track value between 22.5 km and 30 km, if the mission is to remain detected. This value should be adjusted if the hex size is changed.
- An Air to Ground Attack mission will only look in the hex containing the original perceived location for the "target" of its attack. It will not search for or attack the "target" if it is in an adjacent hex. Smaller hex sizes will make Air to Ground Attack missions more restrictive.
- The data parameter ADA Avoidance Weight Enemy has a unit of measure of hexes. It should be adjusted as hex size is adjusted.

- Orbiting aircraft reenter the orbit hex every "hex flight time." Sensors on board the aircraft search every time the aircraft reenters the hex. Not only will this cause more CPU usage for smaller hexes; but since more detection attempts are being made more ground objects will be seen. The IIP Unit and Target detection multipliers may need to be adjusted. The Sensor Effectiveness may also need to be adjusted.
- Missiles in flight will also be detected more frequently for the same reason. The Sensor Effectiveness and/or TW Mid Phase Probability of Detection should be adjusted. This does not include artillery rounds being detected by counter battery radar. Counter battery detection is only calculated once per fire mission, regardless of how many hexes the rounds travel.
- Point defense against missiles. All ADA targets within the impact hex are allowed to fire at the incoming missile without regard to range. A larger hex size may allow more ADA targets to engage the missile than is realistic. A smaller hex size may preclude targets that should be permitted to engage.
- Multi-element ADA sites only engage with a single firing element in a single hex. If this element becomes unavailable in the mission's next hex due to cycle time, a different element can attempt to engage. While a single element target may have to wait for a hex or two to be able to fire again, a multi-element target will be able to engage in each hex. The smaller the hex size, the less the impact of multi-element target restrictions.

4.2 Logistics Concerns

- The SLP Explicit Convoy Distance is the minimum distance between a sending and receiving unit for which an explicit convoy will be sent. At distances less than this implicit convoys are used. This distance may need to be adjusted depending on hex size.
- The IIP Convoy Mean Detection Time is a measure of how long it will take to detect a convoy in the same or an adjacent hex. This value should be adjusted if hex size is changed.

4.3 Naval Concerns

- Ships only move hex to hex, not hourly. The larger the hex, the longer the ship will sit at the same location before it moves, making it an easier target.
- Ships automatically detect other surface ships in the same hex. Smaller hexes will limit these near vicinity detections. Larger hexes will increase them.
- The probability that a ship will encounter a mine in a mined hex is a function of the ship radius, the minefield radius, and the hex size. A larger hex will make it less likely for a ship to encounter a given minefield.
- Active and Passive Sonar on aircraft will be less effective if smaller hexes are used. The range to a submarine in the same hex is considered to be zero, which means there is no noise attenuation. This makes it much easier for an aircraft's sonar to detect a submarine in the same hex as the aircraft.

- For sonar detections, other ship noise is only considered if the other ship is in the same hex as the detecting ship or the ship being detected. Smaller hex sizes make it likely that there will be fewer ships in a single hex.

4.4 Intelligence Concerns

- The TUP or SUP Organic Intel Distance may need to be adjusted. If the value was established to ensure that the unit could see at least one hex beyond its perimeter, the value may need to be adjusted to reflect the new hex size.
- If the range of a sensor or jammer includes the center of a hex, then the sensor/jammer is considered to cover the whole hex. If the range doesn't reach the center of a hex, then the object doesn't cover any part of the hex. A sensor or jammer always covers the entire hex it is located in regardless of how small the sensor/jammer range is.

4.5 Terrain and Target Concerns

- Land Minefields affect all land units entering the hex. There is no probability/possibility of avoiding the minefield. Larger hexes will cause more units to be affected by a given minefield.
- Road networks in JTLS are basically one hex wide. Any unit moving through a Good Road or Poor Road hex gets the trafficability benefit of the road. Smaller hex size will improve the road network representation.
- Terrain Barrier Delays may be a function of hex size. At larger hex sizes rivers either represent the larger rivers or they represent the effect of several smaller rivers. At smaller hex sizes the smaller rivers could be represented individually. If you are only representing larger rivers then you may still only have one set of river hex sides, just more accurately located. There will be more barriers to cross as hex size decreases. You may need to adjust the delays
- National Boundaries follow hex edges; the smaller the hexes will permit better the boundary representation.
- Water Depth and Elevation are a single value per hex. Smaller hexes will provide a better representation.
- A small island must be a complete land hex in JTLS. Smaller hex size permits representation of smaller islands.
- A strait must be a complete water hex in JTLS. Smaller hex size is better.
- The representation of coastlines will be better for smaller hex sizes.
- Bridges, Tunnels and Interdiction Points will affect trafficability across a larger or smaller area as hex sizes are increased or decreased. Smaller hex size will generally improve the representation.
- MHE targets can only be used to support loading or unloading actions occurring in the same hex.
- To use a rail network, a unit must be in the same hex with a rail node.

- Route optimization will take longer for smaller hex sizes. There are many more possible routes to check at 3 km than at 7 km. Optimal path data will probably need to be adjusted. The Min End Overlap and the Min Half Width data parameters unit of measure are in hexes.

4.6 Lethality Concerns

- Nuclear and Chemical effects are limited to the impact hex. As hexes get smaller, the effects will be present over a smaller area.
- The ranges for some short range weapons may have been adjusted to ensure a standoff capability is represented in the model. Short range sensors may have been assigned a range capability based on hex size. These ranges may need to be adjusted based on the new hex size.

5.0 Conclusions

The purpose of this paper is to report the facts of the situation as they currently exist in JTLS. The degree to which these issues will affect the execution of the model depends on how small the hex sizes are set. Generally the feeling of the JTLS development ream has been that any hex size greater than 5 KM could be acceptable within the current modeling limitations. If a user desired to set hex size smaller than that, the above issues would either need to be ignore or fixed in some manner.

Many of the issues addressed in this paper could be eliminated if there was a desire to do so. It would simply take some effort (and therefore funding) to solve the issue. For example, the sensor's probability of detection algorithm for air missions could be changed from its current hex based algorithm to a time to detection algorithm. By far, the largest problem presented in this paper is the restriction of Lanchestrian attrition to adjacent hexes. It would take considerable effort to remove this restriction from the model. The degrees to which this affects the model depends on the scenario, the weapons systems represented and the selected hex size.