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Vehicle Replacement in the International Committee of the Red Cross

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Abstract

This paper studies 4x4 vehicle replacement within the International Committee of the Red Cross (ICRC), one of the largest humanitarian organizations. ICRCpolicy sets the replacement of vehicles at 5 years or 150,000 Km, whichever comes first. Using field data collected at the ICRC headquarters and national level we study the ICRC policy. Our results suggest that the organization can make considerable savings by adjusting its replacement policy. This study contributes to the area of logistics and transportation research in humanitarian operations.

Keywords: Humanitarian Logistics, Vehicle Replacement, Fleet Management, Field Research, Dynamic Programming, Empirical Research, Disaster Management

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1 Introduction

Humanitarian organizations face many challenges to deliver the right goods and services to the right people at the right time and at the right price (Van Wassenhove [16]). Transportation, the second largest cost in humanitarian operations after personnel, offers some interesting research opportunities to improve operational efficiency.

4x4 vehicles are the most widely used in humanitarian operations. These vehicles serve to transport personnel, aid and beneficiaries in field operations. The Fleet Forum, a humanitarian interagency association, estimates that the total number of 4x4 vehicles in the international humanitarian sector is between 70,000 and 80,000 units. The International Committee of the Red Cross (ICRC) operates a fleet of 1,700 4x4 vehicles in more than 80 countries, including 69% of the emerging economies listed in the Morgan Stanley Emerging Markets Index (Hedge Funds Consistency Index).

The mandate of the ICRC is to provide assistance and protect the lives and dignity of victims of war and internal violence. This often involves the transport of people and aid across territories in conflict. For that reason, the ICRC needs reliable and cost effective 4x4 vehicles to support relief operations.

This paper studies 4x4 vehicle replacement within the ICRC, one of the largest humanitarian organizations. The ICRC Standard Replacement Policy (SRP) sets the replacement of vehicles at 5 years or 150,000 Km, whichever comes first. The SRP is suggested by the vehicle manufacturers to commercial companies operating in normal conditions. This SRP is quickly becoming the standard since the ICRC is generally accepted as the benchmark in terms of fleet management by the humanitarian sector. The SRP is also followed by the World Food Programme (WFP), World Vision International

(WVI) and the International Federation of Red Cross and Red Crescent Societies (IFRC) which together account for more than 10% of the whole international humanitarian 4x4 fleet.

However, humanitarian organizations face operating conditions that are very different from those of commercial fleets in developed countries. Some humanitarian organizations, including the ICRC, have a duty free status. This implies a lower vehicle purchasing cost compared to commercial companies. Humanitarian vehicles are usually driven in poor road conditions in rural areas of developing countries increasing the cost of maintenance and repair, and specific accounting rules may affect vehicle disposal and salvage value. For instance, ICRC Vehicles are sold in local markets by ICRC National Delegations but sales revenues go to ICRC headquarters. These are only some of the differences suggesting that commercial fleet replacement policies may not be relevant for humanitarian fleets. However, humanitarian fleets do use recommendations for commercial fleets.

Altay and Green [1] signal the need for better understanding of sources and types of critical data to improve productivity and efficiency in Disaster Operations Management. Even though fleet costs are high for Humanitarian organizations, optimizing fleet is hard because of the huge difficulty in finding reliable field data. This study is the first attempt to do so.

Using quantitative and qualitative data collected both at the headquarters and field level, we study the SRP and its application in ICRC operations. We empirically answer two research questions: (1) Do the ICRC National Delegations follow the SRP? (2) Is the SRP optimal from a cost perspective? We find that the ICRC can do better by studying its operating conditions and its decision making structure. Our empirical research also points to gaps in knowledge and important areas where more data needs to be collected by humanitarians.

Section 2 introduces the data used in our study while section 3 describes 4x4 vehicle management in the ICRC and the SRP. Section 4 discusses parameter estimation based on the ICRC field data. Section 5 presents the dynamic programming model to find the optimal replacement policy and shows the results and robustness checks using stochastic simulation. Finally, section 6 presents the conclusions and the future research agenda.

2 Field study and Data

Transportation and logistics literature in humanitarian operations has been focused on theoretical models for preparedness and efficient response to disasters. The role of transportation in response has been studied for evacuating victims and distributing aid. Mathematical models for victims evacuation can be found in Sheffi et al [12], Sherali et al [13], Barbarosoglu et al [3] and Yi and Ozdamar [19]. Aid distribution models can be found in Viswanath and Peeta [18], Barbarosoglu and Arda [4], Yi and Kumar [20], Tzeng et al [15], and Balcik et al [2]. Most of these papers build optimization models to maximize aid delivery, minimize casualties and time of response or cost. Frequently these models are listed on generated data.

Altay and Green [1] signal the need for empirical research in disaster operations management. The authors identify budgeting for and acquiring vehicles and equipment as one of the typical activities of preparedness for disaster response.

We collected quantitative and qualitative data on humanitarian vehicle replacement. We visited the ICRC - HQ in Geneva and their field operations in Africa to get a better understanding of the way they run their 4x4 fleet. The data collection process took about one year. It was difficult because the ICRC logistics staff spend most of their time in field operations. Preparing the data for analysis was an additional issue. Although the ICRC is one of the most advanced humanitarian organizations in data capturing, data is very noisy and incomplete because it is often captured during emergency operations. Field staff face a trade-off between allocating time to capture data and helping beneficiaries. The Global Fleet Unit located at HQ offices makes a remarkable effort to control data quality and keep up-to-date records. However, the 5 people working in the Fleet Unit are not enough to cover more than 80 national missions around the world.

According to the ICRC Global Fleet Manager, Afghanistan, Ethiopia, Georgia and Sudan are some of the operations with the most reliable data. These four countries are also representative of the types of conditions the National Delegations (ND) vehicles have to operate in once they travel outside of the main cities.

Table 1 shows the percentage of paved roadways in these countries. In terms of size the four countries in our research represent 8 times the area of France. However, France has almost 9 times more kilometers of roads than the four countries aggregated. Moreover, 100% of French roads are paved (CIA World Fact Book).

In terms of quality, according to the ICRC Global Fleet Manager Afghanistan has very bad quality roads and vehicles are required to travel through extremely rocky terrain. Ethiopia combines sandy terrain with both mud and tarmac. Georgia has tarmac surfaced roads although they have serious problems with potholes. In Sudan the ground is very sandy making short journeys in terms of mileage into very long journeys in terms of time.

We had access to 4 data sets of 4x4 vehicles containing the following: procurement

	Afghanistan	Ethiopia	Georgia	Sudan
Land area (Km^2)	647,500	1,119,683	69,700	2,376,000
Total roadways (Km)	42,150	36,469	20,329	11,900
Paved roadways (Km)	12,350	6,980	7,854	4,320
% Paved	29%	19%	39%	36%

Table 1: Paved and total roadways in all countries. Source: CIA World fact book 2008

and sales, monthly mileage, monthly operating costs and accidents in the 4 countries mentioned above. Our data covers the period 2002 - 2006. The procurement data set includes cross-sectional data of 645 vehicles. The operating costs data set is a panel data set with dates and repairs not included in the preventive maintenance schedule. The third data set is a panel data with monthly records of mileage for 461 vehicles. The accidents data set includes cross sectional data of 599 accidents from 2002 to 2006.

2.1 Procurement and Sales

Three out of four active fleets (Afghanistan, Ethiopia and Georgia) have average ages above 4 years and median ages of 5 years (See table 2). All the countries appear to be replacing around the 8^{th} year but Afghanistan and Ethiopia seem to be following the mileage replacement policy. In both countries vehicles were sold at an average age of 7.7 years while the mileage was around 150,000 Km. We use the procurement and sales data set to determine the drivers of vehicle replacement in section 3 and for estimating vehicle salvage value in section 4.

2.2 Monthly mileage

The original database of monthly mileage contained 20,341 observations corresponding to 459 vehicles. Only 13,272 observations (66.8%) representing 454 vehicles were reliable.

		Mean	Median	Std. dev.	Min.	Max.
Afghanistan	Obs = 162, 101 active					
Active	Age (Years)	4.59	5	1.75	1	8
	Odometer (Km)	41,965	44,533	29,637	0	111,368
Sold	Age	7.70	8	1.95	4	12
	Odometer	145,384	138,963	55,550	30,678	254,682
	Salvage value	7,197	6,510	2,809	1,287	13,536
Ethiopia	Obs = 131, 95 active					
Active	Age	4.61	5	2.41	1	14
	Odometer	76,308	86,956	47,028	0	167,012
Sold	Age	7.75	8	1.92	2	14
	Odometer	155,217	156,008	62,056	8,255	243,997
	Salvage value	16,555	16,486	6,305	6,349	27,612
Georgia	Obs = 112, 44 active					
Active	Age	4.55	5	1.15	1	8
	Odometer	91,454	87,819	39,649	0	170,631
Sold	Age	7.84	8	1.24	5	11
	Odometer	208,131	212,470	50,674	49,713	303,380
	Salvage value	7,545	8,211	1,887	2,608	12,459
Sudan	Obs = 240, 189 active					
Active	Age	3.47	3	1.41	1	10
	Odometer	17,569	10,516	20,661	0	103,256
Sold	Age	7.12	8	2.82	1	12
	Odometer	100,424	90,754	64,957	0	270,827
	Salvage value	12,470	11,000	7,305	3,030	45,139

Table 2: Descriptive statistics for procured and sold vehicles, 4 countries. 2002 - 2006

5 vehicles were excluded from the sample because their mileage was inconsistent due to problems of data migration at the ICRC. Table 3 shows the descriptive statistics of monthly mileage. This data set is used for solving the optimal replacement model in section 5.

	Obs	Mean	Median	Std. dev.	Min	Max
Afghanistan	89	1,177	1,027	997	0	17,396
Ethiopia	114	2,164	1,846	1,848	0	9,213
Georgia	69	2,282	2,196	1,410	0	25,313
Sudan	182	1,135	750	1,576	0	18,350

Table 3: Monthly distance (Km) 2002 - 2006. 4 countries

2.3 Operating costs

The operating costs data set includes dates and repairs of any maintenance not included in the ICRC preventive maintenance schedule. It includes repairs due to accidents, part failures, and vandalism among others. Figure 1 plots monthly cost vs age in months for all the vehicles in the data set for all the countries. In total we have 4,286 observations. We use operating costs in section 4 to check the ICRC miscellaneous cost function.

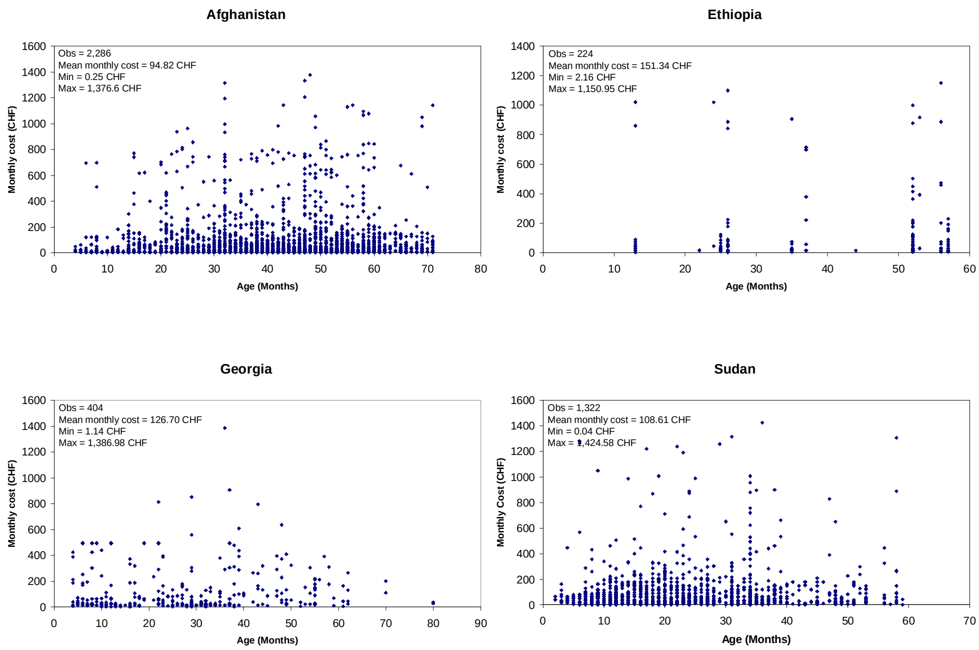

Figure 1: Miscellaneous cost vs age. Four countries

2.4 Accidents

We collected a database with 599 records of accidents for the period 2002 - 2006. These records correspond to 300 vehicles. This gives an average of 2 accidents/vehicle for the vehicles in the database. The database includes a wide range of damage from broken mirrors to total loss but accident descriptions are not available. Additionally, accident costs are not very reliable. We use this data in determining the drivers of replacement in section 3 and the drivers of salvage value in section 4.

2.5 Qualitative field data

To have a better understanding of vehicle use in the ICRC we performed field trips and conducted interviews. We interviewed 6 staff at the HQ level in Europe: the Head of Fleet Unit, the Global Fleet Manager, the Deputy Head of Operations West Africa, the Senior Purchaser, the Head of Administration Division, and Asset Manager. Additionally, we interviewed logisticians at the regional and national level in Africa: the Regional Fleet Manager based in Kenya, the Regional Workshop Manager, and the Parts Manager. In Uganda we interviewed the National Logistics Coordinator, the National Fleet Manager, and a National Logistician. The interviews were recorded and two researchers were present in all of them. We use the qualitative data for describing the 4x4 life cycle and for better understanding of the cost structure within the ICRC.

3 Vehicle management in the ICRC and the SRP

The ICRC vehicles are procured by HQ directly from a Japanese manufacturer. ND make a vehicle requisition to the HQ that approves procurement. From our interviews with the Senior Purchasing Officer and the Global Fleet Manager at HQ we know that purchasing cost does not change across countries. Transportation plus equipment costs are assumed to be 8% of the purchasing cost.

The ICRC has a duty free status. They do not pay the registration taxes in the countries where they operate. In some emerging countries registration costs can be more than 100% of the purchasing cost of the vehicle. For instance, if the ICRC would decide to purchase locally, the manufacturer's suggested retail price for a 2008 model Toyota Land Cruiser in Ethiopia would be approximately twice the global purchasing cost for the ICRC.

The lead time from placing the order to the manufacturer in Japan to the time vehicles reach the ND is approximately 4 months. As soon as vehicles reach either the replenishment warehouses in Brussels (commercial), Nairobi (ICRC), or Amman (ICRC), or occasionally the ND, they are fitted with a radio and painted. Once equipped, vehicles are sent to ICRC field operations.

National registration takes place at the country of operation. The biggest problem for the ND is to import the vehicle duty free. Governmental procedures can delay the registration. The whole process usually takes 3 months but in some cases can be as long as 6 months due to political or conflict reasons (Figure 2).

The fully operational stage of the vehicles starts just after national registration. Vehicles are sent to the subdelegations in the field according to operational needs. Once in the field, the vehicles are used intensively in ICRC missions to transport personnel, beneficiaries and aid. Approximately at the end of the second year vehicles start a moderate operation stage. Vehicles are still driven in the field but in safer areas and shorter missions. The moderate operation lasts until the end of the 4^{th} year.

In the next stage in operational life, vehicles perform administrative tasks in the field or in the ND. Usually vehicles spend most of the time in urban areas and they are used

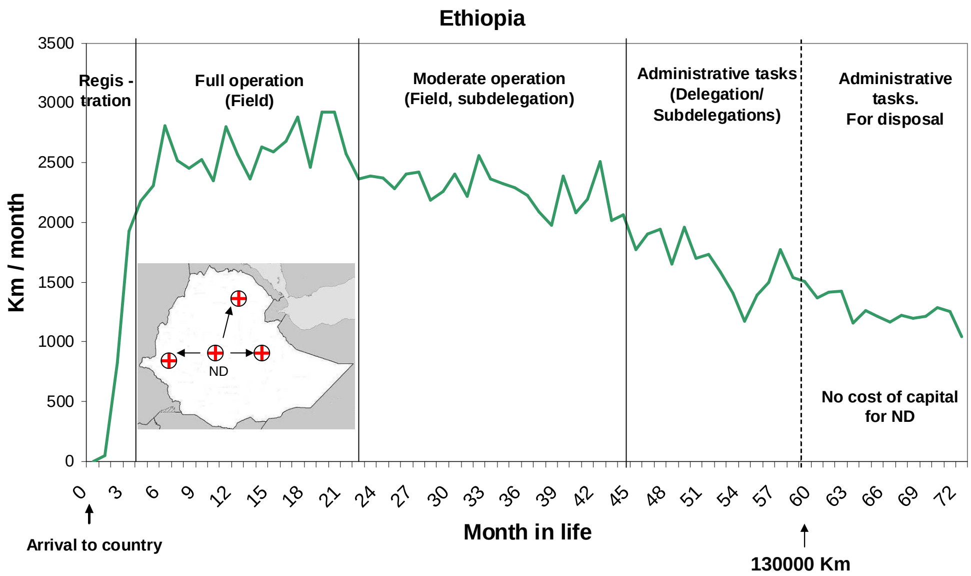

Figure 2: 4x4 vehicle operational life cycle. Ethiopia

to transport personnel. At this stage in life it is rare to send vehicles to field missions.

Ideally, if the SRP is followed, after 5 years or 150,000 Km vehicles are sold in the local market on a tender process or at an auction. The revenue from the sales goes back into the global investment budget belonging to HQ. Standing costs - purchase, initial installation of equipment, and initial shipping - are managed by HQ. ND pay monthly insurance, which is constant throughout the vehicle life cycle. ND are responsible for the operational and maintenance costs including spare parts, fuel and repairs of each vehicle. ND also pay depreciation cost, calculated at 1.66% per month for a period of 5 years. Once vehicles are fully depreciated ND no longer have to pay a monthly fee to keep them. Often ND keep their vehicles longer than 5 years. The maximum age of replacement allowed by HQ is 10 years. Due to an agreement with the manufacturer, the minimum age of replacement is 3 years. According to the manufacturer, ICRC vehicle sales under the age of 36 months could create a secondary market that would compete with the manufacturer's new vehicles at the national level.

First, we wanted to know whether ND were following the SRP. Figure 3 clearly shows they do not. More than 50% of the replaced vehicles were older than 5 years and 150,000 Km before being sold. Only 5% of the vehicles were replaced following the SRP. Figure 3 also shows that on average vehicles were replaced around 150,000 Km but only for the aggregated sample. The average odometer when sold in Afghanistan and Ethiopia is around 150,000 Km while it is 208,131 Km for Georgia and 100,424 Km for Sudan (table 2). Although not included here, the proportions shown in figure 3 hold when the sample is divided by year.

Why is it that ND do not follow the SRP? As stated above, ND stop paying vehicle depreciation at the end of the 5^{th} year. Additionally, revenues from sales go to HQ. According to Suzuki and Pautsch [14] motor carriers should use longer replacement cycles (extend the duration of vehicle use) when salvage value declines. In the ICRC case the ND effectively receive a salvage value equal to zero due to the revenue transfer to HQ. Therefore, their incentive is to keep vehicles beyond the prescribed threshold of replacement.

Second, given that ND do not follow the SRP, which are the real drivers of vehicle replacement in practice? We consider 3 independent variables: age, odometer and accidents. Due to the high dispersion in the odometer for sold vehicles (figure 3), we use the natural logarithm of odometer as our predictor. We use a dichotomous dependent

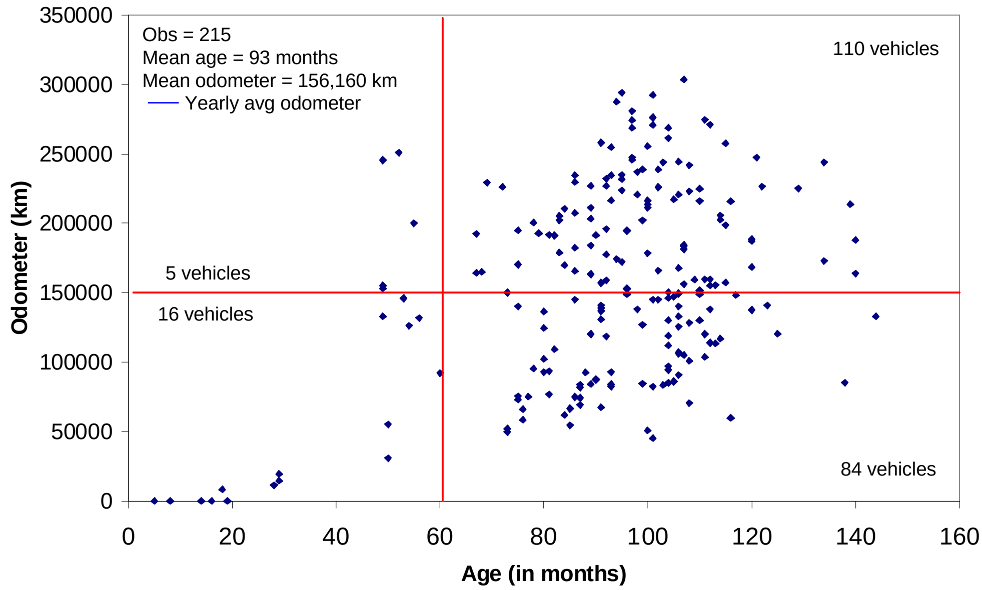

Figure 3: Age vs Odometer at replacement. All countries

variable to indicate whether a vehicle has been sold or not. Because we are dealing with a dichotomous variable we estimate a binary logistic model to understand the ICRC current replacement policy. Table 4 shows that age and odometer are the only significant predictors of the replacement decision. Age is a significant driver of replacement in Ethiopia, Georgia and Sudan. On the other hand, odometer is significant in Afghanistan and Georgia. The odds ratio of reaching 150,000 Km and 5 years is 3.6.

Now we know that ND are not generally following the prescribed SRP but would following it be optimal for the ICRC from a cost perspective? If that is not the case, what is the optimal replacement policy? We address these questions in the next two sections. The next section discusses parameter estimation. We focus our attention on

	Afghanistan	Ethiopia	Georgia	Sudan
Age (months)	0.02	0.05***	0.19***	0.07***
ln(odometer)	2.82***	0.77	3.86**	-0.13
Accidents	0.59	-0.76	0.60	-0.26
Obs	187.00	139.00	113.00	265.00
chi-square statistics	95.25	58.39	121.86	102.31
Pseudo R^2	0.40	0.37	0.80	0.40

Dependent variable: sold = 1 for replaced vehicles
***, **, * coefficient significant at the p $<$ 0.01, 0.05 and 0.1 levels

Table 4: Logistic model for sold vehicles

estimating maintenance cost and salvage value using the ICRC field data. Second, we solve an optimal replacement model and check for the robustness of our results using stochastic simulation.

4 Parameter estimation

The typical objective of vehicle replacement problems is to find the replacement time minimizing a total cost function. Hartman and Murphy [9] consider purchasing, operating and maintenance costs minus salvage value in the cost function. Brosh et al [6] also consider the cost of parts like clutches, breaks, carburetors, fuel pumps, fuel filters, alternator dynamos, starters and distributors. The structure of our data allows us to estimate maintenance costs, including spare parts, and salvage value, the main parameters of the replacement cost function.

4.1 Maintenance cost

4.1.1 Preventive maintenance

Preventive maintenance encompasses preventive services and spare parts. Four types of preventive services are carried out locally as a function of vehicle odometer (table 5). Both the Global and the Regional Fleet Manager agree that the costs of these services are additive. We also assume maintenance schedules are respected. This assumption is not strong since in conflict areas highly reliable vehicles are necessary for security reasons.

Following Brosh et al [6] we include the cost of spare parts in our analysis. Vehicle parts are replaced as a function of the odometer except batteries (table 5). Spare parts are purchased by HQ directly from the manufacturer in Japan. They are delivered to the HQ, cross-checked and sent to ND.

Cost item (i)	**Source of cost**	**Periodicity** (p)	**Measure**	**Cost in CHF** (q)
	Services			
1	Service 1	5,000	Km	200
2	Service 2	10,000	Km	350
3	Service 3	20,000	Km	500
4	Service 4	60,000	Km	600
	Spare parts			
5	Tires	30,000	Km	1000
6	Brakes	40,000	Km	600
7	Timing Belt	60,000	Km	500
8	Tuning	60,000	Km	300
9	Suspension	70,000	Km	800
10	Steering	70,000	Km	700
11	Injectors	120,000	Km	700
12	Oils	120,000	Km	400
13	Clutch	150,000	Km	1000
14	Battery	4	years	200

Table 5: Preventive maintenance costs and periodicity

We model the cost of preventive services and spare parts by using indicator variables. Let $\Theta(a)$ be the total odometer of a vehicle of age a, with $\Theta(a_0) = 0$. The indicator function for the cost items in table 5 is:

$$I_i = \begin{cases} 1 & \text{if} \quad \lfloor \frac{\Theta(a+1)}{p_i} \rfloor > \lfloor \frac{\Theta(a)}{p_i} \rfloor \\ 0 & \text{otherwise} \end{cases} \tag{1}$$

Where $i = \{1, 2, ..., 13\}$ is the cost item (table 5) and $\lfloor x \rfloor = \max\{n \in Z | n \leq x\}$ is the floor function. Similarly, we define I_{bat} to be an indicator function for battery replacement. I_{bat} applies the floor function to the quotient of age divided by 4 years. Preventive maintenance cost, the sum of preventive services and spare parts cost, can be written as

$$m(\Theta(a)) = \sum_{i=1}^{13} q_i I_i + q_{14} I_{\text{bat}} \tag{2}$$

4.1.2 Miscellaneous costs

Anything beyond spare parts and oils is considered a miscellaneous cost. Miscellaneous costs (e) are a function of the odometer of the vehicle. The ICRC's previous experience suggests that:

$$e(\Theta(a)) = \begin{cases} b\left(\frac{\Theta(a)}{75{,}000}\right) & \text{if} \quad \Theta(a) \leq 150,000 \\ b\left(1 + \frac{\Theta(a)}{150{,}000}\right) & \text{if} \quad \Theta(a) > 150,000 \end{cases} \tag{3}$$

Where $\Theta(a)$ is the total odometer for the vehicle of age a and $b = 312$ CHF is the base miscellaneous cost at $75,000$ Km.

We use the operating cost data set to check the ICRC miscellaneous cost function fit. Considering that miscellaneous costs depend on vehicle life cycle, we ran regressions by including structural brakes according to the life cycle described by figure 2. Results are shown in table 6. Full and moderate operational stages are significant in Afghanistan, Sudan and Georgia, respectively. We do not find significant results for Ethiopia. This could be due to the lack of observations of operating costs through vehicle life cycle in that country (figure 1).

Misc. cost	Afghanistan	Ethiopia	Georgia	Sudan
Constant:				
Registration	-231.34		0.14	-51.24
Full operation	-22.46	61.76	85.41*	49.79**
Moderate operation	129.57***	-16.90	-219.96***	128.66***
Admin. tasks	2.93	336.29	-134.58	-548.39
For disposal	55.89	-137.90	200.69	-316.66
β:				
Registration	54.21		28.14	33.84*
Full operation	6.36***	10.31	4.14	3.26**
Moderate operation	-0.74	5.08	9.94***	-0.27
Admin. tasks	0.20	-3.10	4.58	12.05**
For disposal	0.26	3.07*	-1.66	6.18
Obs	2286.00	224.00	404.00	1322.00
F - statistics	67.54	10.37	22.79	56.10
R-squared	0.23	0.28	0.37	0.30

***, **, * coefficient significant at the $p < 0.01$, 0.05, and 0.10 levels

Table 6: Regression estimating the miscellaneous cost. All countries

Following the ICRC, we assume that vehicles remain in the operational stage until disposal. Figure 4 shows both the ICRC miscellaneous cost function and the empirical cost function obtained from the data. To save space we only include the results for Sudan but in general we find that the ICRC miscellaneous cost function is a good approximation to operating costs.

ICRC miscellaneous costs increase with the age of the vehicle. This result is different from the one obtained by Cho and Rust [7] for a rental company in the US. The authors find that daily maintenance costs are flat during the first 150,000 Km of a vehicle's life.

4.2 Salvage value

According to Rust [11], and Cho and Rust [7] salvage value is a function of the age or odometer of the vehicle. Given the special circunstances of operating vehicles in a

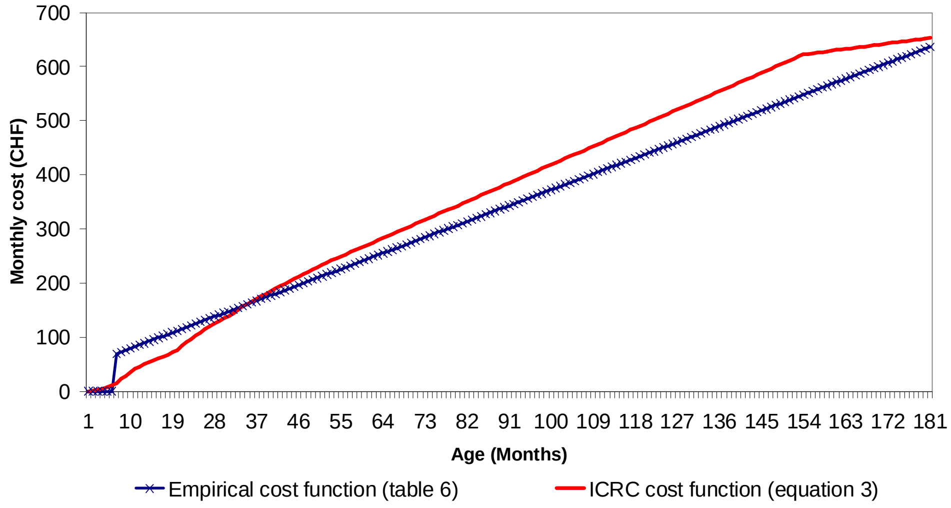

Figure 4: ICRC vs Empirical miscellaneous cost function. Sudan

humanitarian context, we control for the effect of accidents, vehicle model, group sales and conflict intensity on salvage value (table 7). Accidents could decrease the salvage value of the vehicle. There are two different 4x4 models from the same brand which could potentially affect salvage value. Group sales could decrease individual salvage value if discounts were offered. The effect of conflict intensity would depend on the nature and status of the conflict. From our field interviews we learned that in post-conflict areas (Ethiopia and Georgia) an increase in conflict intensity increases humanitarian work because of the need to help affected populations. In contrast, in intense on-going conflict territories (Afghanistan and Sudan) an increase in conflict intensity decreases relief operations for security reasons. Hence, conflict intensity affects the demand for vehicles and therefore their salvage value.

Notation	
Dependent variable	
s	Salvage value
Predictors	
Θ	Total odometer when sold
a	age in months when sold
Controls	
d	Accidents. Indicator variable equal to one if any accident and zero otherwise
m	Vehicle Model. There are two possible models from the same brand
g	Group sales. Indicator variable equal to one if the vehicle was sold in group and zero otherwise
c	Conflict index

Table 7: Salvage value predictors and controls

To study the effect of conflict intensity on salvage value, we consulted a number of databases searching for a monthly index of conflict intensity. The Political Instability Task Force Worldwide Atrocities Data set (University of Kansas) discriminates by date of punctual events related to atrocities. However, it does not include Georgia and not all the information is quantified. The International Crisis Group (ICG) Crisis Watch database (www.crisisgroup.org), starting August 2003, assesses whether the conflict situation has significantly deteriorated, significantly improved or in balance remained unchanged. We use the ICG index as a proxy for conflict intensity by assigning a value 1 to the first month and adding or subtracting a unit each month according to the evolution of the conflict.

We ran OLS regressions to determine the drivers of salvage value. Our regression model for each country is:

$$s = \beta_0 + \beta_1 a + \beta_2 \ln(\Theta) + \beta_3 d + \beta_4 m + \beta_5 g + \beta_6 c \tag{4}$$

Results are given in table 8.

Misc. cost	Afghanistan	Ethiopia	Georgia	Sudan
Age(months)	-15.96	74.61	-29.21	-30.62
ln(odometer)	-2670.31***	-5996.45*	764.31	-761.09**
Accidents	-731.96	5588.29*	125.63	121.30
Conflict	94.00	405.46	-303.74	-175.51
model HZJ75	-918.41	-3178.41	-1290.77	-2692.61
Sold in group	321.77	-3291.02	-1365.80	-1096.43
Const	39674.41	77807.60	3113.62	26191.15
Obs	41.00	26.00	40.00	46.00
F-Statistic	3.86	3.77	1.97	10.13
Adj R^2	0.30	0.40	0.13	0.55

***, **, * coefficient significant at the $p < 0.01$, 0.05, and 0.10 levels

Table 8: Regression estimating the salvage value of vehicles

Odometer is the main driver of vehicle salvage value. It is significant in Afghanistan, Ethiopia and Sudan. Age does not surface as a significant predictor of salvage value. However, odometer and age are strongly correlated, and therefore there is a collinearity issue that makes it difficult to determine the independent impact of these two variables on salvage value (Cho and Rust [7]). We do not find evidence to support the hypothesis that accidents affect vehicle salvage value. This may not be surprising given that the maintenance plan followed by the ICRC in its field operations is very rigorous.

We reject the hypothesis that conflict intensity affects vehicle salvage value. This result contradicts ICRC field experience and may be due to the qualitative conflict index we used. This problem highlights the importance of collecting reliable data related to humanitarian operations. While field experience clearly suggests a link between conflict intensity and salvage value, humanitarian organizations currently do not keep track of conflict intensity in their databases. The fact that our conflict index variable only starts in August 2003 makes us lose 20 out of 60 months of observations, which may also explain why we do not detect a significant relation between conflict intensity and salvage value.

In the case of Georgia none of the variables appear to be a significant predictor of salvage value. We do not show the results here but by excluding the conflict index we can use 28 additional observations and find that odometer is a predictor of salvage value.

Since odometer is the only significant predictor in all the countries we decided to use it as a predictive variable for determining the vehicle salvage value (equation 5).

$$s = \beta_0 + \beta_1 \ln(\Theta) \tag{5}$$

Results are shown in table 9.

	Afghanistan	Ethiopia	Georgia	Sudan
ln (odometer)	-2716.69***	-7943.50***	-1402.84*	-1282.17***
Constant	38504.44	109963.00	24647.00	25319.18
Obs	54.00	31.00	68.00	50.00
F - Statistic	23.39	15.31	3.39	52.58
Adj R^2	0.30	0.32	0.03	0.52

***, **, * coefficient significant at the p < 0.01, 0.05, and 0.10 levels

Table 9: Regression estimating the salvage value as a function of ln (odometer)

Our results are meaningful for vehicles in the range of replacement ages we want to study. As mentioned above, the minimum age of replacement is 3 years. At that age vehicles have on average 44,341 Km, 86,143 Km, 71,431 Km, and 41,186 Km in Afghanistan, Ethiopia, Georgia and Sudan, respectively. The predicted salvage value for those vehicles as a percentage of the purchasing cost is 34%, 70%, 32% and 42%, respectively.

Given the estimated maintenance cost and salvage value for all countries in our analysis, we can now find the optimal replacement policy for the ICRC.

5 Optimal replacement DP model and results

Replacement problems have been extensively studied in the operations research and operations management literature. Examples of optimal stopping and shortest path models solved by dynamic programming can be found in Vemuganti et al [17], Bertsekas [5] and many others. Other common approaches to solve replacement problems, like the one proposed by Dietz and Katz [8], use Markovian decision models.

The ICRC missions are measured in time. Due to the structure of our data we can model a vehicle as a discrete time dynamic system in which the total operating cost is additive over time. Notations are summarized in table 10.

Notation	
t	Stage of the mission, in months
T	Total duration of the mission, in months
a_t	Age of the vehicle in months. $a = \{1, ..., 168\}$
a_{t+1}	Decision variable. $a_{t+1} = a_t + 1$ if the vehicle is not replaced. Otherwise $a_{t+1} = 0$
$o(a_t)$	Average monthly mileage of R vehicles of age a_t
$\Theta(a_t)$	Total odometer of a vehicle of age a_t $\Theta(a_t) = \sum_{j=0}^{a_t} o(j)$
$m(\Theta(a_t))$	Monthly maintenance cost of a vehicle with odometer $\Theta(a_t)$ defined by equation 2
$e(\Theta(a_t))$	Monthly miscellaneous cost of a vehicle with odometer $\Theta(a_t)$ defined by equation 3
P	Purchasing cost
$s(\Theta(a_t))$	Salvage value of a vehicle with odometer $\Theta(a_t)$ defined by equation 5
$c_t(a_t)$	Cost at stage t of a vehicle with age a_t

Table 10: Modeling notation

The Dynamic Programming algorithm is:

$$J_T(a_T) = m(\Theta(a_T)) + e(\Theta(a_T)) - s(\Theta(a_T))$$

$$J_t(a_t) = \min[c_t(a_t) + J_{t+1}(a_{t+1})] \qquad \text{for } t = 0, 1, ..., T-1 \tag{6}$$

$$\text{s.t.} \qquad a_{t+1} \geq \max\{0, I_t a_t\} \tag{7}$$

Where I_{t+1} is an indicator variable equal to 1 if $a_t < 36$ and 0 otherwise. The cost function at period t:

$$c_t(a_t) = \begin{cases} m(\Theta(a_t)) + e(\Theta(a_t)) & \text{if the vehicle is not replaced} \\ m(\Theta(a_t)) + e(\Theta(a_t)) + P - s(\Theta(a_t)) & \text{Otherwise} \end{cases} \tag{8}$$

captures the trade-off between keeping and replacing the vehicle at any stage t. The cost of keeping the vehicle contains preventive services, spare parts and miscellaneous costs which increase as a function of vehicle odometer. The cost of replacing is the difference between purchasing cost and salvage value. Equation 7 captures ICRC's agreement with the manufacturer to avoid early replacements (before 36 months).

We program the optimal replacement DP model and solve it with a C++ application. Using the ICRC data, our model suggests that the ICRC should replace its vehicles every 100,000 Km. Savings are summarized in table 11.

ICRC Policy	Afghanistan	Ethiopia	Georgia	Sudan
Age policy (5 years)	5.52%	8.35%	3.37%	3.92%
Mileage policy (150,000 Km)	7.28%	9.86%	8.21%	9.31%

Table 11: Savings if vehicles are replaced after 100,000 Km (in %)

In average, by adjusting their replacement policy the ICRC would save 8.7% of operating costs. To give an idea of the magnitude of savings, note that only the cost of capital of international humanitarian 4x4 fleet represents over 1.6 billion US $ and most humanitarian organizations follow the SRP. The ICRC operates in conflict and post-conflict territories and it faces poorer roads compared to companies working in normal conditions. Operating in conflict areas with bad roads forces the ICRC to apply very rigorous maintenance policies for field vehicles. This increases the maintenance cost and favors earlier replacements compared to the odometer threshold suggested by the SRP. Additionally, ICRC's duty free status decreases the replacement cost compared to commercial fleets.

Although other humanitarian organizations like the IFRC, WFP, and WVI do not operate in conflict territories, they also drive their vehicles in poor road conditions and they have a duty free status in most of the countries where they have humanitarian operations. This suggests that earlier replacements should be considered by other large humanitarian organizations.

To check robustness of the results, we perform stochastic simulations of ICRC missions. We assume that monthly mileage follows an exponential distribution with $\mu = \frac{1}{o(i)}$. We do not have enough observations in each month to determine the empirical distribution of monthly mileage. We vary purchasing cost, maintenance cost and salvage value by adding and subtracting 10% to the current values in the interval $[-80\%, 80\%]$. Each time we run 1,000 simulations. Table 12 shows the interval of percentages of change for which the 100,000 Km replacement policy performs better than the 5 years and 150,000 Km one.

	Afghanistan (%)	Ethiopia (%)	Georgia (%)	Sudan (%)
Purchasing cost	[-30, 40]	[-80, 30]	[-80, 20]	[-15, 60]
Maintenance cost	[-35, 80]	[-60, 80]	[-25, 80]	[-50, 35]
Salvage value	[-80, 80]	[-40, 80]	[-60, 80]	[-80, 35]

Table 12: Robustness check summary

The general conclusion from table 12 is that our results are quite robust compared to the SRP. Figure 5 shows that the new policy performs better than both ICRC policies for changes of purchasing cost in the interval $[-15\%, 60\%]$ for Sudan. Below 15% decrease in the purchasing cost the 5 years policy performs better and after 60% increase the current cost the 150,000 Km policy should be used. According to our monthly mileage data, on average, a 5 year old vehicle has approximately 65,000 Km odometer. As expected, our model suggests replacing faster when the purchasing cost goes down and keeping the vehicle for a longer period when the cost goes beyond 60% the current purchasing cost.

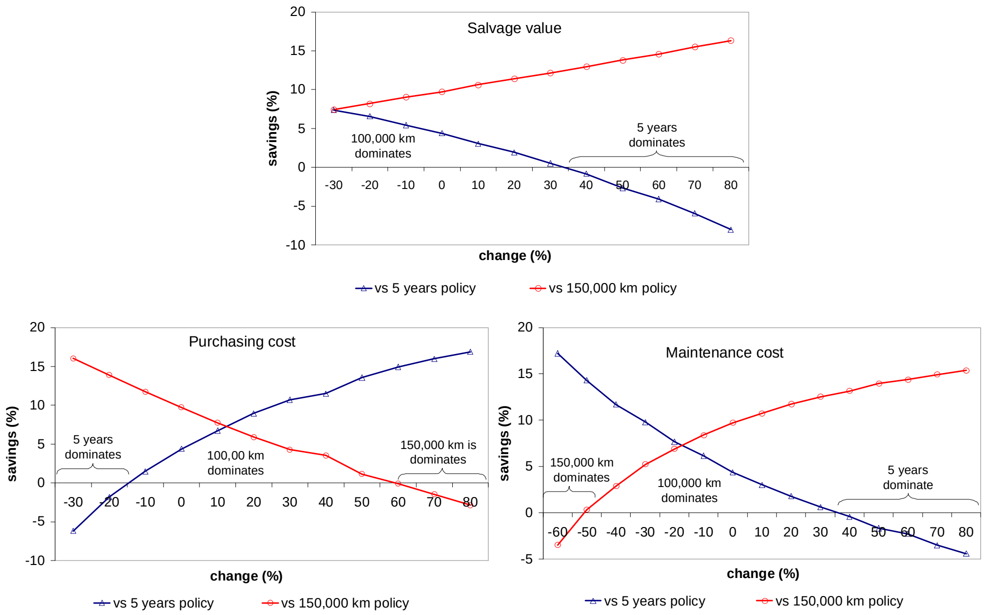

Figure 5: Robustness check Sudan

The 100,000 Km policy performs better than those of the ICRC if the maintenance costs do not increase beyond 35% (figure 5). After that point, the 5 year replacement policy, which in the case of Sudan implicitly dictates replacing earlier, should be followed. Finally, the new policy performs better if the increase in the salvage value is below 35%. If the increment in the salvage value is above 35% then the 5 year replacement policy dominates from a cost perspective which means that earlier replacement is better.

6 Conclusions and future research agenda

We show empirically that significant savings can be made by studying humanitarian fleet management in developing countries. Humanitarian organizations face different conditions than commercial companies operating in normal environments. We find that the standard replacement policy (5 years or 150,000 Km) recommended by vehicle manufacturers to commercial companies is not optimal for the International Committee of the Red Cross. By adjusting its replacement policy to 100,000 Km the ICRC would save approximately 8% of the operating cost. To put this in perspective, note that the total cost of capital of the international humanitarian fleet is estimated at 1.6 billion US$ and that ICRC is considered to be the best practice benchmark of the sector.

Since the ICRC's purchasing cost is below the commercial price, renewing the vehicles more frequently decreases total replacement cost. Additionally, the rigorous maintenance policies due to the critical nature of ICRC operations in terms of security and the poor road conditions in most countries increase total maintenance cost rapidly. Our sensitivity analysis shows that the new replacement policy is robust to a wide range of changes in purchasing price, maintenance cost and vehicle salvage value.

Our findings also suggest that the National Delegations do not follow the replacement policy dictated by Headquarters in Geneva. Very often vehicles reach the 5^{th} year before having 150,000 Km on their odometer but they are generally replaced only when they reach the 8^{th} year or 150,000 Km. A possible explanation for this problem is the misalignment of incentives between the HQ and ND. ND sell vehicles in the local market but the revenues go to the HQ budget. It gives ND incentives to keep vehicles longer than recommended.

Of course, the possible misalignment of incentives problem may also make the implementation of the new replacement policy difficult. Our current research focuses on the alignment of the incentives between ICRC decision making levels to make the new replacement rule operational.

In general, humanitarian organizations face challenges in implementing operating rules and standardized practices. Field workers tend to be independent and creative which can of course be good in some difficult situations they may face. However, these loose interpretations of rules make it difficult to assess whether data are reliable. This makes it necessary to spend enough time in the field to be able to interpret data before feeding it to a decision model. As a simple example, consider that vehicles meant for humanitarian operations can also serve for private needs. Whilst this may be an accepted practice (and part of the expatriate compensation), it can seriously distort mileage and therefore replacement policies.

We highlight the importance of collecting good data and studying the practices of ICRC and other humanitarian organizations. This poses serious challenges since the nature of humanitarian operations makes access to field data very difficult. In emergency operations capturing good quality field data is certainly not the main priority for relief workers. The ICRC is one of the most advanced humanitarian organizations in capturing field data but even so, the data is very noisy and incomplete. We also studied the data and practices of other humanitarian organizations like the International Federation of Red Cross and Red Crescent Societies (IFRC), the World Food Programme (WFP) and World Vision International (WVI), among others. They all collect a lot of data, mostly for pure administrative reasons, but do not seem to use these data for better decision making. We also found that even though many items are tracked, some very basic relevant information (like conflict intensity) is not available. Once the data capturing problem has been overcome, our analysis shows that even simple optimization models can lead to meaningful results.

Given that our comments relate to the better organized humanitarian organizations, it is obvious that data capture and, more generally, professional fleet management is largely absent in the hundreds of smaller NGOs. There is a huge need for more work in this area considering that any savings resulting from better fleet management will be invested in increasing the number of beneficiaries of humanitarian operations.

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