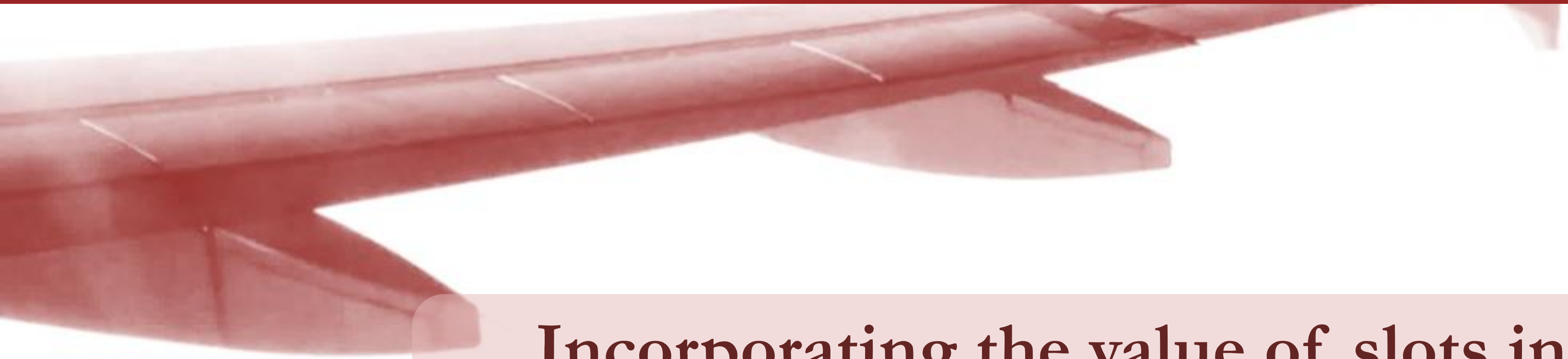

Incorporating the value of slots in airport slot scheduling decisions

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Lancaster University Management School

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Agenda

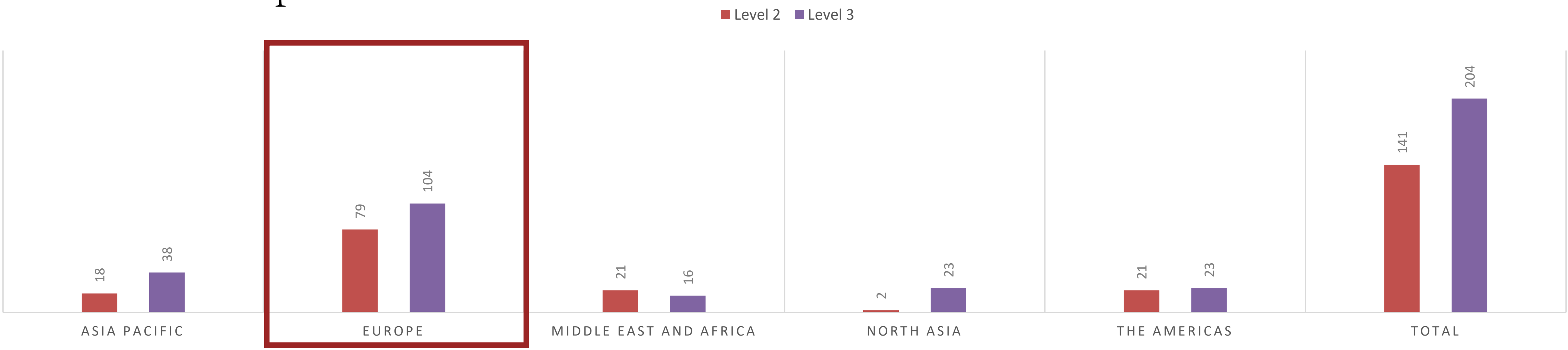
- Presentation's objectives
- Motivation
- IATA world schedule guidelines (WSG) overview
- Related work
  - Optimisation slot allocation models (SAM) considering elements of IATA's WSG
  - Multi-attribute decision-making (MADM) in air transport
- Proposed approach
  - Illustrative application and results
- Discussion on current and future work

Objective

- Propose a mathematical optimisation airport slot allocation model that can consider the preferences of the stakeholders participating in the airport slot coordination process via:
    1. An indicative Analytical Hierarchy Process (AHP) tree structure which considers several airport slot characteristics so as to determine the Slot Valuation Index (SVI)
    2. A two-stage solution approach that:
        I. Calculates the SVI for all airport slot requests submitted at a single airport during a slot scheduling season; and
        II. Incorporates the SVI in an airport slot scheduling integer program (IP)

Motivation - IATA Worldwide Slot Guidelines

- The slot allocation process described in IATA (2019) is the dominant airport demand management mechanism in congested airports (>200 slot coordinated airports)
- The main part of this process is the initial slot allocation, carried out by the appointed coordinator
- The coordinator uses expert systems (e.g. Condor and Score GDC) to allocate the slots based on the rules and priorities



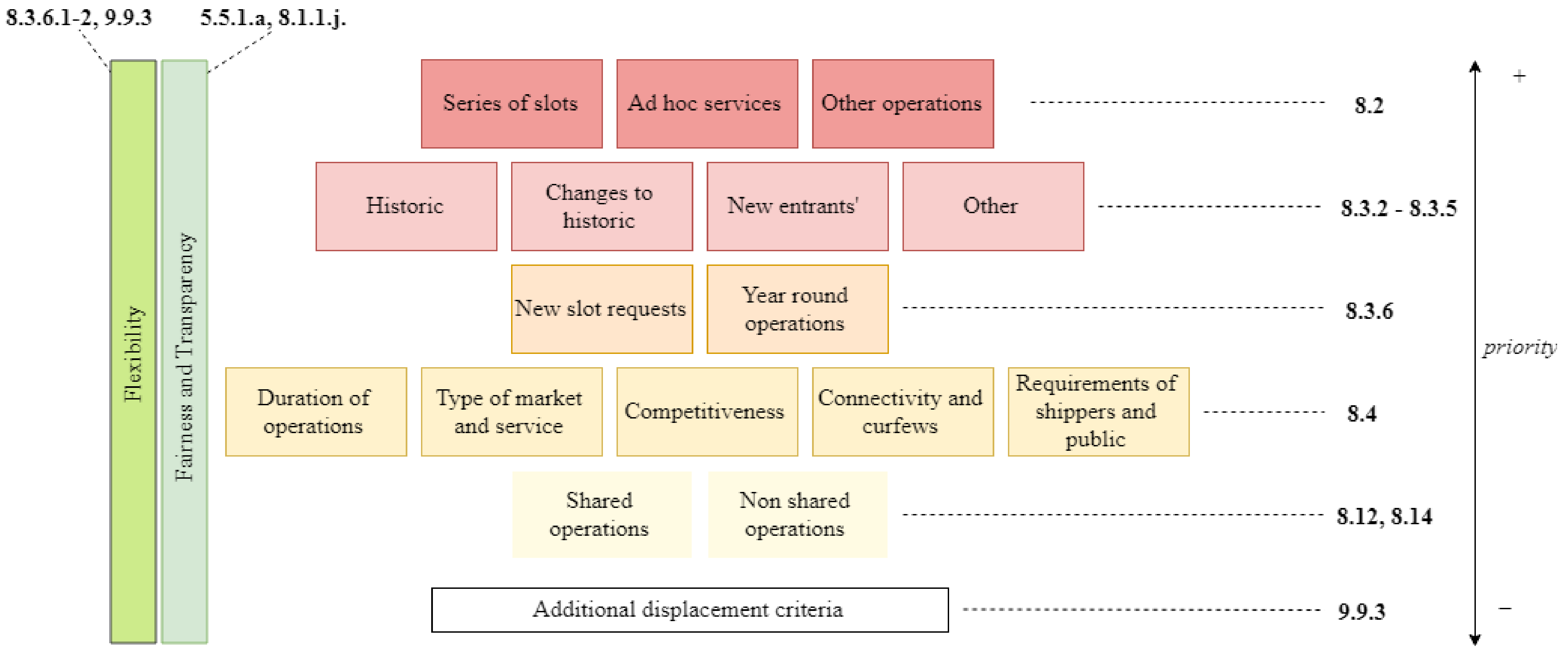
Motivation – recent research trends

- Mixed integer programming has proved to produce efficient airport slot schedules;
- Recently multi-objective optimisation models have been employed to grasp the problem's requirements;
- However, all models assume that 'a slot is slot' and do not distinguish the differences in slots' value; occurring from their differing characteristics (aircraft, distance, route serviced etc.);
- The inclusion of additional elements (e.g. rules and characteristics) increases the complexity of the models, leading to intractable computational times;

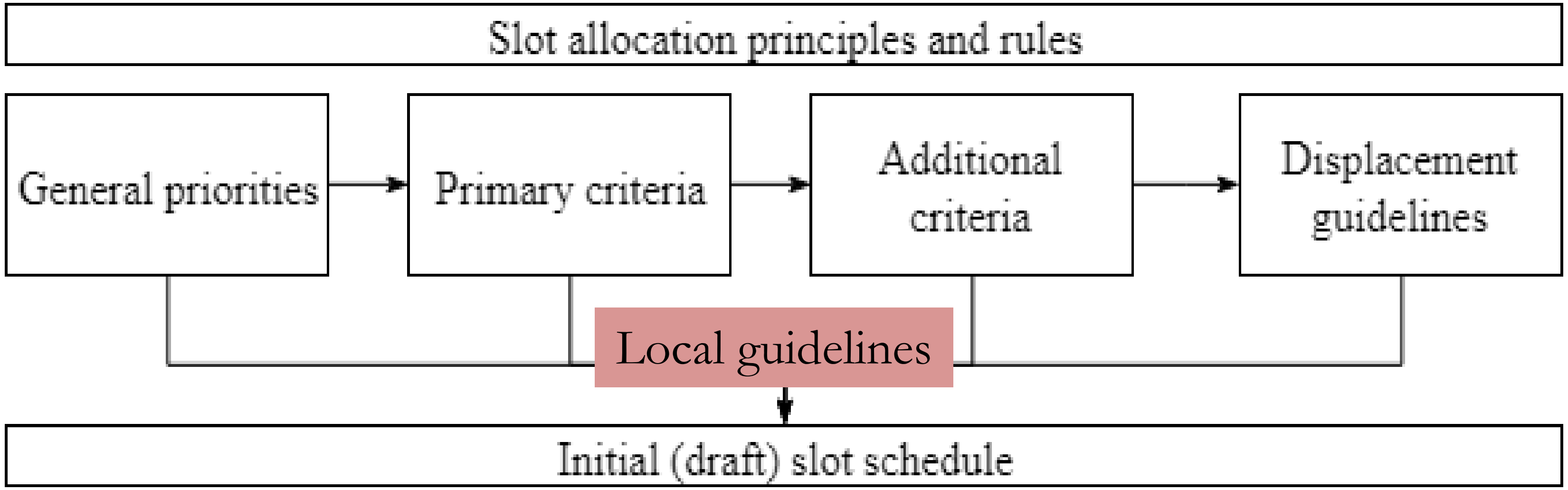
Motivation – research question

Can we provide a **measure for the value of slots** *capturing* **policy requirements** *and* **slot characteristics** *without increasing the complexity of the optimisation models?*

IATA WSG


8.3.6.1-2, 9.9.3
5.5.1.a, 8.1.1.j.
Flexibility
Fairness and Transparency
Series of slots
Ad hoc services
Other operations
8.2
Historic
Changes to historic
New entrants'
Other
8.3.2 - 8.3.5
New slot requests
Year round operations
8.3.6
Duration of operations
Type of market and service
Competitiveness
Connectivity and curfews
Requirements of shippers and public
8.4
Shared operations
Non shared operations
8.12, 8.14
Additional displacement criteria
9.9.3
+
priority
–

IATA WSG


Slot allocation principles and rules
General priorities
Primary criteria
Additional criteria
Displacement guidelines
Local guidelines
Initial (draft) slot schedule

Airport slot allocation models considering certain IATA WSG

	Primary criteria			Duration	Additional criteria					Displacement criteria						Fairness	Flexibility	PSO routes
Model	8.3.2	8.3.3	8.3.4, 8.3.5	8.3.6	8.4.1.a	8.4.1.b.	8.4.1.c.	8.4.1.d, 9.7.3.d	8.4.1.e	9.9.3.a	9.9.3.b	9.9.3.c	9.9.3.d	9.9.3.e	9.9.3.f	5.5.1.a, 8.1.1.j	8.3.6.1-2, 9.7.3.b	CR 95/93 (1993)
Zografos et. al. (2012)	✓	✓	✓	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Zografos and Jiang (2016)	✓	✓	✓	×	×	✓*	×	×	✓	×	×	×	×	✓*	✓	✓	×	×
Zografos et al. (2017)	✓	✓	✓	×	×	×	×	×	×	×	×	×	×	✓*	✓	×	×	×
Ribeiro et al. (2018)	✓	☑	☑	×	×	×	×	×	×	✓	✓*	✓	×	✓*	✓	×	×	×
Fairbrother and Zografos (2018a)	×	×	×	×	×	×	×	×	×	×	×	×	×	✓*	✓	✓	×	×
Fairbrother and Zografos (2018b)	✓	✓	✓	×	×	×	×	×	×	×	✓*	×	✓*	✓	✓	✓	✓*	×
Addressed	✓	✓	✓	×	×	✓*	×	×	✓	✓	✓	✓	✓*	✓	✓	✓	✓*	×

Notes: Historic slot requests (*8.3.2.*), Changes to historic slots (*8.3.3.*), New entrants rules (*8.3.4., 8.3.5.*), Year round operations (*8.3.6.*), Effective period of operation (*8.4.1.a.*), Type of service and market (*8.4.1.b.*), Competitive factors when rejecting slots (*8.4.1.c.*), Curfews (*8.4.1.d.*, 9.7.3.d.), Requirements of shippers and travellers (*8.4.1.e.*), offers shall not place airlines in less favourable conditions than the ones held (*9.9.3.a.*), acceptable/ unacceptable offers (*9.9.3.c.*), consistent turnaround times (*9.9.3.f.*), flexibility sections (*9.9.3.b., 9.9.3.d. 9.9.3.e.*), addressed/ accurately addressed (✓/☑), not addressed (×), * partially considered, Fairness stands for transparency and non-discrimination of airlines.

* There is a parallel stream of research that considers airport slot scheduling in the U.S and does not consider IATA's WSG which is not illustrated in the table above

MADM in air transport

Paper	Application area	Methods	Multiple stakeholders
Zografos, Giannouli (2001)	ATFM system cost effectiveness	AHP	✓
Tsaur et al. (2002)	Airline efficiency	AHP, fuzzy numbers	×
Geimba De Lima et al. (2007)	Airline efficiency	AHP	×
Pestana Barros and Dieke (2007)	Airport efficiency	DEA	×
Madas and Zografos (2010)	Slot allocation policy selection	AHP	✓
Castelli and Pellegrini (2011)	4D trajectory window specification	AHP	✓
Kuo (2011)	Airline efficiency	VIKOR, GRA, fuzzy numbers	✓
Liou et al. (2011)	Airline efficiency	VIKOR	✓
Baltazar et al. (2014)	Airport efficiency	MACBETH, DEA	×
Zietsman and Vanderschuren (2014)	Airport efficiency	AHP	✓
Lupo (2015)	Airport efficiency	ELECTRE III, fuzzy numbers	✓
Olfat et al. (2016)	Airport efficiency	DEA	✓
Bongo and Ocampo (2017)	ATFM action selection	DEMATEL, ANP, TOPSIS, fuzzy numbers	×
Yang et al. (2017)	Multi-aircraft conflict resolution	TOPSIS	✓
Sidiropoulos et al. (2018)	Design of dynamic arrival and departure routes	AHP	✓

Proposed approach – AHP (Suitability)

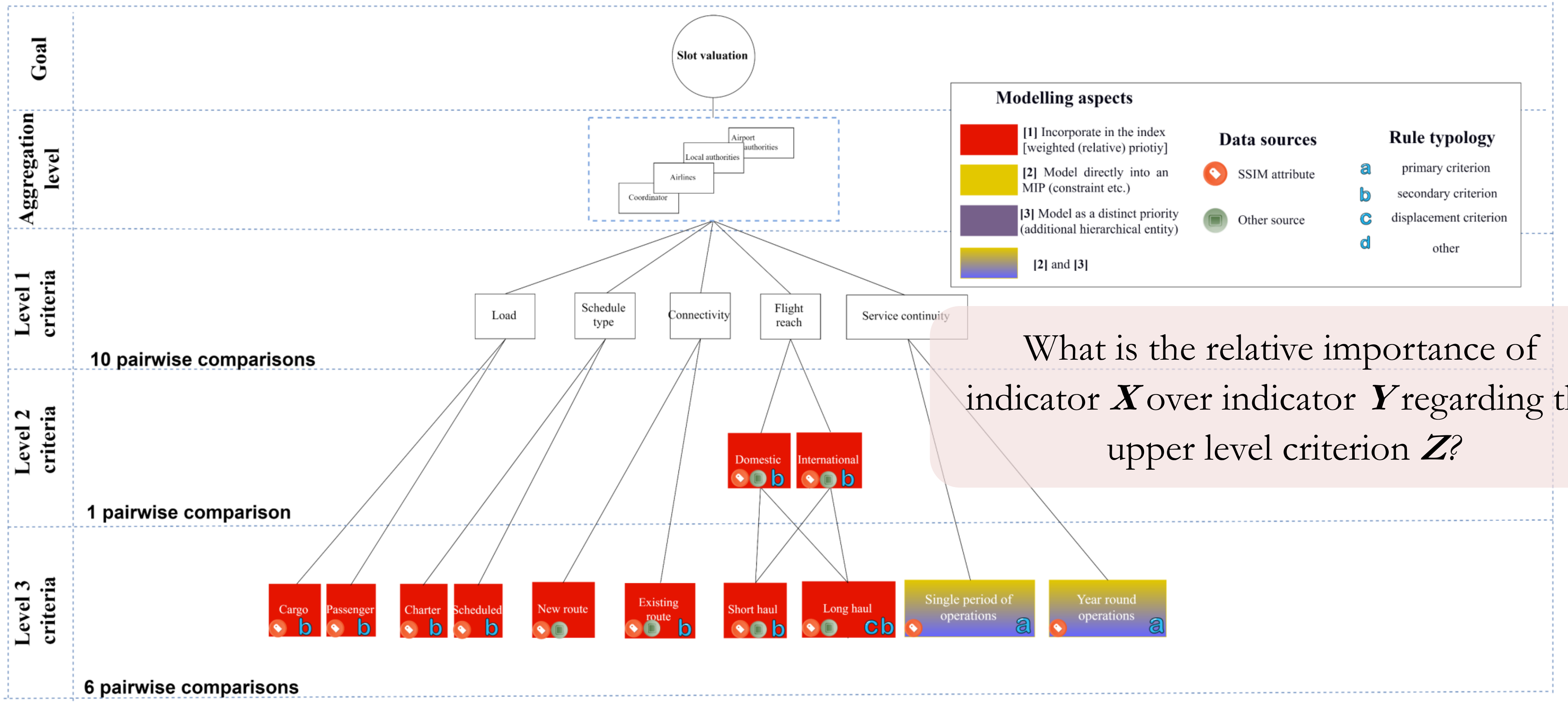
- The MADM technique should be able to provide weights to the considered valuation criteria;
- The process and the results should be transparent and fairly understandable by the stakeholders;
- The technique should be easily converted to a group decision support tool allowing collaborative decision making under the participation of various stakeholders which may have conflicting views;
- The method should be able to consider both objective and subjective criteria and measurements;
- The method should be able to measure/ consider the logical consistency of the responses; and
- The method should facilitate sensitivity analyses on its outcome;

Katsigiannis (2018)

Proposed approach – AHP (1/3)

- The lower level of the tree consists of slot request characteristics which can be used to consider the additional slot allocation criteria which are illustrated in Level 1;
- The goal is to assign weights to each node of the hierarchy so as to determine the importance of each slot characteristic;
- The indication of a suitable opinion aggregation function is required when multiple experts fill the questionnaire (e.g. weighted mean or weighted geometric mean);

Proposed approach – AHP (2/3)



What is the relative importance of indicator ***X*** over indicator ***Y*** regarding the upper level criterion ***Z***?

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Proposed approach – AHP (3/3)

What is the relative importance of indicator ***X*** over indicator ***Y*** regarding the upper level criterion ***Z***?

Response	**Description**	**Meaning**
1	Equal importance	X, Y contribute equally to Z
3	Moderate importance	
5	Strong importance	Experience and judgement strongly favour X over Y
7	Very strong importance	
9	Extreme importance	X is favoured over Y to the greatest extent possible regarding Z
2, 4, 6, 8	Intermediate values	
Reciprocals (1/2, …, 1/9)	The inverse significance is assigned	Y is more important than X regarding Z

(Saaty, 1989)

Proposed approach – Illustrative example (Preferences 1/2)

- A questionnaire with pairwise comparisons among all red-coloured criteria is completed;

Level 1 criteria	Load	Schedule type	Conne-ctivity	Flight reach
Load	1	2	4	3
Schedule type	1/2	1	5	1
Connectivity	1/4	1/5	1	1
Flight reach	1/3	1	1	1

Level 2 criteria	Domestic	International
Domestic	1	2
International	1/2	1

* This example is supplied in order to illustrate the applicability of the method and does not reflect the views of other stakeholder groups

Proposed approach – Illustrative example (Preferences 2/2)

Level 3 criteria	Cargo	Passenger
Cargo	1	1/2
Passenger	2	1

Level 3 criteria	New	Existing
New route	1	1
Existing route	1	1

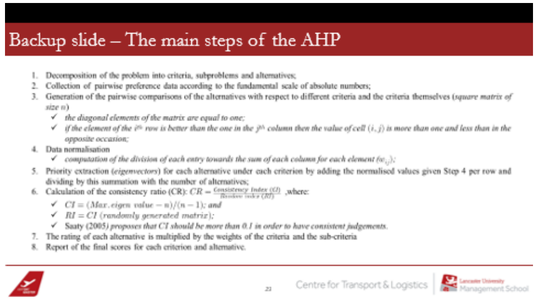
Domestic

Level 3 criteria	Short	Long
Short haul	1	5
Long haul	1/5	1

International

Level 3 criteria	Short	Long
Short haul	1	1/7
Long haul	7	1

Proposed approach – Illustrative application (Criteria weights)



Backup slide – The main steps of the AHP

1. Decomposition of the problem into criteria, subproblems and alternatives;
2. Collection of pairwise preference data according to the fundamental scale of absolute numbers;
3. Generation of the pairwise comparisons of the alternatives with respect to different criteria and the criteria themselves (*square matrix of size n*)
   - ✓ *the diagonal elements of the matrix are equal to one;*
   - ✓ *if the element of the i^{th} row is better than the one in the j^{th} column then the value of cell (i, j) is more than one and less than in the opposite occasion;*
4. Data normalisation
   - ✓ *computation of the division of each entry towards the sum of each column for each element (w_{ij});*
5. Priority extraction (*eigenvectors*) for each alternative under each criterion by adding the normalised values given Step 4 per row and dividing by this summation with the number of alternatives;
6. Calculation of the consistency ratio (CR): $CR = \frac{Consistency\ Index\ (CI)}{Random\ index\ (RI)}$,where:
   - ✓ $CI = (Max.eigen\ value - n)/(n-1)$; *and*
   - ✓ $RI = CI$ *(randomly generated matrix);*
   - ✓ Saaty (2005) *proposes that CI should be more than 0.1 in order to have consistent judgements.*
7. The rating of each alternative is multiplied by the weights of the criteria and the sub-criteria
8. Report of the final scores for each criterion and alternative.

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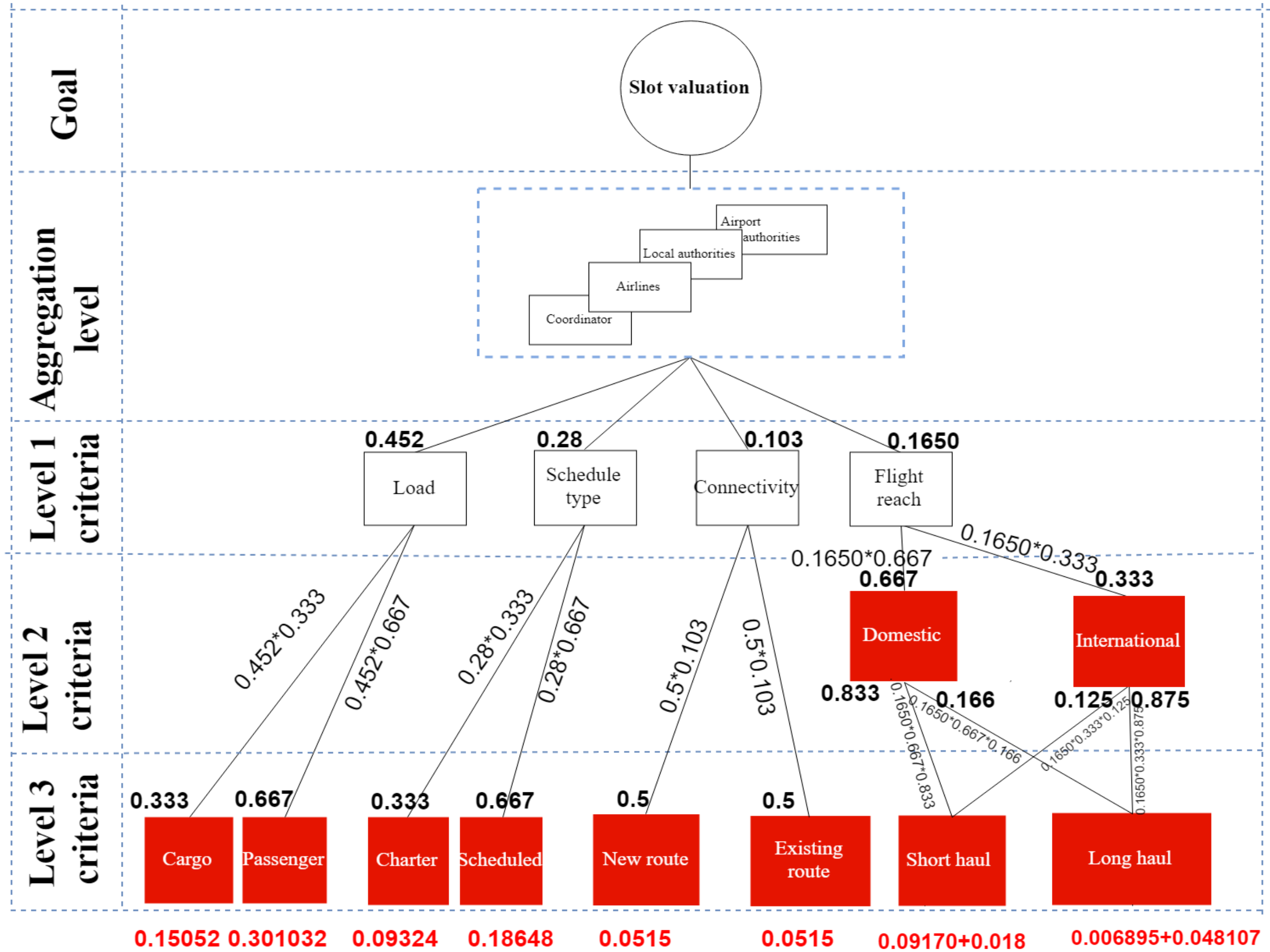
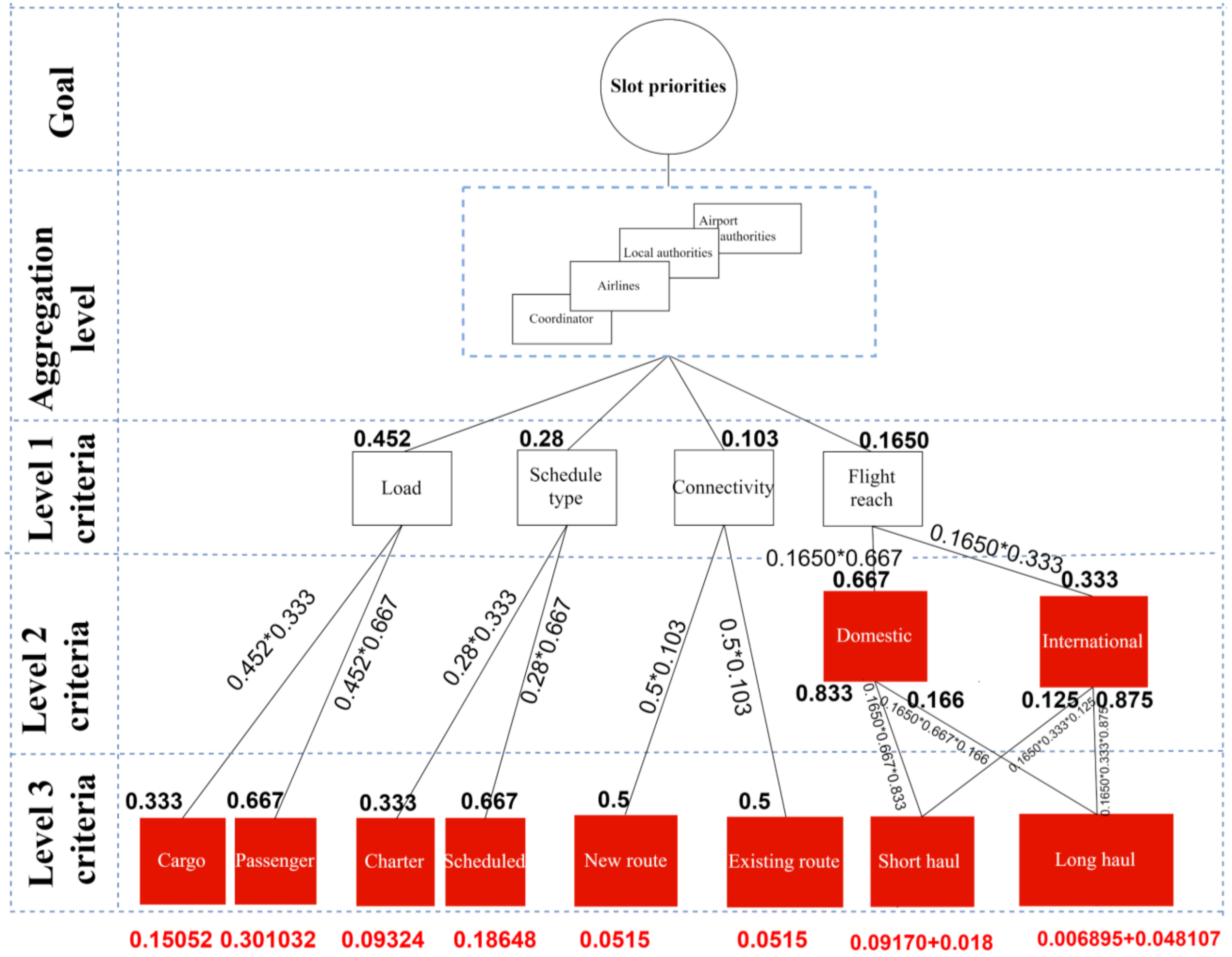


Proposed approach – Illustrative application (SVI)



Let $v_m = \sum_{j \in J} o_{m,j}\, w_j$ be the value of slot request m, where J is the set of level 3 criteria.

Proposed approach – Illustrative application (Case study 1/4)

Proposed approach – Illustrative application (Case study 2/4)

Input sets

M: set of request series denoted by m;

$M^{Arr(Dep)}$: $M^{Arr} \cup M^{Dep} = M^{Total}$, set of arrival (departure) series;

$P \subseteq M \times M$: set of paired requests (m_{Arr}, m_{Dep}) indexed by p;

D: set of days in scheduling season denoted by d;

D_m: set of days that slot m is to operate;

C: set of capacity duration lengths indexed by c;

$T = \{1, \ldots, |T|\}$: set of time intervals per day based on c;

K: $\{Arr, Dep, Total\}$ set of movement types denoted by k.

Parameters

t_m: requested time for slot series m;

$T_{max,p}, T_{min,p}$: maximum and minimum turnaround times of paired request p;

$u^k_{d,t,c}$: capacity for movement k for period $[t, t+c)$ on day d based on time scale c;

$a_{d,m} = \begin{cases} 1, \text{if series } m \text{ is requested on day } d \\ 0, \text{ otherwise} \end{cases}$; and

v_m: valuation index of slot request m

Decision variables and expressions

$$x_{t,m} = \begin{cases} 1, & \text{if request } m \text{ is allocated to time } t \\ 0, & \text{otherwise} \end{cases}$$

Objective function

$$\min Z = \sum_{m \in M} \sum_{t \in T} |t - t_m| \, x_{t,m} \boxed{v_m}$$

Subject to:

$$\sum_{t \in T} x_{m,t} = 1, \forall\, m \in M$$

$$\sum_{m \in M^k} \sum_{t \in [t, t+c-1]} a_{d,m} x_{t,m} \le u^k_{d,t,c}, \forall\, k \in K, d \in D, c \in C, t \in T$$

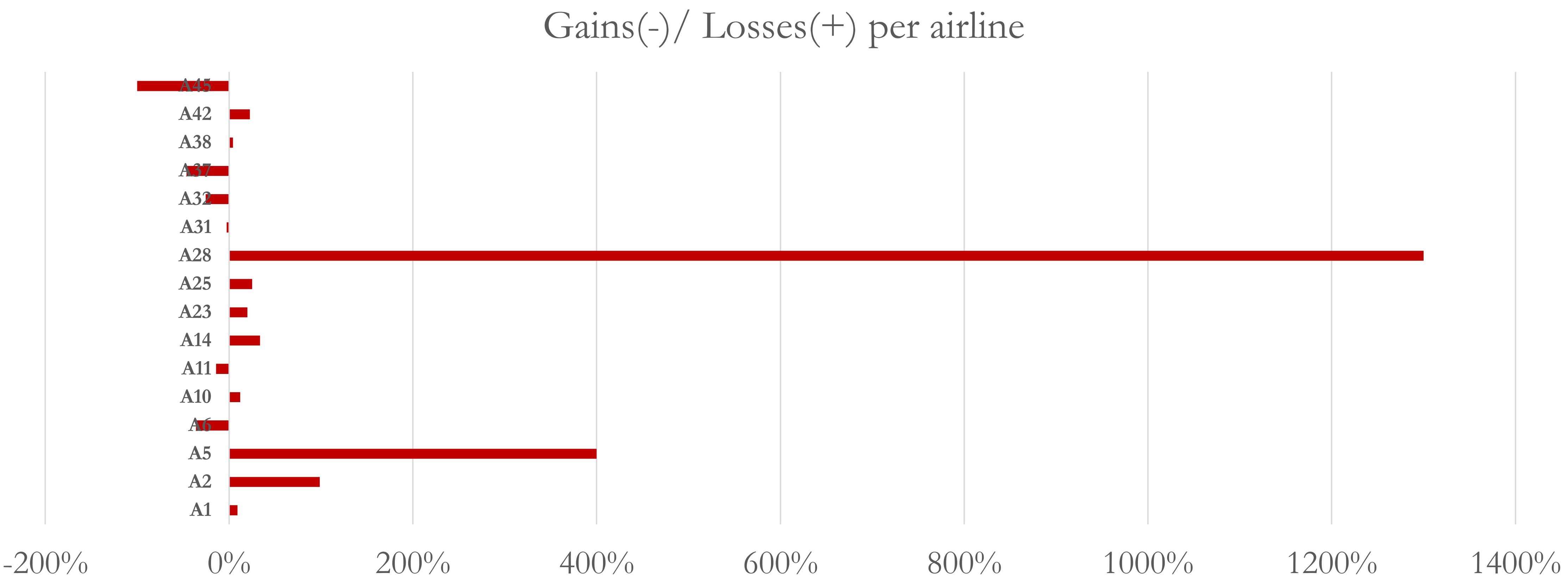
$$\sum_{t \in T} x_{t,m_{Dep}} t - \sum_{t \in T} x_{t,m_{Arr}} t = t_{m_{Dep}} - t_{m_{Arr}} = \mathrm{T}_{\max} = \mathrm{T}_{\min}, \forall\, p \in P$$

(Zografos et al., 2012)

Proposed approach – Illustrative application (Case study 3/4)

Priority levels	Total displacement		
	with v_m	without v_m	%
H	229	229	0.0%
CH	697	711	-1.97%
NE	676	676	0.0%
O	12941	11707	10.54%
Total	14543	13323	9.16%

Proposed approach – Illustrative application (Case study 4/4)



Current work– Conclusions

+ The proposed solution methodology compliments airport SAM optimisation models.

+ It may assign valuation weights to each slot based on the subjective judgements of the stakeholders, concerning numerous policy requirements without adding up to the complexity of the optimisation models.

+ The consideration of the slot characteristics does impact the slot scheduling outcome.

- There is a trade-off between the inclusivity and simplicity of the AHP-tree that has to be considered

- The subjective judgements require the consultation of multiple experts per stakeholder group

- The pairwise preference data may be difficult to obtain

Future work

- Tree validation by industry experts (inclusion and exclusion of criteria and associations based on their significance);
- Collection of preference data (*questionnaires, online surveys*) ;

QnA

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2. Collection of pairwise preference data according to the fundamental scale of absolute numbers;
3. Generation of the pairwise comparisons of the alternatives with respect to different criteria and the criteria themselves (*square matrix of size* n)
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