A Policy for Managing Operational Assets to Minimize Deprivation Costs

joint work with Milad Keshvari Fard and Felix Papier

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Background

Field-related: how to improve service delivery, considering the peculiar characteristics attached to humanitarian supply chain?

Demand can be separated into:

- primary beneficiary demand i.e., relief items.
- secondary support demand i.e., operational assets.

Background

Operational assets: those to support the distribution of aid e.g., vehicles.

Humanitarians assign a sizable portion of their limited financial resources to procure, operate and maintain these assets.

Background

Particularly, we focus on vehicles:

- centerpiece of humanitarian service delivery
- fleet management is the second largest overhead expense for humanitarians
    - during 2002-2006, **UNHCR** spent on average USD 9.6 million to purchase new vehicles every year.
- similar supply chain to [almost] all other types of assets e.g., power generator
- multiple-use asset assigned to missions with different levels of criticality
- subject to environmental threats such as accidents, and sharp depreciation rate

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- how many vehicles to buy?
- how to utilize them?

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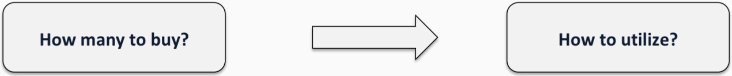
- procurement lead-time and selling limits (in a centralized model)
- high purchase price (in a decentralized model)
- high maintenance costs
- unplanned disposals

Existing literature



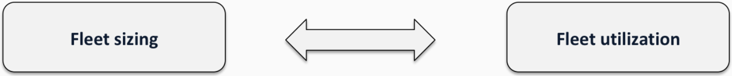
procurement:

- Vehicle supply chain: Besiou et al. (2014) POM; Stauffer et al. (2016) POM.
- Procurement policy and fleet sizing: Ingolfsson et al. (2008) Health Care Mgmt Sci.; Eftekhar et al. (2014) POM.

utilization:

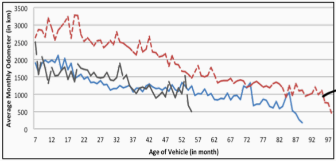
- Vehicle routing: Campbell et al. (2008) Trans. Sci.; Vanajakumari et al. (2016) POM.
- Reliability and replacement policies: Pedraza Martinez & Van Wassenhove (2013) POM; McCoy and Lee (2014) POM.
- Vehicle utilization: Pedraza Martinez et al. (2011) JOM; Eftekhar & Van Wassenhove (2016) JOM.

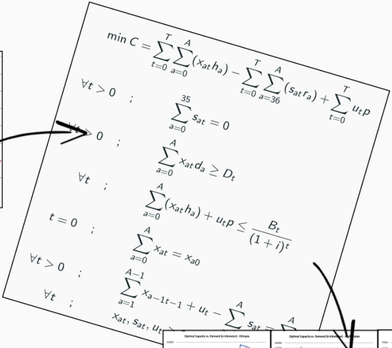
Existing literature



- fleet sizing and fleet utilization cannot be seen in isolation.
- there is a little understanding of field issues.

Existing literature





$$\min C = \sum_{t=0}^{T}\sum_{a=0}^{A}(x_{at}h_a) - \sum_{t=0}^{T}\sum_{a=36}^{A}(s_{at}r_a) + \sum_{t=0}^{T} u_t p$$

$\forall t > 0 \quad ; \quad \sum_{a=0}^{35} s_{at} = 0$

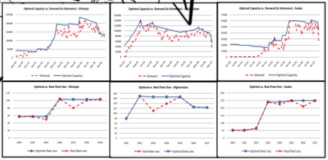
$\forall t > 0 \quad ; \quad \sum_{a=0}^{A} x_{at} d_a \geq D_t$

$\forall t \quad ; \quad \sum_{a=0}^{A}(x_{at}h_a) + u_t p \leq \frac{B_t}{(1+i)^t}$

$t = 0 \quad ; \quad \sum_{a=0}^{A} x_{at} = x_{a0}$

$\forall t > 0 \quad ; \quad \sum_{a=1}^{A-1} x_{a-1t-1} + u_t - \sum^{A} s_{at} = \sum^{A}$

$\forall t \quad ; \quad x_{at}, s_{at}, u_t$



$$\min_{u(t)} J = \frac{1}{2}\int_0^T \left(q[x(t) - D(t)]^2 + r[u(t)]^2\right) \mathrm{d}t$$

$$\dot{x}(t) = u(t) - \frac{x(t)}{\tau}$$

$$x(t) \geq \delta D(t)$$

$$-M \leq u(t) \leq M$$

$$x(0) = 0$$

Goals

optimal fleet sizing and capacity allocation in humanitarian development programs,

considering

- budget uncertainty
- randomness of asset disposal
- saving option
- delivery lead time
- interaction between the number to buy and to operate
- mission importance asymmetry

to minimize *deprivation* costs.

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Model: demand and deprivation cost

For a centralized model, let's assume a non-monotonic sinusoidal demand pattern

$$D_t = \Big[D_m + d \sin(\frac{2\pi}{n}\Big(t + \omega_0)\Big)\Big]$$

Model: demand and deprivation cost

All missions are not equal ⇒ due to resource limitations, prioritizing missions is inevitable ⇒ a convex behavior of the deprivation cost in the number of vehicles assigned.

Model: demand and deprivation cost

Objective function: minimizing deprivation costs (i.e., beneficiaries' suffering due to insufficient humanitarian service delivery)

$$\text{Per period cost function:} \qquad R_t(a_t) = e^{b_t[D_t - a_t]^+}$$

b_t: an aggregated level of diversity of mission criticality at each period.

Model: objective function, and costs

Objective function:

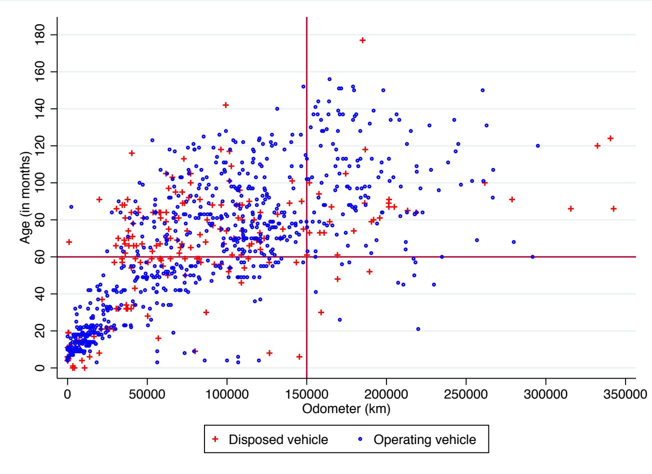
$$J_0(x_0, SB_0) = \min \mathrm{E}\left(\lim_{N\to\infty} \frac{1}{N} \sum_{t=0}^{N} R_t(a_t)\right)$$

Model: objective function, and costs

At the beginning of each period,

- all decisions are made.
- a random budget is available.
- a percentage of budget saved from the previous periods is available.
- the amount spent during the period is known.
- a revenue through selling used vehicles is received.

Model: objective function, and costs



the available fleet size at the beginning of a period, $L(x_t)$, follows a binomial distribution with population x_t and success probability $1 - \gamma$.

Model

$$J_0(x_0, SB_0) = \min \mathrm{E}\left(\lim_{N\to\infty} \frac{1}{N} \sum_{t=0}^{N} R_t(a_t) \right)$$

$$a_t \leq x_t$$
$$x_{t+1} = \min\{L(x_t) + u_t, x^{\max}\}$$
$$S_t \leq SB_t - pu_t - c_o a_t - c_f x_t$$
$$SB_{t+1} = \min\{\rho S_t + r(x_t - L(x_t)) + K_{t+1}, SB^{\max}\}$$
$$x_t, a_t, u_t \in \mathrm{Z}^+, S_t \geq 0$$

3 state variables (t, x_t, and SB_t), 2 decision variables (u_t and a_t), 2 stochastic elements (L and K), and 5 constraints that do not allow the optimal policy to have the required second-order properties.

Simultaneous Allocation Optimization heuristic

The heuristic works in two stages:

1. it estimates the marginal reduction in expected deprivation cost (i.e., the social gain) of every possible amount of operating, purchasing and saving.

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1. it estimates the marginal reduction in expected deprivation cost (i.e., the social gain) of every possible amount of operating, purchasing and saving.

2. applies a portfolio optimization to allocate the available budget to these three options to maximize social gain.

$$V_t^a(a_t^h) + V_t^u(u_t^h, x_t) + V^s(s|\theta)$$

Heuristic

social gain from operating a_t vehicles in period t:

$$V_t^a(a_t) = e^{b_t D_t} - e^{b_t [D_t - a_t]^+}$$

Simultaneous Allocation Optimization heuristic

$$\max_{u_t^h, a_t^h} \left(V_t^a(a_t^h) + V_t^u(u_t^h, x_t) + V^s(s|\theta) \right)$$

$$c_f x_t + c_o a_t^h + p u_t^h \leq SB_t$$
$$a_t^h \leq x_t$$
$$a_t^h, u_t^h \in \mathrm{Z}^+$$

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$$\max_{u_t^h, a_t^h} \left(V_t^a(a_t^h) + V_t^u(u_t^h, x_t) + V^s(s|\theta) \right)$$

- θ determines the concavity of the saving function; $\uparrow \theta \Rightarrow \uparrow$ value on saving.
- rule of thumb: a high θ would be more suitable for situations with high uncertainties.

Numerical experiments

To estimate the model parameters, we benefit from actual **field data** of a large humanitarian organization.

- data of 1,074 Toyota Land Cruiser from 2000-2015
- Syria, Sudan, Kenya, Iraq, and Liberia
- monthly utilization data: purchase price, residual value, age of vehicle, monthly repair costs, maintenance, accident, fuel cost, etc.

Results: sensitivity analyses and discussion

- $\uparrow$budget uncertainty $\Rightarrow$ $\uparrow$deprivation costs, $\downarrow$fleet utilization
- $\uparrow$demand variability $\Rightarrow$ $\uparrow$deprivation costs, $\downarrow$fleet utilization
- $\uparrow$probability of vehicle disposal $\Rightarrow$ $\uparrow$deprivation costs, $\uparrow$fleet utilization: it pushes the delegation to more quickly adjust the fleet size to demand

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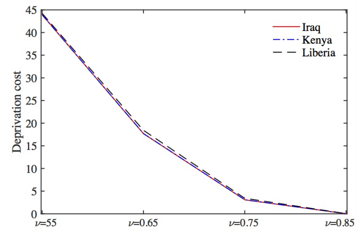
- chasing the demand increases deprivation costs.

Results: sensitivity analyses and discussion

- ↑variation of mission criticality ⇒ ↓expected deprivation cost due to the focus on the most critical missions
- ↑variation of mission criticality ⇒ ↓fleet utilization as the no. of missions fulfilled ↓



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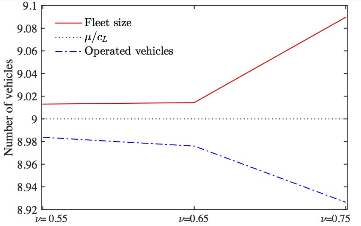
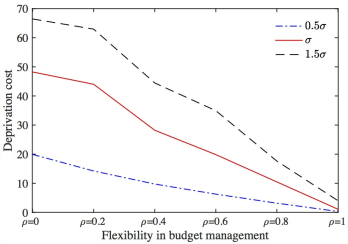
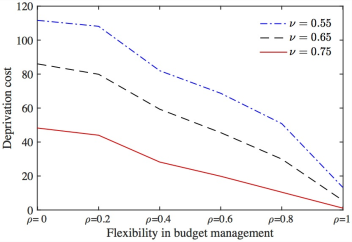


Results: sensitivity analyses and discussion

- Budget savings can significantly reduce the expected deprivation costs, regardless of the budget variation and differences in mission criticality.
- The importance of saving is critical when the budget variation is high.
- The saving option has a positive impact on fleet utilization.





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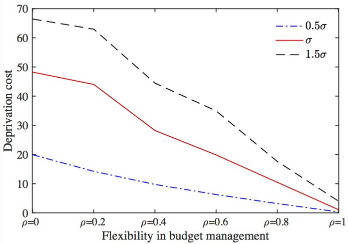

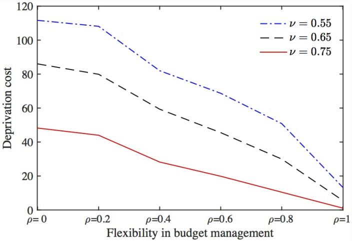

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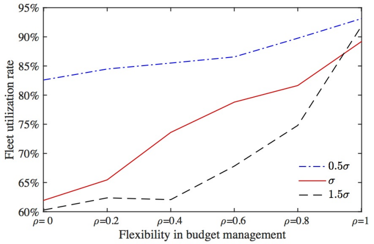

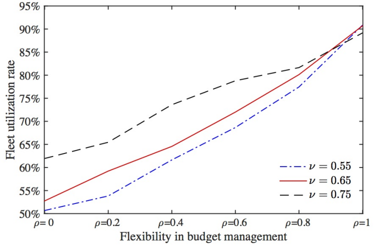

Impact of procurement lead time

Centralized

- Long LT
- Low purchase price

Decentralized

- Short LT
- High purchase price

general belief: due to a shorter LT, decentralized model provides a higher service level, even in the presence earmarked budget.

Impact of procurement lead time

Expected deprivation costs for different scenarios

Lead time	Price markup	σ ×0.5	σ ×1	σ ×1.5	γ ×0.5	γ ×1	γ ×1.5
2	**-**	3.370	3.755	4.801	3.627	3.755	3.879
1	**-**	3.254	3.631	4.600	3.556	3.631	3.719
0	**0%**	3.118	3.502	4.472	3.507	3.502	3.534
0	**50%**	6.323	6.825	7.987	5.110	6.825	8.701
0	**100%**	10.453	11.050	12.288	6.990	11.050	15.067

- centralized policy minimizes both the logistics and deprivation costs.
- the advantages of a centralized fleet policy are particularly strong when the degree of uncertainty is high

Conclusion

Based on our model,

- budget savings between periods can mitigate the negative impact of budget uncertainty.
- chasing the demand at all periods causes larger deprivation costs over time.
- In situations with higher operating costs and/or higher chance of vehicle disposal, smaller fleet size would be optimal: vehicles should be utilized intensively but replaced more frequently.
- in most situations, a centralized procurement model outperforms a decentralized model.

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Questions?

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