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System-of-Systems Iso-performance Search to Inform Multi-actor Policymaking to Reduce Aviation Life Cycle Carbon Emissions

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***Abstract*— This paper presents a system-of-systems formalism for modeling and analyzing multi-actor policy-making to achieve a global system objective. In contrast to a single optimal solution that aggregates objectives of actors, the concept of iso-performance is employed to illuminate multiple global solutions and hence the 'space' for actors to compromise. A case in a policymaking to reduce aviation emissions is presented to demonstrate the approach.**

Keywords—System-of-Systems, iso-performance, multi-actor policymaking, aviation life cycle emissions.

I. INTRODUCTION

Many policymaking activities involving multiple actors and development of technologies have ended up either in a delay, deadlock, or worse, in a court. Such a multi-actor policymaking takes place in an environment where no single actor has the ability to individually determine the overall system performance. Further, global policy objectives (such as reducing aviation carbon emissions) are often in conflict with individual actor objectives (such as profit making and capacity enhancement). Another complicating issue is the asymmetry of cost-benefit distribution among the actors [1]. One actor may pay little costs to pursue the global objective but receive a large portion of direct or indirect benefits. Another may pay much, but benefit less, providing a hindrance to actor participation. In this context, how can decision-makers be informed in a policymaking process involving multiple actors?

This paper proposes a system-of-systems (SoS) construct to structure a policy problem that has global objective beyond that of individual actors. Within a context of multi-actor policymaking (MAP), the main premise in an SoS construct is that the control of overall system performance is distributed across a network of multiple actors, granting each actor a role as co-decision-maker. Further, to inform a coordinated MAP, a so-called iso-performance solution concept is employed to benefit from the fact that the solution to a MAP problem is not unique. In fact, broadening solution options to create solution spaces actors [1] provides more room for compromise among the actors involved than limiting the solution to a single optimal solution.

To provide a framework and solution to MAP, we first elaborate the building blocks (i.e. factors) that make up an SoS for MAP. Next, the interdependencies among the factors are specified. This leads to an iso-performance formulation of SoS for MAP. The rest of the paper applies the formulation to a policy problem of reducing aviation life cycle carbon emissions.

II. SOS APPROACH

A. The Building Blocks of System-of-Systems for MAP

Fig. 1 shows a generic conceptualization of an SoS. Briefly, an SoS comprises constituent systems that due to their nature occupy a hierarchical structure (denoted in the Greek symbols). A system at a higher level (β level and above) encompasses some network of lower level systems. Each system is independent in its own right but needs to interact, both horizontally and vertically, to fulfill an overall system objective (J_z^{SoS}) (see [2] for more details).

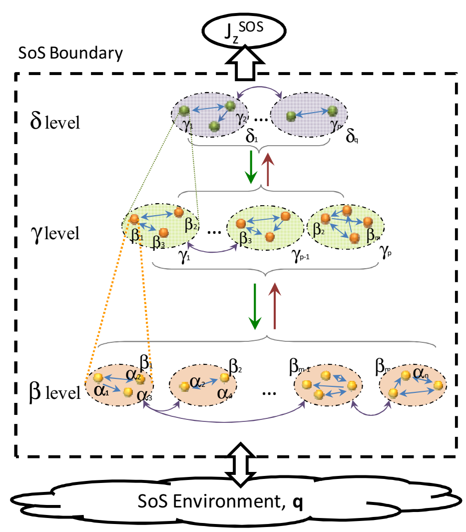

Figure 1. Generic conceptualization of an SoS

For the purpose of modeling MAP, we can distinguish two broad categories of systems:

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(1) Artifact comprised system (ACS) – focuses on the performance and capabilities of relevant physical/ technological systems.

(2) Actor overseen system (AOS) – focuses on the management (e.g. development, operations,) of resources and, possibly, other actor behavior, either horizontally or vertically. For our purpose, the term actor and AOS are used interchangeably.

Taken together, these two categories create flexibility to conceive a wider variety of MAP problems than would be possible in either a 'system design problem' (design of ACS) or 'policy design problem' (design of AOS). Indeed, for MAP, there remains no strict guide for system definition. It still belongs to, as Simon puts it, "science of the artificial" [3].

The variables in a model of a single system can be categorized as (see Fig.2):

- A set of system state variables, **s**
- A set of control variables, **p** namely decision variables actor can control.
- A set of external variables, **x**
- A set of relationships, **f**
- A set of outcomes of interests, **o**
- A set of weights of importance associated to each outcome of interests, **w**. This set constitutes actor's value system.

In addition to the above mentioned variables, there are uncertain external factors that come from outside SoS boundary (i.e. SoS environment, **q**).

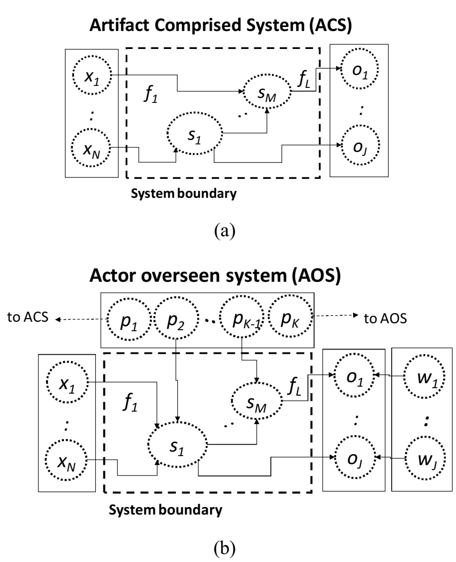


Figure 2. Model variables for a) artifact comprised system (ACS) and b) actor overseen system (AOS)

Depictions of the two system types and their variables appear in Fig. 2. Two major differences distinguish an AOS and an ACS: first, an ACS lacks its own control variables (its direction comes from AOS' set of **p);** second, only actors can assign weight to a set of **o**, which is either related to their associated AOS or relevant ACS.

An SoS for MAP can then be constructed via assemblage of some ACS and AOS systems in a structure resembling the one in Fig.1. Each element in Fig. 1 represents an ACS, which resides at the lowest level (αlevel) and an AOS, which resides at the β level and above.

B. Interdependencies within SoS for MAP

An SoS construct is different from other system approaches partly due to the nested nature of its system constituents with regard to outcomes of interest, ***o*** and system state variables, ***s***. For MAP, this characteristic translates into a relationship in which a system state variable, *s*, at higher level system (ACS) constitutes a function of an aggregate of *o* at the lower level systems (either ACS and/or AOS). The nested SoS characteristics can be formulated as:

$$\exists\ s\ \epsilon \mathbf{s}_{\mathrm{i}}^{\mathrm{level+}}\ \ such\ that\ s_i^{level+} = f\left(\bigcup_{j,level} o_{j,level-}\right), \quad (1)$$

where U here is used as combination/union operator. This relationship implies that an actor at γ level is concerned with an *o* that is broader than, and is of a different nature from, the *o* at β and α level.

Some other interdependencies within an SoS are given in Table I. The interdependencies can be bi-directional: influence in one direction and dependence in another. A dependence linkage can be considered as part of a feedback loop.

TABLE I. TYPE OF INTERDEPENDENCIES WITHIN AN SOS FOR MAP

Linkage of interdependencies	Formalism
1. An outcome of an ACS becomes an exogenous factor for another ACS	$\mathbf{o}_{\mathrm{ACS\ i}} = \mathbf{x}_{\mathrm{ACS\ j;\ i\neq j}}$
2. An outcome of an ACS becomes an exogenous factor for an AOS	$\mathbf{o}_{\mathrm{ACS\ i}} = \mathbf{x}_{\mathrm{AOS\ i}}$
3. An outcome of an ACS affects actor decision	$\mathbf{p}_{\mathrm{AOS\ i}} = f(\mathbf{o}_{\mathrm{ACS\ i}})$
4. Actors' decisions become exogenous factor for an ACS.	$\mathbf{p}_{\mathrm{AOS\ i}} = \mathbf{x}_{\mathrm{ACS\ i}}$
5. An actor decision becomes an exogenous factor for another actor	$\mathbf{p}_{\mathrm{AOS\ i}} = \mathbf{x}_{\mathrm{AOS\ j;\ i\neq j}}$
6. An actor decision affects another actor decision	$\mathbf{p}_{\mathrm{AOS\ i}} = f(\mathbf{p}_{\mathrm{AOS j;i\neq j}})$
7. The outcome of interest of an actor affects the decision of another actor	$\mathbf{p}_{\mathrm{AOS\ i}} = f(\mathbf{o}_{\mathrm{AOS\ j;i\neq j}})$

In this way of specifying interdependencies, we can establish a richer set of actor interdependencies than that normally defined using the conventional game theoretic formulation, which basically only takes actors' decisions (the **p**) into account (i.e. linkage 6 in Table I) (e.g. [4]).

C. Individual System and SoS Performance Definition

The performance or capability of an ACS i can be defined as:

$$perf_{ACS\ i} := \mathbf{o}_i = \mathbf{f_i}(\mathbf{x_{ACSi}}, \mathbf{s_i}), \quad (2)$$

where $\mathbf{x}_{\text{ACSi}} = \{ \mathbf{p}_{\text{AOS}}^{\text{level+}}, \mathbf{o}_{\text{ACS j}}, \mathbf{q}^{\text{SoS}} \}$. This means that the performance of an ACS is a function of the decision of actors at higher level systems, the performance of other ACS, and the uncertainty on relevant factors outside the SoS boundary. In the same way, the utility of an actor overseeing an AOS i can be defined from the input-output relationships as :

$$u_{AOS\ i} := \sum \mathbf{o}_i . \mathbf{w}_i = \mathbf{f_i}(\mathbf{x}_{\text{AOSi}}, \mathbf{p_i}, \mathbf{s_i}), \quad (3)$$

where $\mathbf{x}_{\text{AOS i}} = \{ \mathbf{p}_{\text{AOS j}}^{\text{level+}}, \mathbf{p}_{\text{AOS j}}^{\text{level0}}, \mathbf{p}_{\text{AOS j}}^{\text{level}-}, \mathbf{o}_{\text{ACS j}}, \mathbf{o}_{\text{AOS j}}, \mathbf{q}^{\text{SoS}} \}$. and level0 denotes AOS at the same level as the AOS in question. This means that the utility of an actor is a function of the decision of some actors at higher, same, and lower level systems, the performance of some ACS, and actor's uncertainty about the relevant factors outside the SoS boundary.

about the overall objective, J_z^{SoS}, transcends all $\boldsymbol{o}$ of actors, ultimately depending on the level of $perf_{ACS\ i}$ and all actors' actual decisions. But because ACS performance in turn depends on $\boldsymbol{p}$ and $\boldsymbol{q}$, we can simplify such that:

$$J_z^{SoS} = \mathbf{f^{SoS}}(\mathbf{p}, \mathbf{q}) \quad (4)$$

III. Iso-performance solution for MAP

Though the term Iso-performance seems to have been first coined by de Weck and Jones [5], the origin can be traced back to the work in exploratory modeling [6]. The main idea of the solution concept is to first set a desired performance target and then search model outcomes to find a set of satisfying solutions.

A. Iso-performance Formulation

We take the idea further by adding two conditions: 1) $\text{J}_\text{z}^{\text{SoS}}$ is achieved within a certain tolerance and 2) the discrepancy of cost and benefit among actors must be brought within a certain boundary. Ideally the different between one's cost function and the average should be close to zero, meaning every actor contributes at the same amount. Furthermore, in pursuing $\text{J}_\text{z}^{\text{SoS}}$, actors may need to take measures that they would not take under normal circumstances. So it is important in the analysis to separate such extra measures with those that would be taken anyway. This is to avoid, for example, giving credits to a so-called. "free rider".

Under a condition of exclusive self-interest (i.e. not pursuing a $\text{J}_\text{z}^{\text{SoS}}$), an actor maximizes his utility for a finite period of time, T and under a condition of uncertainty:

$$u_i^* = \max\ E\left\{\sum_{t=0}^{T} \rho^t .\ u_{i,t}\right\}, \quad (5)$$

where E = expectation operator and ρ = discount factor, which indicates how much an actor values short-term versus long-term costs and benefits. The result of this utility function can be considered as a local optimum for an actor

Let there be n actors (each oversees an AOS) and m ACS across SoS. Actor i selects decisions $\mathbf{p}_i$ that belong to decision sets $\mathbf{p}_i$ ($\subset \mathbb{R}^{n_i}$). Further let $c(\mathbf{p}_i, \mathbf{x}_i)$ be a cost function of actor i as a result of pursuing J_z^{SoS}. This measure can have positive value when actor benefits from an SoS endeavor.

$$c_i(\mathbf{p}_i, \mathbf{x}_i) = u_i^{SoS} - u_i^* \quad (6)$$

So, the iso-performance search can be formulated as:

1. Find $\mathbf{p}_{\text{iso}} \in \mathbf{I}$

$$\text{s.t. } \text{I} = \{\mathbf{p} \mid J_z(\mathbf{p}, \mathbf{q}) \approx J_z^{SoS}\} \quad (7)$$

$$\text{where } (1-\Delta)\, J_z^{SoS} \leq J_z(\mathbf{p}, \mathbf{q}) \leq (1+\Delta)\, J_z^{SoS}$$

$$g(\mathbf{p}, \mathbf{q}) \leq 0,\ h(\mathbf{p}, \mathbf{q}) = 0$$

$$\boldsymbol{p}_i^{min} \leq \boldsymbol{p}_i \leq \boldsymbol{p}_i^{max}, \forall \text{ actor i}$$

2. Find $\mathbf{E} = \left\{ \mathbf{p}_{\text{iso}}^* \mid \frac{c_i(\mathbf{p}*_{\text{iso}})}{u(\mathbf{p}*_{\text{iso}})} \leq \text{Threshold}_\text{i}\ \forall\ \mathbf{p}_{\text{iso}}^* \subset \mathbf{I} \right\}$, (8)
where $\text{Threshold}_\text{i}$ represents the upper bound tolerance for actor i .

3. Select $\mathbf{p}_{\text{iso}}^{**} \in \mathbf{E}$ as part of actors negotiation process (9)

B. Technique for Iso-performance Search

To operationalize the iso-performance search, we employ exploratory modeling and Latin-Hypercube Sampling (LHS) [7]. To search among and identify a pattern within performance among alternative solutions, we employ a classification tree model [8]. This approach applies a non-parametric classification algorithm, consisting of a sequence of binary split mechanisms, to the database of model runs. The algorithm involves an iterative process in which two questions are asked and answered: (1) which input variable in the model should be selected to produce the maximum reduction in variability of the output variable and (2) which value (i.e. splitting value) of the selected variable results in the maximum reduction in variability of the output variable.

IV. Illustrative Case

As a proof of concept, we illustrate the approach using a case centered on the goal to reduce aviation carbon emissions. Important technological advances in this area involve, in particular, the development of alternative jet fuels [9]. Because the combustion of "drop in" alternative fuels produces the same amount of carbon emissions as conventional (petroleum-based) jet fuel, the life cycle (LC) emission impact of the fuel production needs to be accounted. Furthermore, our illustrative case considers the possibility of a US carbon cap and trade scheme that includes aviation emissions, with similar implementation as the EU's slated for 2012 [10]. We seek to explore how these developments would impact actors' decisions and their utilities and then report how a coordinated policymaking can achieve an overall emission reduction target.

A. Model Description

Table II presents some key elements of the SoS construct for the case study. They are briefly described below.

α level – The relevant ACS are Aircraft Technology Portfolio System (ACS_1^α) and Alternative Jet Fuel Portfolio System (ACS_2^α). One key system state variable, s, for ACS_1^α is aircraft fuel and payload-range characteristics, which is determined by aerodynamic efficiency, aircraft weight, and engine efficiency, among others. Besides the current technologies, we focus on one new aircraft type: a Boeing 787 (B787). We look at the case in which starting from 2015, only B787 are delivered to accommodate demand. One main o is how much more efficiency gain can be produced in addition to autonomous efficiency improvement resulting from the status quo (set to 1%). This is part of the p of aircraft and engine maufacturers in addtion to their business as usual decisions. For ACS_2^α, two sources of alternative fuels are considered: bio-jet obtained from palm-oil (no change in land use assumed) and biomass. Their life cycle emissions are about 31% (palm-oil) and 14% (biomass) of those of conventional jet fuel [9]. An inequality constraint is imposed at this level such that the blend of bio-jet with conventional fuel should not exceed 50%, since greater percentage affects engine performance (100% biojet would freeze at high altitude). Here, we are dealing with the questions: how early, by how much, how fast, and at what costs the alternative fuel could be made available.

β level – The relevant AOS considered are AOS_1^β (Airlines

TABLE II. SPECIFICATION OF SOS FOR MAP

	Relevant Systems	Relevant System Variables	Interdependency	Value range	Unit
α	ACS_1^α (Aircraft Technology Portfolio System)	x:aircraft technology choice	p (AOS_2^β)		
		s: aircraft payload-range		aircraft specific	kg-nm
		o_1 : fuel burn efficiency		Boeing 787 equivalent	pound per payload and nm
		o2: operating cost unit			
	ACS_2^α (Alternative Jet Fuel Portfolio System)	x: level of investment	p AOS_3^β		
		s : fuel chemical characteristic			
		o :life cycle emission		[85, 120]	g CO2 per MJ
β	AOS_1^β (Airline Operation System)	x1: level of travel demand growth	q2		
		x2: availability alternative fuel	f(o AOS)		
		p1: aircraft orders and retirement	f(q2)		
		p2: use of alternative fuel	f(q1)		
		s: aggregate life cycle emission unit	$\Sigma\, o$ (ACS_1^α, ACS_2^α)		
		o1: carbon emissions			
		o2: profit			
	AOS_2^β (Aircraft / Engine Manufacturer Development and Production System)	x1: aircraft orders	p AOS_1^β		
		x2: government subsidy	p4 AOS_1^γ		
		p1: ac technology choice		B787	
		p2: efficiency target		[1%, 10%]	
		s: technological capabilities			
		o: return on investment			
	AOS_3^β(Refinery Companies Alternative Fuel Investment System)	x: demand for alt. fuel	f(p2 AOS_1^β)		
		s1: source of alt. fuel		biomass, palm oil	
		s2: investment costs per capacity installed		20 (palm-oil) and 120 (biomass)	2004 $ per gallon capacity
		p1: investment level	f (p4 AOS_1^γ)		$ NPV
		p2: introduction year		[2009, 2015]	year
		o: return on investment ROI			
γ	AOS_1^γ (US Government Environmental Policy System)	p1 : standard for setting free allowance amount		"benchmarking"(0) or "grandfathering"(1)	(0)= kg CO2 per RPK flown, (1)=average kg CO2 2005-2008
		p2: start carbon trading		2012	
		p3: emission reduction target and tolerance level		14% and 25%	ton CO2 in 2020 vs. the 2005 level
		p4: subsidy level			US $
		s:aggregate emission level	$\Sigma\, o$ (AOS_1^β)		US $
		o: policy costs			$ of tax payers
	SoS Environment	q1: price of carbon	output of carbon market	[10,30]	$ per ton CO2 saved
		q2: level of demand		[0%, 5%]	

Operation System), AOS_2^β (Aircraft/ Engine Manufacturers Development and Production System), and AOS_3^β (Refinery Companies Alternative Fuel Investment System). A key system state variable for AOS_1^β is aggregate life cycle emissions, which is a function of an aggregation of an *o* of ACS_1^α (fuel burn) and an *o* of ACS_2^α (life cycle emission unit). Each group of actors acts towards their associated AOS and ACS utilities. Airlines and Manufactures, for example, affect the state of the system ACS_1^α based on the rationale to optimize their utility. Key outcomes of interests for the three groups of actors are those related to profitability since all actors are commercial entities.

γ level – The AOS considered here is the US government environmental policy system. We model different decision variables such as the design of carbon trading scheme which determines how the free allowances for airline are determined. The first option is to base allowances on the historical emission level (so called "grandfathering"). Another option is based on benchmarking of a certain performance value (set to 12.64 kg CO2 per 1000 Revenue Passenger Kilometer) (cf. [10]) This gives airlines an incentive to improve its aircraft fleet efficiency by acquiring better fuel efficient aircraft. The decision-maker at this level also decides on the start of the emission trading (set to the year 2012). The government provides subsidy to assist the development of new aircraft technology. The new US administration is still developing its environmental policy, setting the initial target to be a 14% reduction in 2020 compared to the 2005 level. Varying tolerance level around this target is one way to explore possible compromises the government can offer to other actors.

SoS Environment – Here the level of travel demand and the price of CO_2 are treated as the variables outside the SoS boundary. The first is an output of demand dynamics (so another AOS), while the second is based on carbon market dynamics, both of which are treated beyond the scope of the analysis.

B. Simulation

To simulate the resulting emissions from airline operations and fleet choice, we employ a resource allocation model on 5 major US cities that is based on the criteria of minimizing airline's direct operating cost subject to meeting passenger demand and aircraft trip limitations [11]. The number of samples of model inputs is 707 using the LHS method. We simulate only the benchmarking method for allocating allowances and the price of carbon is set to 20 $ per ton.

C. Preliminary Results and Analysis

The funnel of emission trajectories, with upper and lower bound, resulting from the simulation of sampled inputs is given in Fig. 3. The level of LC emissions is normalized using the 2005 level to indicate the magnitude of possible trajectories and is benchmarked against the 14% reduction target level with its 25% tolerance band. Three emission trajectories are depicted to represent those that fail (151

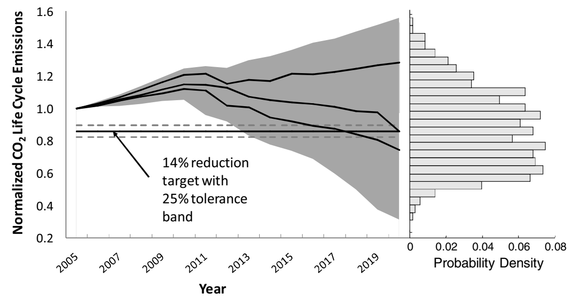
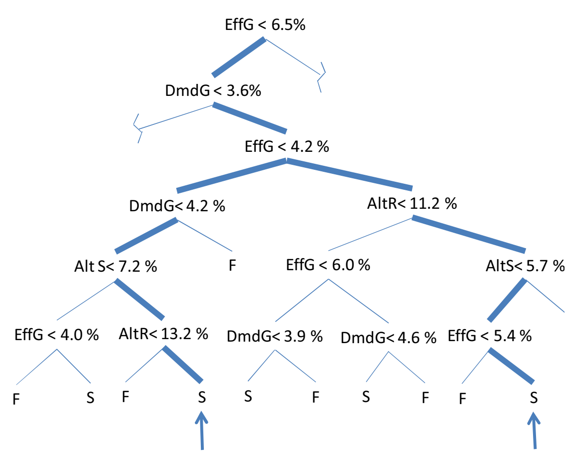


Figure. 3. The funnel of life cycle emission trajectories

cases), succeed (393 cases), and even exceed the target (163 cases). For the first five years the emissions would increase up until 2010 before some drops can be seen mostly as the result of the introduction of alternative fuel.

Applying the classification tree algorithm reveals the necessary conditions for achieving reduction target. Fig. 4 shows the results of iso-performance search in a form of a partial classification tree (due to space limitation) with two categories of J_z^{SoS} outcome at the end nodes: F (reduction target not met), and S (reduction target is achieved within the tolerance level). One pattern of SoS performance is identified by following each split of the tree to the end node. In each instance, the leftward direction indicates a meeting of the conditional value.

Extra aircraft efficiency growth (EffG) and travel demand growth (DmdG) are the most important factors followed by those associated with alternative fuels: their initial share (AltS) and adoption rate (AltR). The partial tree analyzed here is for the EffG < 6.5% and DmdG >3.6% (i.e. the first two splits). Further down the tree, to illustrate the iso-performance search, we take two end nodes of success (S) that are distinguishable by the third split: one with EffG <



EffG: B787 extra efficiency improvement rate	DmdG: passenger demand growth	S: Success
AltS: initial share alternative fuel	AltR: adoption rate alternative fuel	F: Failure

Figure. 4 A partial classification tree for aviation LC carbon emissions

4.2% and the other with 4.2% < EffG < 6.5%. Using the classification tree, one can derive a variety of 'if-then' rules of conditions that lead to the achievement of policy target (i.e. iso-performance). One such rule will read (see right-hand arrow in Fig.4): the emission reduction target will be achieved if 5.4%< EffG <6.5%, DmdG >3.6%, AltR >11.2%, and AltS <5.7%.

The spider chart in Fig. 5 shows in more detail several combinations of conditions of iso-performance. Other variables included are the source of alternative fuel (AltT): biomass (index=0.5) or palm oil (index=1) and the year of its introduction (AltY). In addition, we include the financial impacts on two actors in pursuing the reduction target: one is the marginal NPV investment for alternative fuel (AltI) and the other additional costs incurred by airlines as the result of carbon cap and trade scheme (AlCost).

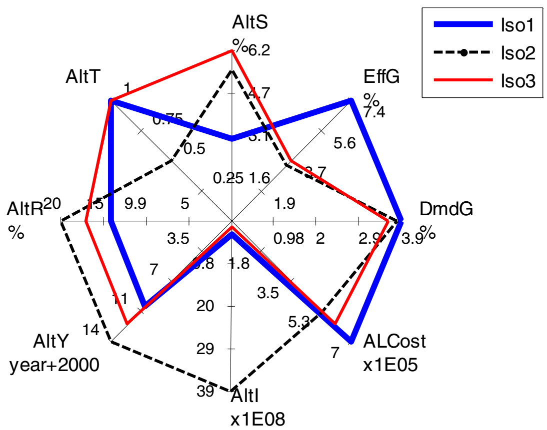


Figure 5. Spider chart of iso-performance

The chart shows how a low realization of one variable can be compensated by high manifestation of another. Alternative fuel from biomass, for example, is more expensive to produce than that from palm-oil (see Iso2). But because biomass fuel produces less LC emissions, the higher costs can be compensated by a lower requirement from aircraft efficiency, which is under the control of different actor (iso1). The trade-off between Iso1 and Iso3 is that Iso1 requires a lower initial share of alternative fuel, which is compensated by a higher aircraft efficiency improvement rate that in turn can accommodate a slightly higher growth of travel demand.

Developing these insights is the main point of the approach presented in this paper. A common mode of measure, such as monetary value, is important to enable actors to negotiate such trade-offs in a MAP.

V. Concluding Remarks

Our paper demonstrates an approach that for an inform a multi-actor policymaking by structuring the MAP as a system-of systems and by using iso-performance search to illuminate the multiple conditions that are required to achieve a global goal beyond that of an individual actor. A global system objective can be achieved by shifting the burden among the actors involved. This sets the possible solutions that each actor can bargain with each other.

One direction for further research is to investigate a mechanism to clear the discrepancies of costs and benefits among actors. Another direction is to include airport and air traffic control operators whose role to increase operational efficiency as part of the proposed next generation (NEXTGEN) air traffic management system would have significant impact on reducing aviation emissions. Further research can benefit from game theory where a policymaking is formulated as a Stackleberg leader-follower game where actors at lower level systems try to outguess the moves of actors at higher level.

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References

[1] A. Mozdzanowska and R. J. Hansman, "System Transition: Dynamics of Change in the US Air Transportation System," International Center for Air Transportation, MIT, 2008.

[2] D. B. Agusdinata and D. DeLaurentis, "Specification of System-of-Systems for Policymaking in the Energy Sector," *Integrated Assessment Journal,* vol. 8, pp. 1-24, 2008.

[3] H. A. Simon, *Science of the Artificial, 3rd Ed.* Cambridge, MA: Massachusetts Institute of Technology Press, 1996.

[4] J. Rao*, et al.*, "A study of optimal design under conflict using models of multi-player games," *Engineering Optimization,* vol. 28, pp. 63-94, 1997 1997.

[5] O. de Weck and M. Jones, "Isoperformance: Analysis and Design of Complex Systems with Known or Desired Outcomes," presented at the 14th Annual International Symposium of the International Council on Systems Engineering (INCOSE), Toulouse, France, 2004.

[6] S. C. Bankes, "Exploratory Modeling for Policy Analysis," *Operations research,* vol. 41, pp. 435-449, 1993.

[7] M. D. McKay*, et al.*, "Comparison of 3 Methods for Selecting Values of Input Variables in the Analysis of Output from a Computer Code," *Technometrics,* vol. 21, pp. 239-245, 1979.

[8] L. Breiman*, et al.*, *Classification and Regression Trees*. Monterey: Wadsworth, 1984.

[9] J. I. Hileman*, et al.*, "The feasibility and potential environmental benefits of alternative fuels for commercial aviation," presented at the 26th International Congress of the aeronautical Sciences (ICAS), Anchorage, USA, 2008.

[10] J. Scheelhaase and W. Grimme, "Emissions trading for international aviation - an estimation of the economic impact on selected European airlines," *Journal of Air Transport Management,* vol. 13, pp. 253-263, SEP 2007 2007.

[11] W. A. Crossley and D. A. DeLaurentis, "System-of-Systems Approach for Assessing New Technologies in NGATS," ed: Purdue University, 2007 (unpublished).