A Dynamic Simulation-Optimization Approach for Managing Casuality Incidents: Potential for the current European Refugee Crisis”

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Organization of the Paper

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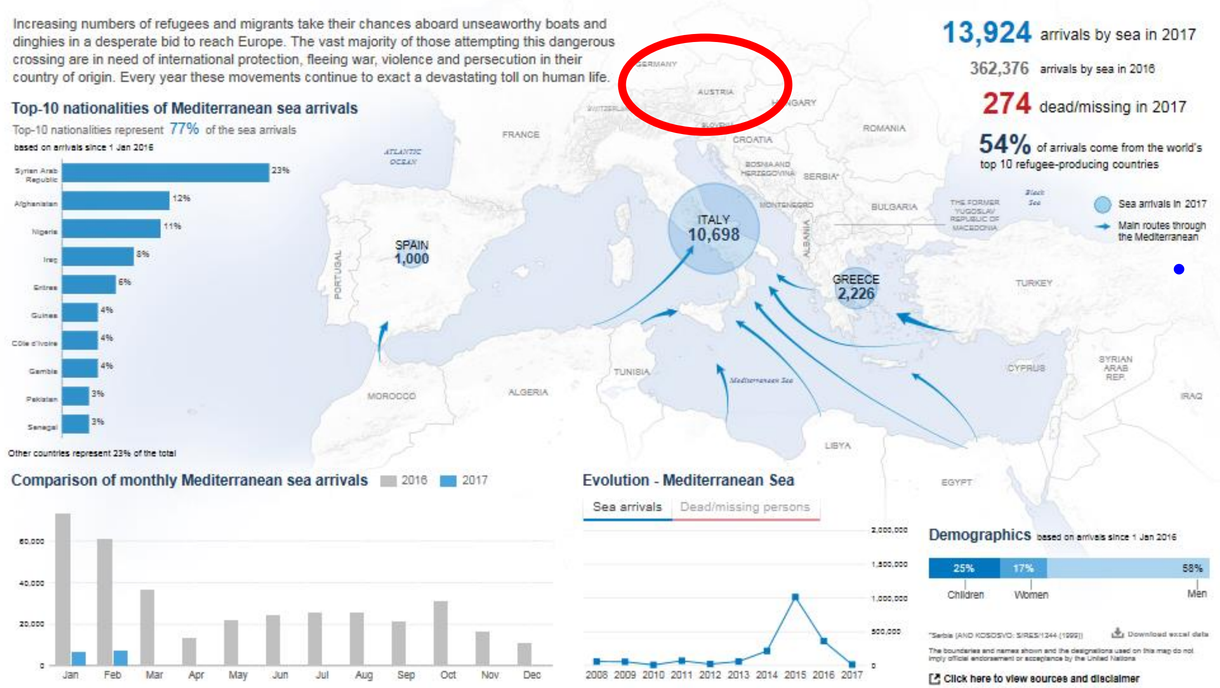
Refugees/Migrants Emergency - Europe

The UN Migration Agency (IOM) reports that 77,004 migrants and refugees entered Europe by sea in 2017 through 14 June, with almost 85 per cent arriving in Italy and the remainder divided between Greece, Cyprus and Spain. This compares with 214,427 arrivals across the region through 14 June 2016. (Source: IOM, 16 Jun 2017)

140 related jobs »

UNHCR: Refugees/Migrants Emergency Response - Mediterranean Regional Overview



1. Introduction

- **More Easily Preparable**
  - Borders
  - Transportation
  - Wild Camps
  - Refugee Camps
- **Hardly Preparable**
  - Disease Outbreaks
  - Terrorist Attack
  - Riots
  - etc.

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http://reliefweb.int/topics/refugeesmigrants-emergency-europe

2. Literature Review – Disaster Policy Models

- Review on **disaster policy models** (e.g., Altay and Green, 2006; Gansterer, 2008)
  - ⇨ Geographical models (e.g., Chen et al., 2008; Dimopoulou and Giannikos, 2004; Kara and Verter, 2004)
  - ⇨ Optimization models (e.g., Dodo et al., 2007; Jacobson et al., 2005; MacLellan and Martell, 1996),
  - ⇨ Simulation-based models (e.g., Aaby et al., 2006; Chen und Zhan, 2008; Miller et al., 2006)
  - ⇨ Covering location models (e.g., Batta and Mannur, 1990; Yi and Oezdamar, 2007)
  - ⇨ Game theory models (e.g., Berman and Gavious, 2007)

- **Time horizon of models**
  - ⇨ Ultra short-term action taken within the first twelve hours
  - ⇨ Long-term with time horizon of up to a year

- **Missing focus of models**
  - ⇨ Only a minority of disaster policy models perform an additional cost analysis,
  - ⇨ Few models investigate emergency medical services for mass casualty incidents!

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2. Literature Review – Emergency Medical Services (1)

- **Model focus**
  - ⇨ Long-term planning (e.g., demand forecast, allocation of vehicles)
    [e.g., Channouf et al., 2007, Gendreau et al., 2006; Ingolfsson et al., 2003]
  - ⇨ Short-term scheduling (e.g., positioning of emergency bases, vehicle dispatch, triage procedure, pre-hospital immediate care, transportation)
    [e.g., Christie and Levary, 1998; Fawcett and Oliveira, 2000; Yi and Oezdamar, 2007]

- **Model components**
  - ⇨ Transportation (e.g., Fawcett and Oliveira, 2000; Gendreau et al., 2006; Ingolfsson et al., 2003)
  - ⇨ Individuals injured
    - standard emergency case (e.g., Channouf et al., 2007; Gendreau et al., 2006; Ingolfsson et al., 2003)
    - mass casualty incidents (e,g, Christie and Levary, 1998; Fawcett and Oliveira, 2000; Yi and Oezdamar, 2007
  - ⇨ Hospitals (e.g., Christie and Levary, 1998; Fawcett and Oliveira, 2000; Ingolfsson et al., 2003)
  - ⇨ Staff (e.g., Ingolfsson et al., 2003; Peleg and Pliskin, 2004; Shuman et al., 1992)
  - ⇨ Equipment and material (e.g., Fiedrich et al., 2000; Gong and Batta, 2007)

2. Literature Review – Emergency Medical Services (2)

- **Model types**
  - ⇨ Discrete Event Simulation (DES) (e.g., Christie and Levary, 1998, Fawcett and Oliveira, 2000)
  - ⇨ DES & cluster models (e.g., Gong and Batta, 2007)
  - ⇨ DES & covering location models (e.g., Gendreau et al., 2006)
  - ⇨ DES & geographic information system (GIS) models (Peleg and Pliskin, 2004)
  - ⇨ DES & network models (e.g., Gong and Batta, 2007)
  - ⇨ DES & optimization models (e.g., Fiedrich et al., 2000; Gendreau et al., 2006; Yi and Oezdamar, 2007)
  - ⇨ Heuristics (e.g., ant colony optimization, genetic algorithms, simulated annealing, tabu search)
  - ⇨ Agent-based simulation model & GIS (e.g., Smith at al., 2009)

- **Model outcome measures**
  - ⇨ Costs
  - ⇨ Emergency services
  - ⇨ Emergency cases

Mass casualty incident policy model for short term-scheduling to investigate not only vehicle and patient scheduling but also staff and material planning!

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3. Organization of Mass Casualty Incidents

- Two major concepts for mass casualty incidents
  1. "Scoop and run," mostly adapted in the Anglo-American countries
  2. "Stay and stabilize," mostly adapted in Europe

- Get the **chaos** under control and do not transfer it to the hospital!

- **Few helpers** with **limited material** for a multiplicity of patients.

- "Avoid time-intensive and staff-intensive maximal medical care of a single patient to ensure the **life-saving minimal medical care of many individuals injured**"

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3. Advanced Medical Post (AMP) – Management Game[1]

- **Current situation**
  - Increasing number of mass casualty incidents
  - High complexity and uniqueness of mass casualty incidents

- Decision makers need OR-based policy models for **training emergency staff on planning and scheduling at the emergency site** (e.g., Austrian Samaritan Organization).

- Our policy model helps to enhance the **quality of planning and outcome** (e.g., staff planning, disclose problems, bottlenecks).

- We calculated from small and simple to big and complex mass casualty **scenarios**.

- Furthermore, the organization of an advanced medical post can be improved in order to **decrease fatalities** as well as **quickly treat and transport injured individuals to hospitals**.

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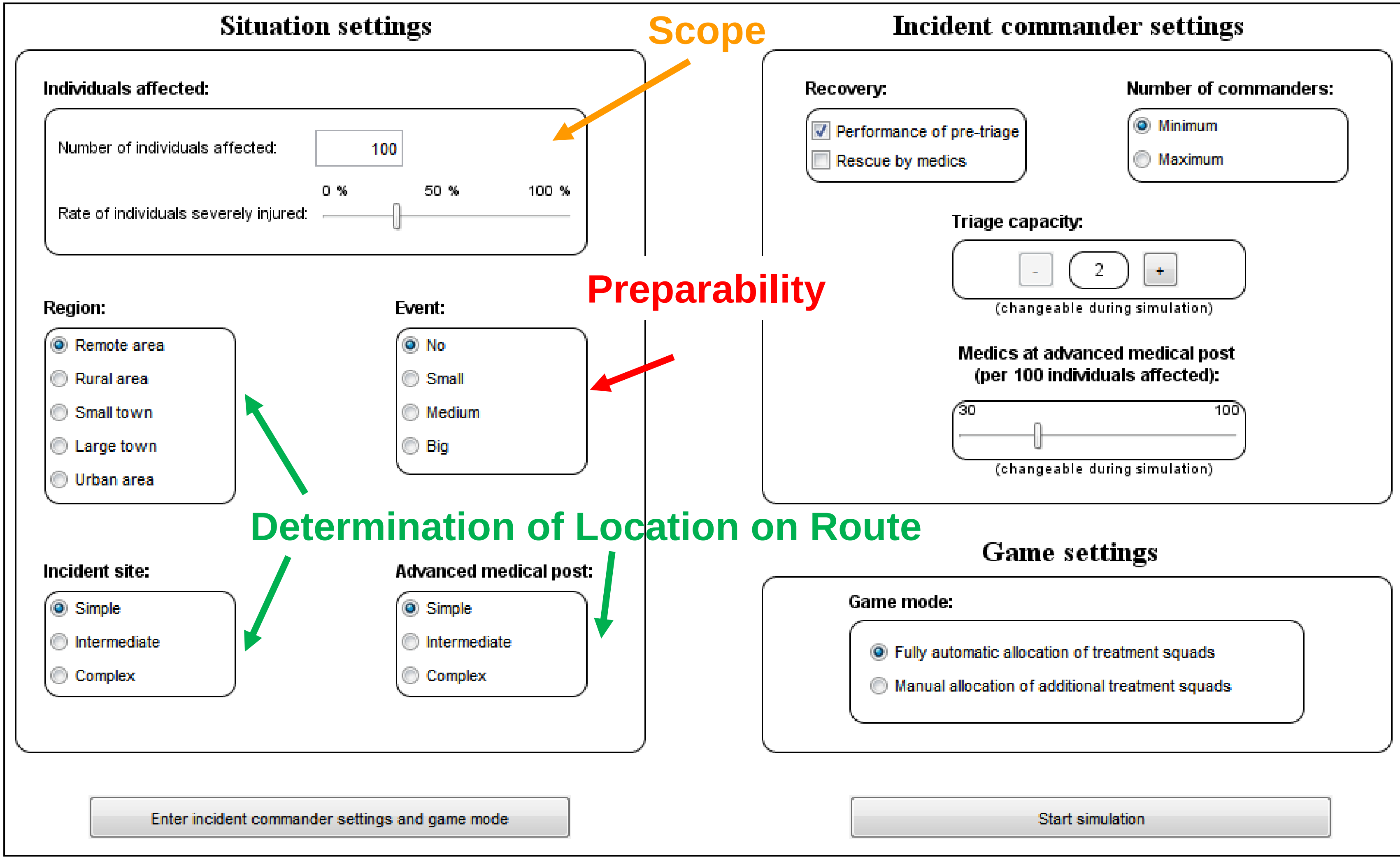
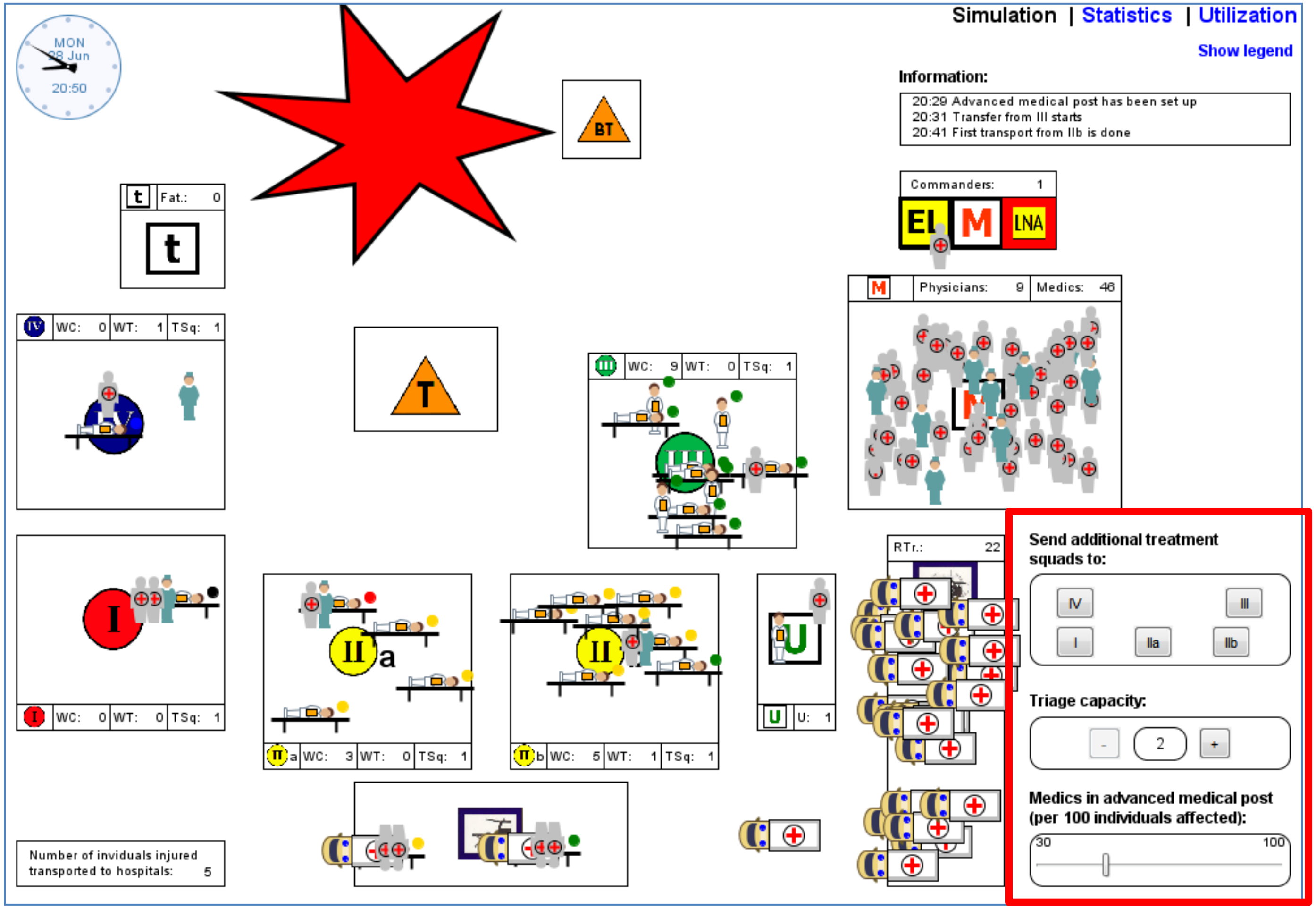
Rauner, M. S., Schaffhauser-Linzatti, M. M., & Niessner, H. (2012). Resource planning for ambulance services in mass casualty incidents: a DES-based policy model. *Health care management science*, *15*(3), 254-269.

Selection of the Policy Framework for the Simulation



Visualization of the Simulation



Decisions

Flow Chart of Injured Persons

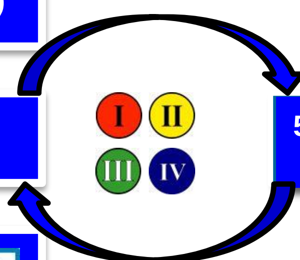
1) Pre-triage (optional)

2) Rescue

3) Triage

4) Transportation to treatment room assigned (I-IV)

5a) Treatment in rooms assigned (I-IV)



5b) Transportation to other treatment rooms assigned (I-IV)

6) Loading into ambulance vehicle

7) Transportation to hospital

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General Policy Implications (I)

Macro level policy decisions by law/rescue organizations (strategic level)		
Rule for incident site	**Consequences at incident site**	**Possible policy change**
Rescue performed by fire patrol in dangerous situations	Medics have to wait until fire patrol arrives	Training of medics for certain dangerous situations to overtake pre-triage from fire patrol or to support them (increased treatment quality, lower number of fatalities, decreased total time for disaster management)
Triage performed by physicians	**Medics have to wait until physicians have triaged injured persons**	**Performance of triage by medics (increased treatment quality, lower number of fatalities, decreased total time for disaster management)**
Distinction between treatment rooms IIa and IIb	Resources for two sub-rooms have to be provided (two queues)	Consolidation of treatment rooms IIa and IIb to a single treatment room II (increased treatment quality, lower number of fatalities, decreased total time for disaster management)
Only injured persons from treatment rooms IIa and IIb can be transferred to hospital	All injured persons have to be transferred first from other treatment rooms to treatment rooms IIa and IIb before they are transported to hospital	Transport to hospital from all treatment rooms I – IV possible (increased treatment quality, lower number of fatalities, decreased total time for disaster management)

General Policy Implications (II)

Micro level policy decisions by incident commander (operative level)	
Situation for incident site	**Consequences at incident site**
Performance of pre-triage (yes/no)	**Yes: Increased treatment quality and total rescue time by pre-triage**
Rescue by medics (yes/no)	Yes: Lower number of medics available for treatment and transport (if rescue is possible without great danger)
Number of commanders (min/max)	Max: Lower number of medics available for treatment and transport
Triage capacity (low/high)	High: Lower number of physicians available for treatment
Number of medics at AMP (low/high)	High: Low number of medics available for transport to hospital

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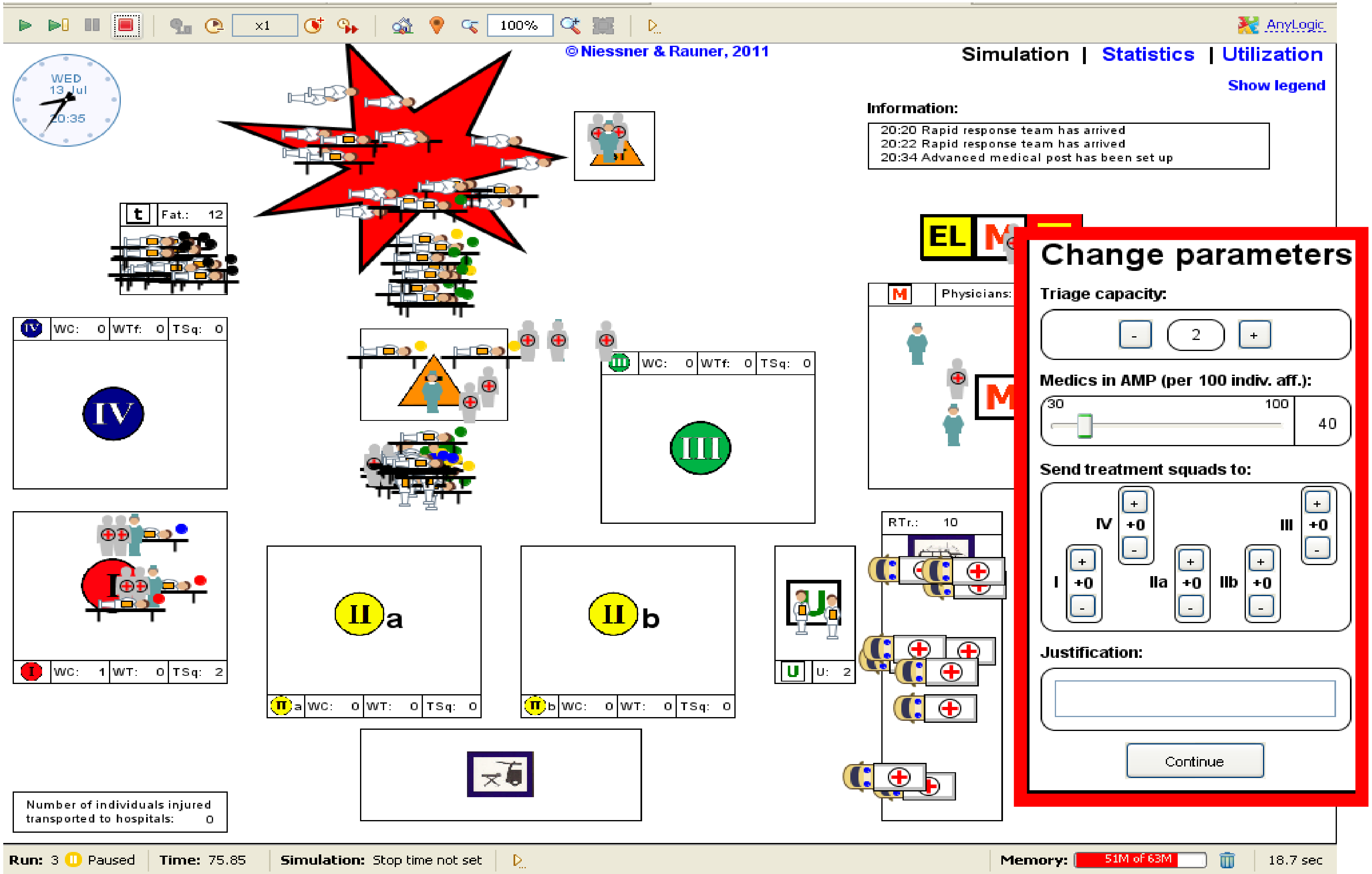
3. Advanced Medical Post (AMP) – Experiment[2]



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Rauner, M. S., Niessner, H., Leopold-Wildburger, U., Peric, N., & Herdlicka, T. (2016). A policy management game for mass casualty incidents: an experimental study. *Flexible Services and Manufacturing Journal*, *28*(1-2), 336-365.

Experimental Design

- **Group size:** 12-15 people (about 49% men; mean 26 years)
- **Duration:** 2.5 to 3 hours (3 runs)
- **Motivation:** 78% students (credits for courses)
  - **12%** practitioners (co-operation partners, former students)
  - **10%** ambulance services (improvement of the organization)
- **Game sessions:**
  - four groups (á about 10 students and 2 practitioners)
  - one group (13 practitioners)
  - two groups (12 and 13 students)
  - one group (6 practitioners from Red Cross)

- **96 valid players -> 3 Runs**

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Results – Benchmarks for Optimization

- **Gas explosion** at a **small town's** farmers' market
- **80** people affected, **40%** severely injured

Target Value	Run 1	Run 2	Run 3
# of Fatalities	17.28	**16.63**	17.97
Total Rescue Time	224.51	**227.63**	224.29

Hypotheses Tested	Result
Results of Run 2 Will be better Than Run 1	Significant (p <= 0.1)
Results of Run 3 Will be the Worst (Trial & Error)	Highly Significant (p <= 0.01)
Practitioners Performed Better Compared to Students	Significant (p <= 0.1)

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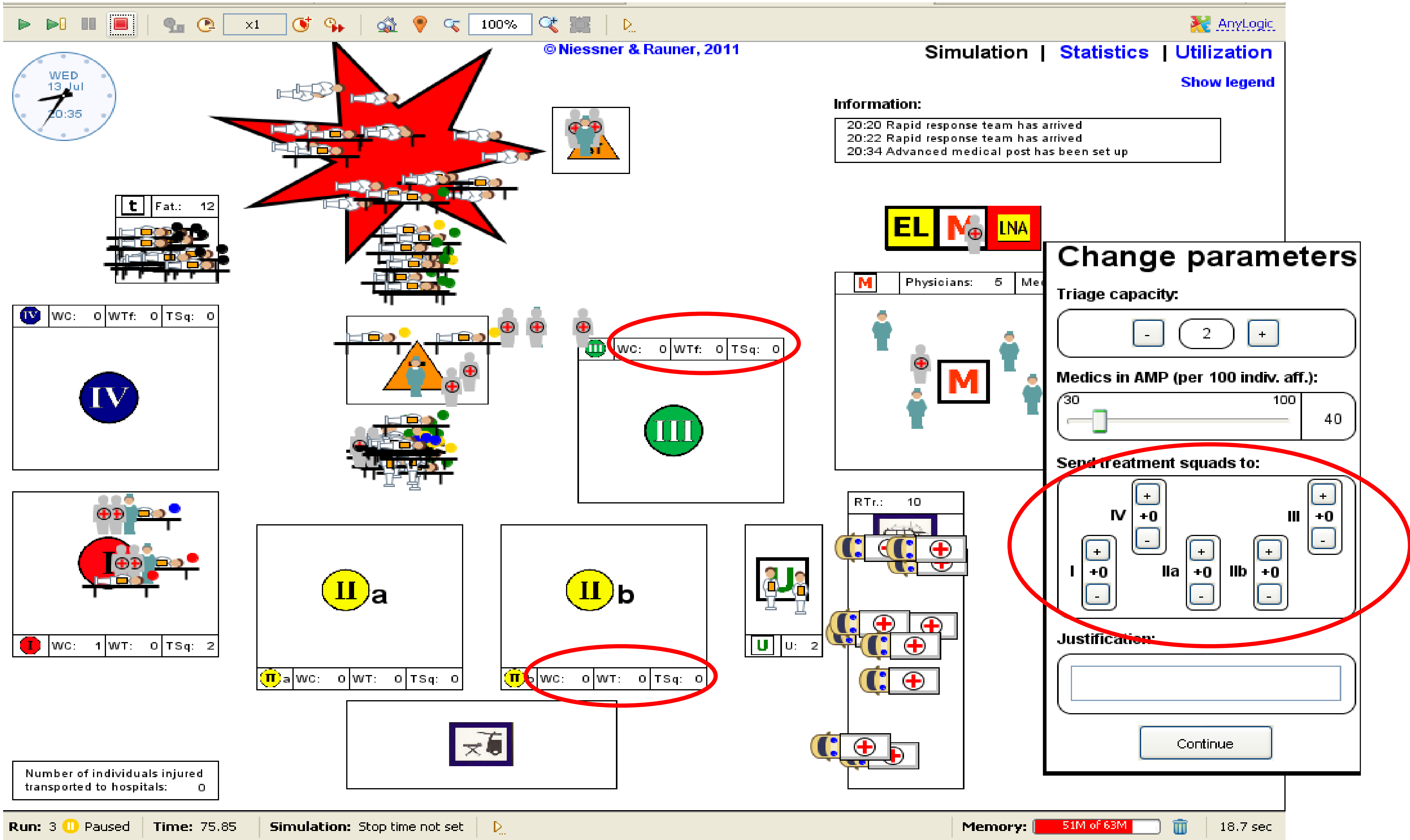
3. Advanced Medical Post (AMP) – Optimization[3]

- Can the results of the **simulation** be improved?
- Can the decisions and results of the **human players** in the experimental management game be improved?
- Can **general policy implications** for incident commanders/policy makers be derived?

[3] Rauner, M., Niessner, H., Gutjahr, W. (2017). Minor Revision – OR in Health Care.

Available Information and Decisions at the Austrian AMP



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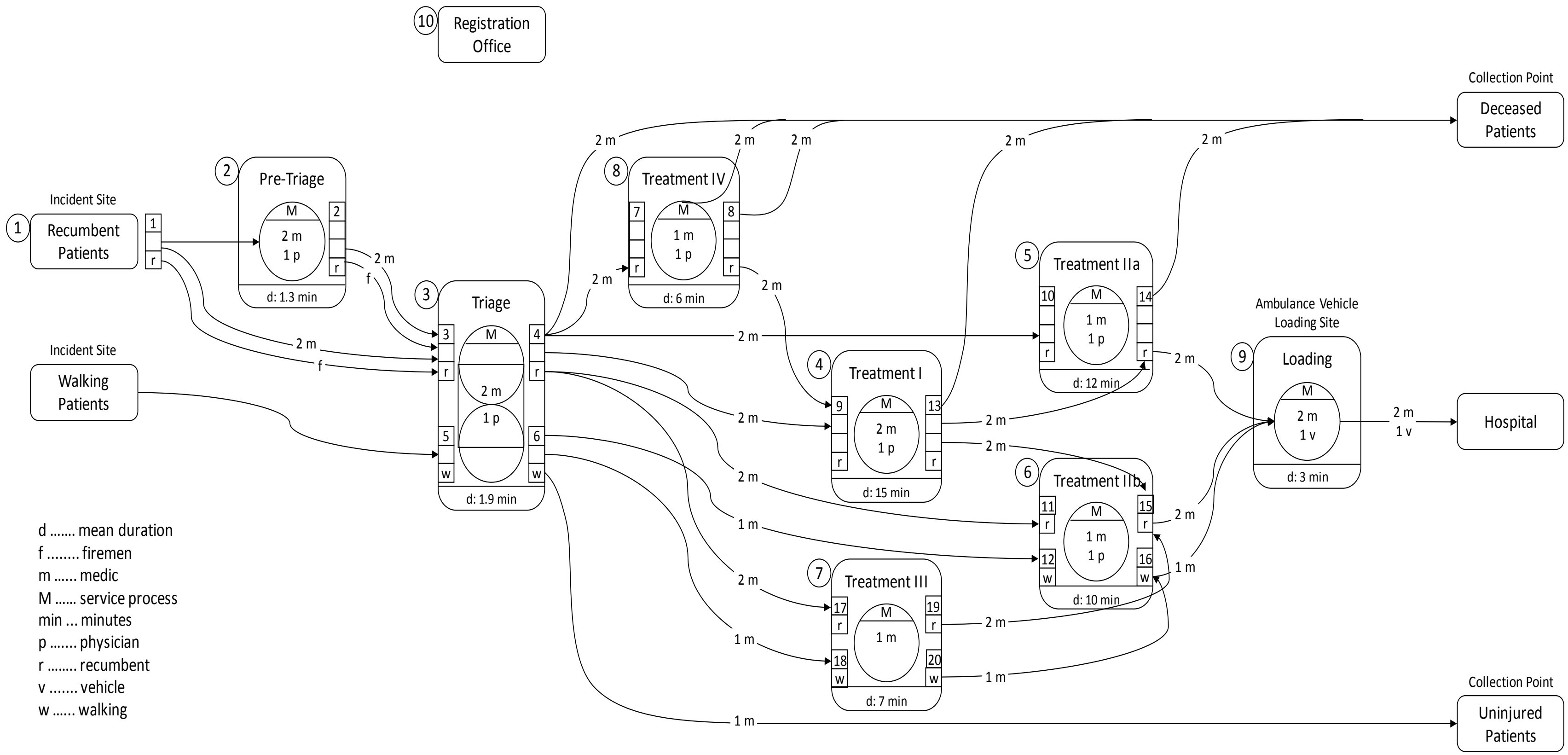
Queuing System at the Austrian AMP



Assignment of Scarce Phycisians to Pool/Triage/Treatment:

- direct queue before triage/treatment
- predecessor queues before triage/treatment

Relevant Queues for the Simulation-Optimization Approaches

Position at the Advanced Medical Post (i)	Relevant Direct In-Queues (Recumbent/ Walking In) (Q_i^1)	Relevant Predecessor In-Queues (Q_i^2)	Relevant Predecessor Out-Queues (Q_i^3)	Number of Weighting Factors for Related Queues i and Positions j for the Optimization Approach ($\beta_{i,j}^{(n)}$)
i=3: Triage	j=3, 5 (#2)		j=1, 2 (#2)	4
i=4: Treatment Room I (immediate care)	j=9 (#1)	j=3, 7 (#2)	j=1, 2, 4, 8(#4)	7
i=5: Treatment Room IIa (urgent care)	j=10 (#1)	j=3 (#1)	j=1, 2, 4 (#3)	5
i=6: Treatment Room IIb (urgent care)	j=11, 12 (#2)	j=3, 5 (#2)	j=1, 2, 4, 6 (#4)	8
i=8: Treatment Room IV (expectant care)	j=7 (#1)	j=3 (#1)	j=1, 2, 4 (#3)	5
	Total Number of all Relevant Direct In-Queues for All Relevant Positions (q_1)	Total Number of all Relevant Predecessor In-Queues for All Relevant Positions (q_2)	Total Number of all Relevant Predecessor Out-Queues for All Relevant Positions (q_3)	Total Number of all Relevant Queues for All Relevant Positions (q)
Full Simulation-Optimization Approach	7	6	16	29
Reduced Simulation-Optimization Approach	7	0	0	7

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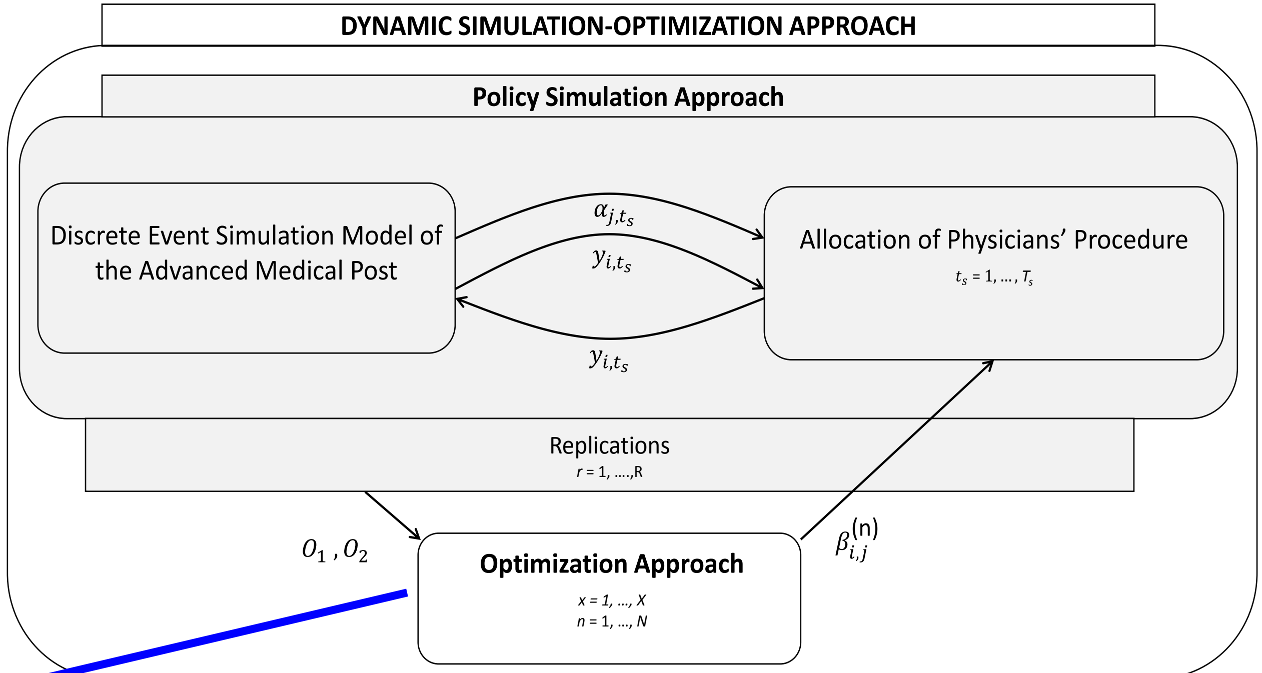
Dynamic Simulation-Optimization Approach



Considerations

- local/global search
- running time
- quality of results
- significance of results

Anylogic Version 7.2 (University Version)

Algorithm Class for Simulation-Optimization	Solution Structure		Optimization	
	Discrete	Continuous	Local	Global
Direct Search	X	X	X	
Gradient-based Methods		X	X	
Lipschitzian Optimization		X		X
Metaheuristics	X	X		X
Model-based Methods	X	X	X	X
Ranking and Selection	X			X
Response Surface Methodology		X	X	X

Full/Reduced Approaches

- ← Kiefer-Wolfowitz Appr.
- ← Opt-Quest (Commercial)
- ← Response Surface Meth.

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Allocation of Physicians – Priority Values for Positions

In the ***full* simulation-optimization approach**, the priority values ω_{i,t_s} **29 queues**

are determined by the following formula:

$$\omega_{i,t_s} = \max\left(0,\ \sum_{j \in Q_i} \alpha_{j,t_s} \cdot \beta_{i,j}^{(n)}\right) \quad \text{if } i \text{ is not a reserve position,}$$

$$\omega_{i,t_s} = \varepsilon \quad \text{if } i \text{ is a reserve position.}$$

In the ***reduced* simulation-optimization** approach, the priority values ω_{i,t_s} **7 direct queues**
are determined by the following formula:

$$\omega_{i,t_s} = \max\left(0,\ \sum_{j \in Q_i^1} \alpha_{j,t_s} \cdot \beta_{i,j}^{(n)}\right) \quad \text{if } i \text{ is not a reserve position,}$$

$$\omega_{i,t_s} = \varepsilon \quad \text{if } i \text{ is a reserve position.}$$

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Gallagher (1991)

Allocation of Physicians – Allocation Rule

The proportional allocation rule for the physicians is:

$$\bar{y}_{i,t_s} = \frac{P_{t_s}}{\sum_i \omega_{i,t_s}} * \omega_{i,t_s} \qquad \forall\, i \in \tilde{I} \text{ and } t_s = 1,\ldots,T_s$$

Application of method by d'Hondt to obtain integer approximations y_{i,t_s} of the values $\bar{y}_{i,t_s}$.

Kiefer-Wolfowitz Algorithm (Gradient-based Method)
Non-Commercial (Self-Implemented in Anylogic)

Iterative gradient approximation for each parameter:

$$x_{n+1}^{(i)} = x_n^{(i)} - a_n * \left(\frac{N\left(x_n^{(i)} + c_n\right) - N\left(x_n^{(i)} - c_n\right)}{2c_n} \right)$$

$$a_n = \frac{K_a}{n}$$

$$c_n = \frac{K_c}{\sqrt[3]{n}}$$

i ……… optimization parameter (*i* = 1, …, 7 or 29)
n ……… iteration (n = 1, 2, …)
a_n ……... multiplication factor in iteration *n*
c_n …….. step size in iteration *n*
$x_n^{(i)}$ …… weighting factor *i* of iteration *n*
K_a ……. constant: multiplication factor
K_c ……. constant: step size
N …….. target function

Kiefer and Wolfowitz (1952)

Opt-Quest (Metaheuristic)
Commercial (Available in Anylogic)

uses state-of-the-art **metaheuristic procedures** including

- **Tabu Search**
- **Neural Networks**
- **Scatter Search, and**
- **Linear/Integer Programming**

into a single composite method.

Response Surface Methodology (RSM)
Non-Commercial (Self-Implemented in Anylogic)

- **Phase 0 of RSM model**
  - data for **Plackett-Burman-Design**
  - two levels per factor (+/-)
- **Phase 1 of RSM model (first-order model)**
  - for each iteration in the first-order RSM model:
    - 8 data points for the reduced approaches (7 weights)
    - 32 data points for the full approaches (29 weights)
    - 8/32 data points with 7/29 independent variables
      - linear regression
      - same step size used in the Kiefer-Wolfowitz Algorithm needed for automatic mode
      - calculation of the direction of the steepest descent

- **Phase 2 of RSM model** (approximating the objective function by a quadratic function instead of a linear one) **not used (second-order model)**
  - consumes a very large number of simulation runs per iteration
  - better to use more iterations in the first phase of RSM as possible

Myers et al. (2016)

Comparison Among the Dynamic Simulation-Optimization Approaches (1/3)

Descriptive Analysis of Total Number of Patients Deceased O_2						
Approach	**Kiefer-Wolfowitz Algorithm***		**OptQuest Approach***		**Response Surface Methodology-Approach***	
Coverage	**Full**	**Reduced**	**Full**	**Reduced**	**Full**	**Reduced**
Mean	**16.25**	16.88	16.32	**16.27**	16.35	16.91
Std. Deviation	**2.993**	3.002	3.026	**2.996**	2.935	2.889

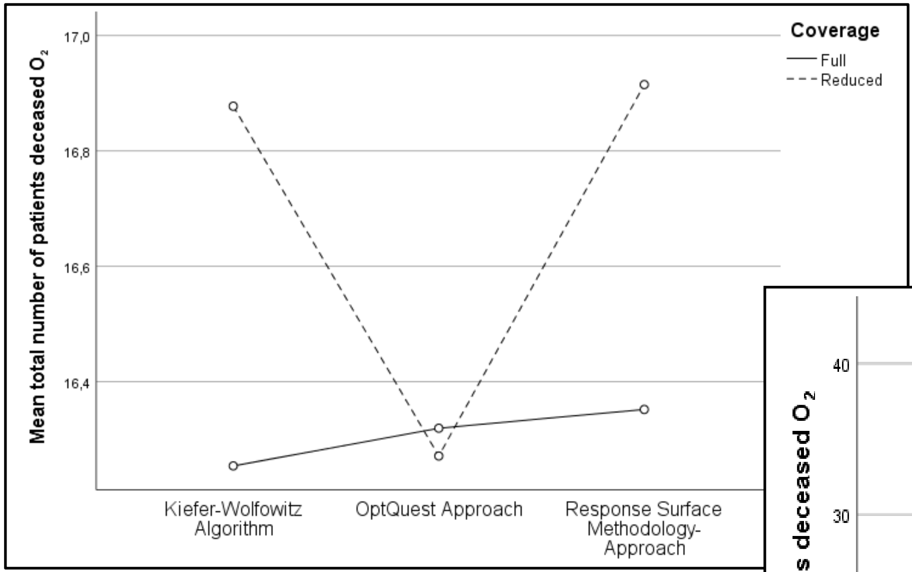
* allocation of physicians is possible $T_{s.}$ times and replications R = 100,000.

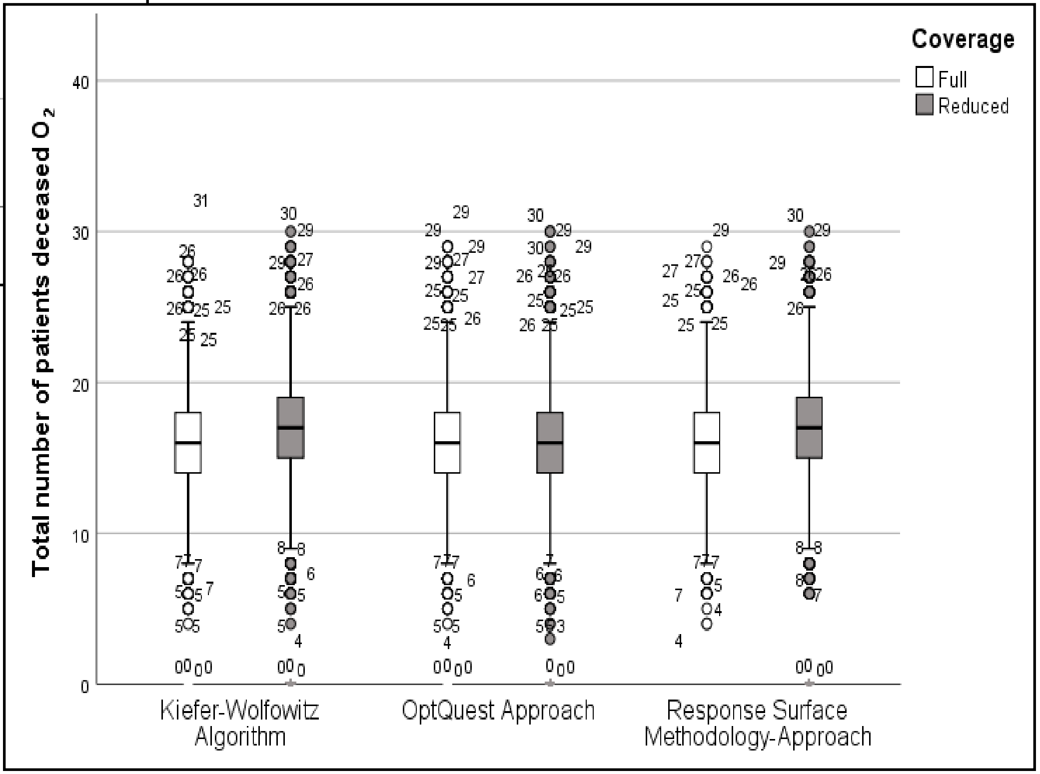
Table 5: Mean and standard deviation of the total number of patients deceased O_2 for the three dynamic simulation-optimization approaches with two coverages

Two-way factorial ANOVA (analysis of variance):

1) the influence of the **algorithmic approach** was highly significant (**$p < 0.001$**),
2) the influence of the **coverage** (full or reduced) was highly significant (**$p < 0.001$**),
3) And a significant **interaction** between the two factors existed (**$p < 0.001$**).

Comparison Among the Dynamic Simulation-Optimization Approaches (2/3)





Rauner, M., Niessner, H., Gutjahr, W. (2017). Minor Revision – OR in Health Care.

Comparison Among the Dynamic Simulation-Optimization Approaches (3/3)

1) **one-way factorial ANOVA**
   - **significant differences among the six algorithmic combinations ($p < 0.001$).**

including two versions of a ***post hoc*** test for ***pairwise comparisons***:

1) **Tukey's Honestly Significant Difference (HSD) test** [on means based on a studentized range distribution]
2) **Bonferroni test**

- **"Kiefer-Wolfowitz full" significantly outperformed (α = 0.001)** all other combinations, except "OptQuest reduced", and was not significantly outperformed (α = 0.05) by any combination.
- **"OptQuest reduced" significantly outperformed (α = 0.01) all other combinations**, except "Kiefer-Wolfowitz full", and was not significantly outperformed (α = 0.05) by any combination.
- Each of the other four combinations was significantly outperformed (α = 0.001) either by "Kiefer-Wolfowitz full" or by "OptQuest reduced".

- **The performance of "Kiefer-Wolfowitz full" and "OptQuest reduced" is not significantly different at level α = 0.05.**

Results 4 - Comparison Between the Policy Simulation Approach and the Dynamic Simulation-Optimization Approaches

Target Value	Simulation-Optimization Approach ($n = N$)	Variants of the Policy Simulation Approach ($n = 0$)		
	Results of Kiefer-Wolfowitz-Algorithm (Full Coverage)*	Results of DES Model (Initial Solution)*	Results of DES Model (Heuristic Allocation)**	Results of DES-based Experimental Game***
Mean total rescue time O_1	**204.57**	215.16	218.74	227.63
Std. deviation of total rescue time O_1	**23.323**	23.314	28.493	44.06
Mean total number of patients deceased O_2	**16.25**	17.08	16.39	16.63
Std. deviation of total number of patients deceased O_2	**2.993**	2.995	3.089	2.813

* allocation of physicians is possible $T_{S.}$ times and replications R = 100,000.
** allocation of physicians is possible unlimited times and replications R = 1,800 (cf. Rauner et al. 2012).
*** allocation of physicians is possible $T_{S.}$ times and replications R = 96 (cf. Rauner et al. 2016a).

A **statistical t-test** (unpaired two-sample test, two-tailed, equal or unequal sample sizes) produced the following results for O_2:

Superiority of the **Kiefer-Wolfowitz Algorithm** over

- the **Initial Solution** — **significant α < 0.01**
- the **Experimental Game** — not significant >> α = 0.05
- the **Heuristic Allocation** — not significant > α = 0.05 (slightly)

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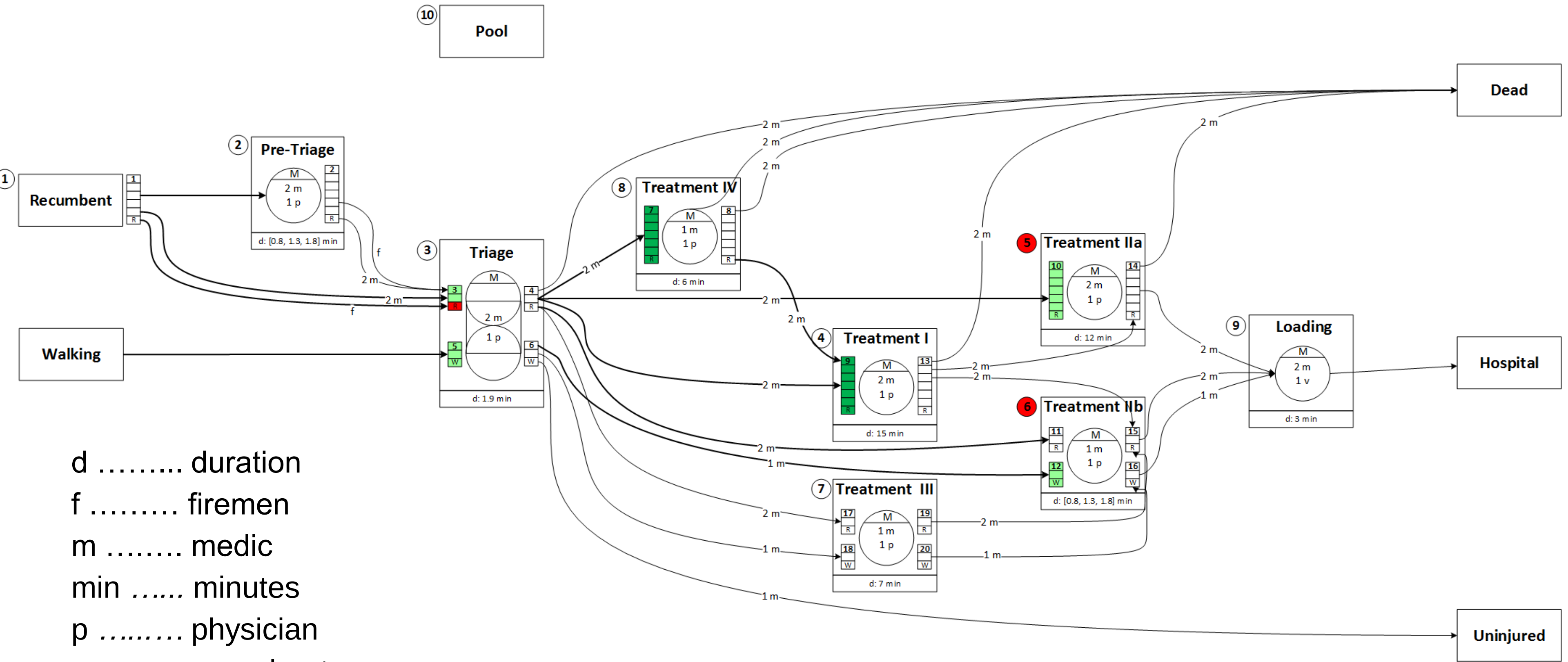
Important Betas to Minimize the Number of Fatalities



d ……... duration
f ……… firemen
m …….. medic
min …... minutes
p …..…. physician
r ……... recumbent
v ……...vehicle
w ……. walking

- Queues before treatment I and treatment IV are highly important!
- If there is a queue before triage, then treatment IIa/IIb will be less important!

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Rauner, M., Niessner, H., Gutjahr, W. (2017). Minor Revision – OR in Health Care.

7. Policy Implications

- **Reduction** of total rescue **time** results in **more fatalities**.
- If **heavily injured** patients are waiting for treatment, incident commanders should **send physicians** to treatment rooms I and IV!
- If patients are waiting for **triage**, physicians should be sent to triage!
- Treatment rooms **IIa and IIb** have **less priority** compared to **triage**!

7. Further Research

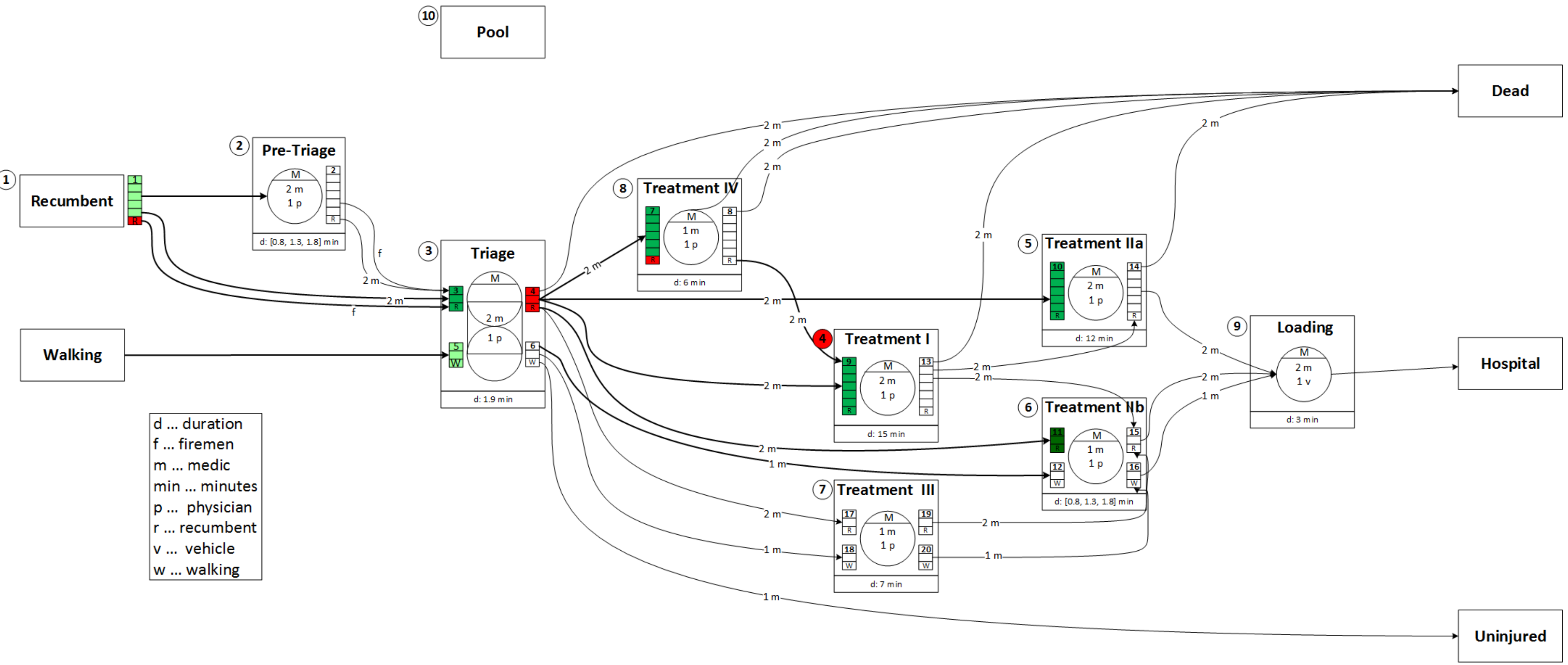
- Simulation-Optimization of **more policy scenarios such as especially for refugee situation.**
- For further research, an **extended simulation-optimization approach** could be investigated where, contrary to the way how humans usually deal with the situation, the algorithm makes decisions at every point in time when the status of the system changes (e.g., **a physician becomes available**).
- **New experimental game** with decisions of players once a physician becomes available.

Thank you for your attention!

WE HAVE TO GET READY!

https://static.independent.co.uk/s3fs-public/thumbnails/image/2017/01/14/14/mediterranean-rescues-january.jpg
http://www.mirror.co.uk/news/world-news/calais-migrant-camp-fire-france-6830330
http://www.huffingtonpost.co.uk/2015/09/17/refugee-crisis-images-tear-gas-water-cannon-hungarian-police_n_8152524.html

Important Betas to Minimize the Total Rescue Time



- Queues before treatment IIb is most important, then the one before treatment IIa.
- Queue before treatment IV has priority compared to the one before treatment I.
- Queues before triage are important.

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