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“Evacuation simulation based on a cognitive decision making model in a socio-technical system”

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Introduction: **Project „SOCIONICAL“**

Research agenda

- Development of complexity science based modeling, prediction and simulation methods for socio-technical systems
- Scenario: crowd dynamics of humans in evacuation

Socio-technical system (STS) *[def.]*

- “Social-technical systems arise when **cognitive and social interaction** is **mediated by information technology** rather than the natural world” *[1]*
- **Combining social and technical components** of a computing system is a **challenging task** (due to domain differences)
- These challenges are due to **lack of knowledge**, e.g. long term behavioral change, due to persistence of technology in the environment
- **STS** are there to **fill this knowledge gap** (modeling, simulation)

[1] B. Whitworth, *Encyclopedia of Human Computer Interaction. Hershey* PA: Idea Group Reference., 2006, chapter “Socio-Technical Systems”, pp. 559–566.

Socio-Technical Systems: **Application for Crowd-based Phenomena**

Scenario

- large **evacuating crowd** in which each individual has (ideally) a unique social/cognitive character
- subset of the crowd is **technology-assisted** (expressed as *percentage*)
- each individual is **affected** by what he/she **perceives in its surrounding**

Behavioral challenges

- **behavioral variation**, i.e., how a crowd behaves in an evacuation situation? (depends on individuals, environment, situation, etc.)
- **empirical evidence**, e.g., it may be impossible to find evidence related to a specific scenario
- **trials**, only small scale and controlled trails are possible to document the reaction of crowd towards technology they have access to (or find in the surrounding)

Modeling challenges

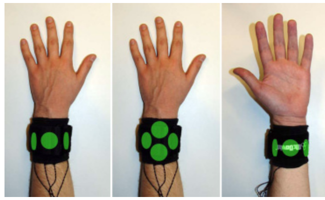
- **behavioral diversity**/individual models → modeling on agent granularity a must
- **Interaction extent**, i.e., each agent must interact with its surrounding all the time
- **Scale** must be, according to the scenario, sufficiently large (range ~10^4-10^7)

Socio-Technical Systems: **Technology Assistance**

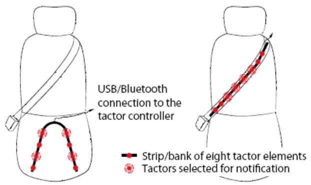
Personal Ambient Intelligence (AmI)

- mobile assistants
- cell phones
- wearables

SPECTACLES



tactile wrist band

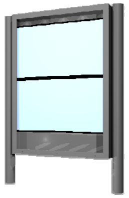


vibro-tactile seat/safety belt

“LifeBelt”

Environmental AmI

- interactive displays/floors
- pos./navigation systems



Interactive DISPLAY

buildings as display

navigation systems

Technology for humans

- issues getting attention
  - *privacy*
  - *(further) isolation of individuals (away from social interaction)*
- arising challenges
  - *sensing and **modeling of emotions***
  - *conflicts between individual feelings and AmI recommendations*
  - ***trust in technology***

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Evacuation Simulation: **A Cognitive Decision Making Model**

Contribution (*this paper*)

- study the effect of **change in beliefs** of agents
  > from potentially a less efficient **(nearest) exit**
  > towards a more **efficient (recommended) exit**
  (do recommendations of surrounding agents change the belief of an agent?)

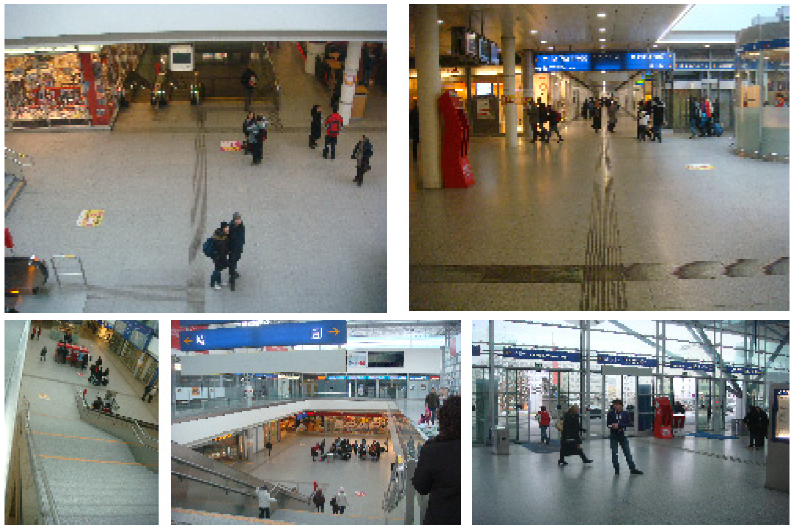
- agent based evacuation simulation
  > microscopic CA based locomotive rules (**evidence based**)
  > **decision making** model **based on emotions** (theoretical social/cognitive/ psychological model)
  > **different behavioral rule sets** for AmI-assisted and "normal" agents

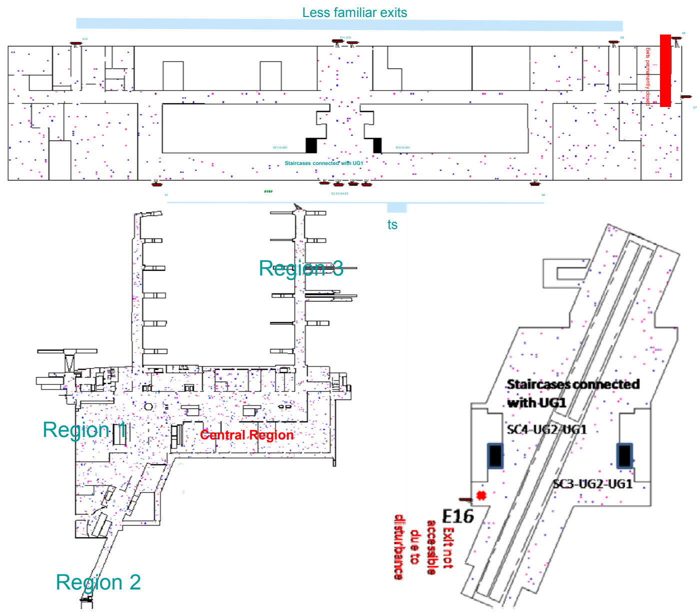
- **trust on information**
  > in (AmI-assisted) evacuation scenarios, trust on the source of information may has an influence on individual emotions, intentions, decisions
  > trust may exist in the following forms
  - trust on not AmI-assisted, agents (unknown, friends, family, firefighters)
  - trust on AmI-assisted agents (e.g., firefighters wearing a "LifeBelt")
  - trust on the technology for AmI-assisted agents (e.g., firefighter's trust on "LifeBelt") ("2nd level trust")

Evacuation Simulation: **A Cognitive Decision Making Model**

Scenario: Evacuation of Linz Main Station (Austrian railway, ÖBB)

- **building structure:** 3 levels (floors) with several exits on all levels
  - **(i) tram station**
    - two platforms connected with main hall through staircases and escalators
  - **(ii) main hall**
    - two staircases connecting main hall to the transit hall
    - two sides connected with tunnels to the main railway platforms
  - **(iii) transit hall**
    - having many central exits



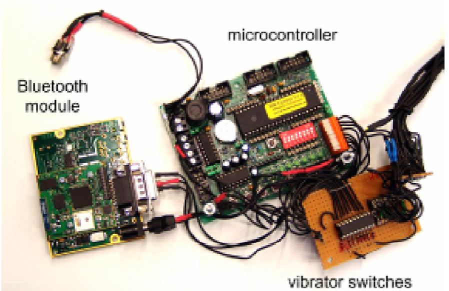


Evacuation Simulation: **A Cognitive Decision Making Model**

AmI: "LifeBelt" (silent directional guidance based on vibro-tactile stimulation)

- **variation of** (i) vibrating frequency, (ii) attenuation, (iii) mode

tactor elements

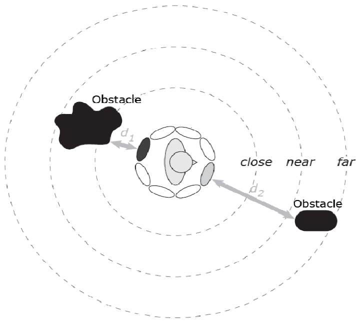


micro controller

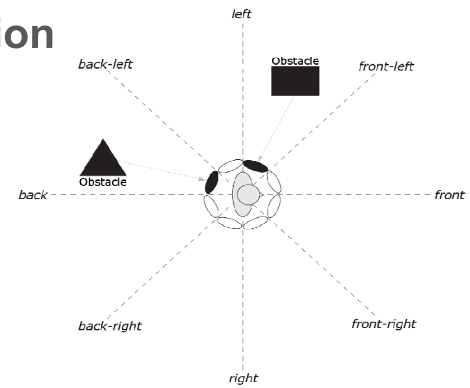
belt system

body worn belt system

- **notification of distance and orientation**



distance: attenuation + location



orientation: location + frequency

A. Ferscha, K. Zia: LifeBelt: Silent Directional Guidance for Crowd Evacuation. Proceedings of the 13th International Symposium on Wearable Computers (ISWC'09), Sept 4-7 2009, Linz, Austria, IEEE Computer Society Press, September 2009.

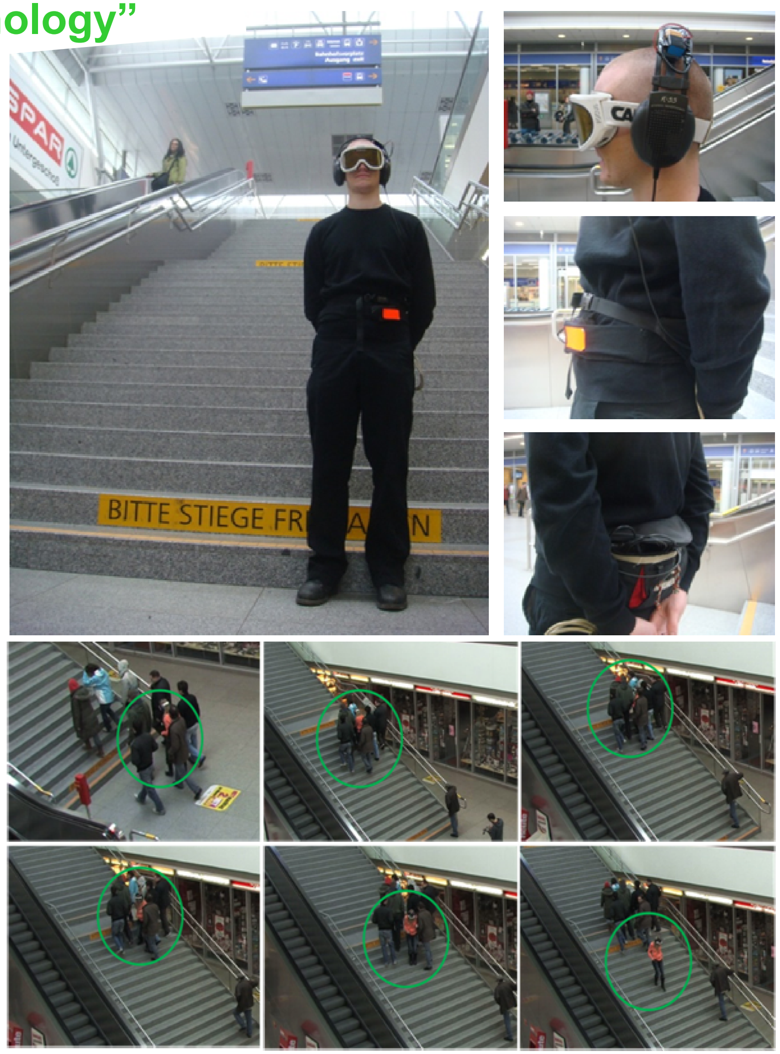
Evacuation Simulation: **A Cognitive Decision Making Model**

Linz main station: Experiment "Trust in technology"

- **limited perception**
  - **auditory distraction**: different levels of noise, screaming, etc. delivered via headphones
  - **visual restrictions**: ski goggles with foil inlay (varying level of blurring and transparency)

- **limited crowd psychology**
  - group of people (n=10) always circling the test person
  - crowd either went "with" test person, or turned around during a walk
  - test person either went "with" the crowd, or turned around during a walk on technology guidance (=by re-commendation)

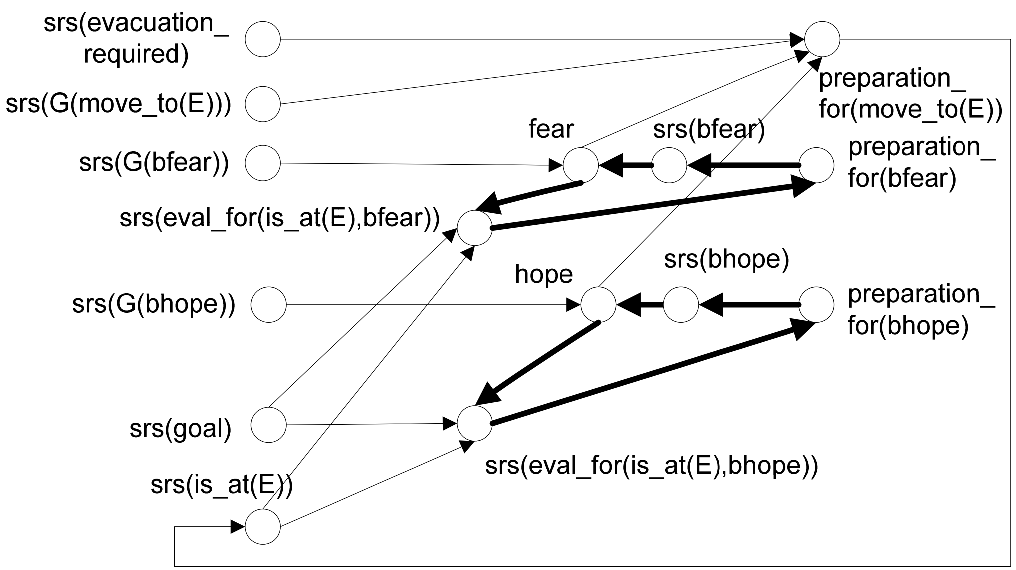
- **findings**
  - **most of the people trusted the recommendations** provided by "LifeBelt" (88%)
  - the **experimental results (modeling, traces) are conform to most of the famous theories of trust** (in the given situation)



Evacuation Simulation: **A Cognitive Decision Making Model**

Cognitive agent model ("which exit?")

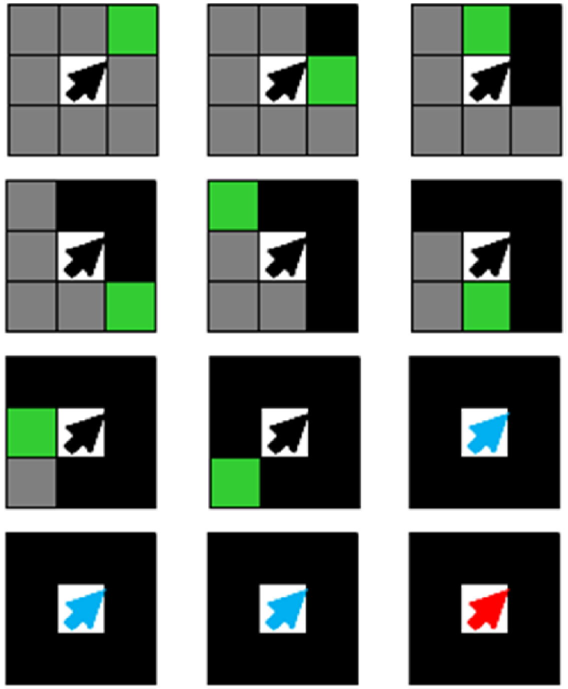
- a general **affective decision making model** to model cognitive processes of an agent (with cognitive attributes related to evacuation situation) include
  > **intension**: "trust" towards neighboring agents and "belief" for options (=exits)
  > **emotions**: "fear" / "hope" for options, and resulting "attraction" for options
  > **individualism**: "expressiveness", "openness" and "contagion"
- the cognitive model is based on a number of theories from neuropsychology, social science and psychology (*many of which were empirically validated*)



emotional decision making model for the option to move to exit "E"

Evacuation Simulation: **A Cognitive Decision Making Model**

Locomotion rules ("how to reach the exit")



Evacuation Simulation: **A Cognitive Decision Making Model**

Cognitive attributes of movable agents

Table: Agent Variables – Emotions		
Name	*Type*	*Description*
Neigh	Number	Current Number of neighbours of an agent
Fear	Table	Value of fear for each possible exit
Hope	Table	Value of hope for each possible exit
Attract	Table	Value of attraction for each possible exit
Belief	Table	Value of belief for each possible exit
Delta	Table	Value of trust for each possible intractable agent
Beta-hope	Number	Personal attribute of hopefulness
Beta-fear	Number	Personal attribute of fearfulness
Beta-att	Number	Personal attribute of attraction
Gamma	Number	Personal attribute of trustworthiness

Global variables defining populations

Table: Population Variables – globals		
Name	*Type*	*Description*
No-of-agents	Number	Total number of agents = tram-station-agents + incoming-tunnel-agents + main-hall-agents
Fractional-incoming-count	Number	Distribution of incoming agents (from tunnels and tram station) into entry points
Agents-count-in-EA-EXIT-ID	Number	Number of agents in respective exit area
Cluster-size	Number	Size of cluster around an agent considered as neighbourhood.
Ambient	Number	Percentage of ambient device enabled agents

Evacuation Simulation: **A Cognitive Decision Making Model**

Environmental variables

Table: Custom Patch and Global Variables		
Name	*Type*	*Description*
Structure-type	Text	Set to one of following values: obstacle, exit, floor or wall. Agents take many decisions based on the type of cell they are residing or types of nearby cells. • *Obstacles = gray* • *Floor = white* • *Exit = red* • *Wall = black* • *The stripes of cells represented in green are "entry points" of the populations entering during the simulation from platforms (in tunnels) and tram station (in centre). Currently hard-coded in the implementation.*
Walkable?	Boolean	Inferred variable from structure-type; can survive without it. Some structures are walkable some are not. *White, red and green are walkable.* *Black and gray are not walkable.*
Region	Text	Different regions of the layout. A cell belongs to which region. Centre, service, tunnel, corridor
Exit-ID	Text	Identity of an exit cell or cells. A cell belonging to exit area also knows the identity of exit it is related with. *Red strips corresponding to exit width.*
Is-EA?	Boolean	Whether a cell is part of an exit area *Shown with dashed areas around exits*
Doms	Table	Direction of motions towards all accessible exits
Steps-to-exits	Table	Steps (hops) to all accessible exits
EA-range (Global)	Numeric	Describes how much area around an exit would be considered as exit area range
T-ExitID (Global)	Numeric	Affective exit area for exit ExitID, excluding non walkable patches

Evacuation Simulation: **A Cognitive Decision Making Model**

Implementation of the cognitive model

```
for each agent a
    1. if has-device? and intentions-update-required?
        1. update-intentions
    2. else
        1. update-proximity-parameters
    3. for each exit e
        1. dist = belief_a(e)
        2. a1 = dist / steps ; where steps = 1
        3. a2 = (steps - dist) / steps
        4. a4 = beta_hope_a - (beta_hope_a * a2)
        5. a3 = (beta_hope_a * a2) + a1 - (beta_hope_a * a1)
        6. if (neighbour_count != 0)
            1. hope_a(e)= (beta_hope_a - beta_hope_a * (1 - ghope) * (1 - a4) + (1 - beta_hope_a) * ghope * a4) / (1 -
               beta_hope_a * (1 - ghope) * a3 - (1 - beta_hope_a) * ghope * a3) ; group variables globally accessable
        7. else
            1. hope_a(e) = a4 / (1 - a3)
        8. temp = a1
        9. a1 = a2
        10. a2 = temp
        11. a4 = beta_fear_a - (beta_fear_a * a2)
        12. a3 = beta_fear_a * a2 + a1 - beta_fear_a * a1
        13. if (neighbour_count != 0)
            1. fear_a(e) = (beta_fear_a - beta_fear_a * (1 - gfear) * (1 - a4) + (1 - beta_fear_a) * gfear * a4) / (1 -
               beta_fear_a * (1 - gfear) * a3 - (1 - beta_fear_a) * gfear * a3)
            2. attract_a(e) = attract_a(e) + (0.2 * (beta_att_a * (1 - ((1 - hope_a(e)) * fear_a(e) * (1 - gattract))) + (((1 -
               beta_att_a) * hope_a(e) * (1 - fear_a(e)) * gattract) - attract_a(e))))
        14. else
            1. fear_a(e) = a4 / (1 - a3)
            2. attract_a(e) = attract_a(e) + 0.2 * (beta_att_a * (1 - (1 - hope_a(e)) * fear_a(e)) + (1 - beta_att_a) * hope_a(e) *
               (1 - fear_a(e)) - attract_a(e))
        15. if (attract_a(e) > choose_val) ; where choose_val and choose_opt are initialized to -1 in each iteration
            1. choose_val = attract_a(e)
            2. Choose_opt = e
    4. curr-exit = choose_opt
    5. curr-dir = get-direction-for-curr-exit
    6. heading = curr-dir
    7. MOVE

update-intentions ; called for 'a' with has-device? = true and update-required?
    1. ex = get-optimal-exit
    2. re-set-beleifs ; re-set beliefs to all exit equal to 0.1, except for ex, for which belief is set to 0.9
    3. update-proximity-parameters
    4. for each agent n in the neighbourhood of a
        1. if NOT has-device? ; belief is only updated for normal agents
            1. for each exit e
                1. belief_n(e) = belief_n(e) / trust_n(a) * (belief_a(e) - belief_n(e))
        2. if has-device?
            1. trust_n(a)= trust_n(a) + belief_a(curr-exit) * (1 / (1 + (10 ^ (-39 * (1 - Abs (belief_n(curr-exit) -
               belief_a(curr-exit))) + 4)))) - trust_n(a)
            2. trust_n(a)= trust_n(a) + belief_a(curr-exit) * (1 / (1 + (10 ^ (-9 * (1 - Abs (belief_n(curr-exit) -
               belief_a(curr-exit))) + 4)))) - trust_n(a)

update-proximity-parameters ; called for 'a' with NOT has-device? Or NOT update-
    required?
    1. for each agent n in the neighbourhood of a
        1. for each exit e
            1. gfear = (gfear + (trust_a(n) * fear_n(e))) / neighbour_count ; group variables are initialized with zero
            2. ghope = (ghope + (trust_a(n) * hope_n(e))) / neighbour_count
            3. gattract = (gattract + (trust_a(n) * attract_n(e))) / neighbour_count
```

Evacuation Simulation: **A Cognitive Decision Making Model**

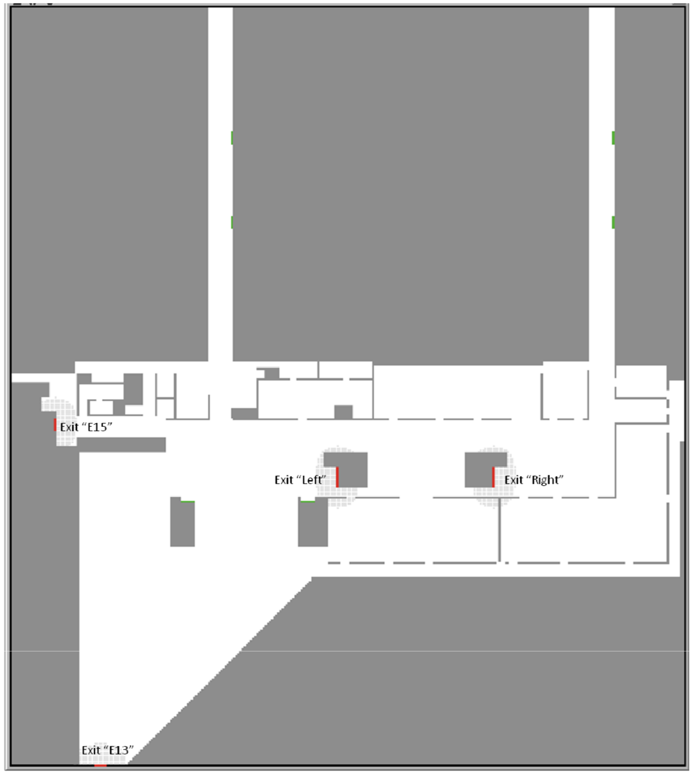
Exit choice strategies

- **strategy 1 "nearest exit"**
  - > **all the agents follow the nearest exit** based on random deployment
  - > **no AmI-assistance** is considered in this case
- **strategy 2 "optimal exit"**
  - > **each agent** is provided with a "**recommended exit**" in each time stamp based on its location and exit area (EA) dynamics
- **strategy 3 "following"**
  - > in this case, the **agents are either of type "AmI-assisted" or "simple agents"**
  - > **AmI-assisted** agents set their **beliefs** based on "optimal exit"-calculations, i.e., 0.9 for the optimal exit, 0.1 for other exits; then each of this agents <u>a</u> updates emotions of each of the <u>n</u> neighbors within interaction range
  - > **after updating the emotions**, each of the AmI-assisted agent <u>a</u> would **update intentions of the neighbors**; the update of belief (for each exit <u>e</u>) would only be performed for simple agents, whereas update of trust would be performed for AmI-assisted agents as well
  - > with newly **updated trust, belief and aggregation of emotions** nearby, the **choice of an exit** by each agent would be performed
  - > the **exit with maximum attraction** value would be selected as the exit of choice which would heavily be dependent on belief of an agent set by an AmI-assisted agent but it would also be **influenced by emotions in the surrounding**

Evacuation Simulation: **A Cognitive Decision Making Model**

Simulation setup – 3 cases (population size)

- in each parameter setting (see below), all the agents are required to evacuate through one of four available exits on the main hall (“e13”, “e15”, “left”, “right”)
- the emotion of agents starting from main hall is entirely different from that of agents joining in from tram station (with extreme fear and less hope) or from platforms (considerably relaxed)



Parameter settings (“cases”)

- **500** (*case 1*)/**1,000** (*case 2*)/**2,000** (*case 3*) agents in the main hall
- additionally, **250/500/750** agents each, joining in during the simulation from tram station and train platforms, respectively
- Initial hope, fear, attraction, etc.

Agent at	Beta_Hope	Beta_Fear	Beta_Attraction
Main hall	0.6	0.4	0.6
Tram station	0.1	0.9	0.1
Platforms	0.8	0.2	0.2

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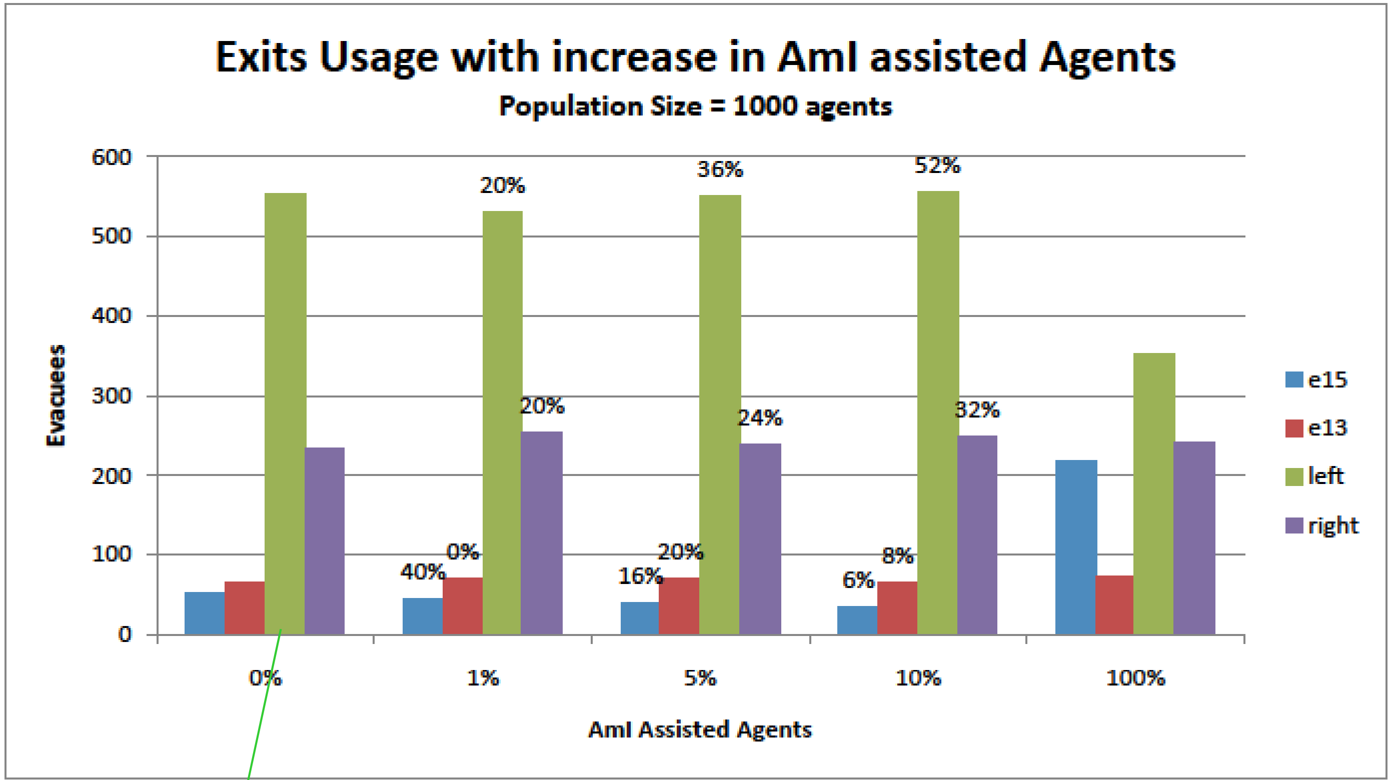
Evacuation Simulation: **A Cognitive Decision Making Model**

Simulation results

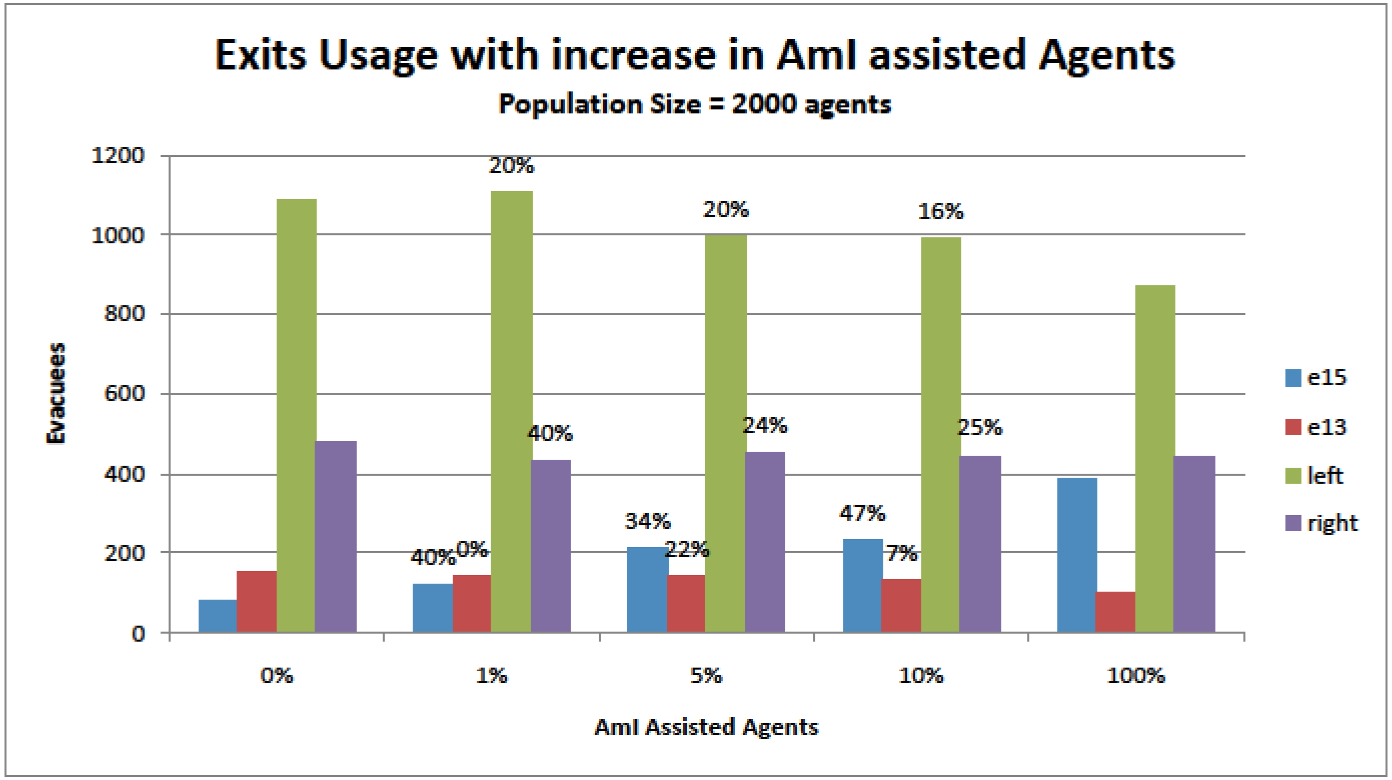


Case 1 (1,000 agents): Almost no effect of increase in AmI assisted %age due to too sparse population of agents.

most agents move to "left" exit → crowd builds up → evacuation is delayed

Evacuation Simulation: **A Cognitive Decision Making Model**

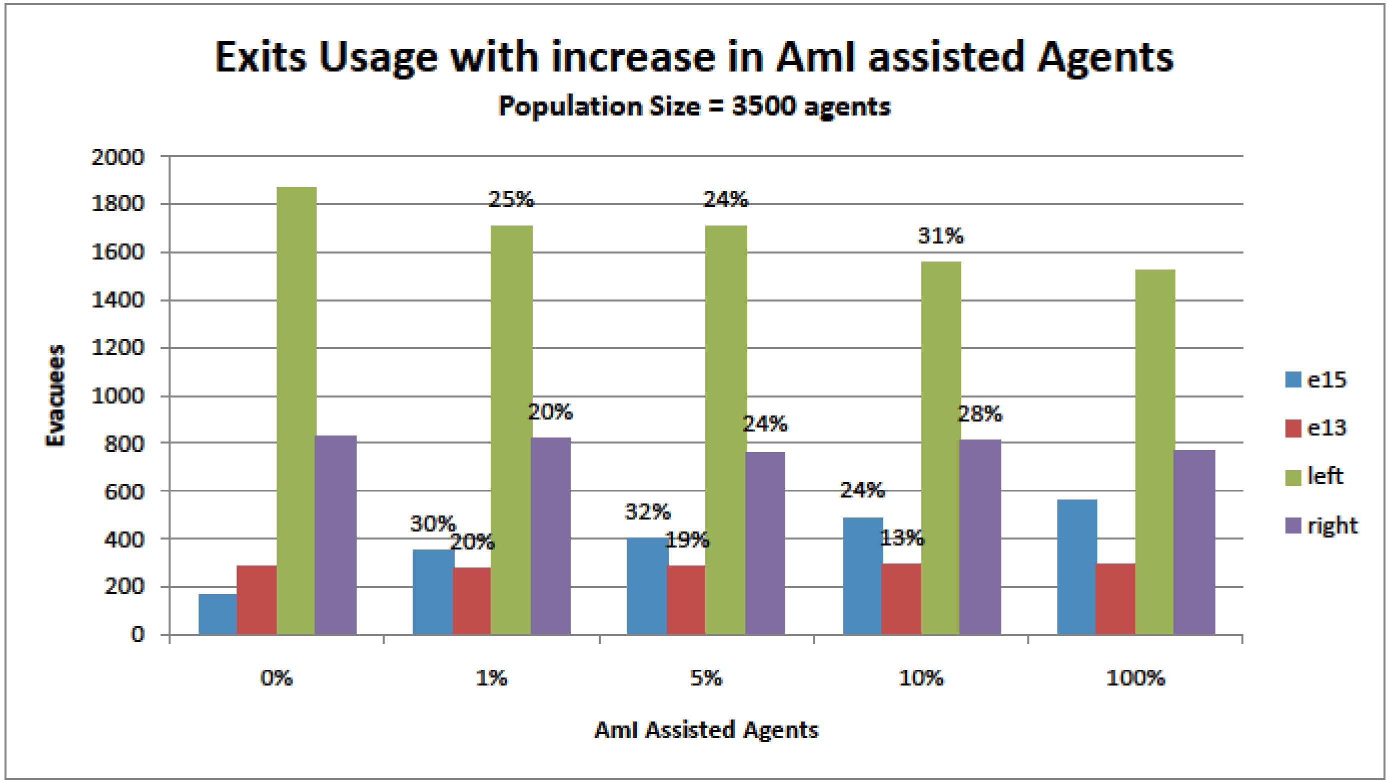
Simulation results



Case 2 (2,000 agents): Optimum exit usage (=benchmark) achieved with 100% AmI assisted agents. The higher the %age (from 1% to 10%), the better the exit usage compared to the benchmark.

Evacuation Simulation: **A Cognitive Decision Making Model**

Simulation results



Case 3 (3,500 agents): Behavior similar to **case 2**. The higher the quantity of agents (3,500 compared to 2,000 in case 2), the better the replication of optimum exit usage (already in case of lower AmI assistant agents).

Evacuation Simulation: **A Cognitive Decision Making Model**

Summary of simulation results

- with an increase in the population size, and as the %age of AmI-Assisted agents increases, the **exit utilization tend to optimize**

Agents		1000				2000				3500			
	Exit	e15	e13	left	right	e15	e13	left	right	e15	e13	left	right
AmI-Assisted													
0%		5.764967	7.206208	61.19734	25.83149	4.603439	8.54132	60.23295	26.6223	5.268169	9.139956	59.28277	26.30911
1%		5.105438	7.880133	58.82353	28.1909	6.651885	7.982262	61.3082	24.05765	11.15689	8.748019	54.13629	25.9588
5%		4.550499	7.769145	61.15427	26.52608	11.6408	7.871397	55.32151	25.1663	12.68633	8.912147	54.1072	24.29432
10%		3.769401	7.206208	61.52993	27.49446	12.82621	7.384786	55.02499	24.76402	15.51396	9.200508	49.52411	25.76142
100%		**24.71655**	**8.163265**	**39.79592**	**27.32426**	**21.44044**	**5.761773**	**48.31025**	**24.48753**	**17.90808**	**9.223455**	**48.33597**	**24.53249**

Evacuation Simulation: **A Cognitive Decision Making Model**

Conclusions

- focusing on an evacuation situation, we have integrated **agent based cognitive decision making model** based on psychological, neurological and social aspects into CA simulation to **analyze the effect of AmI assisted** (with technological assistance) **agents** on the intention of normal agents
- **simulation results** validate the following arguments
  > **technologically assisted agents emerge as leaders** during evacuation – changing the intentions of many agents within their influence

  > even a **small population** of such **leaders** is **sufficient to guarantee a remarkable difference**; particularly improving usage of possible under-utilized exits, e.g.,
  - *in case of a fairly large population of agents (3,500) with 10% being AmI-assisted, there is less than 2.5% difference in the utilization of the exits when compared with 100% AmI-assistance*
- in addition to simulating the model for a **real large scale**, we have to **improve** the model by incorporating more **heterogeneity in the behavior +social character of agents**

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