HUMANITARIAN CRISIS: WHEN SUPPLY CHAINS REALLY MATTER

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"Delivering the right supplies to the right people, in the right place, at the right time and in the right quantities" Davidson

ABSTRACT

The supply chain of humanitarian aid is a complex and interlinked network in which different actors, processes, decisions and information are mixed to serve the needs of the victims in a catastrophe. As aid can be vital, also the correct management of the supply chain in each one of its stages is important not only to support the reconstruction efforts, but to allow a correct and pertinent assistance of the needy population. In a disaster, arrivals, transportation, storage and delivery of necessary goods become a difficult task that requires the mobilization of a great amount of resources. The supply chain is therefore stretched to their limits; that is why, it is so important to understand its behavior, the handling of shelter, food, water, and health care (among other necessities). The main objective of this paper is to model and describe the different phases comprising the supply chain of food aid in a humanitarian crisis using the system dynamics methodology, describing the particular case of the National Relief Agency of the Colombian Red Cross.

Keywords: Supply Chain, humanitarian aid, system dynamics.

1. **Introduction**

A natural disaster can occur anywhere at any time, and all countries in the world must be prepared in order to minimize the eventual damage of the catastrophe. Therefore, the effective management of aid determines the amount of lives that can be saved.

The process of delivering supplies to a community that suffered a natural disaster implies the coordination and execution of multiple processes. Due to the importance of aid, its relevance in the event of a catastrophe (Gustavsson 2003), and an adequate understanding of how humanitarian aid is handled by donors, governments, international, local NGO's, community based organizations (local partners), support teams and finally beneficiaries, is vital.

According to the type of disaster (earthquake, flood, hurricane, etc), the specific requirements of the affected population vary. For example, when a flood occurs, the lack of food is the major concern; but when an earthquake occurs, shelter is one of the immediate requirements. The specific conditions of the place where the disaster occurs also determine the kind of assistance needed. (Wilches-Chaux 2000)

Although all types of catastrophes are different, they share similarities on their consequences: destruction of roads, health diseases, and destruction of infrastructure. (Oloruntoba 2006) This is why an effective coordination of the supply chain and a constant flow of information is the key to improve the delivery and the performance of organizations of aid. (Cruz Roja Colombiana 2009)

This paper emphasizes on the importance of the supply chain in the effort to provide food assistance to the needy ones, considering how different actors interact across the supply chain to face the needs of the population, considering the case of the Colombian Red Cross.

2. Problem Definition

Supply chains are complex. Systems composed by series of stages in which materials and information flow through different steps to fulfill the requirements of the recipients and the objectives to those who send help (Davidson 2006). Profit and non-profit organizations have different types of supply chains; most of them are measured under defined performance parameters and directed to achieve certain objectives.

2.1 The humanitarian supply chain: stages, processes and inefficiencies.

Food aid implies the recollection and delivery of large amounts of goods from different sources: people who want to help sending aid to those affected, governments, NGO`s and private enterprises.

The initial flow of material reflects the immediate reaction of actors according to the information transmitted. (Organización Panamericana de la Salud 2001) As time passes, supply efforts are reduced because donor´s perception of the necessities decreases and with it, the amount of products delivered. According to this behavior, a humanitarian supply chain needs to incorporate the recollection, transportation, classification and delivery of the products from the donors to the affected people, and all the information processes that coordinate each stage with the others. (Gray 2006)

The humanitarian supply chain for food assistance in the Colombian Red Cross begins once a disaster takes place. The national entity in charge (National Relief Agency of the Colombian Red Cross) elaborates a detailed evaluation of the disaster, and suggests the most suitable action procedure according to the stocks of available products and logistic teams in the place of the disaster. Then it verifies if the local teams request for assistance can be received, processed, and delivered according to their logistic resources.

If the local unit is unable to answer to these necessities, the second level of assistance is "activated", the regional and strategic units are contacted to provide aid. If stock levels in these units are not still enough to provide needs of the affected population, the principal unit of assistance (National Unit) is alerted (involving the request for aid from the Regional Unit). Depending on the inventory and the amount of food requested by the Regional Unit, the National Unit determines if it is necessary to buy aid kits, or to ask for donations.

Emergency assistance supply chains share some similarities to "conventional" chains, both consider as an indicator the lack of coordination (management of information along the process) and the inefficient procedures that lead to long delays on the process of delivering aid (Davidson 2006). So, the structure and coordination of the supply chain conditions the success or failure of the effort. (Paché 2009)

On the literature review we have found that several efforts have been made to standardize the process of delivering humanitarian aid (Cruz Roja Colombiana Socorro Nacional 1998). However, some authors have correctly pointed that extreme standardization might be a mistake, because all disasters are different, not only on their causes, but also on the particular characteristics of the region in which they occur (geographical or cultural) and this should be taken into account at the time of delivering aid. (Paché 2009)

A humanitarian supply chain is characterized by the presence of different kind of delays. These occur during three stages of the aid process. In the evaluation of the disaster and the measurement of the quantity of people affected, then during the process of delivery of aid including the logistics needed to transport the aid for the place where donations are received to the location of the disaster, and the process of relief and distribution of aid to the recipients. (Cruz Roja Colombiana y Holandesa s.f.)

2.2 Is system dynamics helpful to understand the problem?

System Dynamics can be used to analyze different stages of the Supply Chain in order to define what could happen under different scenarios, in example if aid were not enough to supply the "demand", and therefore understand possible side effects or delayed consequences of different policies implemented (J. D. Sterman 2000).

Particularly, it is important to understand the so called "bullwhip effect" were distorted information from one end of a supply chain to the other can lead to remarkable inefficiencies (Hau L. Lee 1997).

In the case of the aid supply chain, inventory moves up in the chain and it fluctuates more with donations recollected and in the distribution centers creating a distortion on the demand information.

To study this phenomenon, system dynamics presents an endogenous approach, in which the behavior of the system can be described as a consequence of their underlying structure (J. Sterman 1991), and also makes a distinction on the variables of the model (among instantaneous variables and accumulated variables) (J. Forrester 2003) and the modeling of feedback effects on it related to actors and variables of the system, allowing the modeling of the structure, the decision processes involved and the flow of information (Richardson 2009).

System dynamics is useful to model this situation because the interactions among the agents (1) People affected by the disaster 2) Members of the aid organizations 3) Donors of aid) on the chain are complex, and a model of stocks and flows could elicit how aid (or information) passes among them and affects the performance and effectiveness of the chain.

The model is built to represent the flow of aid, and how it is affected by the information feedbacks, that explain the presence of bullwhips effects on the chain at different periods of time depending on the initial conditions (initial stocks of aid storage on the different parts of the chain) and on exogenous variables.

The goal of this paper is not to calculate the precise amount of aid that should be sent at every period of time or to calculate the optimum quantity of capacity that should be used, because as it is said before, it depends on the particular characteristics of a disaster and of the region in which it takes place. This paper wants to assess, through system dynamics, a preliminary model to favor a better comprehension and planning prior to the problem, to understand its complexity, in order to provide a tool that supports the strategic planning of emergency response on the National Relief Agency of the Red Cross of Colombia.

3. **Model**

After a disaster or an emergency, it is necessary to deliver the required aid, and in our model, we assess the delivery of food aid kits,[1] because for The National Red Cross is food this stock is the most important on the supply chain , it is being modeled specifically the flow of food represented in kits. First, the Red Cross evaluates the damages and needs of the population, and then it determines how many kits of food they will deliver to the population. The main operation center of the National Relief Agency of the Colombian Red Cross is located in Bogota, where the main warehouse is located. Colombia is divided in 32 departments, and the Red Cross has located one regional warehouse in each of these departments. In addition, it has local warehouses, located in the towns in which the Red Cross has presence. They also have "strategic" warehouses, located in some departments of the country that are used when the aid in regional centers is not enough in the face of an emergency. There are four main variables in the model:

- The requirements of food by people affected by the emergency or disaster.
- The delivery of kits of food available in regional and local warehouses.
- The delivery of kits of food available in the strategic warehouse and in the main national warehouse.
- The donations of food that are received by the Red Cross before and after a call for aid has been made.

The model is divided in two main sectors, the orders and the flow of material.

a) The orders made and received by each of the different warehouses of the Colombian Red Cross (regional, strategic, local and national). For example, based on the community requirements, the local warehouses decide if they ask resources to the regional warehouses or not. (Figure 1)

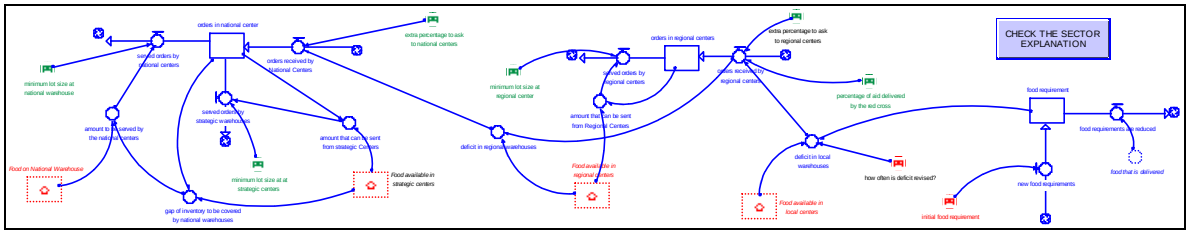


Figure 1: Orders made and received by the Red Cross

b) The material flow through the supply chain. In this case, the material flows in the opposite direction of the information. The aid that is stored in the national warehouse or in the strategic warehouses, including the aid received in donations, is distributed to the regional centers, and when all the aid required is gathered in this

[1] Food aid kit: Represents de quantity of food that supplies the needs of a family of five persons during two weeks.

point (because in aid delivery processes it is better to assist all the population in one intervention) then is delivered the aid to the local centers. (Figure 2)

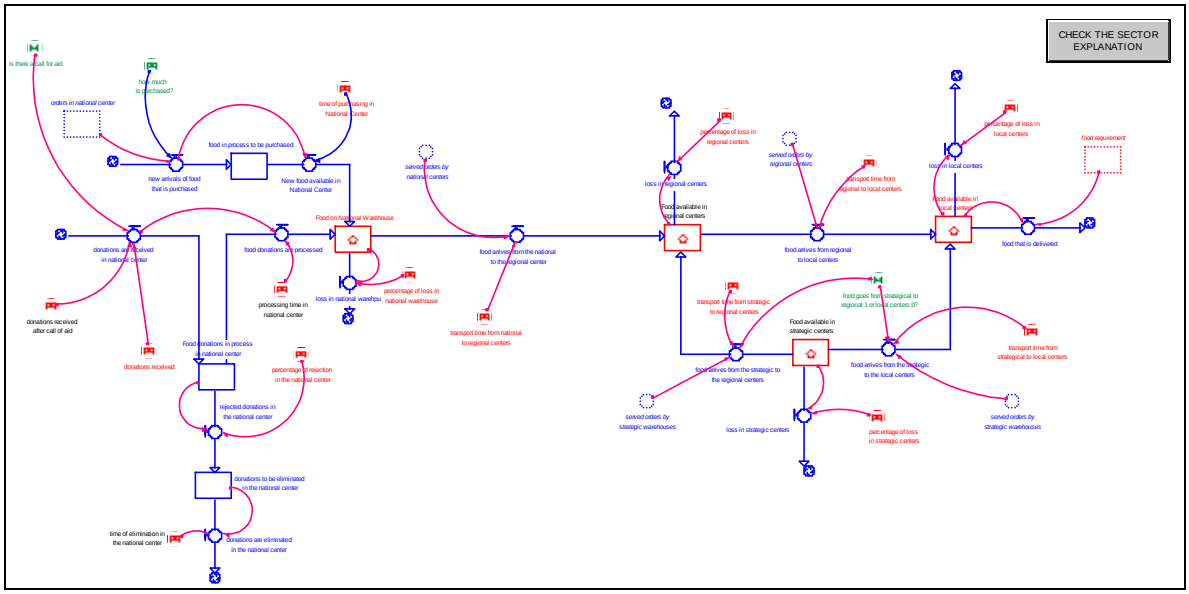


Figure 2: Material flow in the supply chain

3.1 Orders

3.1.1. Orders made by local warehouses based on initial requirements

The model assumes that the initial requirements are given at the beginning of the simulation. This means that only an initial requirement is given, and then the aid chains answers to that initial requirement, which represents the result obtained through the evaluation of damages and needs made by the National Relief Agency of the Colombian Red Cross. Initially, the Red Cross has previously positioned resources in its different warehouses, because many emergencies in Colombia, such as floods or droughts, for example, occur in determined seasons and these can be foreseen but not predicted.

The local center compares this requirement, measured in kits of food kits, with the resources they have stocked in their warehouses. Based on this, they determine how much food kits they will ask (in the model this is defined every 24 hours).

It is assumed that the distribution of food kits occurs almost immediately, and this is made according to the food available at the local warehouses. The local warehouses will deliver aid if there are food requirements. (Figure 3)

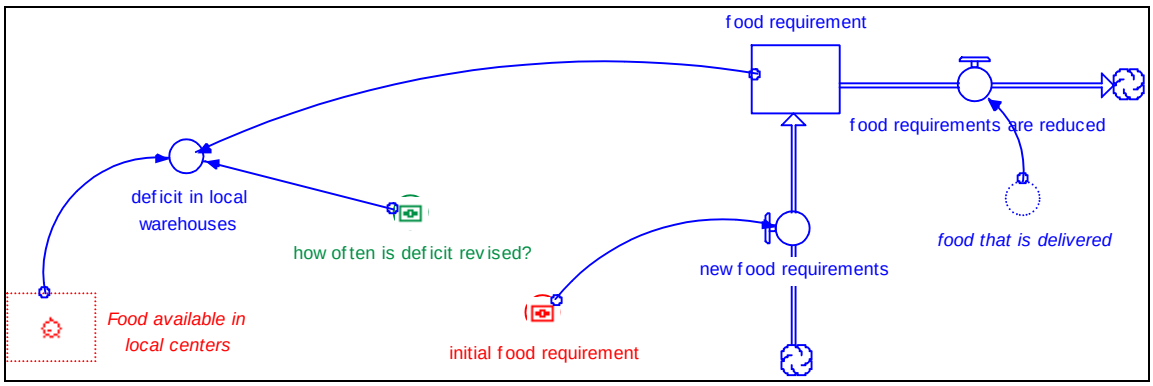


Figure 3: Initial requirements and deficit of local warehouses

3.1.2 Orders made and received by regional warehouses

The deficit that was previously mentioned is the amount that the local centers ask to the regional centers. This value is adjusted by some percentages: it is possible that the regional center would not be able to commit to deliver the whole amount of aid because the resources must also be used to cover other emergencies. They can also send an additional percentage based on the possibility to have some losses or damages in the food kits during their delivery, guaranteeing the supply of aid required.

In this case, the orders received by the regional centers are compared with the amount of food available in the regional warehouse, and a deficit is also calculated. This deficit represents the amount that is ordered to the next stage, the national center.

The aid delivery from the regional centers considers that is not possible to deliver resources continuously from one place to another, and it is preferred to make one or few deliveries with great amount of food kits , based on efficiency in logistics, costs, and the difficulties of making many deliveries. This is why a minimum lot size is determined, and based on this; the delivery is made when the amount of food available in the warehouses reaches this amount. In an extreme case, this lot size could be the order itself, making only one delivery. The same rules apply to the strategic warehouses and national warehouse. This is just an overview of how the model works; the detailed equations are found in the annex presented at the end of this document. (Figure 4)

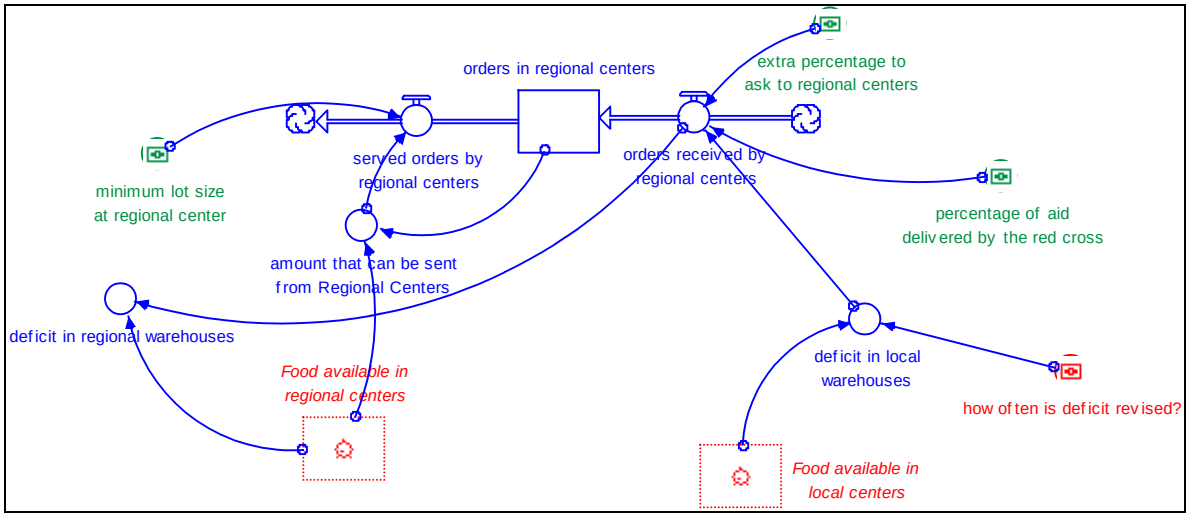


Figure 4: Orders made and received by regional warehouses

3.1.3 Orders received by national and strategic warehouses

The national center receives the orders from the regional center, which correspond to the deficit calculated in the previous stage.

The national center has two ways of attending an order (Figure 5):

- Use the strategic warehouse, authorizing the regional centers to use these resources that have been previously positioned in these warehouses.
- Send kits from the national warehouse located in the capital. There is priority in delivering aid first from the strategic warehouses, and then using the national warehouse, because these ones (strategic warehouses) are usually closer to the place where the emergency occurred, and therefore costs and transport times are reduced.

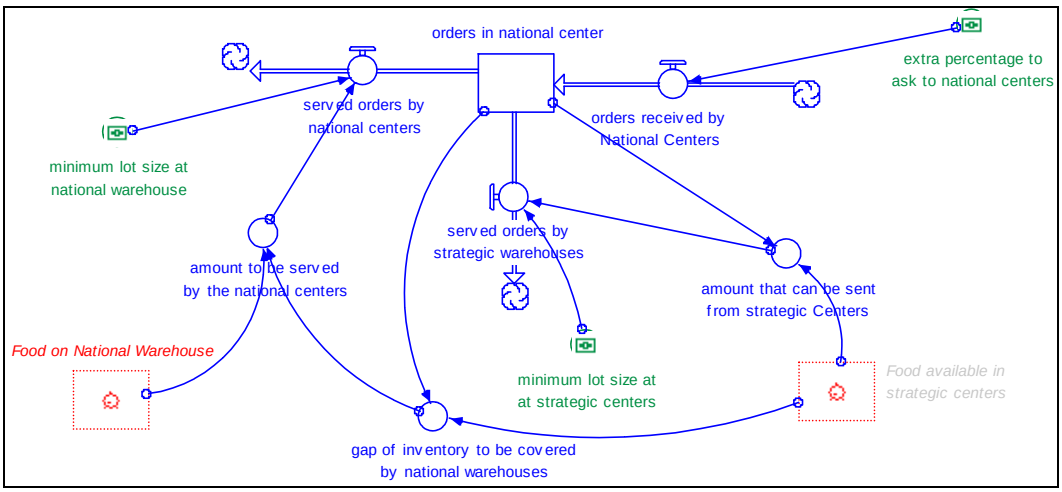


Figure 5: Orders received by national and strategic warehouses

3.2 Delivery of aid

The second sector of the model describes the flow of aid through the supply chain. The material flows from national to regional warehouses answering the need to distribute the aid.

3.2.1 Local delivery of aid

Locally, the food kits are delivered immediately as mentioned before. But the model assumes that the resources do not arrive immediately from the regional to the local centers, and there is a time to transport the resources. There is a delay in the delivery of resources. The material flow depends only of the orders made in each of the stages. No material passes from one stage to the next one, unless this is done to deliver an order. Additionally, it is considered the fact that the food in the warehouses can only last for a certain time, so there is a small and constant loss of resources in the warehouses. (Figure 6)

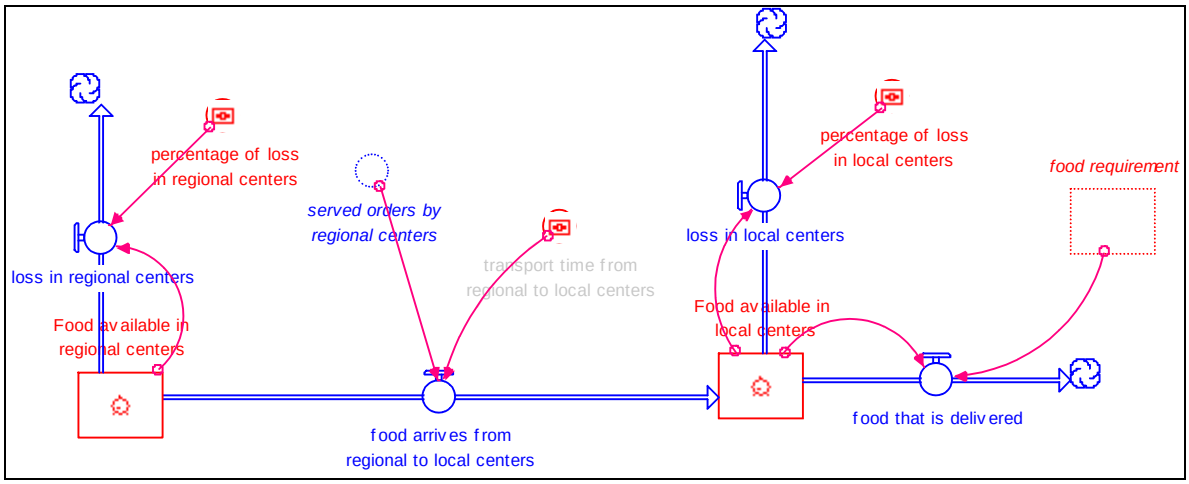


Figure 6: Local delivery of aid

3.2.2 Regional delivery of aid

Food kits are also delivered from the national and strategic centers, depending on the amount of orders that must be served, considering the transport times between one warehouse and the other, and the possible loss of food in the warehouses. Food kits from strategic warehouses can be sent to regional warehouses or directly to the local warehouses. (Figures 7 and 8)

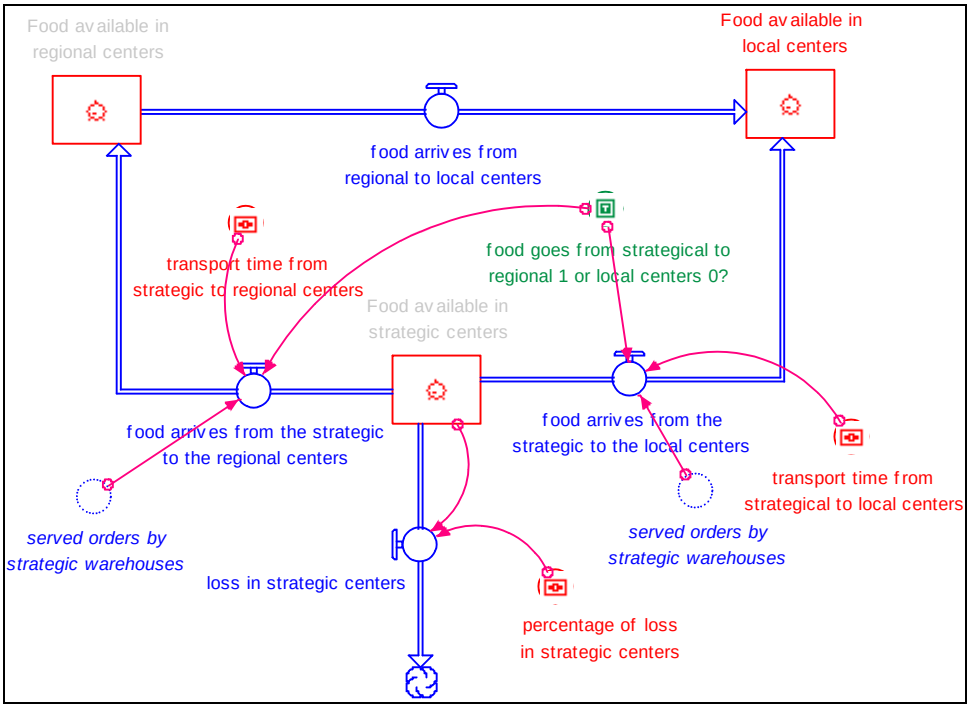


Figure 7: Delivery of aid from strategic to local or regional warehouses

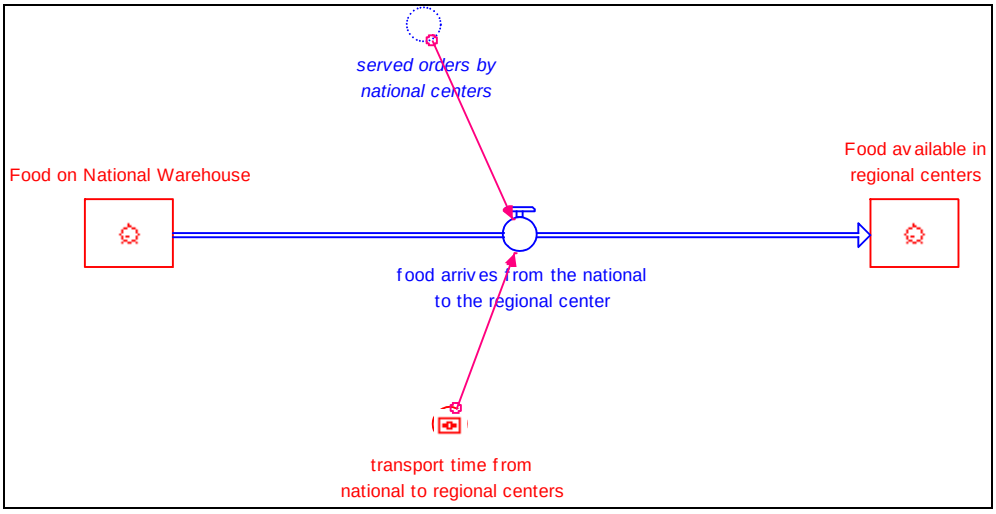


Figure 8: Delivery of aid from national to regional warehouses

3.2.3 Food purchasing and donations

There are certain cases in which the food stored in the national or strategic warehouses is not enough, and one of these two policies must be implemented.

- Buy food kits, a process that takes a certain period of time, before it is delivered. The model allows the user to define this amount.

- Collect resources through donations. Initially, it is known that the national warehouse receive a flow of donations constantly, but a call for aid can be made to all the national population (this is usually made when the disaster requires a big amount for aid, in example, an earthquake). This option is presented in the model, and a great amount of food can be obtained with the help of donors (from 5 to 20 tons every day). Classifying and processing donations takes certain time, so they can be finally distributed. (Figure 9)

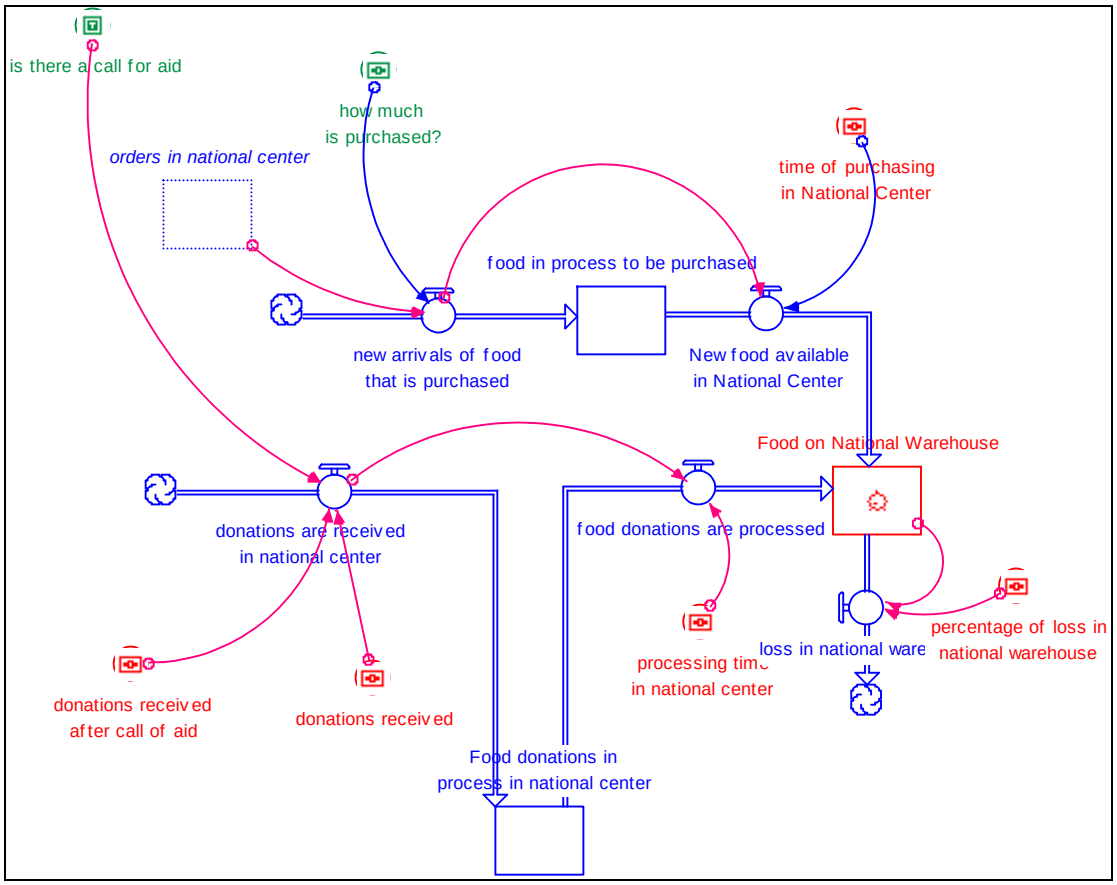


Figure 9: Food purchasing and donations

The model considers that some donations are not useful, and when donations are classified these are rejected and eliminated. (Figure 10)

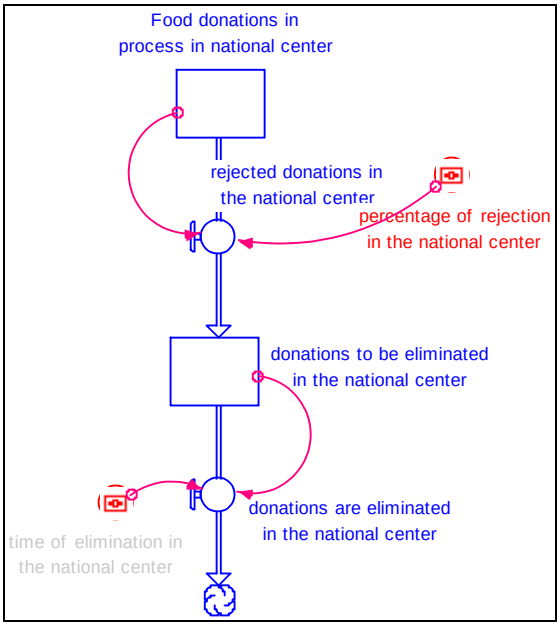


Figure 10: Rejection and elimination of donations

4. Model validation

In order to assess the validity of the model we analyzed the structure and parameters of the model (J. D. Sterman 2000), focusing primarily on the consistence between the purpose and the model itself, and on the consistency of the structure of the model to "mimic" reality, according to the members of the National Relief Agency of the red Cross.

To analyze the structure of the model, a question must be made: To what extent is the structure of the model representing the real system? The model represents the process of distribution of food aid kits. The orders are made from local to national warehouses, and material flow follows the opposite direction: from national to local warehouses. The model considers transport times from one warehouse to another, and incorporates situations in which a call for aid is made to population when an emergency turns into a disaster. However, there are certain things that the model differs from real life.

The inventory model structure is vital, therefore when we checked the model we considered that orders that cannot be fulfilled could not imply an accumulation on the stocks of inventory, nevertheless the backorders cause a reaction on the chain, such as an increase on the orders for aid. Additionally the chain comprise several stages that imply accumulations and delays related to the different steps of the supply chain (and therefore different processes and delays), on the model there are several simplification on the stages, and the simplification of the chain is done by dividing it into the stages explained in the model, but a detailed structure of it can be considered. In the case the distinction mentioned before

implies changes in the behavior of the system, the model should be re-structured to asses this particularities.

¿How are backorders considered?

In this model, if an order cannot be served by a certain warehouse, the “smaller warehouse” orders the deficit to the bigger warehouse up in the chain,. For example, suppose that the regional warehouse receives an order of 200 kits, and has only 100 kits of food available in its stock. Therefore, it must order 100 kits to the national or strategic or national warehouse. Why does the model work then? Every certain amount of time, the local warehouses compare their amount of stock with the food requirements of the population. This is a short time, so constantly orders are generated by the local warehouse. If the food that the local warehouses asked for were not received, they will consider this in the next order, and the needs of the population will be finally covered.

How is deficit in local warehouses calculated?

For the model to work property, the local warehouses compare their stock with the population needs every 24 hours. However, there is a difference between the model and the real system. The local warehouses make orders only considering their levels of stock. They do not consider the stocks of other warehouses, and food that was asked before to cover population needs. The model works differently, because if a certain amount of food is not received, a new order would be made to ask for the deficit.

Are warehouses correctly represented in the model?

The model has four main stocks: Food in local, regional, strategic, and national warehouses. However, the model does not considers cases in which more than one of each kind of these warehouses must be considered in the model. These cases occur when two different strategic warehouses can be used to serve the population, when an emergency affects a population but nearby towns can also contribute to deal with the emergency, or when these neighbors are also affected by the emergency. In this case, what should be represented by the stocks in the model? One solution is to add the capacities of each kind of warehouse, to obtain the amount of food represented in the stock. The assumption here would be that food delivered by stocks of the same kind is delivered exactly at the same time, and they take the same transport time to reach their destiny. This may not be realistic because distances between warehouses may differ, and some stocks may be more efficient than others.

In the case mentioned before, in which two different strategic warehouses can be used to serve a regional warehouse, the main variables to consider is the time that it takes to serve

the warehouse and the amount of food stored in each in warehouse. But this case cannot be analyzed in our model, unless an extension is made.

At the moment of assessing the model, there is also necessary to discuss the pertinence of the boundaries of the model, and the way model answers the question of how it changes when assumptions are relaxed.

The model assumed that the population requirements for aid are a pulse caused by the natural disaster, and the relief provided by aid.

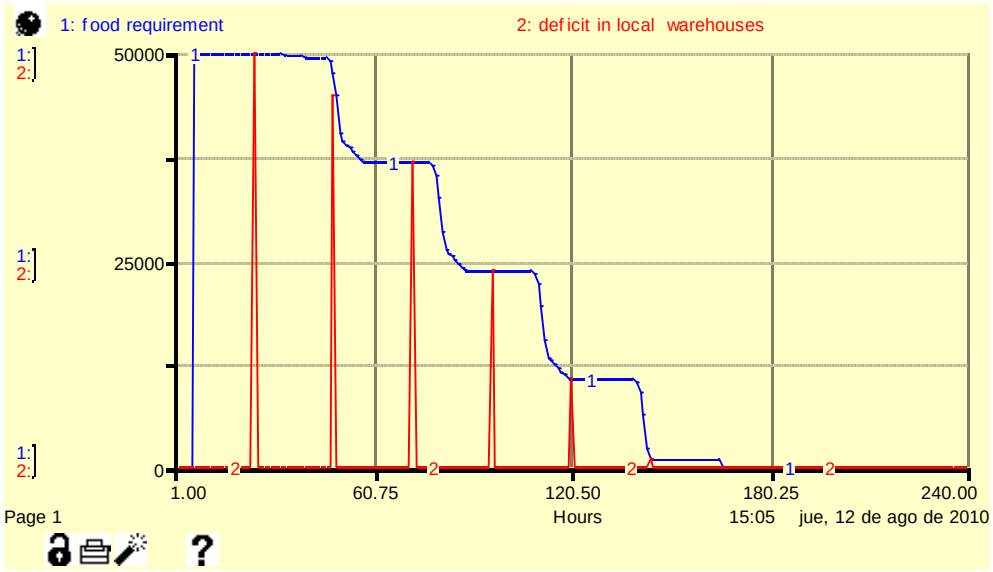
As can be seen in the document, the model has been done in conjunction with The Red Cross, We have done a weekly a meeting with their members in order to understand and validate the process that we wanted to represent and to know important details such as data and basically reserved information that was necessary to model the supply chain.

Sensitivity Analysis

To understand the behavior of the model a base model is considered. This case supposes that a disaster has occurred, and 50,000 food kits are required. The warehouses were not prepared for such a disaster. Therefore, they rely on donations from the population, which must be distributed immediately.

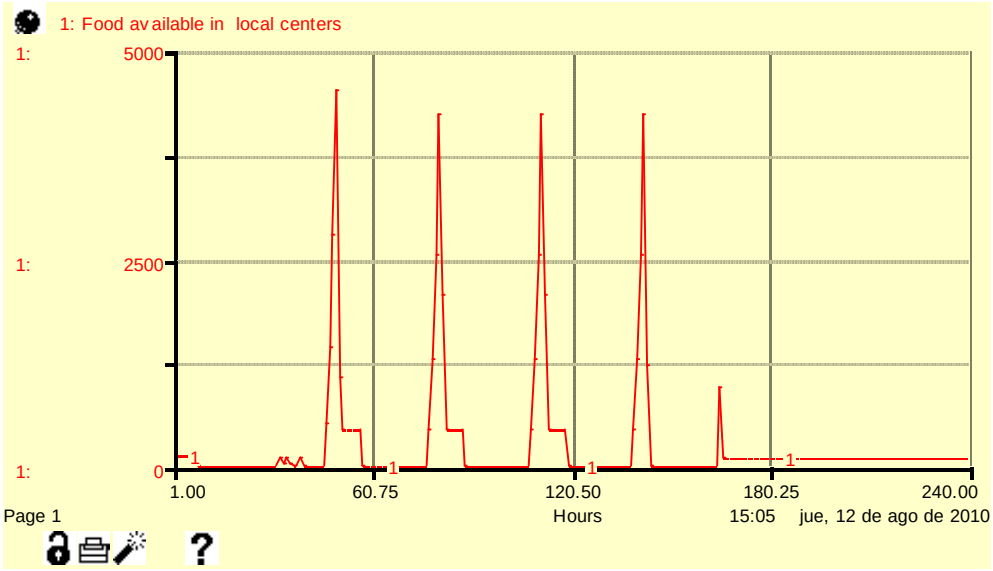
The exogenous variables in the model are initialized, and their values are shown in an annex 1 presented at the end of the paper.

The following results were obtained.



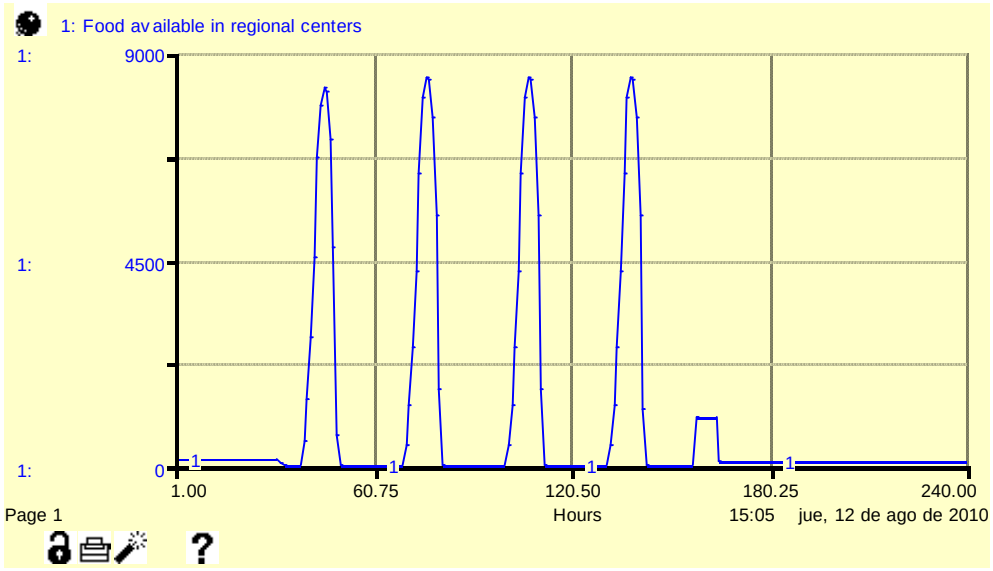
Graph 1: Food requirement and deficit in local warehouses.

There is an initial requirement of 50.000 food kits. The deficit in local warehouses is calculated every 24 hours, which explains the peaks obtained in the graph each day . It can be seen also that food requirerments decrease as orders are attended and new supplies arrive.

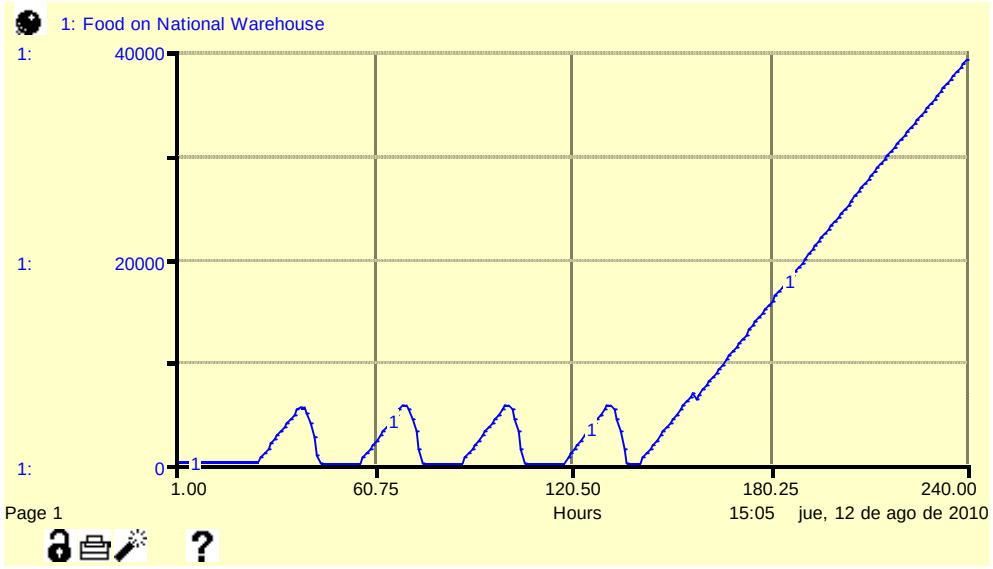


Graph 2: Food available in local centers

The peaks in this graph are obtained because the local centers receive food kits from regional centers and these ones arrive in lots that take a certain time to transit.



Graph 3: Food available in regional centers



Graph 4: Food available in National Warehouse

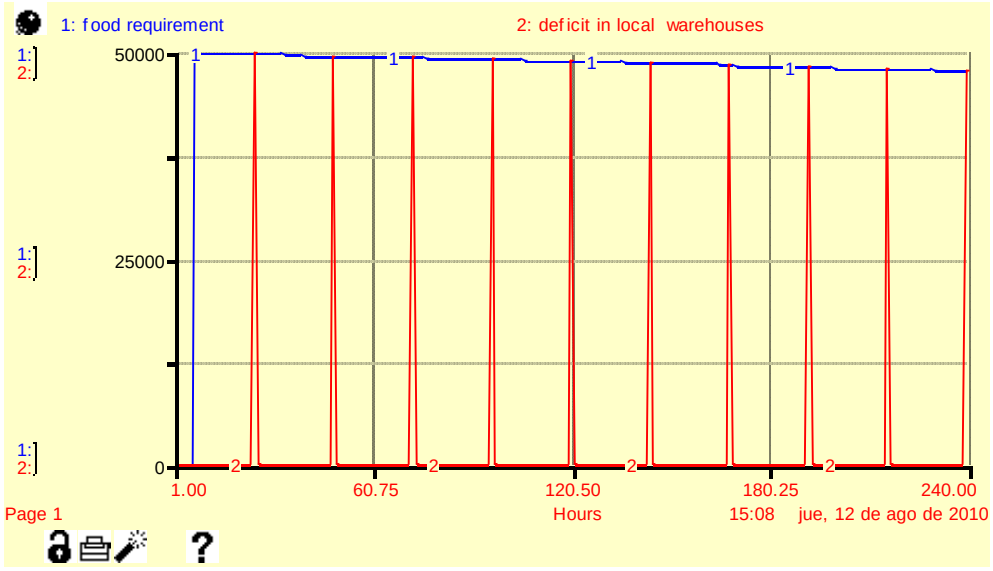
After the disaster has been attended, donations are still being received. Unless the call for aid is interrupted, the amount of food aid kits stocked on the national warehouse will grow indefinitely. The results obtained after reducing food requirements to zero in this graph could be ignored if this last assumption is made.

What would happen if a call of aid was not made?

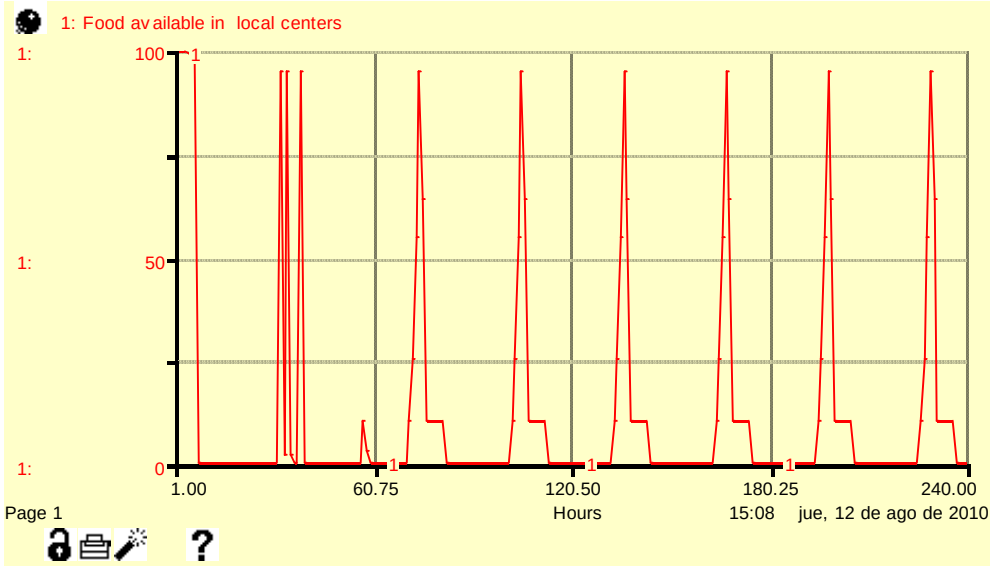
The variable “Is there a call for aid” represents a binary variable that takes the value of 1 if a call of aid is made to the population, and 0 if the Red Cross considers that this is not necessary. The disaster requires the call of aid to be made, because donations are an

important source of aid. The following graphs shows what would happpen in the absence of the extra donations received after a call for aid.

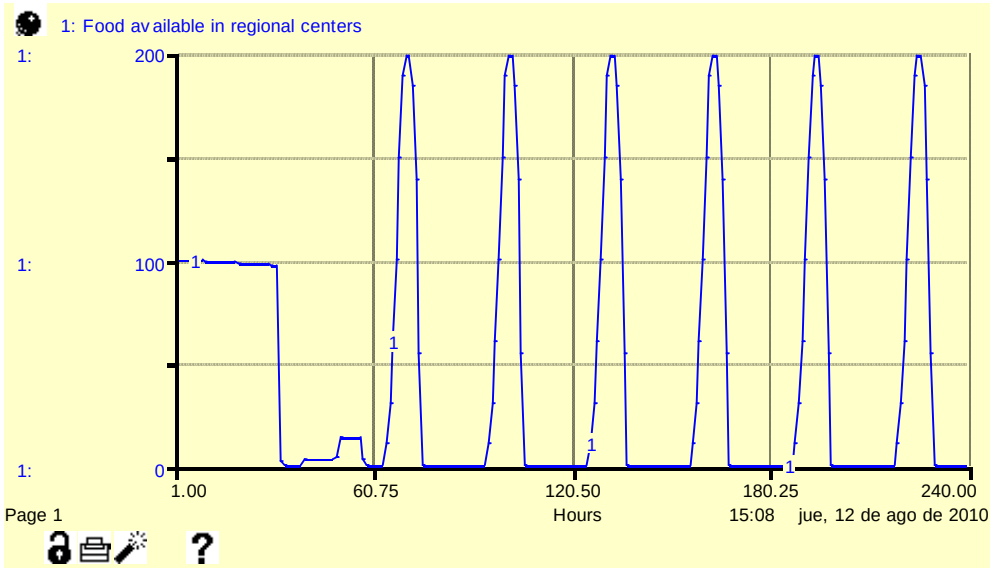
Variable	Value	Units
Is there a call for aid?	0	Binary



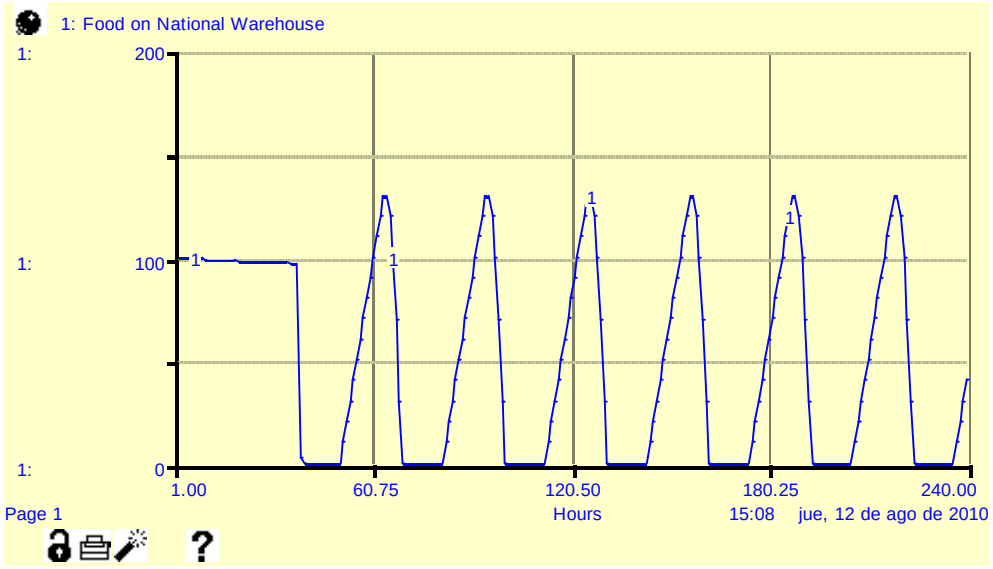
Graph 1A: Food requirement and deficit in local warehouses



Graph 2A: Food available in local centers



Graph 3A: Food available in regional centers



Graph 4A: Food available in National Warehouse

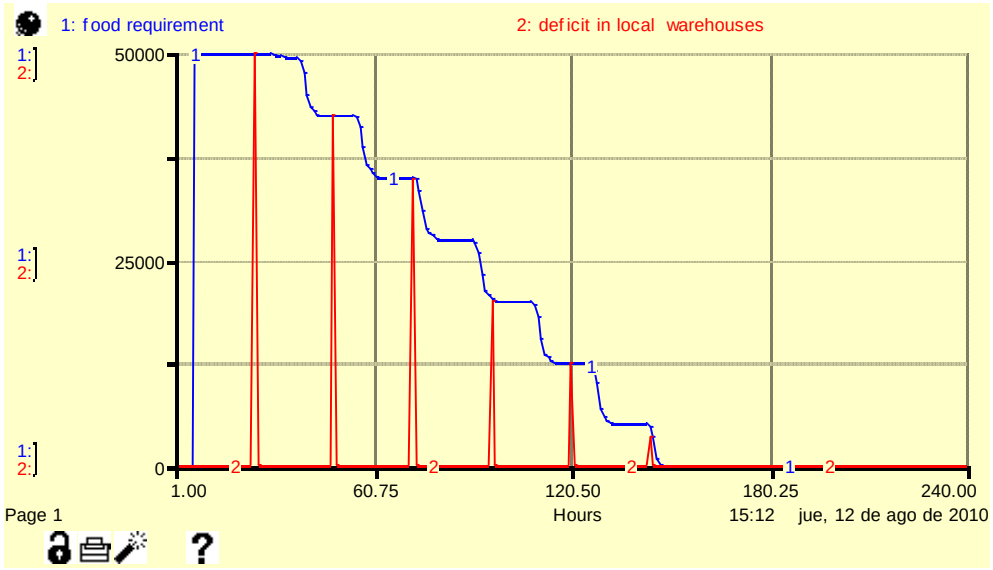
Graphs show that the call of aid was necessary for the relief of the disaster. Otherwise, the food requirements could not be reduced, as shown on graph 1A. Graphs 2A, 3A, and 4A,. Food requirements are finally not reduced during the next ten days.

What would happen if transport times are reduced?

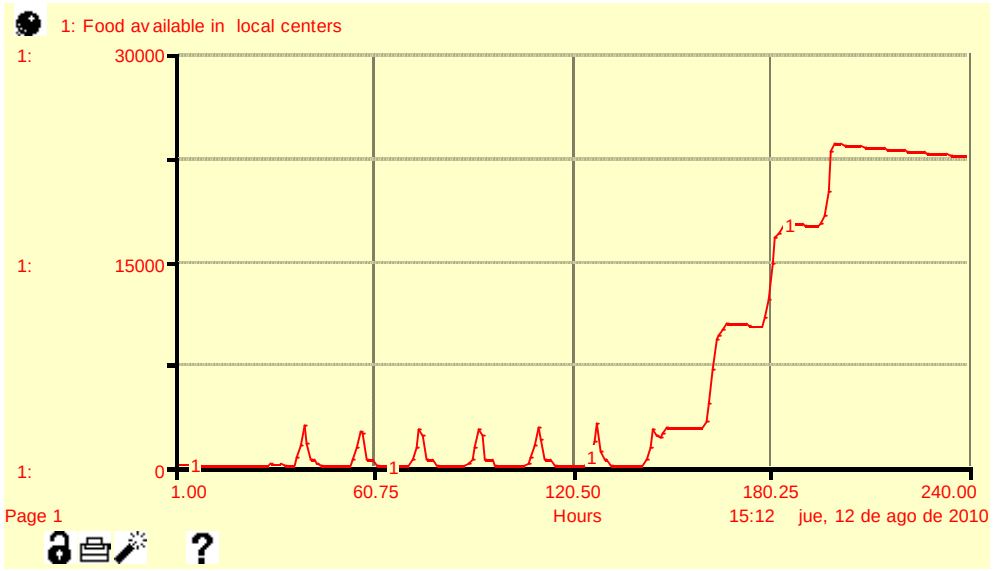
In the following case transport times among the different warehouses are reduced:

Variable	Value	Units
Transport time to regional to local centers	6	Hours
Transport time from strategic to local centers	4	Hours
Transport time from regional to local centers	3	Hours
Transport time from national to regional centers	6	Binary

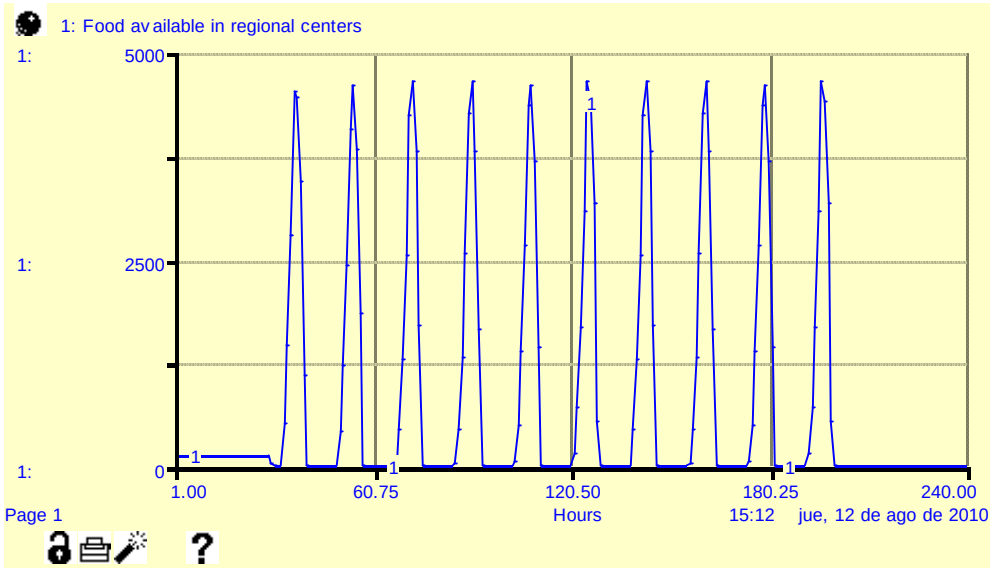
It is expected that food requirements will decrease faster, because food kits take less time between warehouses. Buto also we could expct a higher volatility on the intermediate stocks of the chain.



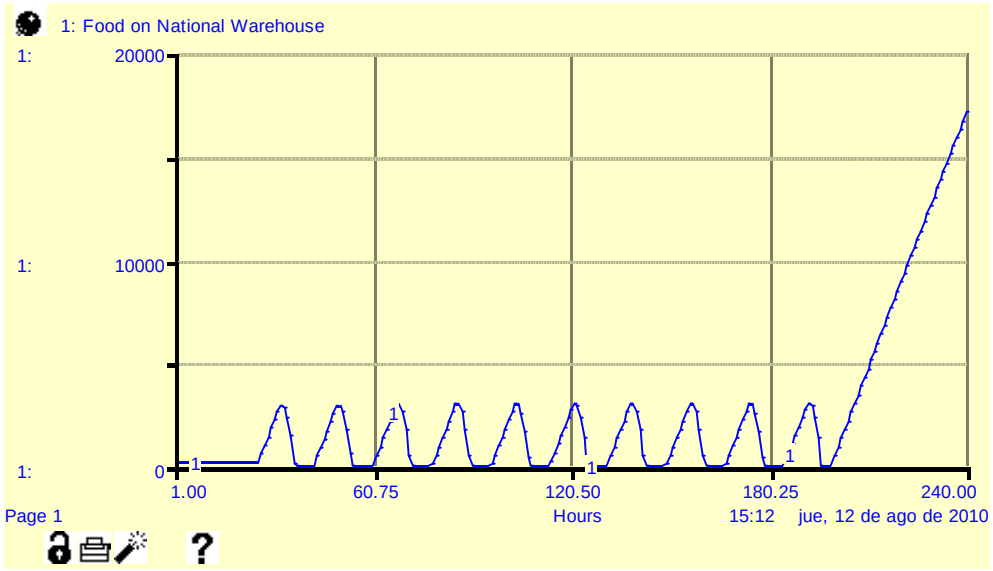
Graph 1B: Food requirement and deficit of local warehouses



Graph 2B: Food available in local centers



Graph 3B: Food available in regional centers

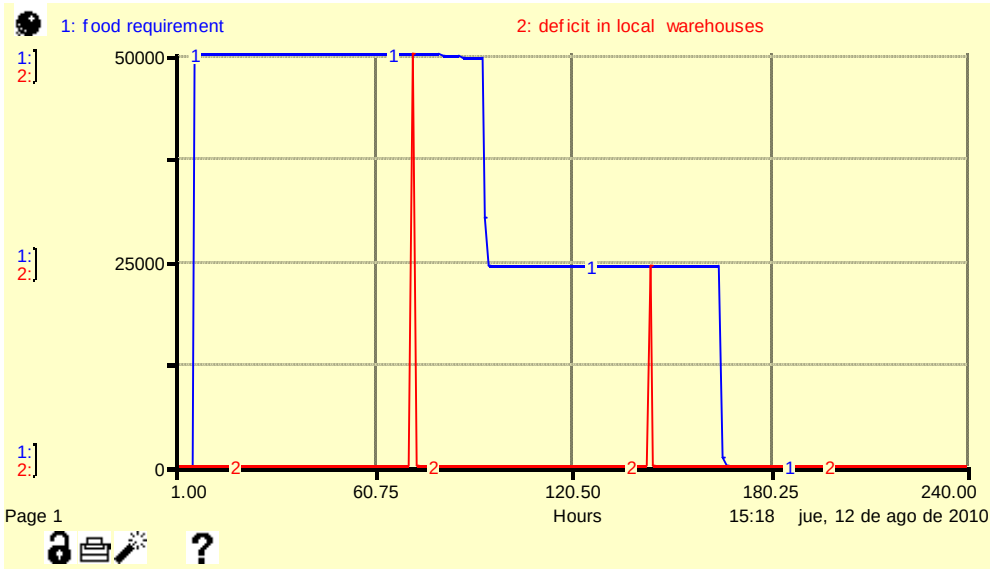


Graph 4B: Food available in National Warehouse

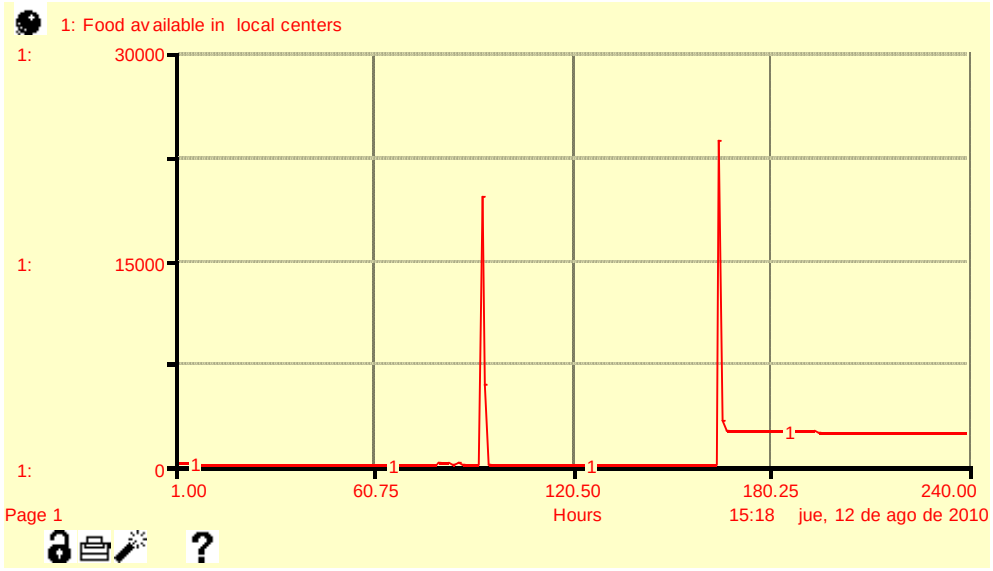
The main differences in the results show that the food requirements are covered in less time. Food is delivered quickly, and with a higher frequency. The results in graph 2B show that if transport times are short, extra orders could be made because local warehouses are not considering the aid in transport-order before making a new order. Therefore, in the end, the food available in the regional centers grow indefinetly bacause aid is stocked and not distributed anymore (it is not necessary to deliver aid that is not required)

What would happen if deficit is revised less often in local centers?

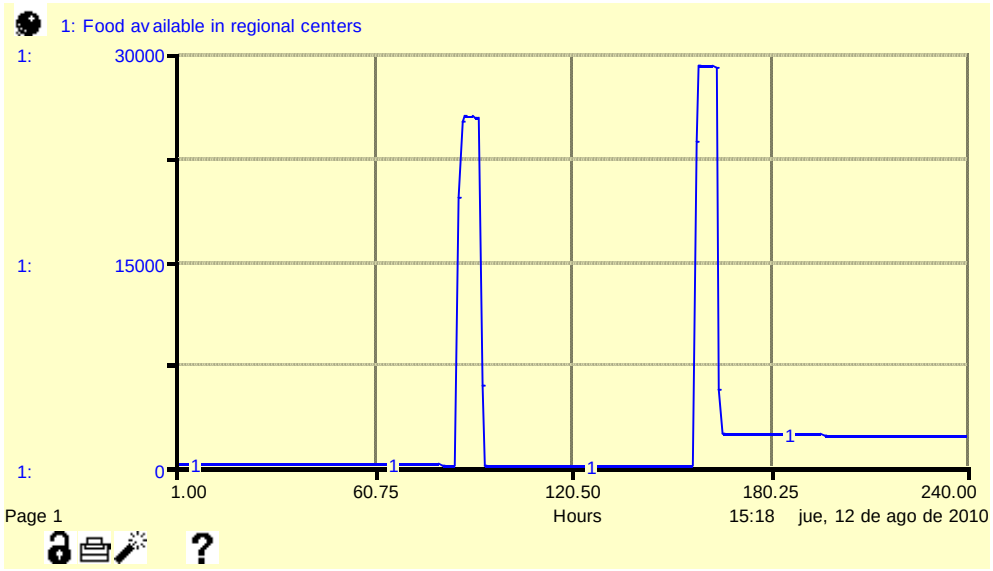
Variable	**Value**	**Units**
How often is deficit revised?	120	hours



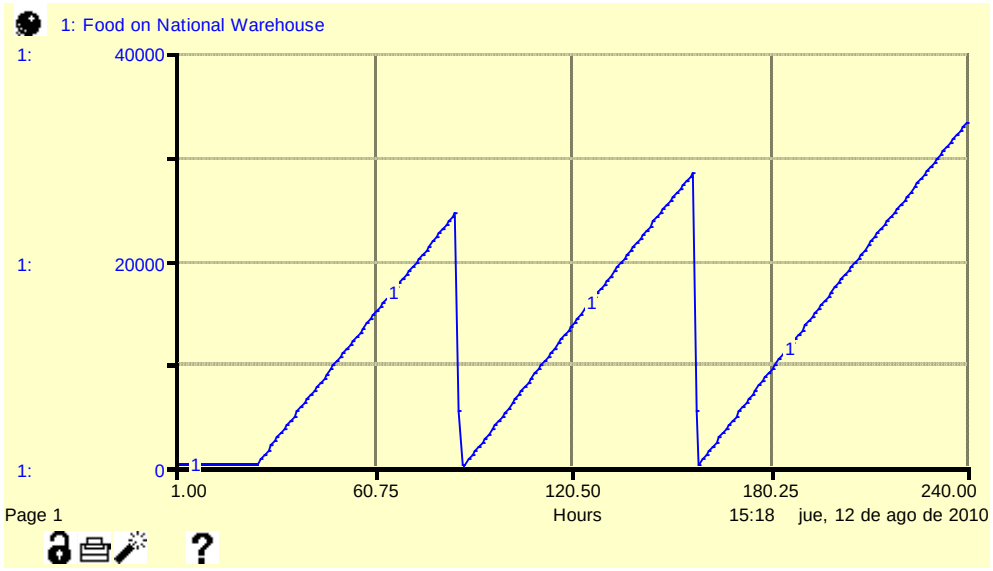
Graph 1C: Food requirement and deficit in local warehouses



Graph 2C: Food available in local centers



Graph 3C: Food available in regional centers

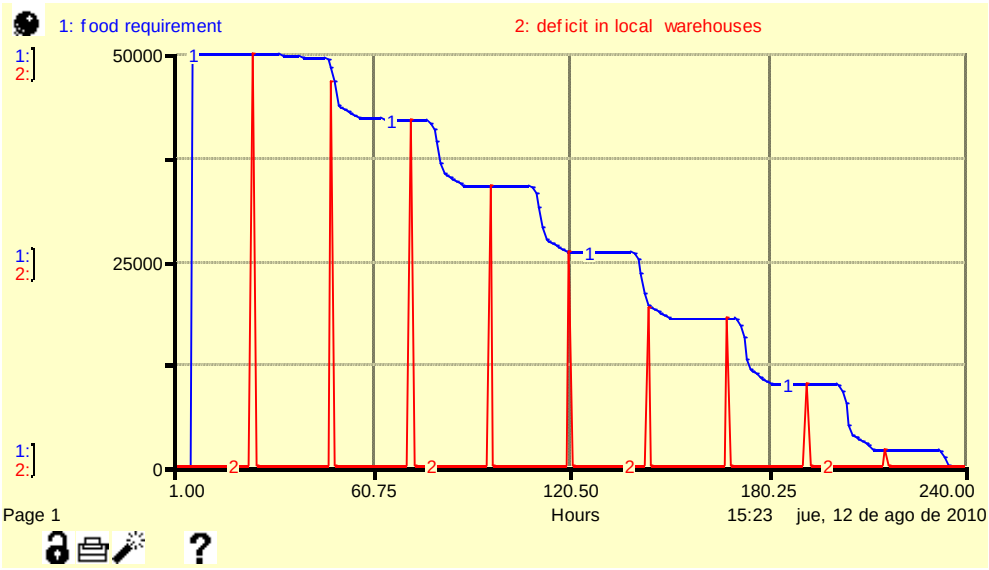


Graph 4C: Food in National Warehouse

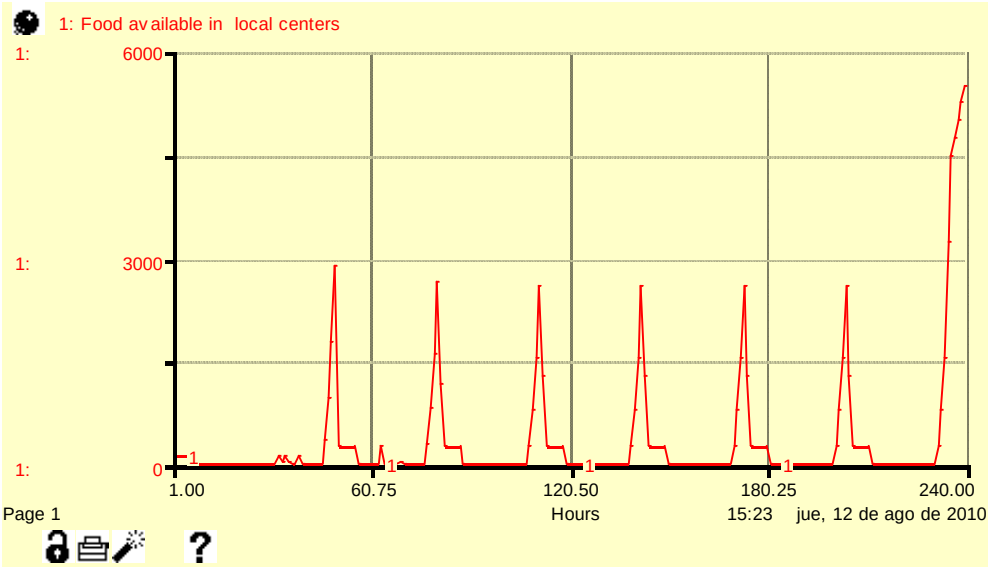
In this case, orders are made less often- every 120 hours. Therefore, less deliveries are also made, and this explains why there are less peaks in each of the graphs. Food requirements are reduced almost at the same time because donations are received at the same rate. Lot sizes would be bigger: Less orders are made but in larder quantities.

What would happen if the amount of donations is reduced?

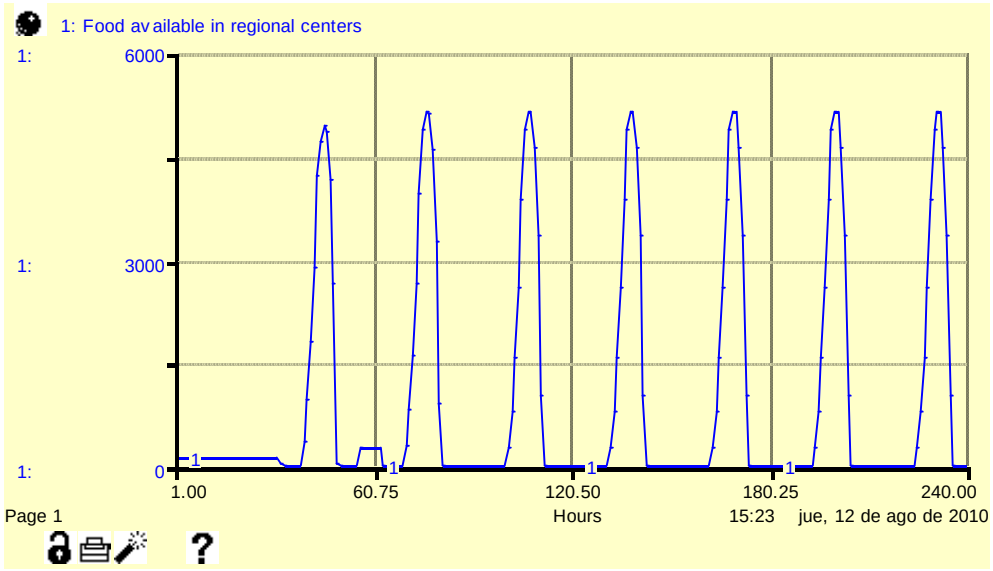
Variable	Value	Units
Donations received after call of aid	6000/24	food kits



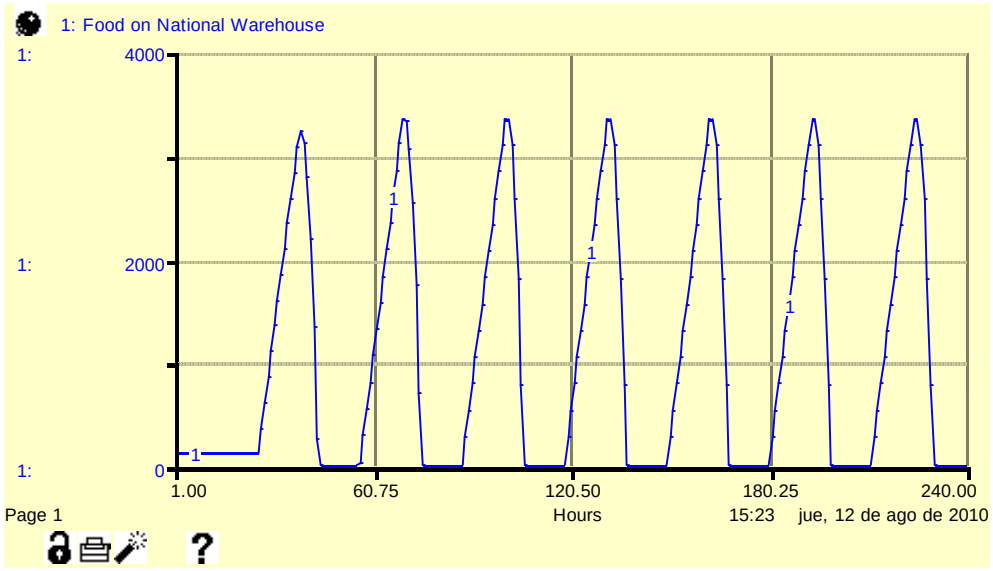
Graph 1D: Food requirements and deficit in local warehouses



Graph 2D: Food available in local centers



Graph 3D: Food available in regional centers



Graph 4D: Food available in National Warehouse

The graphs show that when the amount of donations given by the population is reduced, food requirements persist for a longer time (60 hours in the following example).Food in the warehouses follow the same behavior. The different peaks are given by the time between orders made by the local warehouses.

The structure analysis was made with the Colombian Red Cross, institution that supported our work and validated the obtained results with real life data. Data is treated as deterministic in the model, and therefore, the model does not take into account the variability of most data. Deecisions that are taken in the chain depend on population needs,

and therefore the vaues that are taken as exogenous, can change constanty. Nevertheless, the behavior of inventory through the different stages of the chain is correctly represented, and the understanding of the humanitarian supply chain in the Colombian case was achieved, which was one of the main goals of this work.

Conclusions

The correct management of the supply and the efficiency in each one of its stages is important not only to support the reconstruction efforts, but to allow a correct and pertinent assistance of the needy population.

Although all types of catastrophes are different and the conditions of the place where they occur determine the kind of assistance needed, they share some similarities related to the immediate effects that are originated. The particular case of chain that is analyzed in this paper represents the general behavior of a supply chain.

System dynamics was useful to model this situation because it shows the interactions that represent a complex system that was modeled using differential equations (stocks, flows and their respective delays).

The model results correspond to the behavior that was expected according to the relation of the actors, and the mobilization of the resources (i.e. arrivals, transportation, storage and delivery of necessary goods). However, some break points and inefficiencies that arise in each of the stages were identified (i.e. the distortion of the demand because of the information delay), as in the bullwhip effect.

Related concepts such as inventory, and its relation with infrastructure capacity were incorporated to approach the supply chain. Also, the behavior of the system changes when the assumptions presented were implemented (i.e. given the fact that the supply chain is directly related with an emergency, not necessarily a cost efficient perspective defines the assignment of resources).

According to the data and the information recollected, the model structure reflects the paper purpose; water and food are satisfied locally for a certain period of time, then donations are asked, and the humanitarian chain tries to satisfy water and food needs. Population needs are satisfied until there is no need to ask for donations, and local production is enough to supply the population.

For institutions like the Colombian Red Cross, the implementation of the supply chain in a model, and its respective results (variables, graphs, and break points) is really useful for the planning, of policies and actions towards the prevention and the correct performance of the supply chain in all kinds of disasters. Additionally it is important to remark the necessity to built the model together with the actor involved, in order to make the model more operational and similar to reality; on the other hand this involvement will help to built a common language towards the model so actors, as well as modelers can understand how are they actually working, and what would happen if they improve some of the critical variables of the process.

Annex 1: Initial values of the model

Variable	**Value**	**Units**
Initial food requirement	500	food kits
How often is deficit revised?	24	hours
Food available in local centers	100	food kits
Food available in regional centers	100	food kits
Food available in national centers	100	food kits
Food in national warehouse	100	food kits
% of aid delivered by the Red Cross	100%	adimensional
Extra % to ask to regional centers	10%	adimensional
Extra % to ask to national centers	10%	adimensional
Minimum lot size at regional center	5	food kits
Minimum lot size at strategic center	5	food kits
Minimum lot size at national warehouse	5	food kits
Percentage of loss in local centers	0,1%	Adimensional
Percentage of loss in regional centers	0,1%	Adimensional
Percentage of loss in strategic centers	0,1%	Adimensional
Percentage of loss in national warehouse	0,1%	Adimensional
Transport time from regional to local centers	12	Hours
Transport time from strategic to local centers	8	Hours
Transport time from regional to local centers	6	Hours
Transport time from national to regional centers	12	Hours

Is there a call for aid?	1	Binary
How much is purchased?	10	Hours
Donations received	1.6/24	food kits
Donations received after call of aid	10000/24	food kits
Time of purchasing in national center	24	Hours
Processing time in national center	24	Hours
Percentage of rejection in national center	10%	Adimensional
Food goes from strategical to regional or local centers?	1	Binary

Annex 2 : Equations of the model

ORDERS

food_requirement(t) = food_requirement(t - dt) + (new_food_requirements - food_requirements_are_reduced) * dt
INIT food_requirement = 0
INFLOWS:
- new_food_requirements = pulse(initial_food_requirement,5,10000)

OUTFLOWS:
- food_requirements_are_reduced = food_that_is_delivered

orders_in_national_center(t) = orders_in_national_center(t - dt) + (orders_received_by_National_Centers - served_orders_by_strategic_warehouses - served_orders_by_national_centers) * dt
INIT orders_in_national_center = 0
INFLOWS:
- orders_received_by_National_Centers = deficit_in_regional_warehouses*(1+extra_percentage_to_ask_to_national_centers)

OUTFLOWS:
- served_orders_by_strategic_warehouses = amount_that_can_be_sent_from_strategic_Centers-mod(amount_that_can_be_sent_from_strategic_Centers,minimum_lot_size_at_at_strategic_centers)
- served_orders_by_national_centers = amount_to_be_served_by_the_national_centers-mod(amount_to_be_served_by_the_national_centers,minimum_lot_size_at_national_warehouse)

orders_in_regional_centers(t) = orders_in_regional_centers(t - dt) + (orders_received_by_regional_centers - served_orders_by_regional_centers) * dt
INIT orders_in_regional_centers = 0
INFLOWS:
- orders_received_by_regional_centers = deficit_in_local__warehouses*(1+extra_percentage_to_ask_to_regional_centers)*percentage_of_aid_delivered_by_the_red_cross

OUTFLOWS:
- served_orders_by_regional_centers = amount_that_can_be_sent_from_Regional_Centers-mod(amount_that_can_be_sent_from_Regional_Centers,minimum_lot_size_at_regional_center)

- amount_that_can_be_sent_from_Regional_Centers = min(Food_available_in_regional_centers,orders_in_regional_centers)
- amount_that_can_be_sent_from_strategic_Centers = min(Food_available_in_strategic_centers,orders_in_national_center)
- amount_to_be_served_by_the_national_centers = if(gap_of_inventory_to_be_covered_by_national_warehouses>0)then(min(Food_on_National_Warehouse,gap_of_inventory_to_be_covered_by_national_warehouses))else(0)
- deficit_in_local__warehouses = if(mod(time,how_often_is_deficit_revised?)=0) then max(food_requirement-Food_available_in__local_centers,0) else (0)
- deficit_in_regional_warehouses = max(orders_received_by_regional_centers-Food_available_in_regional_centers,0)
- extra_percentage_to_ask_to_national_centers = 0.1
- extra_percentage_to_ask_to_regional_centers = 0.1
- gap_of_inventory_to_be_covered_by_national_warehouses = max(orders_in_national_center-Food_available_in_strategic_centers,0)
- how_often_is_deficit_revised? = 24
- initial_food_requirement = 50000
- minimum_lot_size_at_at_strategic_centers = 5
- minimum_lot_size_at_national_warehouse = 5
- minimum_lot_size_at_regional_center = 5
- percentage_of_aid_delivered_by_the_red_cross = 100/100

SUPPLY CHAIN

donations_to_be_eliminated_in_the_national_center(t) =
donations_to_be_eliminated_in_the_national_center(t - dt) +
(rejected_donations_in_the_national_center - donations_are_eliminated_in_the_national_center) * dt
INIT donations_to_be_eliminated_in_the_national_center = 0
INFLOWS:
- rejected_donations_in_the_national_center =
  Food_donations_in_process_in_national_center*percentage_of_rejection_in_the_national_center

OUTFLOWS:
- donations_are_eliminated_in_the_national_center =
  donations_to_be_eliminated_in_the_national_center/time_of_elimination_in_the_national_center

Food_available_in_regional_centers(t) = Food_available_in_regional_centers(t - dt) +
(food_arrives_from_the_national_to_the_regional_center +
food_arrives_from_the_strategic_to_the_regional_centers -
food_arrives_from_regional_to_local_centers - loss_in_regional_centers) * dt
INIT Food_available_in_regional_centers = 100
INFLOWS:
- food_arrives_from_the_national_to_the_regional_center =
  delay(served_orders_by_national_centers,transport_time_from_national_to_regional_centers)
- food_arrives_from_the_strategic_to_the_regional_centers =
  delay(served_orders_by_strategic_warehouses,transport_time_from_strategic_to_regional_centers,0)*food_goes_from_strategical_to_regional_1_or_local_centers_0?

OUTFLOWS:
- food_arrives_from_regional_to_local_centers =
  delay(served_orders_by_regional_centers,transport_time_from_regional_to_local_centers)
- loss_in_regional_centers =
  percentage_of_loss_in_regional_centers*Food_available_in_regional_centers

Food_available_in_strategic_centers(t) = Food_available_in_strategic_centers(t - dt) + (-
food_arrives_from_the_strategic_to_the_regional_centers - loss_in_strategic_centers -
food_arrives_from_the_strategic_to_the_local_centers) * dt
INIT Food_available_in_strategic_centers = 100
OUTFLOWS:
- food_arrives_from_the_strategic_to_the_regional_centers =
  delay(served_orders_by_strategic_warehouses,transport_time_from_strategic_to_regional_centers,0)*food_goes_from_strategical_to_regional_1_or_local_centers_0?
- loss_in_strategic_centers =
  Food_available_in_strategic_centers*percentage_of_loss_in_strategic_centers
- food_arrives_from_the_strategic_to_the_local_centers =
  delay(served_orders_by_strategic_warehouses,transport_time_from_strategical_to_local_centers,0)*food_goes_from_strategical_to_regional_1_or_local_centers_0?

Food_available_in__local_centers(t) = Food_available_in__local_centers(t - dt) + (food_arrives_from_regional_to_local_centers + food_arrives_from_the_strategic_to_the_local_centers - food_that_is_delivered - loss_in_local_centers) * dt

INIT Food_available_in__local_centers = 100

INFLOWS:

- food_arrives_from_regional_to_local_centers = delay(served_orders_by_regional_centers,transport_time_from_regional_to_local_centers)
- food_arrives_from_the_strategic_to_the_local_centers = delay(served_orders_by_strategic_warehouses,transport_time_from_strategical_to_local_centers,0)*food_goes_from_strategical_to_regional_1_or_local_centers_0?

OUTFLOWS:

- food_that_is_delivered = if(Food_available_in__local_centers>=food_requirement)then food_requirement else Food_available_in__local_centers
- loss_in_local_centers = Food_available_in__local_centers*percentage_of_loss_in_local_centers

Food_donations_in_process_in_national_center(t) = Food_donations_in_process_in_national_center(t - dt) + (donations_are_received_in_national_center - food_donations_are_processed - rejected_donations_in_the_national_center) * dt

INIT Food_donations_in_process_in_national_center = 0

INFLOWS:

- donations_are_received_in_national_center = if(is_there_a_call_for_aid>0) then donations_received_after_call_of_aid else 0+donations_received

OUTFLOWS:

- food_donations_are_processed = (delay(donations_are_received_in_national_center,processing_time_in_national_center,0))
- rejected_donations_in_the_national_center = Food_donations_in_process_in_national_center*percentage_of_rejection_in_the_national_center

food_in_process_to_be_purchased(t) = food_in_process_to_be_purchased(t - dt) + (new_arrivals_of_food_that_is_purchased - New_food_available_in_National_Center) * dt

INIT food_in_process_to_be_purchased = 0

INFLOWS:

- new_arrivals_of_food_that_is_purchased = if(orders_in_national_center>0) then how_much__is_purchased? else 0

OUTFLOWS:

- New_food_available_in_National_Center = delay(new_arrivals_of_food_that_is_purchased,time_of_purchasing_in_National_Center,0)

Food_on_National_Warehouse(t) = Food_on_National_Warehouse(t - dt) +
(food_donations_are_processed + New_food_available_in_National_Center -
food_arrives_from_the_national_to_the_regional_center - loss_in_national_warehpuse) * dt
INIT Food_on_National_Warehouse = 100
INFLOWS:
- food_donations_are_processed =
  (delay(donations_are_received_in_national_center,processing_time_in_national_center,0))
- New_food_available_in_National_Center =
  delay(new_arrivals_of_food_that_is_purchased,time_of_purchasing_in_National_Center,0)

OUTFLOWS:
- food_arrives_from_the_national_to_the_regional_center =
  delay(served_orders_by_national_centers,transport_time_from_national_to_regional_centers)
- loss_in_national_warehpuse =
  Food_on_National_Warehouse*percentage_of_loss_in_national_warehouse

- donations_received = (40/24)/25
- donations_received_after_call_of_aid = 10000/24
- food_goes_from_strategical_to_regional_1_or_local_centers_0? = 1
- how_much__is_purchased? = 10
- is_there_a_call_for_aid = 1
- percentage_of_loss_in_local_centers = 0.001
- percentage_of_loss_in_national_warehouse = 0.001
- percentage_of_loss_in_regional_centers = 0.001
- percentage_of_loss_in_strategic_centers = 0.001
- percentage_of_rejection_in_the_national_center = 0.1
- processing_time_in_national_center = 24
- time_of_elimination_in_the_national_center = 48
- time_of_purchasing_in_National_Center = 24
- transport_time_from_national_to_regional_centers = 12
- transport_time_from_regional_to_local_centers = 6
- transport_time_from_strategical_to_local_centers = 8
- transport_time_from_strategic_to_regional_centers = 12

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