Assessing the Value of Decision Superiority for Ground Forces

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Abstract

RAND with the assistance of the Joint C4ISR Decision Support Center has developed an agent-based simulation, the ground force C4ISR model (GFCM), which represents command and control (C2) decision-making and C4ISR capabilities, and their impact on combat outcome. GFCM can be used to access the military utility of advanced C4ISR capabilities, and in particular the value of enhanced shared battlespace awareness for maneuver planning and long-range fire allocation by modern “digitized” or network enabled ground forces. Dynamic C2 is modeled realistically at three levels of command. Commanders at different levels plan, interact, request assets, or negotiate during the planning process according to the specified C2 concept of operation. Initial GFCM results indicate that combat outcome depends significantly on C2 decision making speed and communications network performance.

Command and Control

The foundation for GFCM is the agent-based System Effectiveness Analysis Simulation (SEAS) modeling environment. Agents with different characteristics and behaviors can be created using the SEAS tactical programming language. SEAS has built into it a number of high level objects, including components to build communications network between agents, and a full range of sensor models to represent military Intelligence, Surveillance, and Reconnaissance (ISR) capabilities, as well as C2 centers, weapons, and mobile platforms, such as ground vehicles, aircraft, ships, and satellites.[1]

GFCM is two-sided with simulated C2 at multiple echelons on both sides. Red and Blue theater commanders start with initial courses of action (COAs) and maneuver plans along with their own perceived estimates of opposing force COA, force disposition, and force strength. The simulation framework enables the realistic representation of operational environments in which either side can react to and counter the maneuver operations of the opponent. The initial fire support and maneuver plans of simulated Blue and Red commanders are modified using an adjustable planning cycle that can be varied independently on both Red and Blue sides. The Red and Blue decision-making agents use their perception of the battlespace to assess the operational situation and available planning alternatives using the correlation forces and means (COFM) algorithm. In prior research Rand has shown that the COFM algorithm, with appropriate enhancements, is capable of simulating credible maneuver planning decisions. The quality of the decisions resulting from COFM are a function of the quality and the accuracy of the estimates of force strength and force location that are used as inputs to the algorithm and which are the output of the perceived situation awareness available to the simulated decision-making agents.[2] Thus in this way the impact of the quality of information produced by

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[1] SEAS was originally developed to model the information generation and transmission capabilities of space systems. RAND and others have used it to model not only space systems, but also an increasing range of joint military C4ISR capabilities. SEAS is a member of the Air Force modeling and simulation toolkit.

[2] Gonzales, Dan and . Moore, Louis, et. al., *Assessing the Value of Information Superiority for Ground Forces - Proof of Concept,* RAND DB-339-OSD, 2001.

the C4ISR architecture on the command decision-making process and ultimately on combat outcome can be assessed.

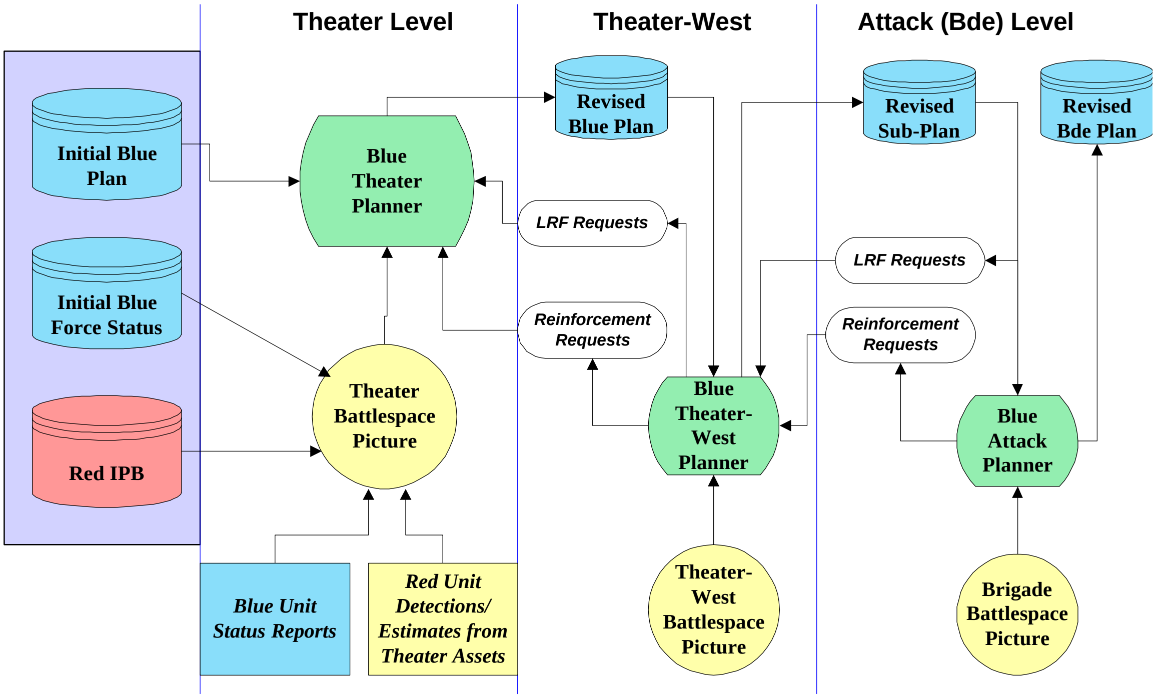

Figure 1- Information Flows and Interactions of Selected Ground Force C2 Planners

Figure 1 illustrates the information flows between Blue planners in the ground force C2 hierarchy currently represented in the model. Each planner makes use of its own battlespace picture to modify and update its maneuver and fire support plans. The information sources used to build the Blue theater commander's battlespace picture are indicated in the figure and include theater level ISR assets that report Red unit detections in near real time or with appropriate Tasking, Processing, Exploitation and Dissemination (TPED) delays via the Blue C4ISR network. The Theater Planner uses its battlespace picture to modify and update the overall theater plan. The plan is then disseminated to the Theater-West and Theater-East planners (only the Theater-West planner is shown above). These Division-level planners use the theater level plan as a starting point for more detailed planning in their areas of responsibility. If the Division-level plans can not be substantiated with the assets already allocated to these units, then the Theater-West or Theater-East Planner will request more assets (additional Long Range Fires (LRFs) or ground maneuver reinforcements). These requests are sent back to the Theater Planner who will allocate additional assets if they are available. If additional assets are not available, the Theater planner will downgrade one or perhaps both of the attacks. Attacks are downgraded in priority order, based on the priority established in the initial Blue theater plan, unless the highest priority attack can not be substantiated even when all available LRFs and reserve units are allocated to the highest priority attack. This sequence of high to lower level more detailed planning is continued to the Brigade level as indicated in Figure 1.

The maneuver and fire support planners implemented in the model use COFM to assess the viability of their plans relative to the perceived threat. This situation assessment and plan assessment algorithm can be adjusted parametrically to vary the risk tolerance of the simulated commander. Thus, it is possible to represent commanders with high risk tolerance (aggressive commanders willing to make risky attack decisions), moderate risk tolerance, and low risk tolerance (cautious commanders). Command risk tolerance and planning cycle time (decision making speed) can be varied at all command echelons represented in the model. For the C2 concept of operation implemented in the current model, the C2 system can be independently varied in six dimensions, three representing decision making speed and three representing risk tolerance.

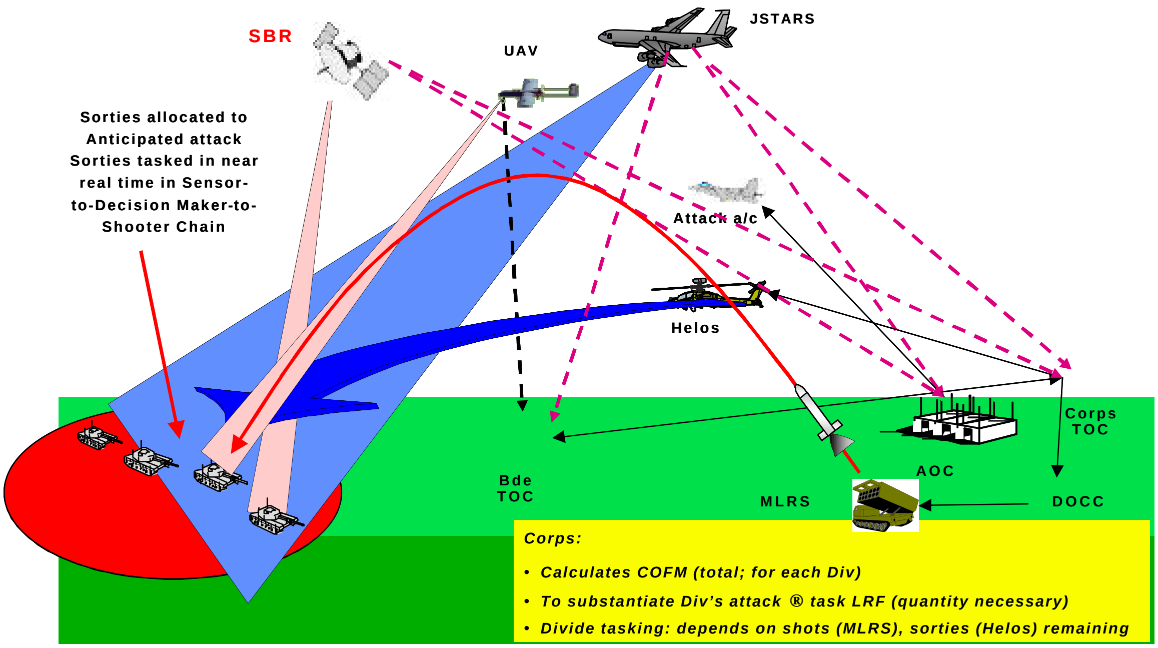

Figure 2- Integrated Long Range Fire Direction and Ground Force Planning

Depicted in Figure 2 are the LRF and ISR systems that are linked together in sensor to shooter chains in the model. The LRF systems modeled are long range surface to surface missiles (SSMs) carried by MLRS, rotary wing aircraft for close support missions, and fixed wing aircraft for deep attack missions. Red and Blue commanders can possess any of the above three types of LRF systems. The specific capabilities of each weapon, i.e., weapons accuracy and lethality, can be varied and may be different for corresponding Blue and Red weapons systems. All LRFs are initially held and controlled at the theater level. The total number of LRF systems available to the theater commander is fixed and is a planning factor input.

A subset of total available LRFs are allocated to specific attacks by the Theater Planner. The remaining LRFs are held in reserve by the Theater Planner for subsequent operations. Long range fires are allocated to the lower echelon attack plans. When those attacks occur and valid targets are detected, the appropriate allocated LRF systems are tasked to strike these targets. The precise linkages – which are a function of the communications networks connecting units and systems - are not shown. When one of the sensors shown above detects a target in an area where an attack is planned or is taking place, one or more long range fire systems can be tasked in near real time to engage those targets.

Intelligence, Surveillance and Reconnaissance

Shown in Figure 3 are Blue ISR systems and their connectivity to battlefield forces represented in the model. Blue systems include National Technical Means (NTM), Space-Based Radar (SBR), and Army tactical UAVs, including a Shadow 200 at each Brigade, and a Shadow 600 at each Division. Shadow UAVs are equipped with electro-optical imaging cameras that downlink visible light or infrared video and imagery. The Blue ISR theater level architecture is composed of one 24-hour JSTARS and one 24-hour Aerial Common Sensor (ACS) orbit. The JSTARS and SBR platforms carry Synthetic Aperture Radar (SAR) and Ground Moving Target Indicator (GMTI) mode radar. Blue airborne ISR systems maintain a constant stand-off distance from the leading invading Red units. Blue ISR architectures in GFCM can also include theater level UAVs, such as Global Hawk and manned ISR systems, such as the U-2. In the initial model runs the latter ISR systems and JSTARS were not connected to the C4ISR network.

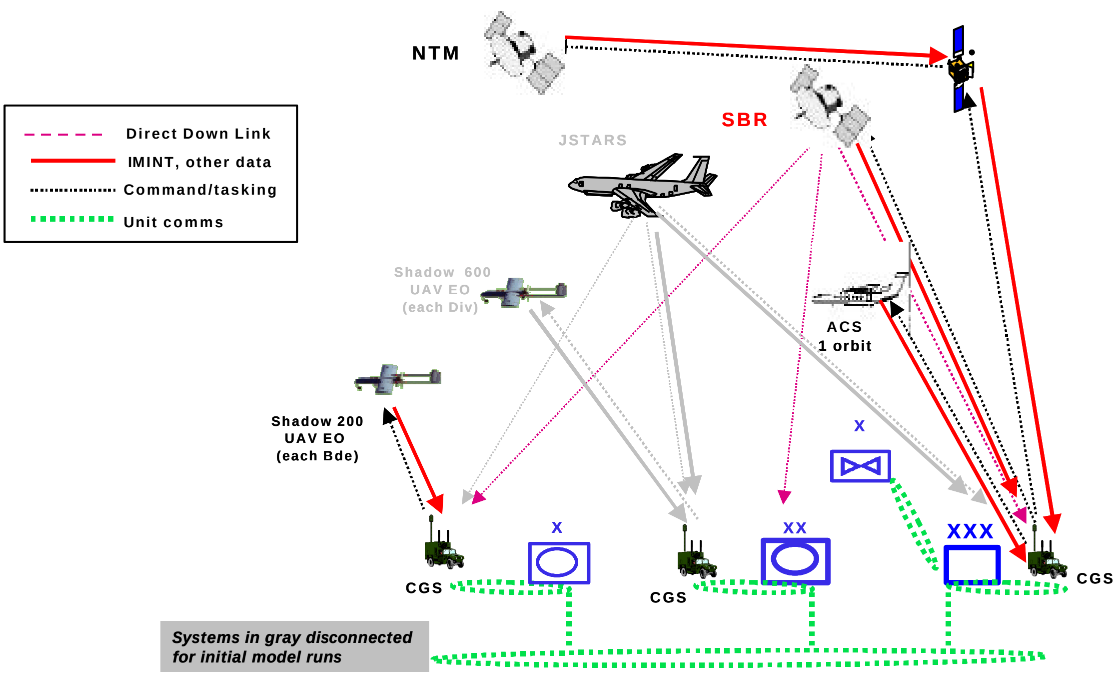

Figure 3- Blue ISR Architecture

Figure 3 shows that Blue (US Army) UAVs can transmit information directly to Common Ground Stations (CGSs) located at the Brigade and Division levels, JSTARS and SBR can transmit information directly to CGSs at all echelons, but other space systems and ACS only transmit directly to the theater level.

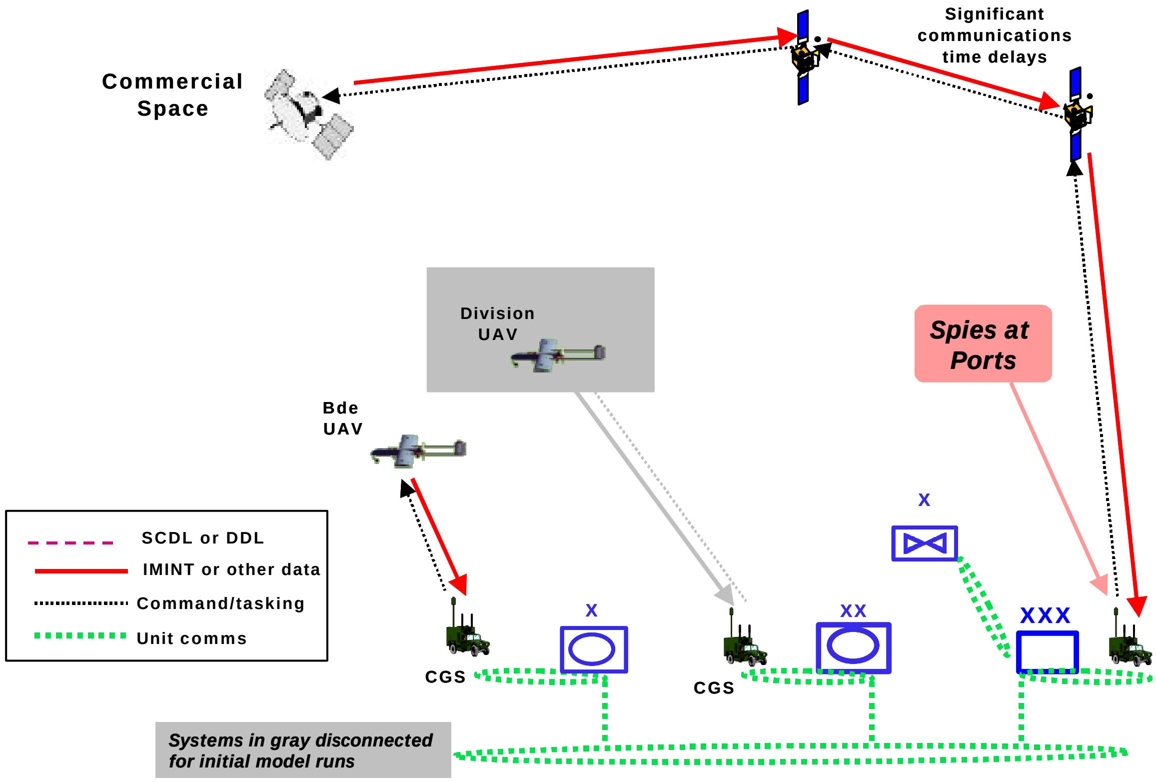

Figure 4- Red ISR Architecture

Shown above are Red ISR systems represented in the model and their connectivity to battlefield forces. A wide range of red ISR systems can be modeled, and the red ISR architecture can be set equal to the blue ISR architecture. For the initial GFCM runs a more realistic red ISR architecture as shown in the figure above was used. The Red systems include commercial remote sensing space systems, and tactical UAVs. For simplicity Red and Blue UAVs were given identical capabilities. At the theater level the Red ISR architecture is composed of only Red spies at key ports where Blue forces may be deployed to the theater. These Red spies detect the presence of arriving Blue forces and report back their location to the Red theater commander. From the chart one can see that Red UAVs can transmit information directly to the Brigade and Division levels.

Communications

SEAS, the underlying simulation used in GFCM, is used to build detailed representations of communications networks. Shown in Figure 5 is a simplified view of the GFCM communications network. In some aspects the communications network is hierarchical and corresponds to the type of network used by a traditional ground force using hierarchical C2 concepts. For example, direct brigade-to-brigade communication links do not exist in this network architecture. If brigade K wants to communicate to brigade L, then it must send a message to brigade L by sending the message first to the division level and then back down to Brigade L. This hierarchical communications network structure is not a limitation of GFCM, it is simply the network structure implemented first in GFCM. In the future a range of communications network architectures will be modeled.

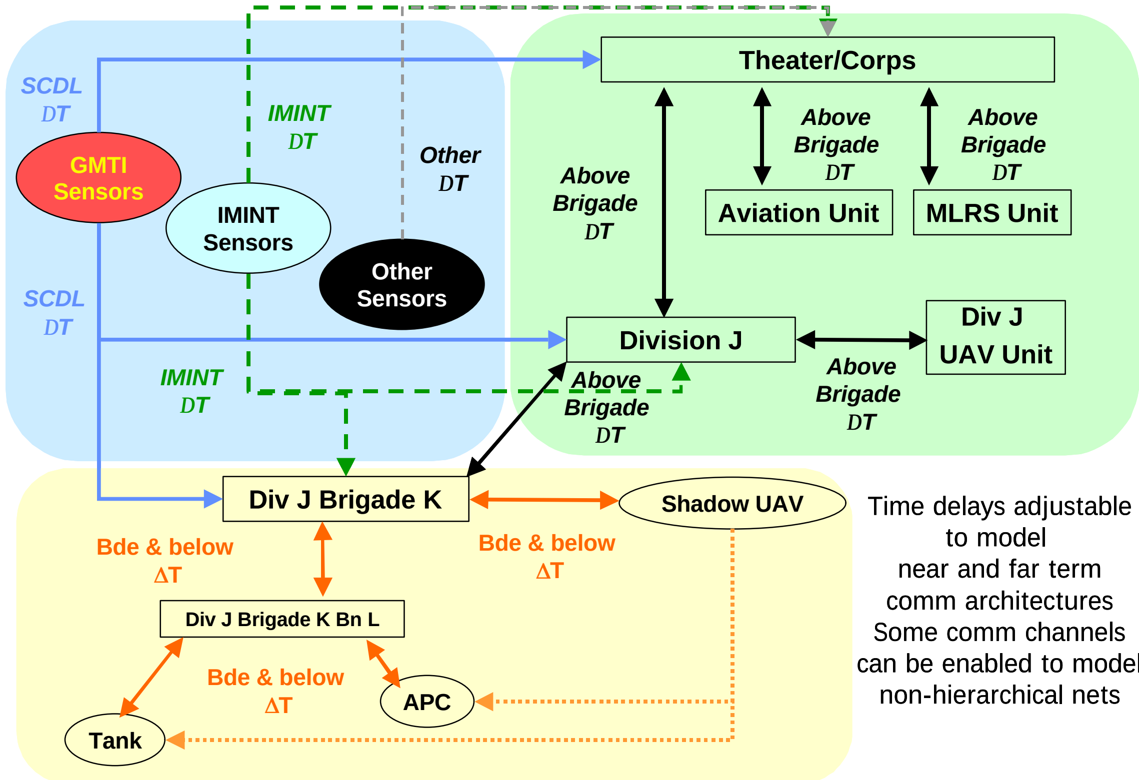

Figure 5- Blue Communications Architecture and Time Delays

In GFCM communication time delays on any link in the network can be adjusted or set independently. To simplify the analysis a few common communication time delays were used to characterize the entire communications architecture. This is indicated in the chart above by the yellow, blue, and green areas. The yellow area indicates the part of the communications network where a “Brigade and Below” communication time delay is set for all links. Typically these correspond to communication links from the brigade level on down to individual tanks and include UAV links to brigades. The green area corresponds to the “Above Brigade” part of the network were all communication link time delays are set equal to the “Above Brigade” time delay. This includes communication links connecting the theater level or corps headquarters to divisions and links that connect the theater headquarters to Army Aviation and MLRS units. Specific sensor-to-shooter loops can be defined in GFCM and these can be given shorter communications time delays to represent “golden thread” sensor-to-shooter communications links.

There is a third class of communication links that can be given time delays independently. These links connect ISR sensors, as indicated in the chart, to force elements and associated planners. For these classes of links we assign independent time delays for the delivery of specific types of sensor information. This is done so that we can take into account the time required for processing, exploitation and dissemination of specific types of sensor information. For example, the time needed for the processing, exploitation, and dissemination of imagery intelligence (IMINT) can be significantly longer than that needed to process exploit and disseminate other types of ISR information. On the other hand, GMTI sensor information can be processed, exploited, and disseminated much faster than IMINT. In the depiction of the Blue communications architecture above communications links can transmit GMTI sensor information from airborne platforms such as JSTARS or SBR satellites to Army CGSs at the theater, division, and brigade levels are shown. Similar links exist for the transmission of IMINT to the same units and planners. Separate and typically much longer time delays can be set for the latter communications links to represent IMINT TPED time delays. Finally, other additional sensors that will not be discussed in this paper are modeled in GFCM. Separate communications time delays can be set for the delivery of the latter type of information as well.

Scenario and Movement Network

Shown in Figure 6 is the theater of operations represented in the scenario. Also shown is the road network represented in the model. Red and Blue maneuver forces can decide to use or not use the road or movement network. If maneuver forces use the roads they move along the road network at their normal speed. If they choose to move off-road their speed is reduced to represent their reduced speed and maneuverability in desert locations in Saudi Arabia and the Persian Gulf area. Maneuver units can independently choose the route they take to move to their objectives or assigned locations in the maneuver plan. They choose an optimal path along the movement network using Dykstra's algorithm. The Dykstra algorithm implemented in the model enables both off-road and on-road movement by maneuver units, with an adjustable off-road speed degradation factor. In the initial model runs the off-road speed degradation factor was set to one half, meaning that maneuver units could only move at one half their roadway speed while off-road.

Now we briefly describe the Red and Blue plans and objectives used in the initial model runs. The primary three objectives of the Red course of action (COA) are to capture Riyadh, the political capital of Saudi Arabia, and Ad Damman and Doha, two the key ports on the Gulf Coast which would be needed by the U.S. to deploy additional ground forces into the theater of operations. In this scenario and in the Red COA Red is on the offensive. If Red is successful in executing its theater level plan it will capture one or more of these objectives within the time constraints and with military forces given in its plan.

The Blue COA has as its initial objectives to defend as far forward or northward in Saudi territory as possible and in particular north of the key ports. The initial Blue objectives are where U.S. forces set up defensive positions: King Khalid Military City (KKMC), Hafar Al Batin, Al Khafji , and Al Jubayl. One measure of Blue success in executing its theater level plan is whether it can maintain its defensive positions at the above forward locations.

In GFCM one has to specify the perceived objectives of the opponents, or the opposing force IPB. In the model, it is possible to set a priori the opposing force IPB to the actual opposing force COA, or to set to the IPB to some other set of objectives. Therefore, it is possible to give either the Red or Blue force a good or a bad IPB. In the initial set of GFCM runs both Red and Blue forces were given a good IPB, i.e., the perceived opposing force objectives coincided with the actual objectives of the opponent.

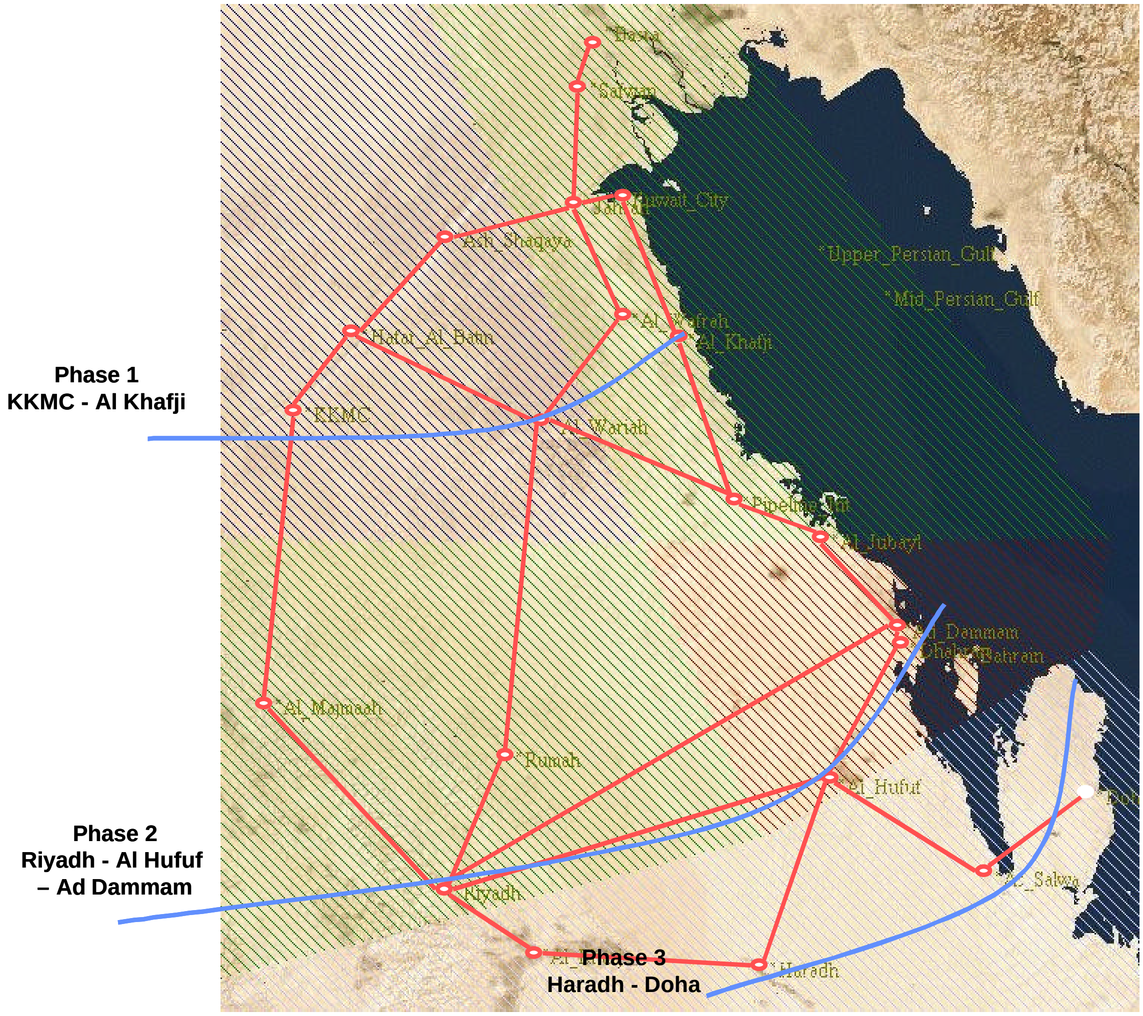

Figure 6- Ground Forces Can Maneuver On or off-Road

A range of Red and Blue units are represented: Blue and Red armored and mechanized battalions, armor brigades, a Blue attack helicopter brigade, a Blue ATACMs Co, Blue tactical air interdiction and close air support assets, and finally a Red Scud Brigade. However, model runtime can increase significantly when more Blue and Red units are added. In the basic GFCM scenario four Red and four Blue divisions are represented along with the LRF units indicated above. Each division is composed of three brigades. Each brigades is composed to armor and one mechanized battalion.

The scenario starts may or may not start with Red forces invading Kuwait and Saudi Arabia. The scenario can play out according to the initial Blue and Red COAs. However, Red may decide not to invade or may move it units only a small distance towards their ultimate goals before aborting the invasion. How far the invasion proceeds depends on Red commander’s risk tolerance, how good Red ISR capabilities are, how well and quickly Blue adjusts to the Red invasion plan, and the force ratio as it evolves during conflict. In these respects the GFCM is largely an unscripted model.

The model has considerable scenario flexibility, as the number and deployment timelines for Red and Blue units can be adjusted in the initial Red and Blue plans. In the initial model runs the Red invading force was composed of four armored divisions. For simplicity, Red was not given any long-range fires. Blue forces were composed of four armored divisions, however two of those divisions were not available or deployed within the scenario timeframe. Thus, Red possessed a 2 to 1 armor advantage in the initial model runs. Blue did however possess a LRF advantage as indicated above. Blue's LRF advantage was varied in model runs.

Run Matrix

A wide range of cases have been examined with the GFCM model to explore how different combat outcome measures depend upon C4ISR system and C2 decision making performance. In this paper only a subset of these exploratory analysis cases and results will be presented. The cases considered in this paper are described in Table 1.

Table 1- Run Matrix

	Blue	Red	Communications Network Delays						Red	Blue	Blue	Blue
	Planning Cycle	Planning Cycle										
Case/ run no.s	Bde Div Corp	Bde Div Corp	Bde& Below	Above Bde	Planner-ISR	Bde Below	Above Bde	Planner ISR	IPB Factor	Divert Range	Vehicle Speed	LRF Factor
Eb1	*Fast*	Slow	1	1	1	10	10	10	0.5	20	1.0	0.1
Eb2	*Fast*	Slow	1	1	1	1	1	1	0.5	20	1.0	0.1
Eb3	*Fast*	Slow	10	10	10	10	10	10	0.5	20	1.0	0.1
Eb4	*Fast*	Slow	10	10	10	1	1	1	0.5	20	1.0	0.1
Eb5	*Slow*	Slow	1	1	1	10	10	10	0.5	20	1.0	0.1
Eb6	*Slow*	Slow	1	1	1	1	1	1	0.5	20	1.0	0.1
Eb7	*Slow*	Slow	10	10	10	10	10	10	0.5	20	1.0	0.1
Eb8	*Slow*	Slow	10	10	10	1	1	1	0.5	20	1.0	0.1
L1-L8	"	"	"	"	"	"	"	"	0.5	0	1.5	0.1
M1-M8	"	"	"	"	"	"	"	"	0.5	20	1.0	0.0
M9-M16	"	"	"	"	"	"	"	"	0.5	20	1.0	0.2
R1-R8	"	"	"	"	"	"	"	"	0.7	20	1.0	0.1
Q1-Q8	"	"	"	"	"	"	"	"	0.5	0	1.0	0.1
T-T8	"	"	"	"	"	"	"	"	0.7	0	1.0	0.1

In the all cases considered Red commanders at all echelons always have slow planning cycles. We vary Blue planning cycle from fast to slow as indicated above. The Blue IPB scaling factor (how much the Blue theater commander discounts the combat strength of units in his opposing force IPB) is set to 1 (no discounting). For all the cases considered Blue commanders have moderate risk tolerance and Red commanders have high risk tolerance (Red is aggressive).

Consider the Eb case. Blue has fast planning cycles for the first four runs in the Eb series. For the last four Eb runs Blue has slow planning cycles. Also in the Eb series we vary message delivery delays in various subnets of the Red and Blue communications network, as indicated in the table.

In runs for the other cases, i.e., L,M, N, Q, and T series, Red and Blue planning cycles and communications network time delays are varied exactly as they are in the Eb series. This is indicated by the ditto marks in the grey columns. The other factors that are varied in these later cases are highlighted in the white cells of the table. These factors include the speed of Blue combat vehicles. In the base case (the Eb series) Red and Blue vehicles have equal speeds. In the L series Blue vehicles are 50 percent faster than Red vehicles. Another factor we vary is the Red IPB scaling factor. Finally, we vary a factor called the Blue Divert Range. This is the maximum range a brigade is permitted to divert to attack enemy armored vehicles that appear on a brigade "Common Operational Picture."

Results

Attrition results for the cases described above are shown in the figures below. For the results in Figure 7 the Blue Divert Range is equal to zero, so Blue forces defended from prepared positions if they had sufficient time to dig-in before Red attacked (these results correspond to the L, Q, and T series cases).

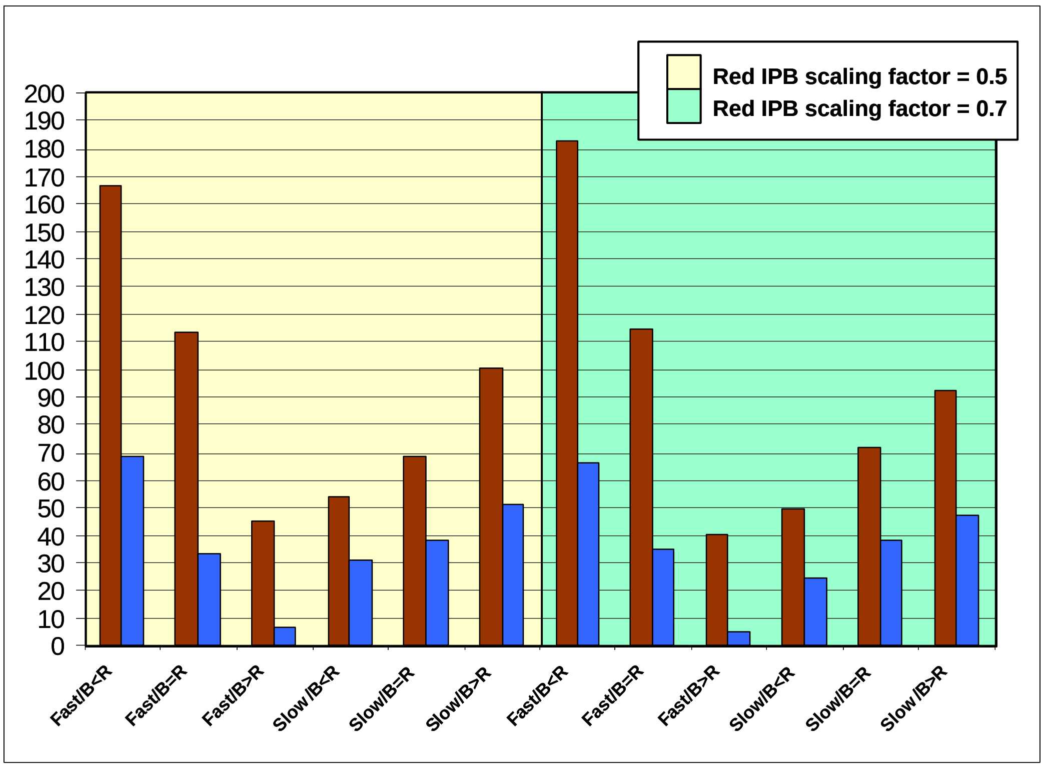

Figure - 7 Red and Blue Losses When Blue Divert Range = 0 km

Red IPB scaling factor varies as indicated on the left and right hand sides of the chart. Blue planning cycles are varied from fast to slow speeds. Cases where Blue communications delays are *less* than Red, i.e., where Blue has a better network than Red, are indicated by *B<R*. Cases where Blue communications delays are *greater* than Red,

i.e., where Red has a better network than Blue, are indicated by *B>R*. Cases where Red and Blue have equal delays are indicated by *B=R*. These results indicate that a Blue force in a scenario where Blue is on the defensive and when it has time to dig-in to defend at prepared positions, has significantly increased combat power when it is has a planning cycle speed advantage and better communications networks than the opposing invading force. In other words, Blue makes decisions faster about where to defend and then has the time to maneuver to those positions and dig-in. This combat advantage persists even if Red has a better IPB. It is interesting to see that the overall attrition levels decrease with decreasing communications delays when Blue has a decision making speed advantage, and that the attrition levels increase when Blue has a decision making speed disadvantage.

The results shown in Figure 7 are means obtained from 25 to 125 replications (depending upon the individual case). A significant degree of non-linear behavior can be found when examining detailed results. The distribution of results for most cases do not conform to a typical normal distribution. A wide variation in possible outcomes is expected in a stochastic model when individual simulated commanders can make many independent decisions and we see evidence of that in the underlying distributions. In fact we see evidence of bi-modal and tri-modal distributions that appear to result from particular operational level decisions made during the course of a largely unscripted conflict scenario. We have done a detailed statistical examination of the results presented here. Excerpts from this ANOVA analysis are presented in Figures 8 and 10 below.

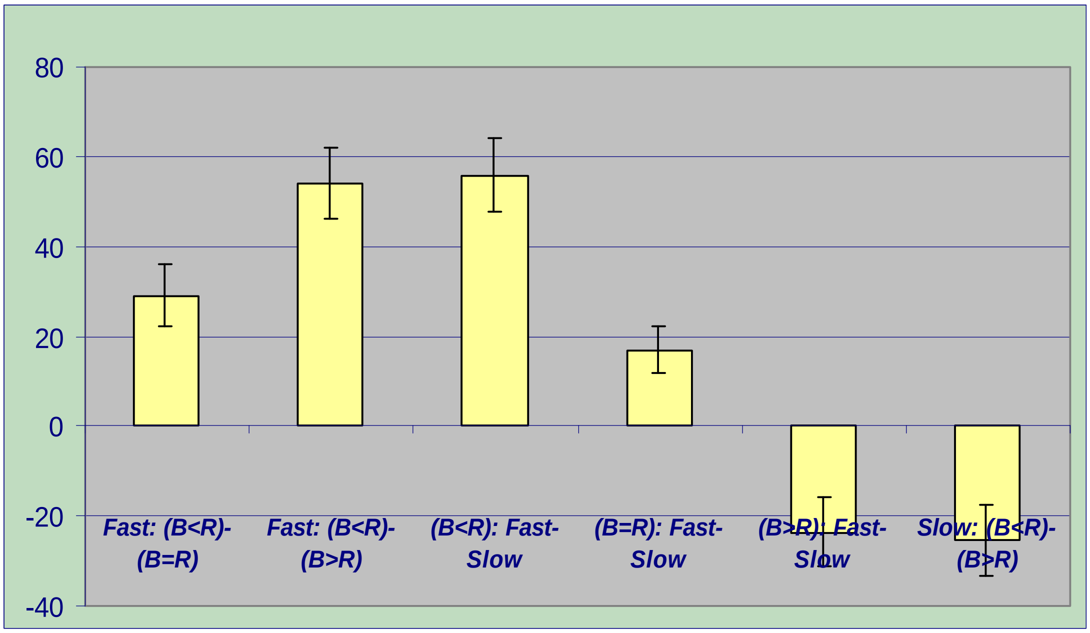

Figure 8 – Difference in Red Losses Between Selected Blue Divert = 0 Cases

Figure 8 indicates the magnitude of the difference between the means of different cases found in the right hand side of Figure 7. The “error bars” indicate the 95% confidence interval for these pair-wise differences. One can see that the differences observed in Figure 7 are all statistically significant at the 95% confidence level.

Figure 9 shows attrition results for a parallel series of cases to those above but where the Blue divert range is now set to 20 km. One can see Blue force effectiveness is reduced considerably, especially for those cases where in the previous cases Blue had a C2 decision making speed or communications network performance advantage. One can see however that at least in the case where Red IPB = 0.7 that trends observed earlier in terms of attrition levels persist although in much more muted terms.

Figure 9 - Red and Blue Losses When Blue Divert Range = 20 km

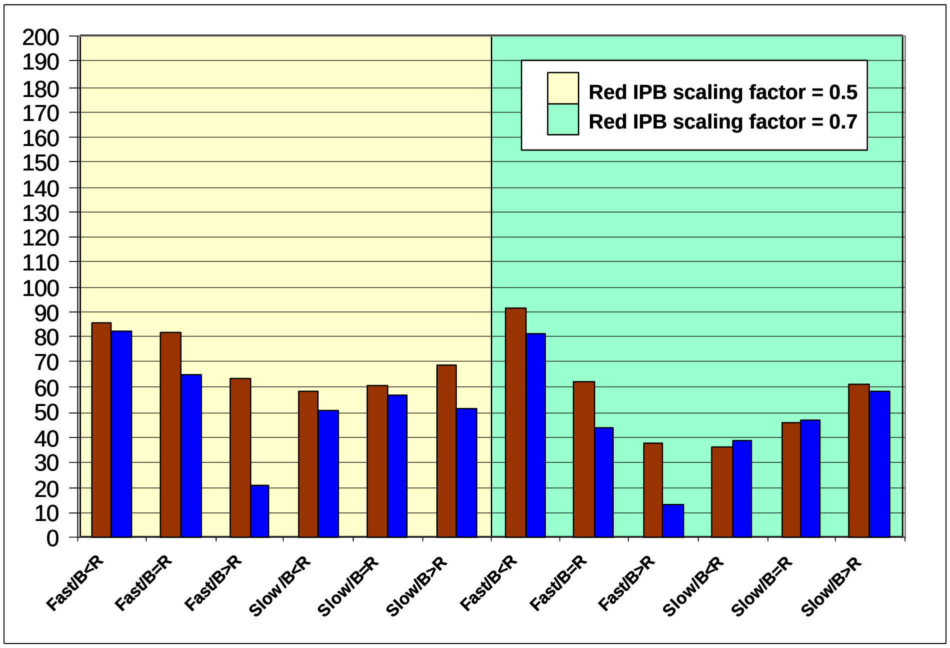

Figure 10 shows a statistical analysis of results in Figure 9 to see whether the differences observed when the Red IPB scaling factor is changed from 0.5 to 0.7 are statistically significant. One can see from the figure below that the differences observed in many cases are not significant.

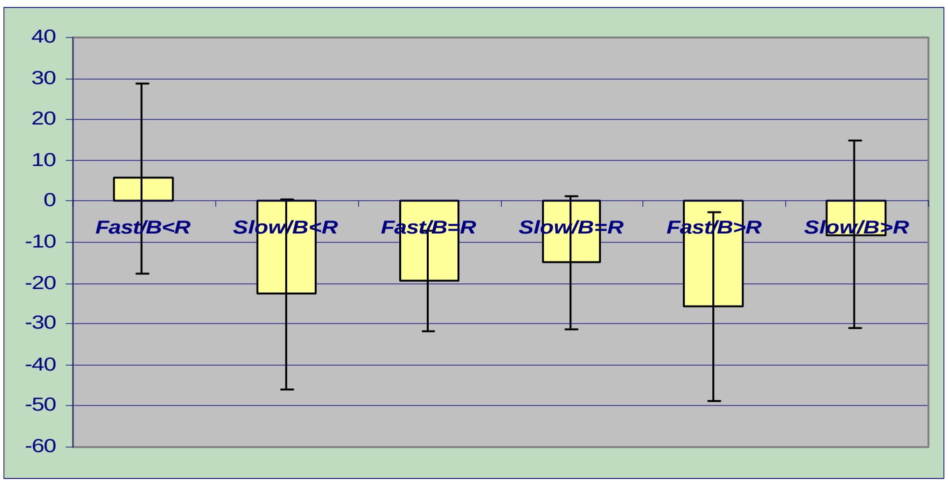

Figure 10 - Difference in Red Losses Between Selected Blue Divert = 20 Cases

Next we examine whether Blue vehicle speed has a significant impact on combat outcome. The results in Figure 11 indicate that Blue vehicle speed is not significant. Blue C2 decision making or planning speed and communications network performance are more important in determining combat outcome. It is striking to observe that Red losses increase by over a factor of 2.4 when Blue planning speed is changed from slow (the same are Red's) to fast. Not Surprisingly, Red losses are much more sensitive to Blue planning speed changes than Blue losses. Also, when Blue has a decision making speed advantage, both Red and Blue losses decrease as Blue communications network delay advantage decreases. This effect is not entirely understood and is being studied further.

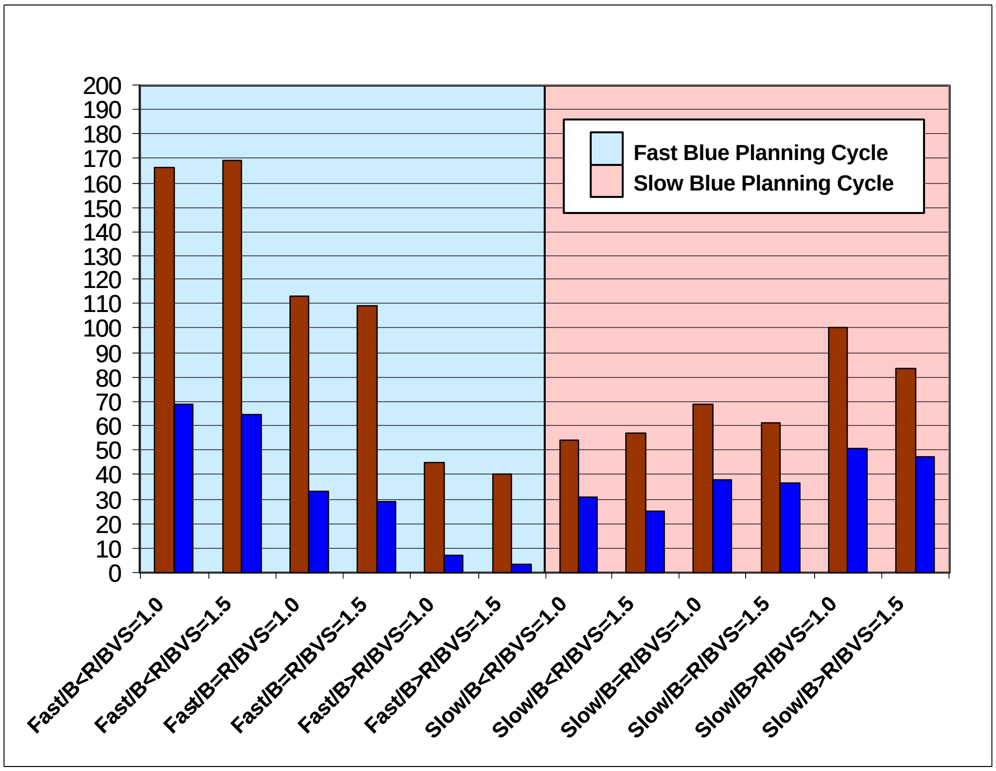

Figure 11 - Red and Blue Losses As A Function of Blue Vehicle Speed When Blue Divert Range = 0 km

The increase in combat effectiveness observed in Figure 11 also translates into a less territory captured by Red in the invasion. Red invasion distance has been examined as a function of the number of interdiction or LRF assets available to Blue and we do see a sensible interdependence of these two factors. Shown below in Figure 12 is the mean distance between the leading elements of the Red invasion force to the final three Red objectives: Riyadh, Ad Dammam, and Doha. The results shown in Figure 11 are for the L series cases where Blue vehicles have a speed advantage over Red vehicles and where Blue forces do not divert to attack from prepared defensive positions. From the figure one can see that Red distance from Red goals is on average greater for the cases where Blue has a decision making speed advantage (Red captures less territory). Red advances the furthest to Doha and Ad Dammam when Blue C2 decision making speed is slow and both Red and Blue have large (10 minute) communications delays. Red advances the least when Blue has fast C2 decision making speed and when both Red and Blue have short communications time delays.

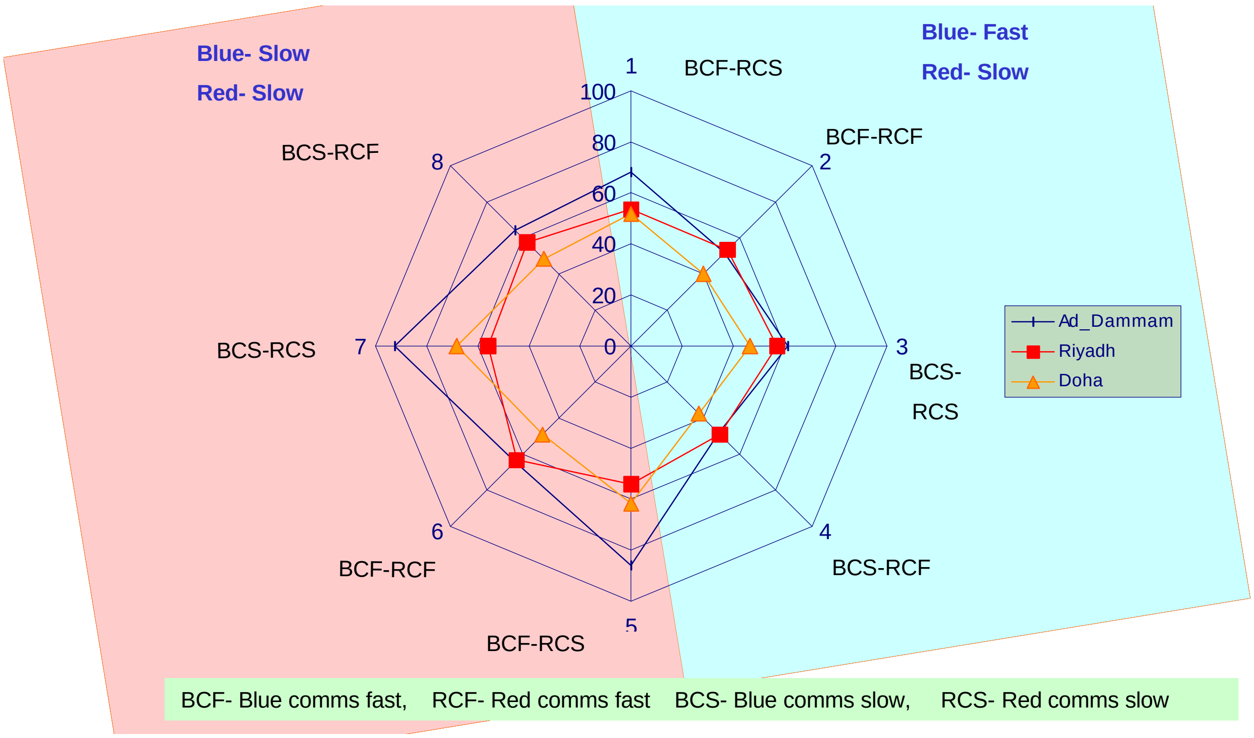

Figure 12 - Red Invasion Percentage Distance to Goals When Blue Divert = 0 -L Series Results -

Summary

An agent-based simulation model, GFCM, has been developed that can be used to assess the military utility of C4ISR systems in ground maneuver warfare and in joint operations. This model explicitly represents the flow of information from sensors, through communications networks, to decision makers (C2 agents), and of targeting information and commands to weapons and platforms. Consequently, it can be used to assess the impact of the quality of information delivered by a C4ISR architecture and on combat outcome.

Initial results obtained using GFCM for a South-West Asia scenario indicate that for a defending Blue force with C2 decision making and communications network performance advantages over Red, Blue force effectiveness as measured by Red attrition is approximately 2.4 times greater than in the case where Blue has no decision making or communications network advantage. In addition, as indicated in Figure 12, the territorial extent of the Red invasion increases an average of 32 to 36 percent if one compares the case where Blue has both decision making and communications network performance advantages (Figure 12 Case 1) to the case where Blue has neither advantage over Red (Figure 12 Case 7).