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CONCEPTUAL MODELING AND VALIDATION OF A HA/DR SCENARIO USING A WEIGHTED SYSTEM DECOMPOSITION MODEL

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ABSTRACT

Humanitarian Aid / Disaster Relief (HA/DR) missions are a continuing concern for world governments and NGOs. The vastness and complexity of the HA/DR missions emphasizes the need for quality conceptual model (CM) development (CMD). Two challenges of CMD are correctly determining the fidelity to model the system and validating the CM. CMD relies heavily on qualitative assessments from subject matter experts. Likewise, its validation is qualitative; often performed through reviews. This approach works well for simpler or familiar systems; however for complex or unfamiliar systems a more quantitative approach to CMD and validation is required. Weighted System Decompositions (WSD) are proposed as a method for addressing these challenges. Quantitative impact relationships from the WSD are used to inform the fidelity decisions during CMD. CM validity is assessed by comparing WSD relationships to the objective simulation outputs. The proposed approach is demonstrated though an application to a HA/DR scenario.

1 INTRODUCTION

Humanitarian Aid / Disaster Relief (HA/DR) missions continue to be major operations of critical importance around the globe as evidenced by the numerous humanitarian disasters of incomprehensible destruction, e.g. 2004 Indian Ocean earthquake [286,000 killed] (U.S. Geological Survey 2015a), 2008 Sichuan earthquake [69,195 killed] (U.S. Geological Survey 2015b), 2008 Burma cyclone [138,00 killed] (Swiss Reinsurance Company Ltd 2009), 2010 Haiti earthquake [100,000-316,000 killed] (U.S. Geological Survey 2011), 2010 Pakistan floods [1,781 killed, 20,000,000 affected] (Singapore Red Cross 2010), 2011 Pakistan floods [497 killed, 9,275,568 affected] (Pakistan National Disaster Management Authority 2011), 2011 East Africa drought [13,300,000 required assistance] (UN News Center 2012), 2014-2015 West Africa Ebola outbreak [10,398 killed, 25,030 infected] (World Health Organization 2015). The diversity, scale, and complexity of disasters present difficulties in being able to comprehend and simulate HA/DR missions. The diversity of HA/DR missions span across various natural and man-made disasters, e.g. earthquakes, floods, droughts, hurricanes, war, civil unrest, insurgencies. The scale of these disasters can range from affecting hundreds to affecting millions of people and can cover miles or continents. Finally, the main aspect of HA/DR missions involve people. The diversity of independent actors range from the individual to the multi-national entity and interact though cooperation or conflict. Human behaviors and organizations are ever changing, complex systems that pose the greatest challenge to modeling and simulation.

Often HA/DR models focus on the analysis and optimization of logistic networks, prepositioning of resources, or asset selection to deliver aid to the population (Balcik and Beamon 2008; Lee, Ghosh, and

Ettl 2009; Greenfield and Ingram 2011; Alexander et al. 2011; Cohen et al. 2013). A few other HA/DR models simulate the population's behavior (Alexander et al. 2011; Turner, Balestrini-Robinson, and Mavris 2011; Cohen et al. 2013). In the literature fidelity decisions made during Conceptual Model Development (CMD) and Conceptual Model (CM) validation activities are vague. Due to the complexity of HA/DR scenarios both CMD and CM validation should be a well-defined and quantitative processes.

The literature is consulted to address the issues with CMD and CM validation of HA/DR simulations. The subject of conceptual modeling has received increased attention in the literature since the mid-2000s. A 2006 paper by Robinson identified six issues with conceptual modeling: definition, requirements, development, representation/communication, validation, and teaching conceptual modeling (Robinson 2006). Methods for CMD presented in the literature include a step for defining the appropriate level of fidelity of the model (Balci and Ormsby 2007, van der Zee 2012, Robinson 2013); however the specific process of assigning fidelity remains vague. The CMD methods rely heavily on qualitative assessments from subject matter experts. Likewise, CM validation is qualitative; often performed through panel reviews (Balci 1998, Robinson 2006). This approach works well for simpler or familiar systems; however complex or unfamiliar systems require a more quantitative approach to CMD and CM validation. The paper presents a method for quantitative CMD and CM validation.

Weighted System Decompositions (WSD) are proposed as a simple solution for determining the required fidelity of the system model and for quantitative CM validation. WSD are defined here as hierarchical decompositions of a system where the linkages between the subsystems or system variables are assigned weightings, often assigned subjectively, e.g. Quality Function Deployment.

Quantitative variable relationships from the WSD are used to inform the fidelity decisions during CMD. CM validity is assessed by comparing WSD relationships to the objective simulation outputs. An overview of this method is presented in the following section. This is succeed by an application of the method to a HA/DR mission. The HA/DR mission is focused on delivering aid to a flood affected region in Western Africa. The intent of the application is to demonstrate the potential benefits of using WSD in the CMD and CM validation. To achieve this demonstrative goal the logistics of distributing aid is modeled. The application of WSD to aid in modeling of behavior remains future research.

2 METHOD

The method presented in the paper uses WSD to inform model fidelity decisions and provide a basis for CM validation. The method can be broken into four main steps as illustrated in Figure 1. The first step, System Decomposition, will result in a hierarchical decomposition as shown in the upper left of Figure 1. The decomposition starts with a single objective measure, e.g. tones of aid delivered, number of people helped, number of criminal events. The objective measure is then decomposed into the variables affecting its response. These variables are henceforth referred to as impact variables (IVs). The IVs are then decomposed further until a sufficient depth has been reached. The selection of depth is problem dependent and up to the discretion of the modeler. The following terminology is used to describe the System Decomposition. Each node of the decomposition is referred to as an IV, except for the initial node, which is referred to as the objective measure. The edges, i.e. the arrows between the nodes, are referred to as impact variable relationships (IVRs). Though not shown in Figure 1, It is possible for an IV to have multiple IVRs to higher nodes.

The next step, Subjective Impact Matrix, involves assigning weightings to the IVRs. These weightings are determined subjectively using pairwise comparisons among the IVs. For example, in Figure 1 E1 is affected by three IVs: P1, P2, and P3. It is estimated that the P3 impact is five times as important to E1 than P1, and the P2 impact is four times as important to E1 than P1. This assessment results in the E1-P1, E1-P2, E1-P3 IVR weightings to be 10%, 40%, and 50% respectively. This process is repeated for each set of IVRs. Indirect IVR weightings are then calculated using multiplication. For example, if the impact of P1 on E1 is 10% and the impact of E1 on O1 is 75%, then the indirect IVR weighting of P1 on O1 is estimated to be 7.5%. The results of the Subjective Impact Matrix can be seen in the upper right of Figure 1.

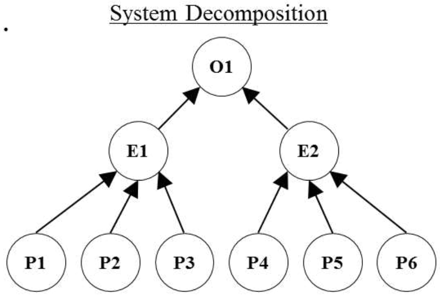
The third step, Fidelity Assessment and Selection, involves using the information generated from the Subjective Impact Matrix step to make model fidelity decisions. A distinction needs to be made between the importance of an IV and the importance of an IVR. During simulation analysis, one is often concerned with the importance of system variables. However, the act of modeling is the process of building relationships between system variables. Therefore, for assessing model fidelity the IVRs are of greater concern. The importance of an IVRs is determined by removing the relationship of interest and calculating the missing contribution to the objective. In the example shown, every IV has one relationship. This results in the IV importance being equivalent to the IVR importance.

Model fidelity decisions are made on the model representation of system variable relationships using the IVR importance values and a Morphological Matrix. The options for representing the relationship are listed from highest fidelity to lowest across the columns, where the option not to model is present. A selection is then made and documented. An example is shown in the lower left of Figure 1.

Finally the computerized model is developed. Using the computerized model sensitivity analyses can be performed and compared to the Subjective Impact Matrix. This method uses normalized Brownian Correlation to create the Objective Impact Matrix. Normalized Brownian Correlation is used because it is similar to standardized coefficients with the added benefit measuring non-linear behavior.

The Objective Impact Matrix is then compared to the Subjective Impact Matrix. Agreements between the two matrices provide support to the validity of the model. Disagreements provide an opportunity to investigate the system theories. Disagreements are a result of three possibilities: a bug in the computerized model, incorrect model representation, or inaccurate theories of the system's behavior. Iterating through step two through four will be required for disagreements. Addressing and resolving disagreements will result in a better model and/or a better understanding of the system.

1. System Decomposition



2. Subjective Impact Matrix

$$
\begin{array}{c}
O1 \\ E1 \\ E2 \\ P1 \\ P2 \\ P3 \\ P4 \\ P5 \\ P6
\end{array}
\begin{bmatrix}
100\% & 75\% & 25\% & 7.5\% & 30\% & 37.5\% & 2.5\% & 10\% & 12.5\% \\
 & 100\% & - & 10\% & 40\% & 50\% & 0 & 0 & 0 \\
 & - & 100\% & 0 & 0 & 0 & 10\% & 40\% & 50\% \\
 & & & 100\% & - & - & - & - & - \\
 & & & - & 100\% & - & - & - & - \\
 & & & - & - & 100\% & - & - & - \\
 & & & - & - & - & 100\% & - & - \\
 & & & - & - & - & - & 100\% & - \\
 & & & - & - & - & - & - & 100\%
\end{bmatrix}
$$

3. Fidelity Assessment and Selection

Relationship	Value	H	M	L	None
P1-E1	7.5%			●	
P2-E1	30%	●			
P3-E1	37.5%	●			
P4-E2	2.5%				●
P5-E2	10%		●		
P6-E2	12.5%		●		
E1-O1	75%	●			
E2-O1	25%	●			

4. Objective Impact Matrix

$$
\begin{array}{c}
O1 \\ E1 \\ E2 \\ P1 \\ P2 \\ P3 \\ P4 \\ P5 \\ P6
\end{array}
\begin{bmatrix}
100\% & 76\% & 24\% & 6.8\% & 29.3\% & 38.9\% & 2.3\% & 10.6\% & 12.1\% \\
 & 100\% & - & 10\% & 40\% & 50\% & 0 & 0 & 0 \\
 & - & 100\% & 0 & 0 & 0 & 10\% & 40\% & 50\% \\
 & & & 100\% & - & - & - & - & - \\
 & & & - & 100\% & - & - & - & - \\
 & & & - & - & 100\% & - & - & - \\
 & & & - & - & - & 100\% & - & - \\
 & & & - & - & - & - & 100\% & - \\
 & & & - & - & - & - & - & 100\%
\end{bmatrix}
$$

Figure 1: Method overview.

3 HUMANITARIAN AID / DISASTER RELIF MODELING

3.1 Scenario

The scenario developed is based on the work conducted at the Naval Postgraduate School (Alexander et al. 2011; Cohen et al. 2013). This fictional scenario is a 60 day humanitarian relief effort in response to severe flooding in a populated region of West Africa. The relief effort is focused on delivering food, water, and security to the affected region. The massive flooding has damaged the seaports and the airports; therefore, the relief effort will be delivered from the sea using helicopters and military landing craft. Food and water will be delivered from the Sea Base (SB) to the Forward Logistic Sites (FLS) using landing craft. Two types of landing craft are used for this operation, the Landing Craft Air Cushion (LCAC) and the Landing Craft Utility (LCU). The material will be delivered from the SB to the Forward Logistic Satellite Site (FLSS) using helicopters. Three types of aircraft are used for this operation, the MH-53E, S-60B, and MV-22. The FLS are large facilities and few in number. The FLSS are small facilities and great in number. The population will receive food and water from both the FLS and FLSS. A visualization of this operation can be seen in Figure 2.

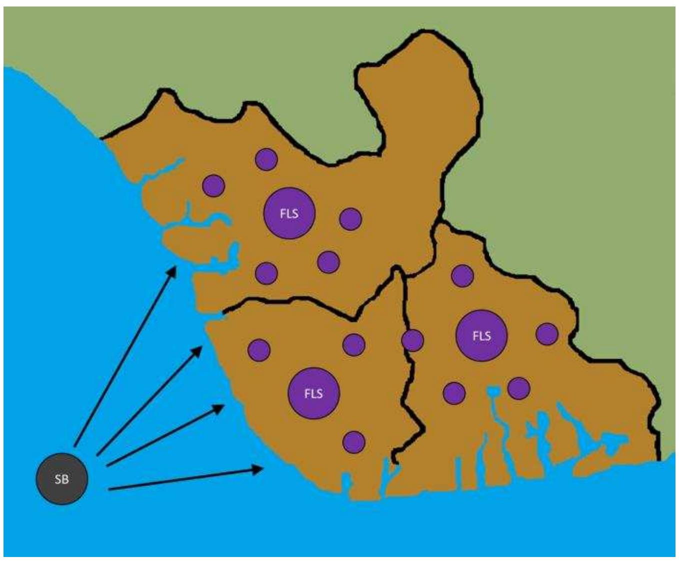


Figure 2: West Africa HA/DR operational view.

Security is an important aspect of any HA/DR effort. Security is provided at the FLS, FLSS, and at regions of instability. The human terrain can be described as the following. The affected area is encompassed within the three southern states of fictional country Orange, with a population of 179 million. The states are referred to as State A, State B, and State C from northwest to south east. These three states are home to a diverse set of ethnic groups. The south is plagued by terrorist activities and thievery by insurgent groups and criminal gangs. In the north external radicals have contributed to instability and tensions between the north and south.

Two of the high level questions asked of this scenario are how well is aid being distributed to the population and what is the stability effect of HA/DR operations on the population? These questions highlight the diversity and complexity of HA/DR analysis. One question address the operational, physical challenge of distributing aid. The other question address the social, behavioral challenge of distributing aid.

3.2 System Decomposition of HA/DR Mission

The development of the conceptual model begins by identifying the top level objectives and decomposing the objectives into their IVs. Based on the previous work, the first level of objective and IVs can be seen in Table 1. For the purposes of demonstrating the usefulness of WSD in creating and validating the CM, only Impact 1 form Objective 1 will be decomposed further.

Table 1: Decomposition of objectives into level 1 impacts.

Objective 1		Distribute aid to the population
	Impact 1	Throughput rate of aid from seabase to civilian population (tons/hr)
	Impact 2	Population reached with aid (millions)
Objective 2		Provide security for peaceful HA/DR operations
	Impact 3	Count of recorded criminal events (hundreds)

The flow rate of aid, i.e. food, water, misc. equipment, to the civilian population can be decomposed into the flow rate of aid to the civilian population from the FLS and FLSS. The system decomposition of the FLS flow rate is shown in Figure 3. A dashed outline indicates that the variable's decomposition is excluded from this view. The two impacts to the flow rate are the flow rate form the surface craft to the FLS and the FLS Operations. Note that FLS Operations is represented with a rectangle. This denotes that the IV has no direct measurement. These IVs are further decomposed to form three more layers. The bulk of the decomposition is focused on the parameters defining the LCAC and LCU operations.

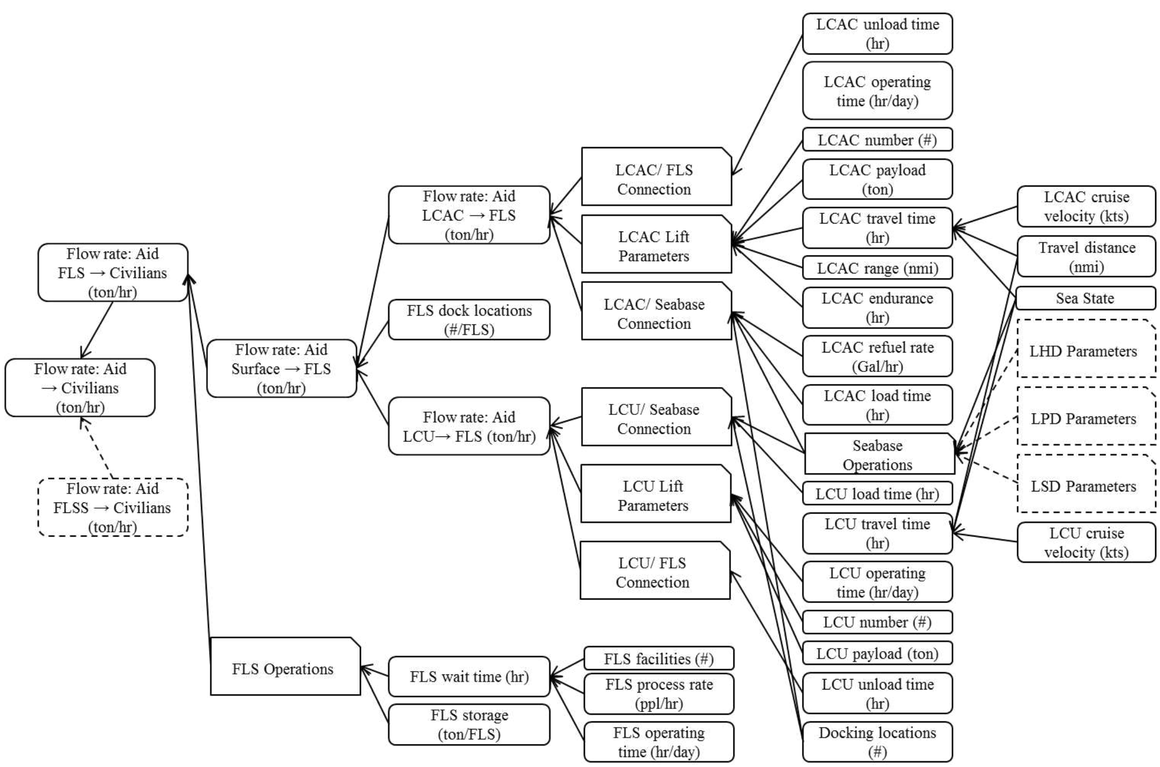


Figure 3: FLS flow rate decomposition (L1-L7).

The system decomposition of the FLSS flow rate is shown in Figure 4. A portion of the decomposition is omitted due to space limitations. The decomposition of the FLSS flow rate is similar to that of the FLS. The primary difference is the FLSS decomposition is dominated by the parameters of the three aircraft as opposed to the surface craft.

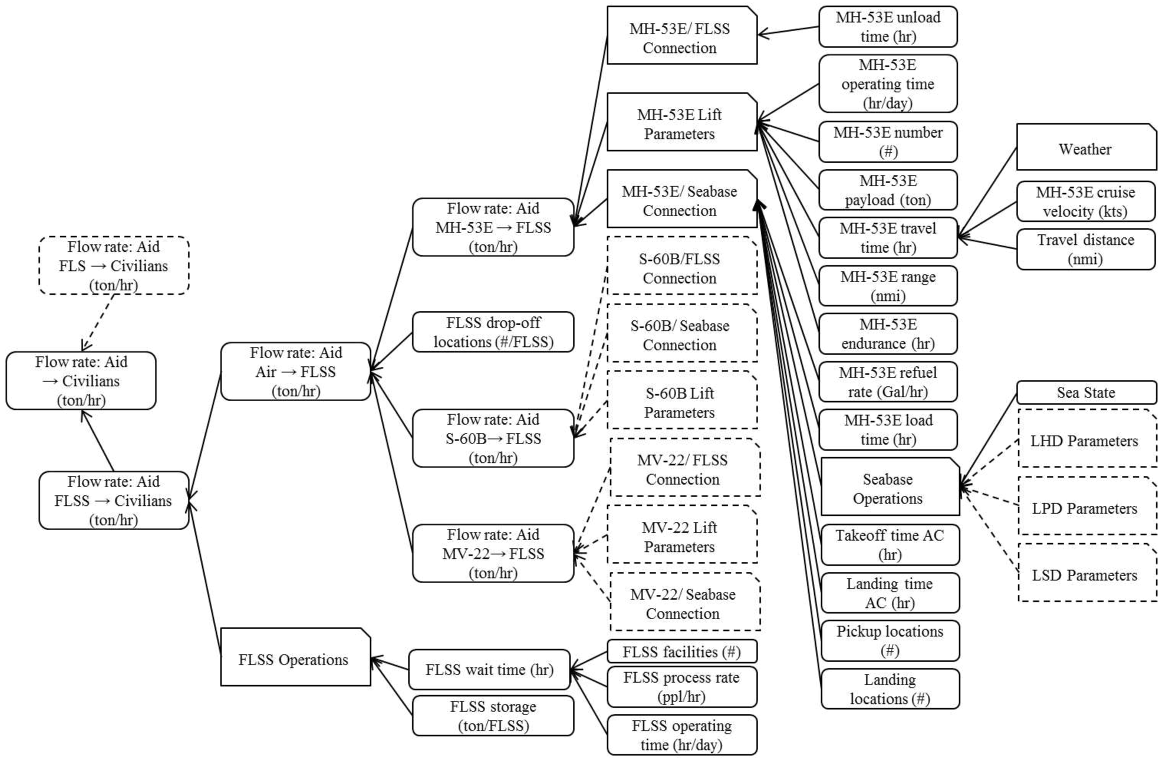


Figure 4: FLSS flow rate decomposition (MH-53E expansion L1-L7).

3.3 Subjective Impact Matrix of HA/DR Mission

The impact matrix is formed from the system decomposition. When possible, back of the envelope calculations should be made to estimate the IVR weightings. Impact 1 lends itself to this form of approximation; however, Impact 3 does not and would be more dependent on subject matter expert estimation. Known aspects of the scenarios are used to make this estimation. The number of facilities for the FLS and the FLSS are 3 and 41, respectively. The FLS is a larger facility and is equivalent to 5 FLSS facilities in terms of storage and throughput. Thus, it is approximated that the FLSS flow rate is 2.7 times more important than the FLS flow rate, i.e. FLSS contributes to 73% of the flow rate to the civilian population. These weightings are referred to as L1-L2 weightings as shown in Table 2. The level 3 IVs are flow of aid to the facilities and the facility operations. Since the failure of either would cause the flow rate of the facility to fail, the weightings of the two IVs are considered equivalent. The indirect weightings of the level 3 IVs on level 1 variables, i.e. L1-L3 weightings, are calculated with matrix multiplication. These results are shown in Table 2.

The Flow Rate from Surface Craft (SC) and Aircraft (AC) are calculated in a similar manner. Only the Flow Rate form SC is detailed here. The number of LCACs and LCUs are 5 and 1, respectively. The tonnage of the LCAC and the LCU is 75 and 170 tons, respectively. Given the speeds and estimated distances, the LCAC can make two trips per day and the LCU can make one trip per day. The estimated LCAC impact on the FLS flow rate is 4.4 times as important as the LCU. The LCAC and LCU deliver supplies a couple of times a day; therefore, the number of FLS docking locations is considered insignificant.

Table 2: Impact matrix L1-L2-L3 view.

		L2		L3			
		Flow Rate from FLS	Flow Rate from FLSS	Flow Rate from SC	FLS Operations	Flow Rate form AC	FLSS Operations
L1	Flow Rate to Civilians	0.27	0.73	0.1350	0.1350	0.3650	0.3650
L2	Flow Rate from FLS			0.5	0.5		
	Flow Rate from FLSS					0.5	0.5

The decomposition of the FLS and FLSS operations are equivalent. It is subjectively estimated that the impact from the wait time is 10 times as important as the storage capacity of the facility. The results of the estimates are show in Table 3. The system is then decomposed further; however, due to space limitations the lower level decompositions are not shown.

Table 3: Impact matrix L3-L4 view.

		L4										
		Flow Rate from LCAC	Flow Rate from LCU	FLS Dock Locations	FLS Wait Time	FLS Storage	Flow Rate from MH-53E	Flow Rate from S-60B	Flow Rate from MV-22	FLSS Drop-off Locations	FLSS Wait Time	FLSS Storage
L3	Flow Rate from SC	0.81	0.18	0.01								
	FLS Operations				0.91	0.09						
	Flow Rate from AC						0.30	0.03	0.67	0.01		
	FLSS Operations										0.91	0.09

3.4 Fidelity Assessment and Selection of HA/DR Mission

The model fidelity can be selected using the Impact Matrices from the previous section. Four levels of fidelity are described in Table 4. The fidelity decisions start at the top of the decomposition, because if a relationship is not modeled with high fidelity, then the proceeding IVRs do not need to be addressed.

Table 4: Model representation levels.

High	Function of lower level variables
Medium	Represented as a distribution
Low	Represented as a deterministic variable
None	Relationship is not modeled

The calculation of the IVR importance value is simplified because each IV has a single IVR for decomposition levels one through five, as shown in Figures 3 and 4. The IVR importance value is equivalent to the IV weighting on Flow Rate to Civilians. The IVR importance values in L1-L2 and L2-L3 of the system decomposition contribute to a significant portion of the objective response as shown in Table 2. Each IVR will be represented with high fidelity. Some of the relationships in L3-L4 of the decomposition contribute very little to the overall system. It is easily seen in Table 5 that the relationships from FLS Dock Locations and the FLSS Drop-off Locations can be ignored and not modeled. Other low importance IVR are FLS Storage, FLSS Storage, and S-60B. These IVRs contribute the same amount to the overall objective. The S-60B will not be modeled, and the FLS and FLSS storage will be modeled with a simple deterministic variable. The S-60B is not modeled due to the increased difficulty in modeling its relationships over the facility storage relationships. The remainder of the L4 IVRs are modeled with high fidelity.

Table 5: Model representation of L4 impact variable relationships.

Relationship	**Importance**	**High**	**Medium**	**Low**	**None**
Flow Rate from LCAC	10.9%	●			
Flow Rate From LCU	2.4%	●			
FLC Dock Locations	0.1%				●
FLS Wait Time	12.3%	●			
FLS Storage	1.2%			●	
Flow Rate from MH-53E	11.0%	●			
Flow Rate from S-60B	1.1%				●
Flow Rate from MV-22	24.5%	●			
FLSS Drop-off Locations	0.4%				●
FLSS Wait Time	33.2%	●			
FLSS Storage	3.3%			●	

The model representation of the FLS and the LCAC are shown in Table 6. The LCAC load time, unload time, and operating time are each represented with a distribution. The variables are represented with a truncated Gaussian Distribution. The number of vehicles is equally as important; however, only a low fidelity representation is sensible. Travel time could also be represented with a Gaussian Distribution; however, it was determined that it would be easier to represent it with the vehicle velocity and the distance between the SB and the FLS. The typical vehicle parameters, velocity, range, endurance, refuel rate, and payload, contributed surprisingly little to the objective. Therefore, the range, endurance, and refuel rates were not modeled. The velocity is modeled with low fidelity, because it is required to contribute to the travel time variable. The payload is represented with low fidelity, i.e. a simple variable, because it is assumed that this process is not typically stochastic. The FLS variables have equal importance, which is higher than the LCAC variables. Therefore, the process rate and operating time is modeled with a Poisson and Gaussian distribution, respectively. The number of facilities is represented with a simple number, because it is the only sensible selection. The lower level model representations are not discussed here due to space limitations. The FLSS model representations will be the same as the FLS. The LCU model representations will be the same as the LCAC.

Table 6: Model representation of L5 and L6 impact variable relationships (LCAC and FLS).

Variable	Importance	High	Medium	Low	None
LCAC Load Time	1.1%		●		
LCAC Unload Time	1.6%		●		
LCAC Operating Time	1.1%		●		
LCAC Number	1.1%			●	
LCAC Travel Time	1.1%	●			
LCAC Velocity	0.3%			●	
LCAC Range	< 0.1%				●
LCAC Endurance	< 0.1%				●
LCAC Refuel Rate	< 0.1%				●
LCAC-Payload	1.1%			●	
FLS Facility #	4.1%			●	
FLS Process Rate	4.1%		●		
FLS Operating Time	4.1%		●		

3.5 Objective Impact Matrix of HA/DR Mission and Model Validation

The next step in the method is to compare the Subjective and Objective Impact Matrix. To do this, the model representation decisions are used to create the conceptual model. Using the conceptual model a computerized model is built. The computerized model was developed in NetLogo, an agent based modeling software tool. The model tracks 46 input variables and 16 output variables. A total of 2,000 executions were made with the computerized model. These executions were comprised of a 500 point Latin Hypercube Sampling (LHS) Design of Experiments (DOE) with four replications. Normalized Brownian Correlations were calculated and compared against the Subjective Impact Matrix. These results can be seen in Figure 5 and Figure 6. The figures show the subjective and objective variable impact weightings on the flow rate of aid from the FLS to the civilian population and the flow rate of aid from the LCAC to the FLS, respectively. Beside each variable the subjective impacts and the objective impacts are shown. The top number is subjective and the bottom is objective . The variables that were not modeled are faded out.

As seen in Figure 5, there is broad agreement between the subjective and objective impact values. The contribution from the surface vessels is shown to be slightly larger than expected. Decomposing this branch further, the flow rate from the LCAC is only slightly larger than expected. This branch shows general agreement and supports model validity. Decomposing the FLS Operations branch to its lowest level shows some disagreement between the subjective and objective estimates. The FLS process rate has a smaller impact than was expected. Beyond programming errors, two possibilities can explain this difference: incorrect model representation or inaccurate theories of the system’s behavior. A focused investigation of the simulated model can inform the path forward, i.e. modify and simulate the modified model or accept the new information about the system.

Similarly, the subjective and objective results are compared and investigated throughout the system. Figure 6 shows the LCAC decomposition. The major discrepancy between subjective and objective estimates occurs with the LCAC Operating Time. After examination of the simulation a possible explanation is found. The range of the operating time resulted in a step function of aid being delivered. Once the operating time passed a threshold, one more tip could be made by the LCAC; therefore the impact is greater than was anticipated. The theories about the system are then updated.

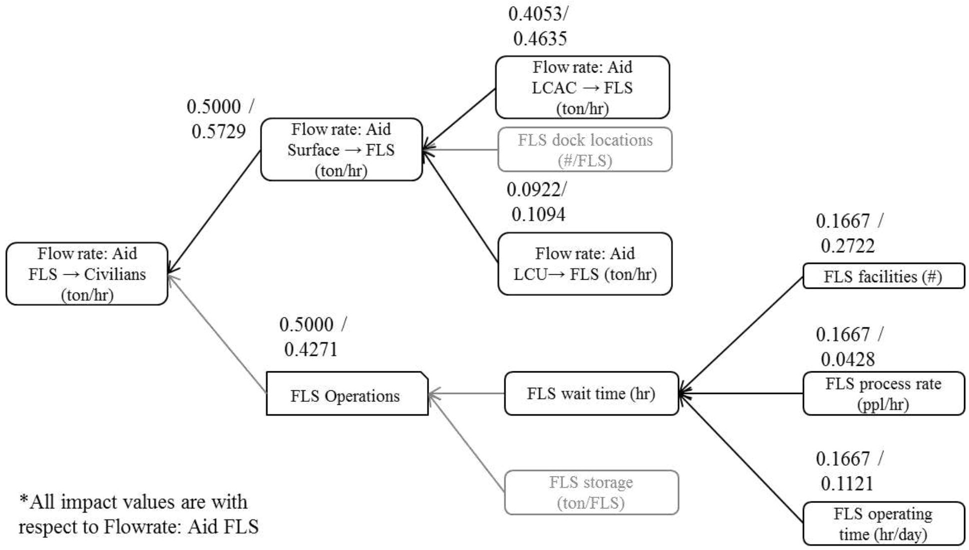


Figure 5: Subjective and objective system comparison (FLS flow rate L1-L4).

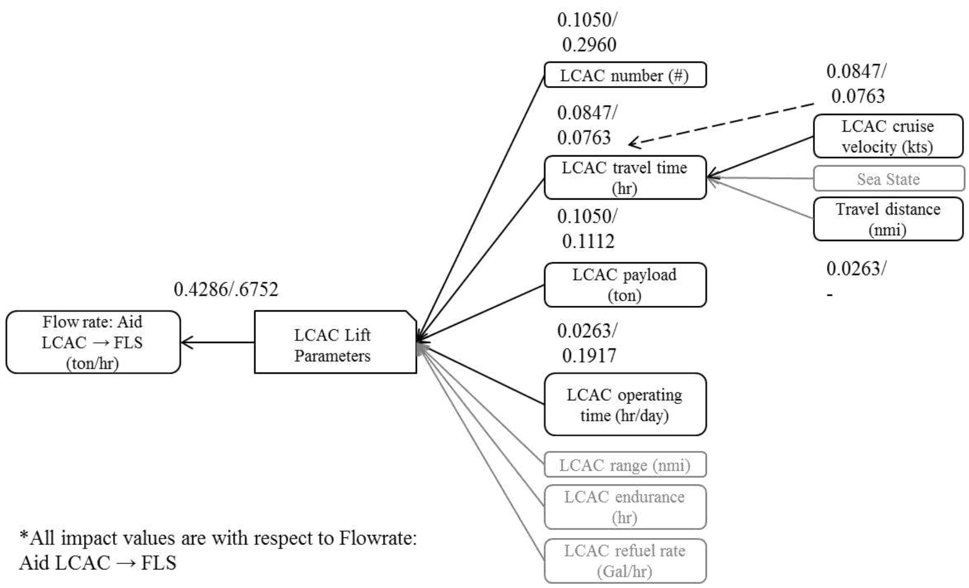


Figure 6: Subjective and objective system comparison (LCAC flow rate L4-L7).

4 CONCLUSIONS

Correctly determining the fidelity to model the system in CMD and validating the CM are two primary challenges of modeling complex systems. The traditional approach to CMD and validation is primarily qualitative. WSD are shown here as a feasible method for making CMD and CM validation more quantitative. It was shown that the subjective impact relationships from the WSD can be used to inform the fidelity decisions during CMD. Additionally, it was shown that WSD can provide a baseline to which a CM can be quantitatively validated. Finally, it was shown that during validation WSDs can provide focused investigation and modification of the model. When disagreement occurs, the specific area of disagreement is highlighted. Focused investigation and modification of the model can then be made.

The application of WSD to modeling can be strengthened through continued research. Future topics of research include: application to behavior models, comparing objective mathematical measures to SME subjective estimates, and determining the best methods for sampling the simulation for impact calculations.

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REFERENCES

Alexander, S., P. Beery, W. Brinkley, J. Bubulka, J. Cohen, M. Kenfield, T. Roberts, and J. Quilenderino. 2011. "Influence of Foreign Humanitarian Assistance/Disaster Relief in a Coastal Nation." M.S. thesis, Systems Engineering Department, Naval Postgraduate School, Monterey, CA.

Balci, O. 1998. "Verification, Validation, and Accreditation." In Proceedings of the 1998 Winter Simulation Conference, edited by D. J. Medeiros, E. F. Watson, J. S. Carson, and M. S. Manivannan, 41-48. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Balci, O. and W. Ormsby. 2007. "Conceptual Modelling for Designing Large-scale Simulations." Journal of Simulation 1:175-186.

Balcik, B. and B. Beamon. 2008. "Facility Location in Humanitarian Relief." International Journal of Logistics: Research and Applications 11:101-121.

Cohen, J., J. Quilenderino, J. Bubulka, and E. Paulo. 2013. "Linking a Throughput Simulation to a Systems Dynamics Simulation to Assess the Utility of a US Navy Foreign Humanitarian Aid Mission." Defense & Security Analysis 29:141-155.

Greenfield, C. and I. Cameron. 2011. "An Analysis of U.S. Navy Humanitarian Assistance and Disaster Relief Operations." Monterey, CA: Naval Post Graduate School.

Lee, Y., S. Ghosh, and M. Ettl. 2009. "Simulating Distribution of Emergency Relief Supplies for Disaster Response Operations." In Proceeding of the 2009 Winter Simulation Conference, edited by M. D. Rossetti, R. R. Hill, D. Johansson, A. Dunkin, and R. G. Ingalls, 2797-2808. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Pakistan National Disaster Management Authority 2011. "Summary of Losses/Damaes Due to Rain in Balochistan Flood – 2011." Accessed March 30, 2015. http://www.ndma.gov.pk/new/aboutus/flood_2011.pdf.

Robinson, S. 2006. "Conceptual Modeling for Simulation: Issues and Research Requirements." In Proceedings of the 2006 Winter Simulation Conference, edited by L. F. Perrone, F. P. Wieland, J. Liu, B. G. Lawson, D. M. Nicol, and R. M. Fujimoto, 792-800. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Robinson, S. 2013. "Conceptual Modeling for Simulation." In Proceedings of the 2013 Winter Simulation Conference, edited by R. Pasupathy, S.-H. Kim, A. Tolk, R. Hill, and M. E. Kuhl, 377-388. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Singapore Red Cross. 2010. "Pakistan Floods:The Deluge of Disaster - Facts & Figures as of 15 September 2010." Accessed March 15, 2015. http://reliefweb.int/report/pakistan/pakistan-floodsthe-deluge-disaster-facts-figures-15-september-2010.

Swiss Reinsurance Company Ltd. 2009. "Natural Catastrophes and Man-Made Disasters in 2008." Accessed March 30, 2015. http://www.preventionweb.net/files/8841_Sigma22009e.pdf

Turner, A., S. Balestrini-Robinson, and D. Mavris. 2011. "Representation of Humanitarian Aid / Disaster Relief Missions with an Agent Based Model to Analyze Optimal Resource Placement." In Proceedings of the 2011 Winter Simulation Conference, edited by S. Jain, R. R. Creasey, J. Himmelspach, K. P.

White, and M. Fu, 2654-2665. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

U.S. Geological Survey. 2011. “Earthquake Information for 2010.” Accessed March 30, 2015. http://earthquake.usgs.gov/earthquakes/eqarchives/year/2010/.

U.S. Geological Survey. 2015a. “Magnitude 9.1 – Off the West Coast of Northern Sumatra.” Accessed March 30, 2015. http://earthquake.usgs.gov/earthquakes/eqinthenews/2004/us2004slav/#summary.

U.S. Geological Survey. 2015b. “Magnitude 7.9 - Eastern Sichuan, China.” Accessed March 30, 2015. http://earthquake.usgs.gov/earthquakes/eqinthenews/2008/us2008ryan/#summary.

UN News Center. 2012. “UN Says Somali Famine Over, but Warns Action Needed to Forestall New Crisis.” Accessed March 30, 2015. http://www.un.org/apps/news/story.asp?NewsID=41133&Cr=somalia&Cr1=famine#.VRnJpflDn2o.

van der Zee, D. 2012. "An Integrated Conceptual Modeling Framework for Simulation - Linking Simulation Modeling to the Systems Engineering Process." In Proceedings of the 2012 Winter Simulation Conference, edited by C. Laroque, J. Himmelspach, R. Pasupathy, O. Rose, and A. M. Uhrmacher, 3723-3734. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

World Health Organization. 2015. “Situation Summary: Latest Available Situation Summary, 30 March 2015.” Accessed March 30, 2015. http://apps.who.int/gho/data/view.ebola-sitrep.ebola-summary-latest?lang=en

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