Disaster Relief Simulation

DATA 604: Simulation & Modeling

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1 Abstract

2 Keywords

3 Literature Review

The number of disasters witnessed over time appear to be increasing in terms of frequency and impact. Figure 1 for example, depicts the average number of people killed or adversely impacted (i.e. made homeless, injured or economically affected) due to natural disasters from the year 1900 to date. This information is based on disaster data pertaining to *notable* events in each year (EM-Dat, 2016).

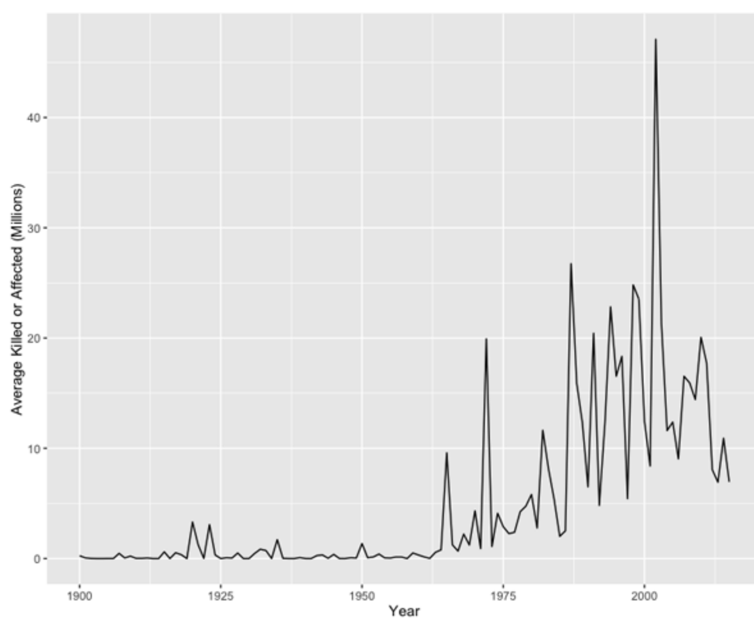


Fig 1: Averaged number of people killed or affected by disasters by year

While there are fluctuations from year to year, there is a clear trend showing a growth in the numbers or people who are affected or killed by disasters over time.

Responding to these types of disasters is a highly complex process. Often multiple stakeholders will be engaged, working under stressful environments with severe time pressure and significant uncertainty with respect to whether they can work to save lives. In this context, we are beginning to see an increase in the amount of research into models and systems that can potentially help humanitarian workers make informed decisions. For example Kung et al (Kung, Chen, and Ku, 2012) present three prediction models and an inference engine using linear regression, multivariate analysis and back propagation networks to assess potential debris flows resulting from earthquakes. In another example, Rottkemper et al (Rottkemper, Fisher, and Blecken, 2012) present a mixed-integer programming model for an integrated relocation and distribution planning solution designed to minimize both operational costs and unmet demand for relief items.

Within the logistics aspects of emergency management, Ozdamar et al (Ozdamar, Ekinci, and Kucukyazici, 2004) present a model to complement decision support systems related to logistics planning following a disaster. The study contrasts various algorithmic approaches to solving for multi-period, multi-commodity network flow problems coupled with a vehicle routing problem.

Ozdamar et al's study helps to designate routing decisions for vehicles. The authors also note that the resolution to the various optimization choices are NP-hard. They suggest heuristic methodologies be applied to find solutions to large scale problems. Building on this recommendation, the current study, aims to understand the dynamics of in-country humanitarian logistics via simulations. In running the simulation, we aim to design a model of a simplified humanitarian logistics chain for the purpose of understnding the behaviour of the system and for evaluation certain strategies.

We aim to model aspects of the humanitarian logistics chain using computer simulation software (Simio). The intent is to understand the realities of moving humanitarian aid, particularly to the last mile of distributions (something that has not garnered as much research in the literature).

4 Methodology

4.1 Structure

The basic objective of a logistics system is to deliver the appropriate supplies, in good condition, in the quantities required, and at the places and time they are needed. Some emergencies generate a limited need for very rapid and very specific deliveries of supplies, commodities and resources from outside the affected area. This process entails the implementation of the international humanitarian logistics chain (IHLC) as depicted in the following chart.

Humanitarian Log Chain.jpeg

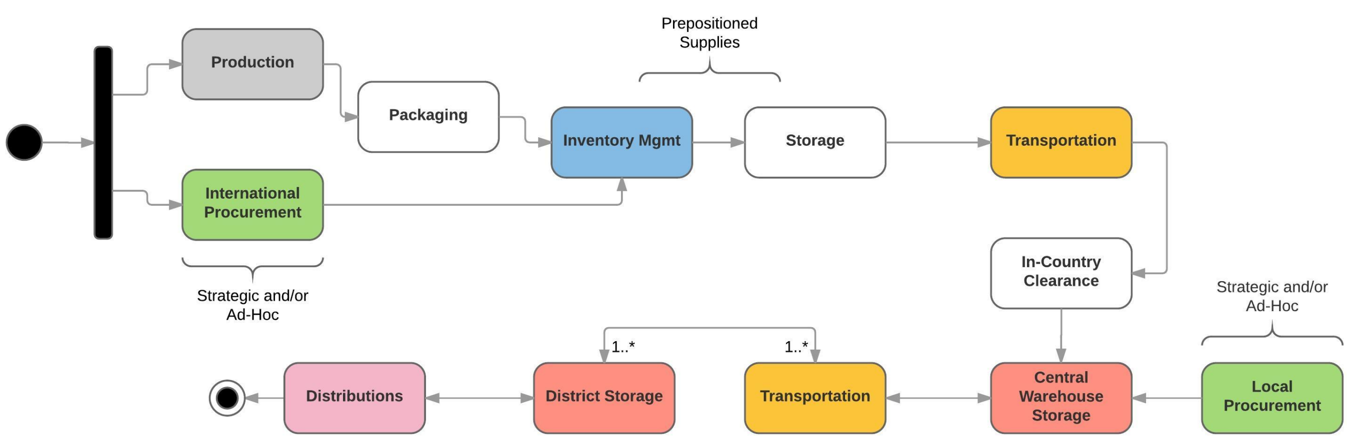


Fig 2: The International Humanitarian Logistics Chain

The IHLC is an involved process adding much complexity to the movement of relief resources. It is also important to note that the bulk of relief logistic operations never receive international attention. In an effort to simplify the modelling of the logistic chain, and in keeping with the latter fact, this project will consider the simulation needs of a in-country based logistic chain. The simplification of the model is shown in Figure 3.

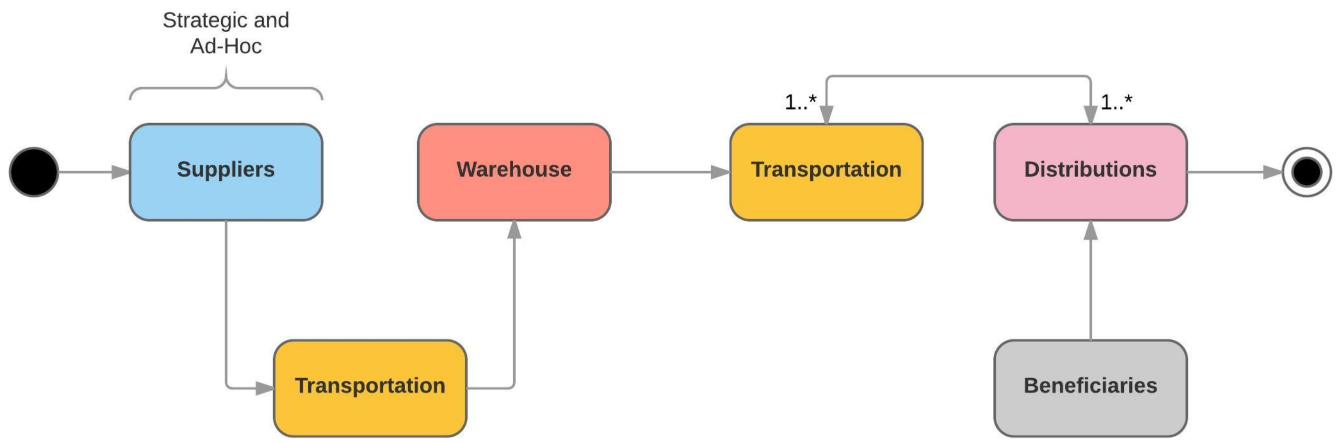


Fig 3: The Simplified Humanitarian Logistics Chain

Key entities are readily recognized from Figure 3. A short description follows on each entity that is modelled.

4.1.1 Supplier

A Supplier entity is included in the simulation model. This entity is the source of ReliefSupplies. This entity is used, through design of experiments, to simulate both reliable partner suppliers as well as ad hoc suppliers (more variability in their supply). The following variables (Referenced Properties) were created to facilitate the study:

- The time to deliver a shipment of supplies: *SupplierTravelTimeToWarehouse*.
- The maximum number of relief supplies which the supplier will provide: *SupplierMaximumArrivals*
- The time between produced relief supply available for movement to the warehouse: *SupplierReliefSuppliesInterarrivalTime*

The delivery vehicle, SupplierVehicle, was set to require a full load prior to departing for the Warehouse.

- The capacity of the SupplierVehicle: *SupplierVehicleCapacity*

4.1.2 Warehouse

A Warehouse was added to store disaster relief supplies in preparation for a disaster. This entity was modelled as a server which processes incoming ReliefSupplies and stores them in a ready state for movement to a DistributionSite.

The following variables were created to facilitate design of experiments:

- The storage capacity of the warehouse: *WarehouseStorageCapacity*

The delivery vehicle, WarehouseVehicle, was set to require a full load prior to departing for a distribution site and have periodic failures.

- The capacity of the WarehouseVehicle: *WarehouseVehicleCapacity*
- The frequency of failure: *WarehouseVehicleUptimeBetweenFailures*

The selection weight on the paths from the Warehouse to the Distribution Sites were set to dynamically adjust based on the number of Relief Beneficiaries waiting for Relief Supplies.

4.1.3 Distribution Sites

Two distribution sites are included in the simulation and are modelled as combiners which match Relief Supplies to Relief Beneficiaries.

The following variables were created to facilitate design of experiments:

- The processing time needed to provide a ReliefSupply item to a ReliefBeneficiary: DistSiteProcessingTime

4.1.4 Relief Beneficiaries

The Relief Beneficiaries represent entities who are affected by the disaster and require ReliefSupplies. Two separate sources were included in the model to simulate separate points from which beneficiaries would origination for each distribution site.

The following variables were created to facilitate design of experiments:

- The interarrival time of the ReliefBeneficiaries: *ReliefBeneficiaryInterarrivalTime*
- The maximum number of ReliefBeneficiaries from a given source: *DisasterVictimMaximumArrivals*

4.1.5 Disaster

The "Disaster" is set to begin at a designated time into the simulation. This gives some time to prestage relief supplies through the warehouse (priming the pump).

The following variables were created to facilitate design of experiments:

- The amount of time between simulation start and onset of the disaster: *DisasterTimeOffset*

4.2 Measured Outcomes

4.2.1 Average Beneficiary Time in System

Measured in hours, this response is an important indicator of the performance of the system.

4.2.2 Relief Supplies Distributed

How many relief supplies were distributed?

4.2.3 Unsatisfied Beneficiaries

Naturally, we wanted this response to be zero (0) throughout all simulations.

4.2.4 Maximum Distribution Site 1 Time Waiting

Measured in hours, this response helped us understand the degree of the worst case scenario for distribution site 1 beneficiaries in need of relief supplies.

4.2.5 Maximum Distribution Site 2 Time Waiting

Measured in hours, this response helped us understand the degree of the worst case scenario for distribution site 2 beneficiaries in need of relief supplies.

4.3 Design of Experiments

A variety of experiments were performed in the context of the simulation. The following table lists the baseline values for the control variables. Each of the experiments modifies a single variable and recorded a outcome of interests, as described in the following subsections.

Table 1: Simulation Control Variables

Name	Value	Units
DisasterTimeOffset	3	Days
DisasterVictimMaximumArrivals (per Dist Site)	10000	Beneficiaries
DistSiteProcessingTime	Random.Exponential(1)	Minutes
Entry2DistSitePath	TimePathToDistSite2	Path Name
ReliefBeneficiaryInterarrivalTime	Random.Exponential(2.5)	Minutes
SupplierMaximumArrivals	Infinity	Relief Supply Items
SupplierReliefSuppliesInterarrivalTime	Random.Normal(1, 0.1)	Minutes
SupplierTravelTimeToWarehouse	Random.Normal(6,0.5)	Hours
SupplierVehicleCapacity	5000	Relief Supply Items
WarehouseStorageCapacity	Infinity	Relief Supply Items
WarehouseTravelTimeToDistributionSite1	Random.Normal(6,0.5)	Hours
WarehouseTravelTimeToDistributionSite2	Random.Normal(6,0.5)	Hours
WarehouseVehicleCapacity	1000	Relief Supply Items
WarehouseVehicleUptimeBetweenFailures	Random.Exponential(100)	Hours

4.3.1 Supplier: Partner vs Ad Hoc

How does a dedicated supplier whose production time is lower (more units of production are committed to our orders), versus an ad hoc supplier whose production time is longer, affect the measured outcomes?

The following table shows key parameters (control variables) for this scenario:

Name	ReliefSuppliesInterarrivalTime
Adhoc Supplier	Random.Normal(4, 0.1)
Midlevel Supplier	Random.Normal(2.5, 0.1)
Partner Supplier (Baseline)	Random.Normal(1, 0.1)

4.3.2 Distribution Site: Level of Access

How does the level of access, modeled as travel time between the warehouse and distribution site 1, affect outcomes?

Name	WarehouseTravelTimeToDistSite1
Partner Supplier (Baseline)	Random.Normal(6,0.5)
Midlevel Access to Dist Site 1	Random.Normal(4,0.5)
Quick Access to Dist Site 1	Random.Normal(2,0.5)

4.3.3 Warehouse Vehicle: Propensity for Failure

How does the likelihood of the warehouse delivery vehicle for failure affect outcomes?

Name	WarehouseVehicleUptimeBetweenFailures
Partner Supplier (Baseline)	Random.Exponential(100)
Warehouse Vehicle Midlevel Failures	Random.Exponential(50)

Name	WarehouseVehicleUptimeBetweenFailures
Warehouse Vehicle No Failures	Infinity

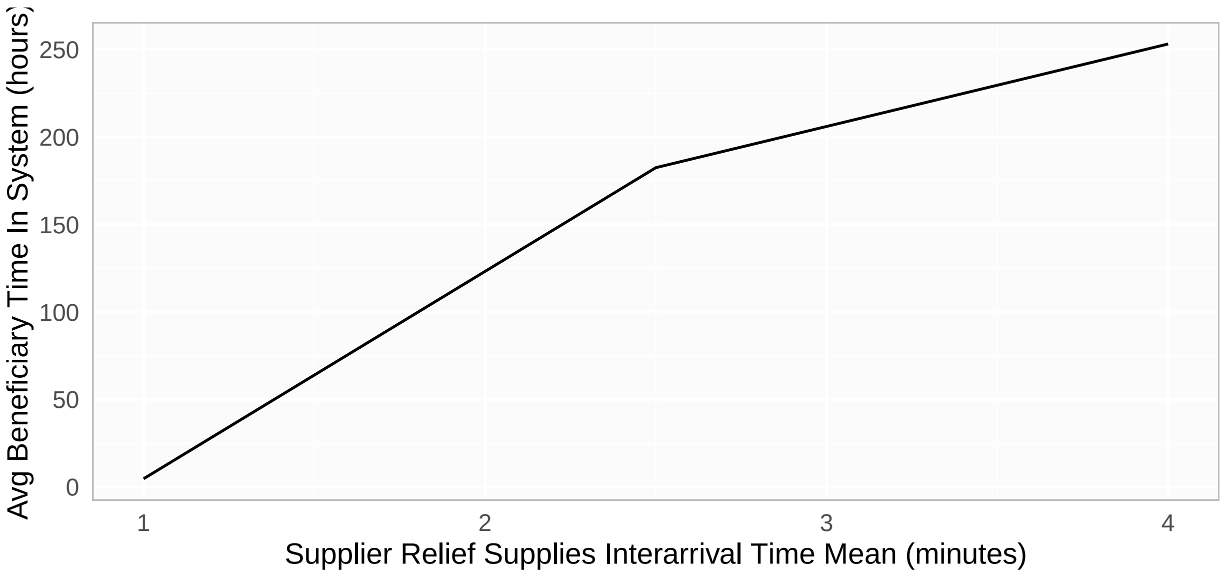
4.3.4 Distribution Site Closure

How does a distribution site closure affect outcomes?

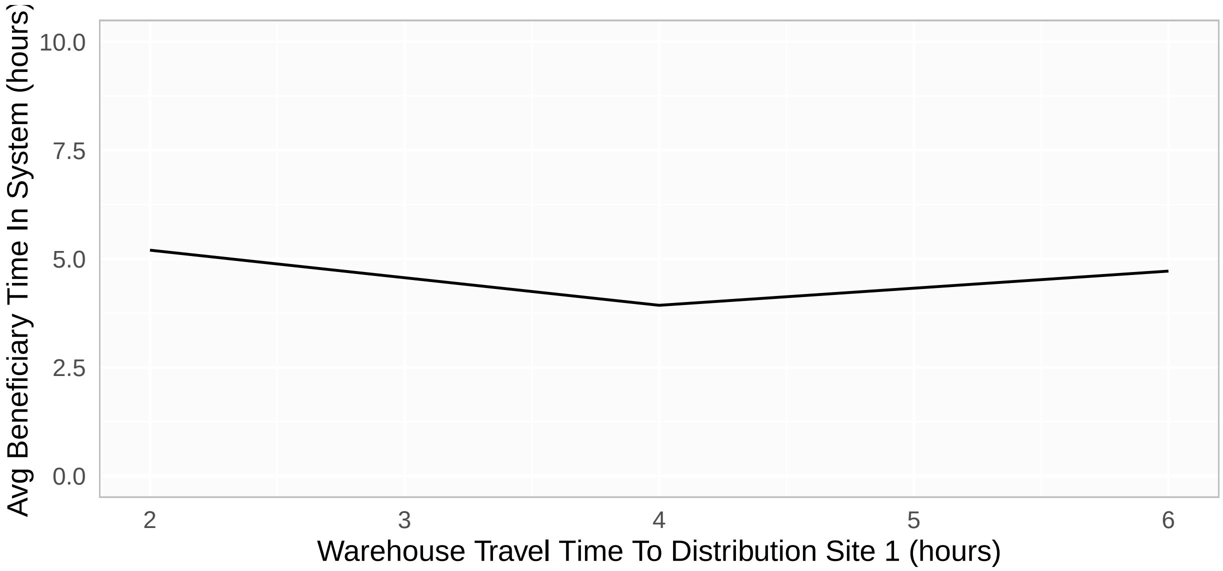
Name	Entry2DistSitePath
Partner Supplier (Baseline)	TimePathToDistSite2
Distribution Site 2 Closed	TimePathToDistSite1

5 Results

5.1 Supplier: Partner vs Ad Hoc

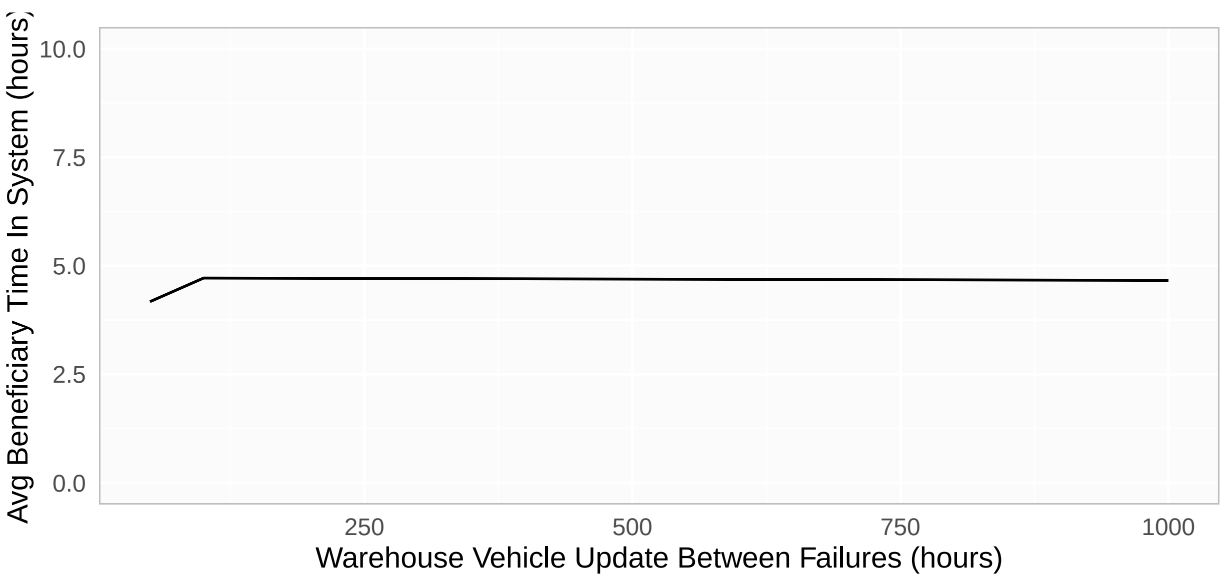


5.2 Warehouse Access to Distribution Site



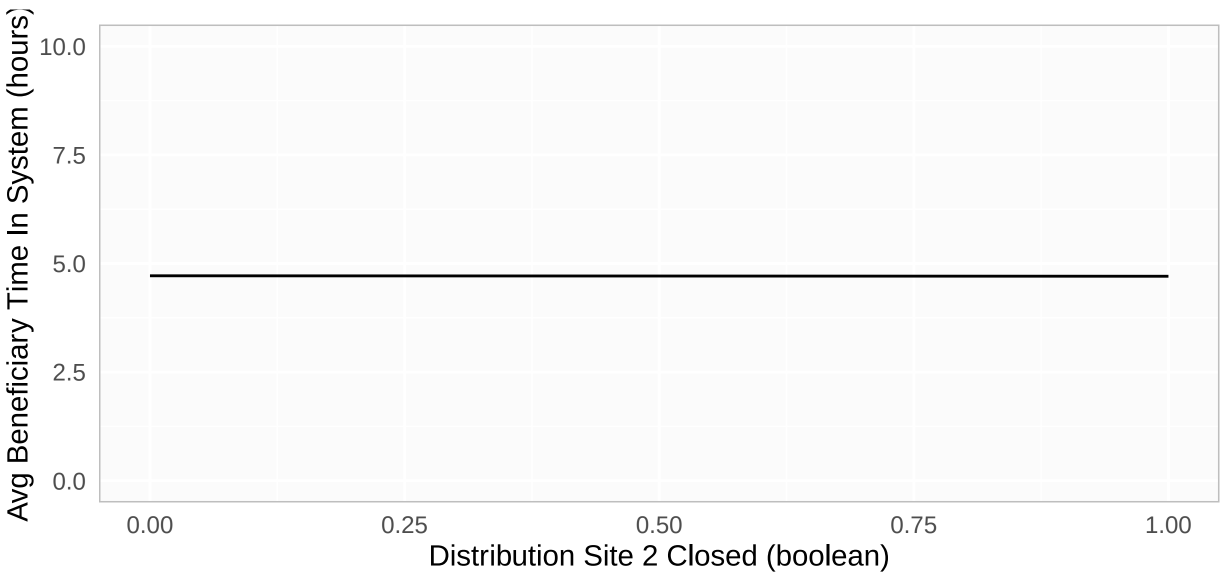
5.3 Warehouse Vehicle Failures

The warehouse vehicle failures yielded interesting results. It appears the difference between a 100 hour exponential mean and no failures is negligible. Strangely, the outcome of average beneficiaries time in system reduces for the mean failure rate of 50 uptime hours between failures. The confidence interval for these values reveals that an overlap suggesting an insignificant difference.



5.4 Distribution Site Closure

The distribution site closure did not have much of an effect on the primary outcome, average beneficiaries time in system. This requires further investigation but could indicate the travel time for the extra beneficiaries was too low. Additionally, it seems the capacity of the relief distribution system (as modeled) has sufficient head room to take on the additional demand at a single distribution site.



Suggestions for future work

6 Summary

7 References

EM-Dat. International Disaster Database. 2016. URL: http://www.emdat.be/advanced_search/index.html.

Kung, H., C. Chen and H. Ku. "Designing intelligent disaster prediction models and systems for debris-flow in Taiwan". In: Expert Systems with Applications (2012). DOI: 10.1016/j.eswa.2011.11.083.

Ozdamar, L., E. Ekinci and B. Kucukyazici. "Emergency Logistics Planning in Natural Disasters". In: Annals of Operations Research (2004). DOI: 10.1023/B:ANOR.0000030690.27939.39.

Rottkemper, B., K. Fisher and A. Blecken. "A transshipment model for distribution and inventory relocation under uncertainty in humanitarian operations". In: Socio-Economic Planning Sciences (2012). DOI: 10.1016/j.seps.2011.09.003.

8 Appendix: Response Data

Table 6: Supplier: Partner vs Ad Hoc Responses

Scenario	Response	Mean	95% CI Lwr	95% CI Upr
Partner Supplier	ReliefSupplyItemTimeInSystemAverage	116.067162	115.254999	116.879324
Partner Supplier	ReliefBeneficiaryNumberCreated	20000.000000	20000.000000	20000.000000
Partner Supplier	UnsatisfiedBeneficiaries	0.000000	0.000000	0.000000
Partner Supplier	ReliefSuppliesDistributed	20000.000000	20000.000000	20000.000000
Partner Supplier	MaxDistSite2TimeWaiting	36.100330	28.513714	43.686947
Partner Supplier	MaxDistSite1TimeWaiting	35.754016	31.111059	40.396974
Partner Supplier	AvgBeneficiaryTimeInSystem	4.717122	4.162509	5.271735
Adhoc Supplier	ReliefSupplyItemTimeInSystemAverage	217.834869	216.337952	219.331786
Adhoc Supplier	ReliefBeneficiaryNumberCreated	20000.000000	20000.000000	20000.000000
Adhoc Supplier	UnsatisfiedBeneficiaries	15000.000000	15000.000000	15000.000000
Adhoc Supplier	ReliefSuppliesDistributed	5000.000000	5000.000000	5000.000000
Adhoc Supplier	MaxDistSite2TimeWaiting	289.963402	277.515510	302.411295
Adhoc Supplier	MaxDistSite1TimeWaiting	291.130365	279.314909	302.945821

Scenario	Response	Mean	95% CI Lwr	95% CI Upr
Adhoc Supplier	AvgBeneficiaryTimeInSystem	253.084095	247.417765	258.750425
Midlevel Supplier	ReliefSupplyItemTimeInSystemAverage	154.665275	153.364968	155.965583
Midlevel Supplier	ReliefBeneficiaryNumberCreated	20000.000000	20000.000000	20000.000000
Midlevel Supplier	UnsatisfiedBeneficiaries	10055.300000	9986.644543	10123.955458
Midlevel Supplier	ReliefSuppliesDistributed	9944.700000	9876.044542	10013.355457
Midlevel Supplier	MaxDistSite2TimeWaiting	243.629077	216.651744	270.606411
Midlevel Supplier	MaxDistSite1TimeWaiting	283.182952	257.416530	308.949375
Midlevel Supplier	AvgBeneficiaryTimeInSystem	182.449092	178.851824	186.046360

Table 7: Warehouse Access to Distribution Site Responses

Scenario	Response	Mean	95% CI Lwr	95% CI Upr
Partner Supplier	ReliefSupplyItemTimeInSystemAverage	116.067162	115.254999	116.879324
Partner Supplier	ReliefBeneficiaryNumberCreated	20000.000000	20000.000000	20000.000000
Partner Supplier	UnsatisfiedBeneficiaries	0.000000	0.000000	0.000000
Partner Supplier	ReliefSuppliesDistributed	20000.000000	20000.000000	20000.000000
Partner Supplier	MaxDistSite2TimeWaiting	36.100330	28.513714	43.686947
Partner Supplier	MaxDistSite1TimeWaiting	35.754016	31.111059	40.396974
Partner Supplier	AvgBeneficiaryTimeInSystem	4.717122	4.162509	5.271735
Midlevel Access to Dist Site 1	ReliefSupplyItemTimeInSystemAverage	115.639422	114.160935	117.117909
Midlevel Access to Dist Site 1	ReliefBeneficiaryNumberCreated	20000.000000	20000.000000	20000.000000
Midlevel Access to Dist Site 1	UnsatisfiedBeneficiaries	0.000000	0.000000	0.000000
Midlevel Access to Dist Site 1	ReliefSuppliesDistributed	20000.000000	20000.000000	20000.000000
Midlevel Access to Dist Site 1	MaxDistSite2TimeWaiting	33.744925	29.221874	38.267975
Midlevel Access to Dist Site 1	MaxDistSite1TimeWaiting	33.066987	28.029844	38.104129
Midlevel Access to Dist Site 1	AvgBeneficiaryTimeInSystem	3.930074	3.464660	4.395489
Quick Access to Dist Site 1	ReliefSupplyItemTimeInSystemAverage	117.234860	114.722353	119.747368
Quick Access to Dist Site 1	ReliefBeneficiaryNumberCreated	20000.000000	20000.000000	20000.000000
Quick Access to Dist Site 1	UnsatisfiedBeneficiaries	0.000000	0.000000	0.000000
Quick Access to Dist Site 1	ReliefSuppliesDistributed	20000.000000	20000.000000	20000.000000
Quick Access to Dist Site 1	MaxDistSite2TimeWaiting	46.082564	32.603982	59.561145
Quick Access to Dist Site 1	MaxDistSite1TimeWaiting	30.134080	24.634148	35.634013
Quick Access to Dist Site 1	AvgBeneficiaryTimeInSystem	5.199038	3.472673	6.925403

Table 8: Warehouse Access to Distribution Site Responses

Scenario	Response	Mean	95% CI Lwr	95% CI Upr
Partner Supplier	ReliefSupplyItemTimeInSystemAverage	116.067162	115.254999	116.879324
Partner Supplier	ReliefBeneficiaryNumberCreated	20000.000000	20000.000000	20000.000000
Partner Supplier	UnsatisfiedBeneficiaries	0.000000	0.000000	0.000000
Partner Supplier	ReliefSuppliesDistributed	20000.000000	20000.000000	20000.000000
Partner Supplier	MaxDistSite2TimeWaiting	36.100330	28.513714	43.686947
Partner Supplier	MaxDistSite1TimeWaiting	35.754016	31.111059	40.396974
Partner Supplier	AvgBeneficiaryTimeInSystem	4.717122	4.162509	5.271735
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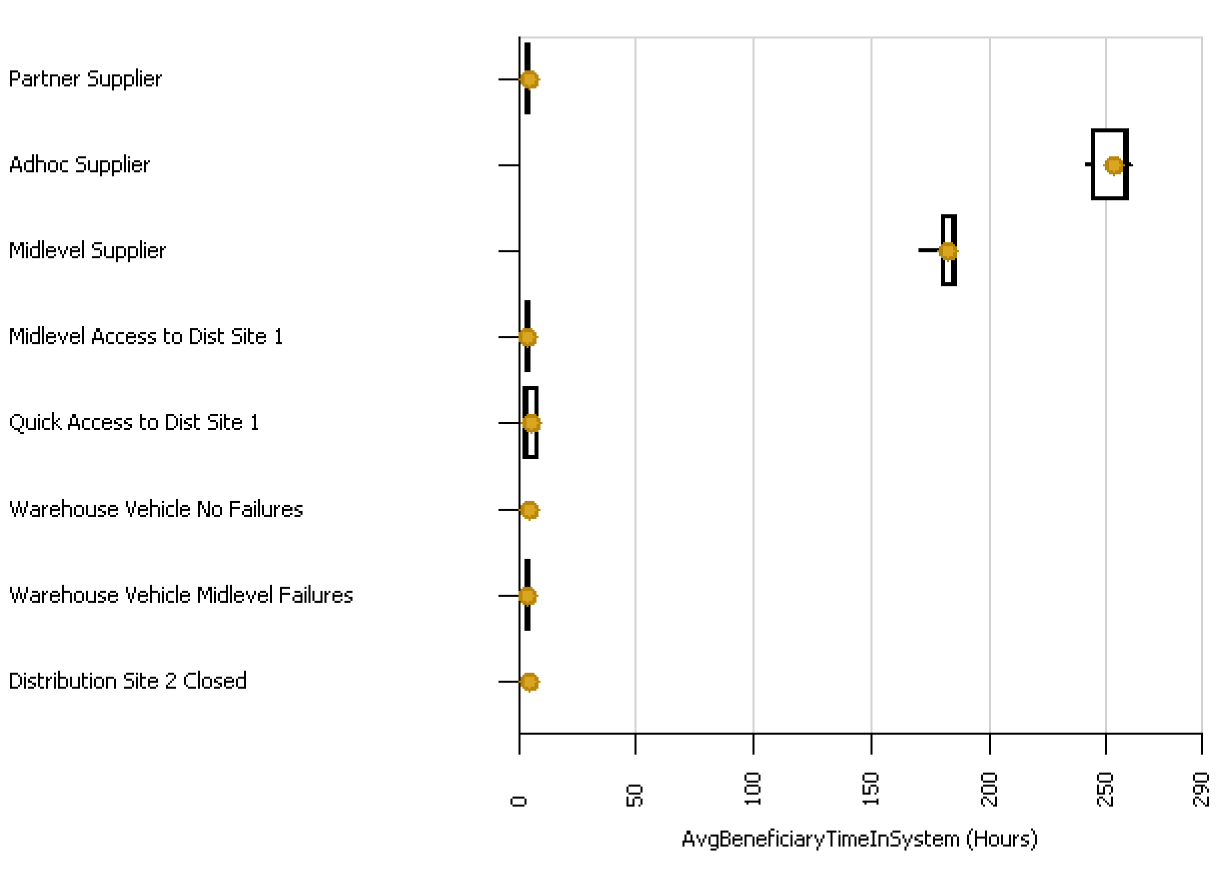

Fig N: All Scenarios - Average Beneficiaries Time In System

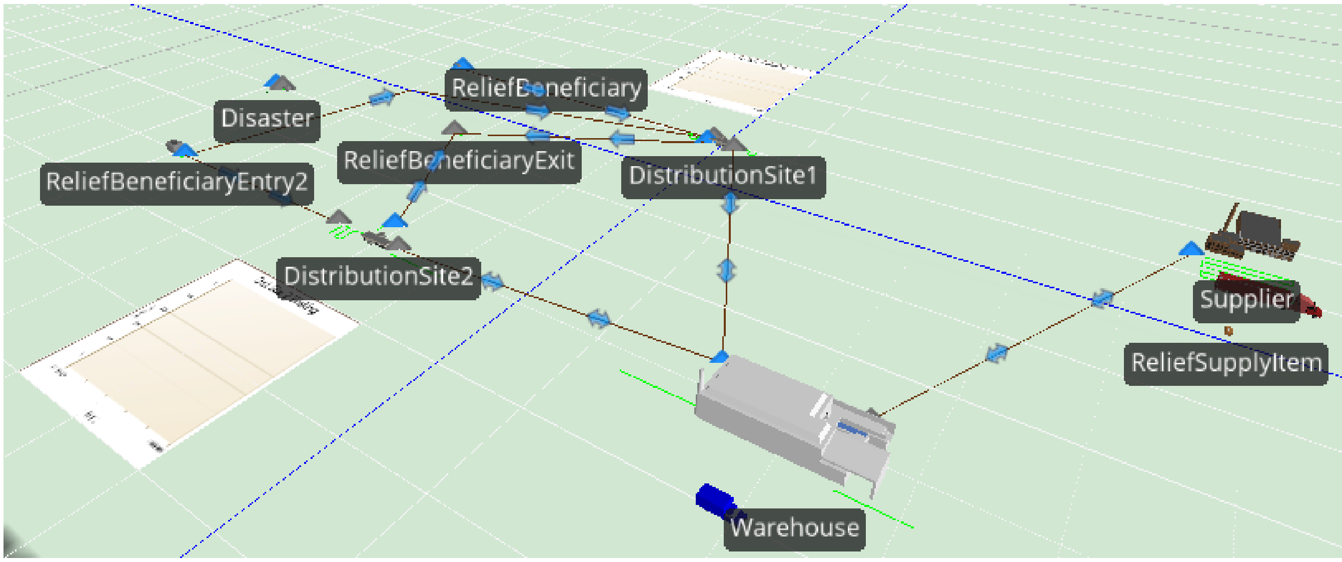

Fig N: Simio Simulation Model - 3D