Decentralization and Earmarked Funding in Humanitarian Logistics for Relief and Development

International Humanitarian Organizations (IHO) often implement relief and development programs simultaneously. With headquarters in Europe or USA and programs (operations) in developing countries, IHO are frequently decentralized. Moreover, IHO program delivery is funded by donors and funding is typically earmarked for specific programs increasing even more the decentralization levels. Using system dynamics methodology we study the IHO dual mission of relief and development in stochastic operations with different levels of earmarked funding. Focusing on metrics of equity and efficiency we find that earmarked funding and relief programs affect operations in counter-intuitive ways. First, our analysis focuses only on development programs. Second, we add relief operations to better understand the impact of the dual mission. Finally, we study the impact of earmarking. Due to the interaction of dual mission and earmarked funding, a system with local procurement and a short lead time may consistently take longer to supply transportation for disaster response (relief) than a system with global procurement and high lead time. Our results have important implications for humanitarian fleet management practice. Specifically, what organizational structure to adopt in different organizational environments.

Key words: Humanitarian Logistics, System Dynamics, Fleet Management

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1. Introduction

International Humanitarian Organizations (IHO) are non-profit organizations that provide relief and humanitarian assistance. With headquarters in Europe or USA and programs (operations) in developing countries, IHO are typically decentralized. However, existing humanitarian logistics literature has focused on analytical models assuming centrally planned humanitarian systems. In reality IHO often implement relief and development programs simultaneously. Nevertheless, this dual mission has been mostly ignored in previous research. Moreover, whereas IHO program delivery is funded by donors and funding is typically earmarked for specific programs, extant literature often assumes non-earmarked funding. Based on case studies from actual humanitarian operations (Pedraza-Martinez et al 2011), we study the IHO dual mission of relief and development in decentralized, stochastic operations with different levels of earmarked funding. Focusing on equity and efficiency metrics, we find that decentralization and earmarked funding affect operations in counter-intuitive ways. Due to the interaction of these characteristics, a system characterized by local procurement and a short lead time may take consistently longer to supply transportation for disaster response (relief) than a system with global procurement and high lead time. This effect persists even assuming an infinite local sourcing capacity.

Our study builds on the growing body of humanitarian logistics literature on transportation and vehicle fleet management (henceforth referred to as fleet management). Transportation is not only critical to distribution in humanitarian operations, it is also costly (Disparte 2007). Based on detailed field work on the International Committee of the Red Cross (ICRC), International Federation of Red Cross and Red Crescent Societies (IFRC), World Food Programme (WFP) and World Vision International (WVI) Pedraza-Martinez et al (2011) found that vehicle fleet management in humanitarian logistics serves the dual mission of relief and development, each involving different levels of earmarked funding.

In IHO fleet management for relief operations usually focuses on equity. Based on field information, the duration of relief programs is short: three to four months at most and the first weeks of response are critical to successful operations. To reach the affected population as fast as possible, fleet management for relief aims to minimize the time of response as well as to maximize stochastic demand fulfillment. A fast response usually means additional costs (Pedraza-Martinez et al 2011). In sum, fleet management for relief is characterized by short duration, high urgency, highly stochastic demand and short response times (Pedraza-Martinez et al 2010).

In IHO fleet management for development usually focuses on cost efficiency. In all the IHO encountered in the cases (Pedraza-Martinez et al 2011) the duration of development programs typically ranges from one year to more than 10 years, with annual performance evaluations. Given that development programs often have budget constraints, reducing cost enables IHO to enhance demand fulfilment. However, cost savings typically imply longer response times (Pedraza-Martinez et al 2011). In sum, fleet management for development is characterized by long duration, low urgency, low demand stochasticity and long response times compared to relief operations (Pedraza-Martinez et al 2010).

The three different fleet management models, based on different levels of decentralization, that we model in this paper are the models that ICRC, IFRC, WFP and WVI operate. Previous research has described these models and named them after vehicle procurement: centralized, decentralized, and hybrid. The alternatives that we model in this paper were encountered in at least one of the above organizations. Specifically, ICRC operates like the centralized model. In the centralized model vehicle procurement is globally managed by a fleet management unit (FMU). Located at the headquarters level, the FMU compiles vehicle requisitions from development programs in the different operating countries. The FMU procures directly from vehicle manufacturers once or twice per year. This allows the centralized model to benefit from volume discounts. However, the lead time for vehicle delivery to programs is several months. Development programs reimburse the FMU for vehicle depreciation in the form of a monthly fee over five years using an internal vehicle rental program (Pedraza-Martinez and Van Wassenhove 2010). When a relief program is implemented, the centralized model can deploy spare capacity from the development programs or from neighboring countries to the disaster area. It also has an emergency stock strategically located for relatively fast deployment. Local vehicle rental for relief is allowed.

WVI operates like the decentralized model. In the decentralized model vehicles are procured directly by programs either from regional or local dealers. Based on real data that arose from field work the average purchasing cost can be more than 50% higher than for the centralized model, but the lead time for vehicle delivery to programs is measured in weeks (Pedraza-Martinez et al 2011). When a relief program is implemented, the decentralized model can bring into the disaster area vehicles from the development programs as well as vehicles purchased locally or regionally. Local rental for relief is allowed.

IFRC and WFP operate like the hybrid model. The hybrid model combines global and local procurement. Based on real data, approximately 80% of the fleet is procured following the centralized model procurement strategy, while local procurement accounts for the other 20%. The fleet is operated following an internal vehicle rental program similar to the centralized model. To respond to disasters, the hybrid model can bring in the area of the disaster vehicles from the development programs or from neighboring countries. It also has an emergency stock strategically located for relatively fast deployment and can procure or rent vehicles locally.

For each of the three fleet management models the level of earmarked program funding will differ. Earmarked funding - donations that are to be used for a specific program - constrains internal budget allocation and/or the mobility of assets between programs. Based on real information, the centralized model involves partial earmarked funding to the program. Vehicle procurement is considered an overhead cost and it is funded by the IHO general budget. Program services are considered direct costs and are funded by donors (Pedraza-Martinez et al 2010). Budget reallocation between headquarters and programs is constrained. Nevertheless, programs reimburse headquarters for vehicle depreciation using an internal vehicle rental program.

In contrast, in the decentralized model the same donor funds transportation and program services, but different donors fund different programs. In reality, transferring assets between programs funded by different donors is either not allowed or will require the IHO to negotiate with the donors. In the hybrid model, funding depends on the party procuring the vehicle. Note that different donors fund different programs independently of the fleet management model used by the IHO.

In comparing these three fleet management models in terms of equity and efficiency for relief and development, it is important to stress that we model relatively small to medium scale cyclical disasters such as floods and low-impact hurricanes. Our model has not been created to explain the behavior of the system in response to disasters which are exceptionally devastating such as the Asian tsunami or the Haiti earthquake. Most of the previous research focuses on devastating disasters that receive extensive media coverage. Actually, devastating disasters are not representative of most disasters. According to the international disaster database (em-dat) every year 400 disasters occur on average, but many of them do not receive media attention. For example, IFRC is currently involved in 60 local disasters in Africa alone (Olsen, 19 October 2011). The representative, local-less-mediatized disasters that still need vehicles have not been researched extensively.

From a starting point of implementing relief programs, most IHO made the transition to focusing mainly on development programs. However in recent years IHO have once again been evolving to focus on relief programs. This change of focus resulted in a change in the IHO objectives (Jennings 2002). But even if there is a shift in their program focus, most IHO do not change their fleet management structure. Pedraza-Martinez et al. (2011) found in their empirical research that the organizational structure of the fleet management and the performance of the IHO are related. In this paper we study the impact of this real-world change of focus on the performance of the IHO. Our results also show that the dual objective of relief and development poses structural challenges to IHO that make apparent the need for flexibility in procurement and funding strategies. Therefore any strategic decision to implement more (less) relief programs in the future should determine the fleet management model that the IHO should implement. Hence, changes in balance of relief and development should lead IHO to reconsider their organizational structure. Our paper can help IHO to model their operations in order to choose the structure that would maximize their performance.

To sum up, in this paper we compare the real-world fleet management structures that IHO operate for development programs in terms of equity and efficiency. Then, using real information and data encountered in different IHO, we add the relief operations to see how the dual mission of relief and development affects equity and efficiency. Finally, the effect of earmarked funding on fleet management for relief and development is studied.

2. Literature Review

The disaster management lifecycle is composed of preparedness, response, rehabilitation and mitigation (Carter 1991, Norman 2003, Tomasini and Van Wassenhove 2009). Relief programs carry out activities related to disaster preparedness and disaster response, i.e. they focus on improved reaction to crises. Development programs carry out activities of rehabilitation and mitigation, i.e. they focus on building local capacity and resilience. IHO simultaneously implement relief and development programs. From a combined expenditure of US$4.4 billions by ICRC, IFRC, WFP and WVI in 2009, 48% was used in relief and 52% was used in development programs (ICRC 2009, IFRC 2009, WFP 2009, WVI 2009). Relief programs are characterized by high urgency, high uncertainty and short duration, while development programs are characterized by low urgency, low uncertainty and long duration. Not surprisingly, as seen in reality setting up logistics systems to simultaneously respond to IHO's dual mission of relief and development is operationally challenging.

Nevertheless, existing research in humanitarian logistics often studies relief and development in isolation. Previous work has focused on mathematical and simulation models for relief logistics. Demand uncertainty in disaster response has been widely studied (Barbarosoglu and Arda 2004, Balcik et al 2008, Regnier 2008, Salmeron and Apte 2010). Trade-offs between equity and efficiency in disaster response have also received attention (Tzeng et al 2007, Campbell et al 2008, Beamon and Balcik 2008). The literature typically assumes that relief programs are created exclusively to respond to disasters but does not consider their integration with existing development programs.

Logistics for development has received less attention from researchers. De Treville et al (2006) use queuing models to study the problem of lead times in the distribution of tuberculosis medicine by the World Health Organization. They find that lead time can be significantly reduced by introducing basic queuing principles. Pedraza-Martinez et al (2010) use heavy traffic models to analyze fleet management systems in development operations. They conclude that operational capacity-based mechanisms provide incentives to coordinate decentralized fleet management systems. For analytical tractability, the effects of possible disasters in the supply chain are excluded from their analysis.

The interaction of relief and development programs faced by IHO has not been analytically studied by the humanitarian logistics literature, hence it is not clear how equity and efficiency trade-offs should be managed in the dual mission of relief and development. To the best of our knowledge ours is the first attempt to analyze the entire relief/development system in the humanitarian logistics field.

While humanitarian operations are often decentralized (Van Wassenhove 2006), the literature typically assumes a central planning perspective (Campbell et al 2008, Regnier 2008). Recent studies have shown that the decentralized structure of IHO combined with earmarked funding structures create incentive misalignments in humanitarian logistics (Pedraza-Martinez and Van Wassenhove 2010, Pedraza-Martinez et al 2010). These misalignments challenge the results of optimization models based on central planner assumptions. By introducing relief and development objectives, our research contributes to a better understanding of decentralized humanitarian logistics.

Research in the humanitarian domain has for the most part been built on generated data. Optimization models on relief typically use generated data to calibrate their parameters. Some exceptions are De Treville et al (2006), De Angelis et al (2007) and Pedraza-Martinez et al (2010). In a relatively new area like humanitarian logistics, the use of generated data without sufficient investigation of possible parameter values may yield erroneous conclusions which are then used to inform practice. Our evidence-based system dynamics model has been built using data from previous research based on real humanitarian operations. The fleet management descriptions by Pedraza-Martinez et al (2011) and Stapleton et al (2009) provide the qualitative basis for our research. The values of quantitative parameters have been obtained from Pedraza-Martinez and Van Wassenhove's (2010) study on vehicle replacement in humanitarian operations.

In summary, our contribution to the humanitarian logistics literature is threefold. First, we take into account the realistic but not sufficiently studied decentralized setting of humanitarian operations by incorporating the three different fleet management structures that IHO operate. Second, this is the first study to analyze the dual mission of relief and development implemented by IHO. Third, we incorporate earmarked funding, a distinguishing characteristic of humanitarian operations, obtaining new insights into unexplored aspects of humanitarian logistics.

This research requires a methodology appropriate to model both the short-term effects of the relief programs and the long-term effects of the development programs. Due to the decentralized structure of the fleet management models, the methodology should also be appropriate to study dynamic complex systems with multiple feedbacks. As indicated above, existing optimization modeling of humanitarian logistics study relief and development in isolation, ignoring the multiple feedbacks that the dual mission creates by having to split resources. Additionally, it ignores the time delays induced by different decisions. Optimization models are highly stylized representations of problems that achieve robust results while sacrificing contextual information. Considering that the system under study has been extensively described and that we are still gaining insights into the characteristics of humanitarian fleet management, we chose a methodology that allows us to achieve insights into the behavior of the system rather than precise solutions to the sub-problems that may crop up, i.e. the system dynamics methodology (Forrester 1961).

By using the system dynamics approach, we integrate the characteristics of operations research models with the advantages of control theory and simulation disciplines into a real world humanitarian system. Sterman (1991) suggests that, "*If the system to be optimized is relatively static and free of feedback, optimization may be the best technique to use*". However, supply chains rarely satisfy the latter conditions (Georgiadis et al 2005) and most humanitarian supply chains certainly do not. System dynamics also provides an understanding of changes occurring within an environment, focusing on the interaction between physical flows, information flows, delays and policies that create the dynamics and thereafter searches for policies to improve system performance. It is used to model short-term effects (simulation timestep) and long-term effects (simulation horizon). Its suitability for capturing the dynamic behavior of complex systems full of feedbacks, where both the short-term and long-term effects are important, renders this methodology an appropriate tool for our study. System dynamics has been applied to various business policy and strategy problems (Forrester 1961, Coyle 1996, Sterman 2000). A handful of publications have used system dynamics in supply chain modeling, but most refer to commercial supply chains. Hafeez et al. (1996) describe the analysis and modeling of a two-echelon industry supply chain in the construction industry. Minegishi and Thiel (2000) use system dynamics to improve the knowledge of the complex logistic behavior of an integrated food industry.

Gonçalves (2008) was the first to use system dynamics for humanitarian operations. His model focuses on relief operations. Specifically, he studies decision making of IHO that use resources both to respond to emergency situations and to build capacity. He finds that allocating more resources to relief operations than to capacity-building reduces the long-term efficiency of the IHO. He also suggests that the feedbacks and delays from the SD methodology are consistent with IHO characteristics. Some examples are the tradeoffs between subsystems (programs) and the broader system (IHO), and those between short-term (relief) and long-term (development) decisions. Besiou et al (2011) present the initial stages of two system dynamics models. The first model analyzes a well-defined subsystem of humanitarian operations; field vehicle fleet management. The second model studies the impact of media on unsolicited donations for a specific disaster. This research illustrates that system dynamics has the capacity to accurately represent the dynamic complexity of humanitarian fleet management.

As shown in the next section, the system under study is dynamic, complex and exhibits multiple feedbacks. These characteristics, in addition to the suitability of system dynamics for capturing both the short-term and long-term effects of the decision-making, influenced our choice of methodology. Our confidence in this methodological approach also comes from the fact that it has been successfully used to analyze supply chains in the past.

3. System Under Study

We study field vehicle fleet management in humanitarian logistics. Field vehicles are used to coordinate and execute last mile distribution in humanitarian programs (Pedraza-Martinez et al 2011). As mentioned previously, the system is operated by three different fleet management models used by ICRC, IFRC, WFP and WVI with different decentralization levels: centralized, decentralized and hybrid. We compare the behavior of these three different models using information and data encountered in the case studies of the above IHO. Then we provide a succinct description of the system and models examined. A comprehensive description of these models can be found in Pedraza-Martinez et al (2011).

3.1. Centralized model

ICRC operates like the centralized model. Based at headquarters, the FMU makes strategic decisions regarding fleet management in a centralized way. Such decisions include the vehicle replacement policy, fleet size and emergency stock for relief. Operational decisions regarding vehicle use are made independently at the program level. In the case of development programs, national offices appeal for donations if their vehicle needs surpass their current national inventory (fleet size) of vehicles (Figure 1). Such donations are used to rent vehicles internally from the FMU. Development programs estimate their transportation needs based on previous demand records (Pedraza-Martinez et al 2010).

The national inventory is used to satisfy the program needs. Vehicle requisitions are compiled annually by the FMU at headquarters based on reported needs from the programs. The FMU procures vehicles directly from manufacturers in Japan. We refer to 4x4 vehicles used to coordinate and execute last mile distribution. Examples of these vehicles are Toyota Land Cruiser, the dominant vehicle model in the humanitarian sector, and Nissan Patrol, the second most used brand.

The centralized model′s purchasing cost is the lowest of the three models as it benefits from volume discounts and discount agreements with the manufacturer. However, lead times for vehicle delivery are the longest of the three models as shown in Table 1, which is based on real data obtained through detailed field work from the ICRC, IFRC, WFP and WVI (Pedraza-Martinez et al. 2011). Hence these numbers represent real orders of magnitude and not just random generated numbers.

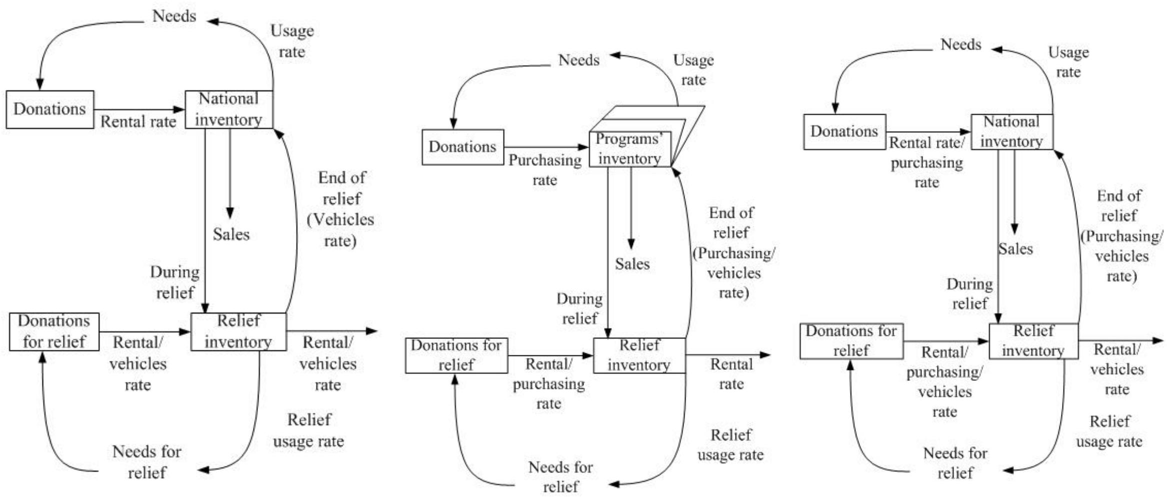
Variable	Centralized	Hybrid	Decentralized
Average purchasing cost	1	1.25	2
Average lead time (Weeks)	26	21.6	4
Earmarked vehicle funding	Partial	Partial	Total
Earmarked vehicle use	No	No	Yes

Table 1 **Procurement costs and lead times for the three models**

Vehicles are part of the operational overhead cost and are procured using the headquarters budget. After being received and equipped in regional warehouses, they are sent to the countries of operation. The national offices pay a monthly fee to headquarters for vehicle depreciation over five years (taken from the study of Pedraza-Martinez et al. 2011). Thereafter, national offices are supposed to sell the vehicles in the local market and the salvage value is transferred to headquarters. Hence, national offices have an incentive to delay vehicle replacement (Pedraza-Martinez and Van Wassenhove 2010). National offices cover the running cost of the vehicles, while programs are the final users of the fleet. Vehicles are not earmarked for specific programs. Due to the fact that programs do not own the vehicles, the national office can determine fleet allocation based on priorities at the country level.

In the case of relief programs, the IHO appeals for additional donations. The centralized model in reality satisfies its field vehicle needs by a) reallocating vehicles from excess national inventory, b) reallocating vehicles from the neighboring countries, c) reallocating vehicles from the regional warehouse stock, d) renting vehicles locally. Each alternative scenario bears a specific cost and time delay, and has a limited capacity. After the disaster, the vehicles that were reallocated are returned to the source of supply, while those that were rented are returned to the rental agencies (Besiou et al 2011).

When calculating the donations required, the FMU has to consider future vehicle needs. It must also consider the field vehicles that are already in use to meet the needs of their development programs as well as those that will be brought into the national inventory at the end of the relief programs. Following the logic of the disaster management life cycle, when a relief program ends a new development program will begin. Tracking these changes for decision-making purposes over a long-term time horizon is too complex for



(a) Centralized model (b) Decentralized model (c) Hybrid model

Figure 1 Models in humanitarian fleet management

the human mind due to the multiple feedback loops and time delays. However, it can be achieved using the system dynamics model. Figure 1a presents the simplified structure of the centralized model.

Figure 2 presents the causal-loop diagram of the real model, where we identify 16 feedback loops (12 balancing loops and 4 reinforcing loops). In system dynamics, causal-loop diagrams are used to describe the system's feedbacks (Sterman 2000). The arrows in Figure 2 represent the relations between variables. The direction of the influence lines is the direction of the effect. The sign (+) or (-) at the upper end of the influence lines shows the sign of the effect. When the sign is (+), the variables change in the same direction, reinforcing the reaction; otherwise they change in the opposite direction, balancing the reaction. If an initial increase (or decrease) of a variable in a feedback loop ultimately results in an effect on the same variable in the same direction, then the feedback loop is identified as a reinforcing (positive) feedback loop. If an initial increase (or decrease) of a variable ultimately results in an effect on the same variable in the opposite direction, then the feedback loop is identified as a balancing (negative) feedback loop.

The operations for development programs begin from the upper right corner of Figure 2. The needs for development programs ("Needs for Dev" in Figure 2) are aggregated and are satisfied when the programs start using the vehicles. The greater the future needs, the greater the appeals for donations made by the IHO. The national offices use these donations to rent vehicles from headquarters. These form the national inventory and are used to satisfy the needs of beneficiaries. Programs can use more vehicles subject to availability in the national inventory (balancing loop B1). The more vehicles used, the lower the fleet backlog for development programs (balancing loop B2). Vehicles reach the end of their lifecycle at the replacement time (balancing loop B3), and are then retired and sold (balancing loop B4). Relief programs are implemented to respond to disasters. The relationship between the variables in relief programs can be derived from Figure 2 in the same way as for the development programs. At the end of the relief operations, vehicles are returned to sources and can be used in the event of new relief operations (reinforcing loops R1, R2 and R3) or development operations (reinforcing loop R4).

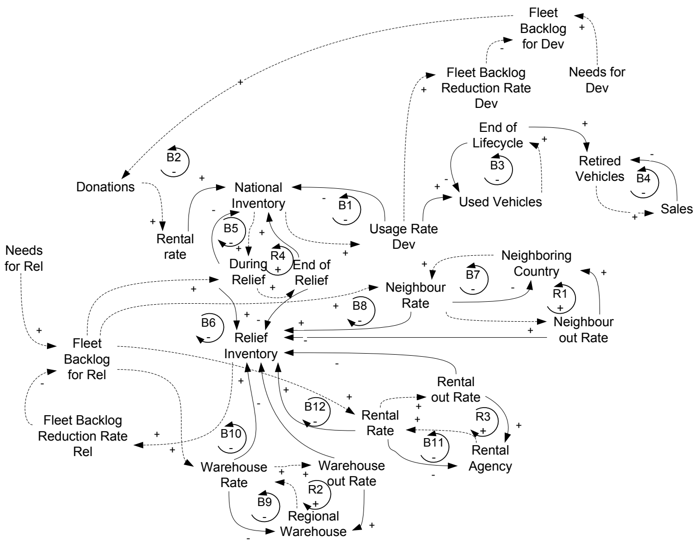


Figure 2 Feedbacks of the centralized model

3.2. Decentralized model

WVI operates like the decentralized model. In the decentralized model there is no global FMU and decisions regarding vehicle management and use are made independently at the program level. Programs procure vehicles independently either from regional dealers serving several countries or from local dealers. Based on discussions with humanitarian fleet managers we assume that 67% of the vehicles are procured regionally and the remaining 33% are procured locally. These proportions may change from IHO to another. The purchasing cost is higher than the centralized model but lead times for vehicle delivery are shorter, subject to available sourcing capacity in local and regional markets (Pedraza-Martinez et al 2011).

Vehicle use is earmarked to programs. Often, different donors fund different programs. In reality, due to the fact that programs are the owners of their vehicles and face donor constraints in terms of vehicle use, transferring vehicles between programs is not a common practice. Hence in the case of development programs donations are used to satisfy the vehicle needs of each program.

Programs purchase vehicles on an ad-hoc basis. At the end of the program the vehicles are sold in the local market and the salvage value is transferred to national offices. The recommended vehicle replacement policy is five years or 150,000 km, whichever comes first. We assume that programs do not accept donations of used vehicles, hence all vehicles entering the national inventory are new. This is a realistic assumption for large IHO; small/local humanitarian organizations often accept donations of used vehicles. While accepting donations of used vehicles is very common and may be cheaper for some IHO, it actually increases fuel consumption and maintenance costs as well as the frequency of accidents due to the lack of knowledge of maintenance history (Pedraza-Martinez et al. 2011).

In the case of relief programs, making additional appeals for donations aims to satisfy needs. The decentralized model satisfies its fleet needs by a) reallocating vehicles from excess program inventory, b) purchasing vehicles locally, c) purchasing vehicles regionally and d) renting vehicles locally. Again, each alternative scenario bears a specific cost, time delay and is of limited capacity. When the relief program ends, the purchased vehicles can be used for the development program supported by the donor that offered the donation (earmarked funding). Vehicles that have been brought from development programs are returned, while rental vehicles are returned to the rental agencies (Besiou et al 2011). Figure 1b presents the simplified structure of the decentralized model.

3.3. Hybrid model

IFRC and WFP operate like the hybrid model. In the hybrid model decisions regarding global fleet management are made centrally by an autonomous FMU in cooperation with the national level. Decisions regarding vehicle usage are made independently at program level (Pedraza-Martinez et al 2011). Typically 80% of vehicles are procured directly from manufacturers and 20% locally as described in the study of Stapleton et al (2009). The average purchasing cost as well as the average lead time for vehicle delivery lie in between the centralized and decentralized models. The national offices pay a monthly fee to headquarters for vehicle depreciation during a period of five years (Pedraza-Martinez et al. 2011), after which they are supposed to sell these vehicles in the local market and transfer the salvage value to headquarters. The national offices retain the salvage value of any vehicles purchased locally. They also pay the running cost of the vehicles, while programs are the final users of the fleet.

Since in reality vehicle ownership is not earmarked to programs, vehicles can be reallocated at the local level without facing donor constraints. So in case of relief programs, vehicle needs are satisfied by making appeals for donations for relief. The hybrid model satisfies its vehicle needs by a) reallocating vehicles from excess national inventory, b) reallocating vehicles from neighboring countries, c) purchasing vehicles locally, d) reallocating vehicles from the regional warehouse stock, and e) renting vehicles locally. Again, each alternative scenario bears a specific cost, time delay, and is of limited capacity. In the aftermath of the relief program, in a real-world case field vehicles that were reallocated are returned to the source of supply, purchased vehicles can be used to satisfy the needs of the development programs, and rental vehicles are returned to the rental agencies.

3.4. System setting

In this paper "equity" refers to the service level (fleet size is used as the unit of measurement of service level in order to show how many vehicles are in excess or are lacking to serve the needs of beneficiaries during the whole simulation period) (Stapleton et al 2009, Pedraza-Martinez et al 2010). This approach to the service level arose through discussions with IHO that aim to help a specific number of people within a specific number of weeks, like the internal monitoring system in IFRC. This way the IHO measures the number of people that do not receive aid, for example medical kits, on time. "Efficiency" refers to total cost (the unit of measurement of total cost is the Swiss franc-CHF) (Salmeron and Apte 2010). The trade-off between these two metrics is apparent: the greater the fleet size, the higher the service level and the higher the total cost of the system. We compare the metrics of equity and efficiency for centralized, decentralized and hybrid models in a single country setting.

The country of operation is connected to two neighboring countries that may have spare fleet capacity that can be transferred if required. We assume an initial population of 490,000 people in need. We capture the uncertainty of demand for development by using a uniform distribution with parameters between 444,500 and 535,500 people in need, which are its minimum and maximum values. We assume that one vehicle is required to serve 7,000 beneficiaries. These numbers are based on actual population ratios in the Zambezia Province served by World Vision Mozambique in 2008. Nevertheless, we are aware that the ratio of vehicles per beneficiary can vary greatly depending on the nature of the program. For instance, one vehicle may be needed to visit a village with 20,000 people if the visit is related to a water and sanitation program, whereas a health-care provision program in the same village may require a significantly greater number of vehicles to serve the same number of beneficiaries. Assuming the same number of vehicles per beneficiary for the three models allows us to compare results.

We assume relatively small to medium-scale cyclical disasters in the country every two years. Examples of the type of disasters we study are floods and low-impact hurricanes. We capture the uncertainty of demand for relief by using a uniform distribution with parameters between 49,000 and 147,000 people in need. Hence, in our base case, the workload of relief/development (that is ratio of the number of people in need of relief programs to the number of people in need of development programs) is equal to 20%. In our sensitivity analysis we change this ratio from 0% to 100% in steps of 10%.

As indicated, based on the disaster lifecycle literature we assume that each disaster leads to the creation of a relief program. Each relief program lasts four months and is followed by a development program that will last for a determined number of years. To study the impact of the program duration we test alternative values from 1 to 14 years with time steps of 1 year.

To satisfy the needs of people, in reality the centralized and hybrid models for development programs procure vehicles once per year every year. The decentralized model does not procure vehicles so often. Specifically, if the duration of the development program is less than or equal to five years, then the decentralized model procures vehicles only at the beginning of the program. If the duration of the development program is more than five years, for the first five years it procures vehicles at the beginning of the program and then annually. Funding allocation in the decentralized model corresponds to the description of Pedraza-Martinez et al (2011).

For relief programs, the centralized and hybrid models do not have earmarked vehicle use. In contrast, the use of vehicles in the decentralized model is earmarked per geographical area. We assume that the development programs in the decentralized model are funded by five donors each funding 20% of the territory (Figure 3). For the relief operations the wealthiest donor can fund up to 50% of the needs immediately, the second 20%, the third 15%, the fourth 10% and the smallest 5%. The probability of the emergency occurring in any of these five areas is 20%. We assume that geographical regions are independent. Following Pedraza-Martinez et al (2011) and based on our field experience, there are two constraints in this model in case of relief: a) at most 40% of excess program inventory can be transferred between regions, and b) the transfer takes three weeks. These two constraints are critical to our model and are intended to capture the effect of earmarked vehicle use on fleet management. As will be seen in section 4, earmarked vehicle funding has an important effect on fleet management. We study this further in section 4.3 by changing the distribution of donors.

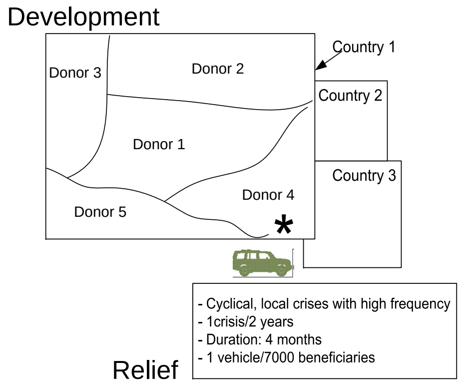


Figure 3 **System setting**

3.5. Data

We use qualitative and quantitative data. Qualitative system descriptions by Pedraza-Martinez et al (2011) and Stapleton et al (2009) are the foundation of the system dynamics model.

We use quantitative data on vehicle use (salvage value, operating, maintenance and miscellaneous cost per vehicle) available in Pedraza-Martinez and Van Wassenhove (2010) and in Stapleton et al (2009). Vehicle purchasing costs, maintenance costs, and salvage values are obtained from the papers. The appendix presents the values and sources of quantitative data used in the study.

4. Model Validation and Results

The next step is to build the system dynamics model. The information presented in section 3 is translated into a system of differential equations, solved via simulation. We used the software package Powersim. The equations of the model are provided as supplementary material.

4.1. Tests of Structural Validity

We checked the model's structural validity by conducting tests of dimensional consistency, extreme conditions, integrated errors, and replication of previous results (Sterman 2000). First, we tested the dimensional consistency. Specifically, we checked all the variables of the model and the equations that they form to test their dimensions and units of measurement.

Second, we conducted extreme-condition tests to check if the model behaves realistically even under extreme policies. For instance, we checked that if there are no donations or no needs, then there is no vehicle procurement. If there is no need for relief, then vehicles are procured only for development programs. If a specific source has no capacity, then no vehicles can be reallocated/procured from it.

Third, we conducted integration error tests. In our model we used the *Euler* numeric method instead of the integration method *Runge-Kutta*. According to the literature, *Runge-Kutta* should be avoided in models with stochastic disturbances (Sterman 2000). We chose a simulation horizon of 152 years to study the behavior of the system for more than one development program (the duration of one development program can be up to 14 years so we wanted to study also the transition of one to the next). Standard practice in system dynamics suggests that the integrating time step should be a maximum of one quarter of the shortest time constant in the model. Therefore we set the time step initially at one week, since the model's shortest time constant is set to one month. Then we cut the time step in half and ran the model again. The results were robust to changes in the time step.

Fourth, we tested the ability of the model to replicate previous results. We reproduced results reported by Pedraza-Martinez and Van Wassenhove's (2010) study of vehicle replacement in the ICRC. They use a deterministic dynamic programming model to calculate the optimal vehicle replacement policy in order to minimize total cost. The total cost is calculated using the procurement cost of the vehicles, their operating, maintenance and miscellaneous costs, and their salvage value. They find that it is optimal for the ICRC to replace vehicles every 100,000 km or its equivalent in age. The problem analyzed by these authors is equivalent to our centralized model for development with deterministic demand. In our model we assume that the average mileage per year per vehicle is 20,000 km. We obtained the optimal replacement age of 100,000 km or five years (Figure 4). This result is consistent with that of Pedraza-Martinez and Van Wassenhove (2010) in the total cost curve of headquarters.

We replicated an additional result by Pedraza-Martinez and Van Wasenhove (2010). In their paper on vehicle replacement, the authors show an incentive alignment problem caused by what we call "partial earmarked funding". According to Pedraza-Martinez and Van Wassenhove (2010), ICRC national offices do not follow the vehicle replacement policy recommended by headquarters. Instead of replacing every five years as prescribed by headquarters, national offices replace on average every seven or eight years depending on the country. This is explained by two facts. First, national offices pay the full depreciation of the vehicles

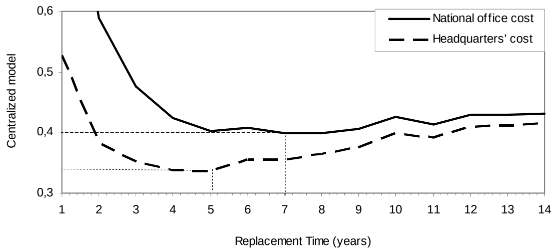


Figure 4 Replication of results obtained by Pedraza-Martinez and Van Wassenhove (2010)

during a period of five years only, i.e. they do not have to pay for vehicle use during the sixth and later years of vehicle life. Second, they are responsible for selling the vehicles in the local market at the end of the life cycle but they have to give the salvage value back to headquarters (FMU). Therefore, the cost of capital for national offices is greater than that for headquarters. In consequence, national offices keep the vehicles longer than prescribed to benefit from a reduction in the cost of capital per vehicle. We are able to replicate this incentive misalignment with our model (Figure 4). For headquarters, which receive the salvage value (headquarters' cost curve), the optimal replacement age is five years, whereas for national offices that incur a higher cost of capital the optimal replacement age is seven years (national office cost curve).

In this subsection we have performed a number of tests to validate the model. First, we tested the system dynamics model's dimensional consistency. Second, we conducted extreme-conditions tests. Third, we conducted integration errors tests. Fourth, we reproduced the behavior and results reported in previous research. These tests give us confidence that our model captures the main features of the system under study.

The results are presented in two subsections. First, we show the results for development only. Second, we compare these results with the ones obtained for the development and relief model, and offer theoretical explanations for the differences.

4.2. Fleet Management System for Development Programs Only

We start by modeling a development setting and compare the three fleet management models. As expected, the centralized model has the lowest total cost of the three models due to the low purchasing cost following the central procurement strategy (Figure 5a). The values are normalized using as a reference the highest value, which in this case is the total cost of the decentralized model that follows a local procurement strategy. The hybrid model lies in between, given that 80% of procurement is centralized and 20% is decentralized.

Mission	**Model**		
	Centralized	**Hybrid**	**Decentralized**
Development	0.965	0.995	1
Development and relief	0.882	0.994	0.855

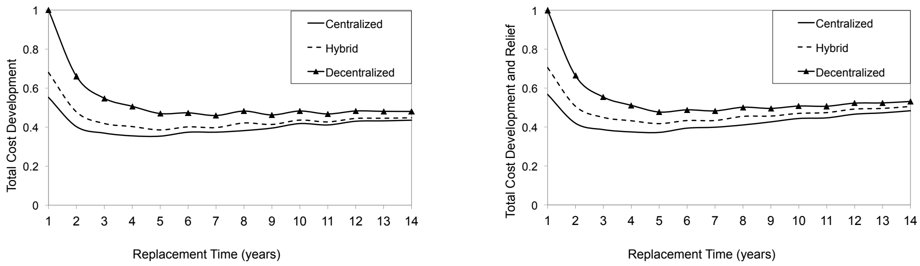
Table 2 Normalized Equity: Development vs. Development and Relief System

All the models have high service levels (Table 2). The decentralized model has the highest service level because of the lowest purchasing lead time. The centralized model may have the lowest total cost but has also the lowest service level because of the highest purchasing time, while the service level of the hybrid model is in between. By estimating the cost per served beneficiary, i.e. the total cost divided by the number of beneficiaries actually served, we obtained the same qualitative results as for the total cost (Figure 6a). However, the curves of the centralized and the hybrid models are a little closer due to the small difference in service levels.

Although not included here, we also simulated our model using exponential and normal distributions to represent demand. We obtained the same system qualitative behavior for the total cost and the service level as for the uniform distribution. Our results were robust to different demand distributions.

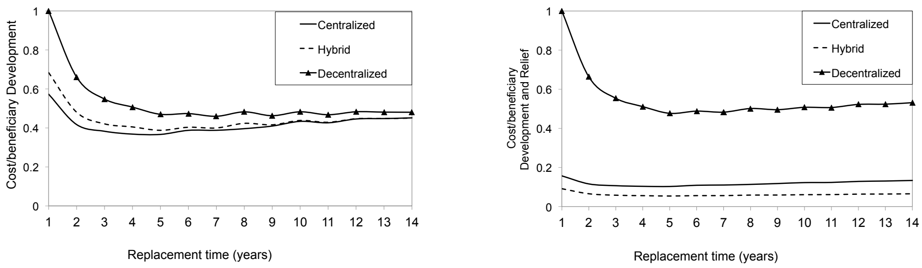
To study the impact of the procurement times on the service level of the development programs, we increased the global and local procurement lead time by 25% starting from 50% lower than the values in the appendix to 50% higher. As expected, the simulations revealed that in all models the service level decreases with increasing lead time. Finally, in the hybrid model the lead time for global procurement affects the service level much more than the lead time for local procurement; this is due to the higher proportion of global procurement compared to local procurement. So in the hybrid model it makes more sense for the IHO to decrease the global rather than the local procurement lead time in order to improve its service level.

To study the impact of the global versus local procurement in the hybrid model in the case of development programs, we changed the global procurement percentage (80%) from 0% to 100% in steps of 10%. Intuitively, when the global procurement percentage increases, the cost falls since the average procurement cost of the field vehicles decreases. When procurement is fully global the hybrid model behaves like the centralized model. We observe that when the global procurement percentage increases, the service level deteriorates because of increasing average lead times. When there is no global procurement the hybrid model behaves like the decentralized model.



(a) Development system (b) Development and relief system

Figure 5 Model Total Cost. The vertical axis is the normalized total cost per vehicle per year



(a) Development system (b) Development and relief system

Figure 6 Cost per served beneficiary

4.3. The Effect of Relief Operations and Earmarked Funding

4.3.1. Effect of Relief. Compared to the development model, the development and relief model has a similar behavior regarding total cost (Figure 5b). This result is intuitive. It is explained by the fact that the procurement strategies for relief in the hybrid and decentralized models have similar total cost since they procure more expensive vehicles locally. On the other hand, the procurement strategies for development and for relief and development are more cost efficient in the centralized model.

Regarding the service level, our results are surprising (Table 2). The hybrid model has the highest service level because it benefits from flexible procurement (global and local) and no earmarked vehicle use. The centralized model has a lower service level than the hybrid model due to the complex internal procurement process. Surprisingly, the decentralized model has the lowest service level. Why is it that a system using local procurement and low lead times takes consistently longer to supply vehicles for relief programs? The answer to this question lies in total earmarked funding and the resulting earmarked use of vehicles. Recall that in reality the decentralized model satisfies its vehicle needs by a) reallocating vehicles from the excess program inventory, b) purchasing vehicles locally, c) purchasing vehicles regionally and d) renting vehicles locally. We comment on the effect of earmarked funding on each of these sourcing strategies.

First, earmarked vehicle funding deters the relocation of available program inventory for disaster response. This is due to the fact that earmarked funding usually results in constraints in the use of assets. The implication is that vehicles are confined to routes within the geographical area funded by each donor. This is what we call earmarked vehicle use. Although there are protocols to reallocate vehicles between programs funded by different donors, they usually imply bureaucratic processes that may take from one week to several months. Hence, the only available immediate inventory for disaster response is the one in the geographic area of the disaster. If there is no excess of inventory in that area, then immediate reallocation of vehicles is not feasible.

Second, local and regional vehicle purchases are highly likely to be constrained due to earmarked funding. Funding for immediate disaster response in the decentralized model is initially constrained to that provided by the donor funding ongoing development programs in the geographic area. If the donor has enough resources then the local purchase can be expected to be fast. Otherwise, it may take up to three weeks to get the money to purchase new vehicles. We will show that even assuming infinite local sourcing capacity regarding new and rented vehicles, the decentralized model is, on average, the slowest to respond to the needs of relief programs.

Finally, local vehicle rental is also affected by earmarked funding. Specifically, if the donor has enough resources then local renting can be expected to be fast; otherwise, vehicle rental will be delayed.

When calculating the cost per served beneficiary, the results follow a similar pattern as the service level (Table 2). Specifically, the decentralized model that has the highest total cost and the lowest service level is the one that requires the highest cost per served beneficiary (Figure 6b). The hybrid model that is in between concerning total cost but has the highest service level is the one that requires the lowest cost per served beneficiary. The centralized model that has the lowest total cost and is in between concerning the service level is also in between concerning the cost per served beneficiary. This is due to the big difference between the service level of the hybrid model and the service level of the centralized model which is not compensated by the smaller difference in the total cost between the two models.

4.3.2. Effect of Earmarking. In order to obtain more insights into the impact of earmarked funding for relief programs on the behavior of the decentralized model we compared five different scenarios (Table 3). The first scenario includes the five donors that support different geographic areas presented in section 3.4. The wealthiest donor funds 50% of the cost of the relief program and the others fund 20%, 15%, 10% and 5% respectively. In the second scenario, each of the five donors fund 20% of the cost. In the third scenario, there is only one donor funding the whole relief operation (local, centrally-planned funding). Note that this scenario is equivalent to no earmarked funding since the IHO does not face earmarked vehicle use constraints within the borders of the country. In the fourth scenario, similar to the first scenario, there are five donors funding 50%, 20%, 15%, 10% and 5% of the cost but the relief program always takes place in the area of the 5% donor. In the fifth scenario, similar to scenarios 1 and 4, there are five donors funding 50%, 20%, 15%, 10% and 5% of the cost but the relief program always takes place in the area of the 50% donor.

Decentralized scenarios	(%)	Donor 1	Donor 2	Donor 3	Donor 4	Donor 5	Total Cost Normalized value	Service level Normalized value
1 (Base)	Disaster probability	20	20	20	20	20	0.9996	0.477
	Funding capacity	50	20	15	10	5		
2	Disaster probability	20	20	20	20	20	0.9996	0.478
	Funding capacity	20	20	20	20	20		
3	Disaster probability	100	0	0	0	0	0.998	1
	Funding capacity	100	0	0	0	0		
4	Disaster probability	0	0	0	0	100	1	0.428
	Funding capacity	50	20	15	10	5		
5	Disaster probability	100	0	0	0	0	1	0.63
	Funding capacity	50	20	15	10	5		

Table 3 Decentralized Model Scenarios

Concerning total cost, the third scenario with only one donor is the best. In this case the model is equivalent to having a local, centrally-planned operation. Conversely, the fourth and fifth scenarios (where the relief programs always take place in the same area) are the ones that have higher total costs. The first and second scenarios are in between and they have the same total cost.

Regarding service level, the third scenario with a single donor has the highest service level, which means that the equity of the model is affected significantly by earmarking. When the relief operations take place in the area of the 50% donor (fifth scenario), then the model has the second highest service level. When they take place in the area of the 5% donor (fourth scenario) the model has the lowest service level. The first and second scenarios are in between but the second scenario (equal donors) has a slightly higher service level than the first scenario.

To make sure that our results are not due to the constraints on sourcing capacity, we ran the model assuming infinite sourcing capacity at the local level. Under this assumption the total cost increases since all the required vehicles are procured locally with a higher procurement cost instead of regionally. We compared these results with the ones for the centralized and hybrid models, assuming for the hybrid model infinite sourcing capacity at the local level and for the centralized model infinite capacity of the regional warehouse stock.

Regarding service level, the third scenario of the decentralized model (one donor) with no constraints has the best performance, followed by the hybrid model (without constraints) and the hybrid model (with constraints). The third scenario of the decentralized model with constraints (one donor, no earmarked donations) has the fourth highest service level, followed by the centralized model and the fourth scenario of the decentralized model (the disasters happen in the area of the 5% donor) has the lowest service level.

We conclude that the decentralized model has a poor performance when there are several donors and the disaster occurs in a geographic area funded by a not-wealthy donor. In this case, the additional time required to find funding for transportation is greater than the duration of a long procurement process such as the one used by the centralized model. In contrast, the decentralized model is very effective when there is only one wealthy donor funding the entire country.

4.3.3. Effect of the Workload on Relief and Development Programs. Different IHO have different workloads; for example IFRC has a greater proportion of relief programs than WVI. One of the most important concerns of decision-makers in an IHO is whether they should reconsider their fleet management model. To address this concern we studied the impact of the development and relief workload on the behavior of the system. In the system under study, when the IHO has both development and relief programs, on average 588,000 people are in need, of which 98,000 people are in need of relief and 490,000 in need of development programs, equivalent to a 20%-80% division. To study the impact of workload we change this percentage of relief/development from 10% to 100% in steps of 10% (Table 4).

The simulations show that the centralized model has the lowest total cost, the decentralized model has the highest total cost, while the hybrid model is in between. Moreover, for all the three models when the workload of relief activities increases, the total cost increases.

When the workload of relief activities increases, the service level decreases. Moreover, for a workload of relief operations less than or equal to 40%, the hybrid model has the highest service level, while for a workload of relief operations greater than or equal to 40%, the decentralized scenario equivalent to no-earmarked funding dominates (Decentralized scenario 3). This is due to the high responsiveness to immediate needs coming from local sourcing combined with free budget allocation characterizing the decentralized scenario 3.

	Total Cost							Service level							
Relief Work-load (%)	Centra-lized	Hybrid	Decentralized Scenarios					Centra-lized	Hybrid	Decentralized Scenarios				
			1 (Base)	2	3	4	5			1 (Base)	2	3	4	5
10%	**0,159**	0,190	0,263	0,263	0,262	0,263	0,263	0,508	**1,000**	0,286	0,290	0,751	0,250	0,417
(Base) 20%	**0,176**	0,223	0,327	0,327	0,327	0,328	0,328	0,163	**0,357**	0,110	0,110	0,231	0,099	0,146
30%	**0,189**	0,251	0,381	0,381	0,380	0,381	0,381	0,084	**0,157**	0,067	0,067	0,124	0,061	0,084
40%	**0,201**	0,275	0,426	0,426	0,426	0,426	0,426	0,057	**0,089**	0,050	0,050	**0,089**	0,045	0,061
50%	**0,246**	0,367	0,603	0,603	0,603	0,603	0,603	0,025	0,028	0,025	0,025	**0,042**	0,023	0,030
60%	**0,291**	0,460	0,781	0,781	0,780	0,781	0,781	0,016	0,016	0,016	0,016	**0,027**	0,015	0,020
70%	**0,303**	0,484	0,826	0,826	0,825	0,826	0,826	0,015	0,015	0,015	0,015	**0,025**	0,014	0,018
80%	**0,316**	0,512	0,879	0,879	0,878	0,879	0,879	0,013	0,013	0,014	0,014	**0,023**	0,013	0,016
90%	**0,332**	0,545	0,942	0,942	0,941	0,942	0,942	0,012	0,012	0,013	0,013	**0,021**	0,012	0,015
100%	**0,342**	0,572	1,000	1,000	1,000	1,000	1,000	0,011	0,011	0,011	0,012	**0,019**	0,011	0,014

Table 4 Workload Model Scenarios. Best performers in bold font

When the relief programs take place in an area lacking funding for relief (Decentralized scenario 4), then the decentralized model has the lowest service level. The decentralized scenario with unequal donors (Decentralized scenario 1) has the second lowest service level. The decentralized scenario with equal donors (Decentralized scenario 2) has the third lowest service level.

In Figure 7 we present the optimal fleet management model that arose for different combinations of earmarked funding and workload of relief and development. From a cost per served beneficiary perspective, we observe that when the percentage of relief is low the hybrid model is optimal, while for high percentages of relief workload the centralized model is the optimal. The number of donors (earmarked funding) does not appear to affect the optimal fleet model.

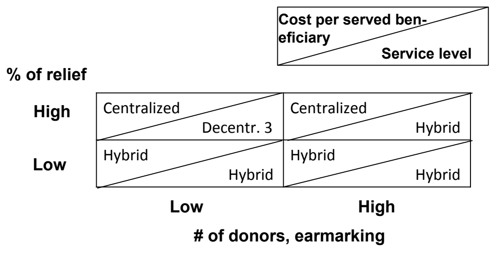


Figure 7 Summary of results. Cost per served beneficiary and service level.

Regarding service level, we observe that for low relief percentages, or when the number of donors is high, the hybrid model is optimal. For high values of relief workload and low number of donors the decentralized model with one donor (non earmarked funding) is optimal.

In this section we have shown that the combination of decentralization and earmarked funding has an important effect on relief and development operations. As before, we also ran the model using exponential and normal distributions to represent the demand. We obtained the same system behavior we found for the uniform distribution.

5. Conclusions and Further Research

In this paper we develop a system dynamics model to study the effect of earmarked funding on fleet management for relief and development among IHO in decentralized, stochastic operations. Focusing on metrics of equity and efficiency, we integrate different levels of decentralization by modeling three fleet management models that arose from field research: centralized, decentralized and hybrid (Pedraza-Martinez et al 2011, Pedraza-Martinez and Van Wassenhove 2010, Stapleton et al 2009). The data used are also taken from our field research making the insights and recommendations relevant to real-world humanitarian operations. We model relatively small to medium scale cyclical disasters that have not been researched extensively.

The vehicle fleet management system we study is characterized by the combination of short-term and long-term decisions. Due to a managerial structure involving multiple parties, the system is complex and exhibits multiple feedbacks. For these reasons, we chose the system dynamics methodology for modeling purposes. Established more than 50 years ago, this methodology has been used successfully to model various supply chains. System dynamics has also been applied to humanitarian logistics problems before proving to be of value in representing complex contextual issues.

Our system dynamics model has been carefully tested. In addition to the structural validity tests recommended by literature, we replicated several results from previous research. For instance, we obtained the same result as Pedraza-Martinez and Van Wassenhove (2010) regarding optimal vehicle replacement. We also replicated the incentive misalignment highlighted by these authors.

We compare the fleet management structures and practices of ICRC, IFRC, WFP and WVI in terms of equity and efficiency. Firstly, the comparison concerns only development programs. The findings show that the decentralized model has the highest service level because of the lowest purchasing lead time while the centralized model has the lowest total cost and the lowest cost per served beneficiary. Then, we add relief operations to see how the dual mission of relief and development affects equity and efficiency. The results are counter-intuitive showing that in terms of service level, when the percentage relief operations is low or when the number of donors is high the hybrid model is optimal, while for high levels of relief operations the decentralized model with one donor is optimal, i.e. when there are no local allocation constraints. The centralized model is again the one with the lowest total cost. Regarding the cost per served beneficiary, when the workload of relief is low the hybrid model is optimal, while for high values of relief workload the centralized model is optimal.

We studied in more detail the impact of increased earmarking, which is one of the reasons forcing IHO towards decentralization. The centralized model is again the one with the lowest total cost. However, the long lead times for vehicle procurement hurt the model in terms of response times for relief programs. Earmarking does not change the optimality of the centralized fleet management model in terms of cost per served beneficiary. However, for service level the hybrid model is optimal independent of the relative workload for relief and development. By combining global and local procurement this model achieves flexibility to respond to the needs of relief programs faster than the other two models. By getting rid of earmarked funding at the local level, the responsiveness of this model is independent of donor configuration.

Our paper shows that the interaction of decentralization and earmarked funding has a profound effect on operational performance for relief purposes. For example if the disaster occurs in a country where there is only one donor, then the performance depends only on the available vehicles and on their lead times. If there are two donors then the performance deteriorates because of the earmarking that causes significant procurement delays. In consequence, the fleet management model with local procurement and short lead times can take longer on average to fulfill the transportation needs of relief programs than the model that uses global procurement and long lead times. The explanation is twofold. First, earmarking of vehicles for specific programs deters the reallocation of available program inventory. Second, local and regional vehicle purchases are highly likely to be constrained due to earmarked funding.

We find a threshold for model performance: If the workload for relief programs is less than or equal to 40% of the IHO's total workload, the hybrid model exhibits the highest performance. Otherwise, the decentralized model with one wealthy donor has the highest service level. Given that IHO increasingly focus on relief operations, with multiple donors operating in a region (earmarked funding) and more frequent disasters than before, their performance may deteriorate, especially if their organizational structure is not appropriate. IHO do not usually analyze the impacts of the change in their focus and the earmarked funding on their performance, they rather make decisions intuitively. WFP has changed intuitively the fleet management model by centralizing it (they took the vehicles out of the programs) and also went around earmarking, by taking the procurement from the programs. Our model may be helpful as a Decision Support System to conduct extensive what-if analyses on a regular basis, both for decision-makers in IHO (to study which fleet management model they should implement), and for donors (to increase the efficacy of their donations).

Our results have important implications for humanitarian fleet management practice. Summarized, they reveal that for IHO focusing on development programs, the organizational structure decisions would most probably be seriously influenced by a greater concern for cost minimization. We find that the optimal fleet management model is a hybrid one (Figure 7). This model minimizes cost per served beneficiary with high service level, and therefore clearly dominates. For IHO with substantial relief programs, costs are minimized by centralization but service is maximized using decentralization. However, this decentralization only works if there are no local reallocation constraints due to earmarked funding. In case there are many donors with earmarked funds, vehicle procurement decisions should be taken out of the (decentralized) programs in a hybrid type of fleet organization model. Obviously, when relief operations largely dominate development ones, the focus will be more on fast response to beneficiaries, at the expense of increased costs. Therefore, service considerations would dominate decisions on organizational structure. Overall, as Figure 7 shows, the hybrid model looks like the most appropriate organizational form. As mentioned above, some of the larger IHO are indeed slowly moving to this type of fleet management structure but there are of course many resistances to change in these humanitarian organizations that may have functioned for years with a given structure and now need to convince their country and field offices that changes in the environment (e.g. more relief operations and increased earmarking) may call for a different organizational structure.

We note once again that donor earmarking, the dual mission of development and relief and decentralization affect significantly the performance of IHO. Therefore we believe that future research should integrate these characteristics. It would be interesting to explore how these findings may change in the context of different types of disasters.

The results presented here clearly do not exhaust the possibilities for investigating all the effects of the dual mission of relief and development, the decentralization of decision-making, and the earmarked funding on the operations of the IHO. More research should be conducted to explore strategies that will improve the service level without significantly increasing the cost. One limitation of our formulation is the deterministic duration and occurrence of the relief operations. A second limitation is that we do not consider societal issues related to procurement: some IHO may prefer local vehicle procurement to help reactivate the economy in the countries where they operate.

Appendix. Data

Parameter	Base value	Units	Source
Purchasing cost globally (C and H)	28000	CHF/vehicle	Pedraza-Martinez and Van Wassenhove (2010)
Leasing cost from the headquarters (C and H)	28056	CHF/vehicle	Pedraza-Martinez and Van Wassenhove (2010)
Purchasing cost regionally (D)	50000	CHF/vehicle	Pedraza-Martinez and Van Wassenhove (2010)
Purchasing cost locally (D and H)	65000	CHF/vehicle	Pedraza-Martinez et al (2011)
Reallocation cost from the regional warehouse stock (C and H)	1000	CHF/vehicle	Discussions with fleet managers
Reallocation cost from the excess capacity (C, D and H)	0	CHF/vehicle	
Reallocation cost from the neighboring countries (C and H)	500	CHF/vehicle	Discussions with fleet managers
Rental cost for relief (C, D and H)	1000	CHF/week/vehicle	
Purchasing lead time (C)	26	weeks	Pedraza-Martinez and Van Wassenhove (2010)
Purchasing lead time (D)	4	weeks	Pedraza-Martinez et al (2011)
Purchasing lead time (H)	21.6	weeks	Stapleton et al (2009)
Purchasing lead time for relief locally (D and H)	0	weeks	
Purchasing lead time for relief regionally (D)	4	weeks	Discussions with WVI fleet manager
Reallocation lead time from excess capacity (C, D and H)	0	weeks	
Reallocation lead time from the neighboring countries (C and H)	0	weeks	
Rental lead time for relief (C, D and H)	0	weeks	
Immediate reallocation lead time from the regional warehouse stock (C and H)	4	weeks	Discussions with ICRC fleet manager
Second hand reallocation lead time from the regional warehouse stock (C and H)	7	weeks	
Reallocation capacity from neighboring countries (C and H)	excess capacity	vehicles	
Purchasing local capacity for relief (D and H)	7	vehicles	Discussions with WVI relief manager
Purchasing regional capacity for relief (D)	infinite	weeks	
Immediate reallocation capacity of the regional warehouse stock (C and H)	10	vehicles	Discussions with ICRC fleet manager
Second hand reallocation capacity of the regional warehouse stock (C and H)	infinite	vehicles	
Local rental capacity of vehicles for relief (C, D and H)	2	vehicles/week	
Yearly mileage per vehicle	20,000	Km/vegicle	Discussions with fleet managers, quantitative data from ICRC

Table 5 **Model parameters. C: Centralized; H: Hybrid; D:Decentralized**

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