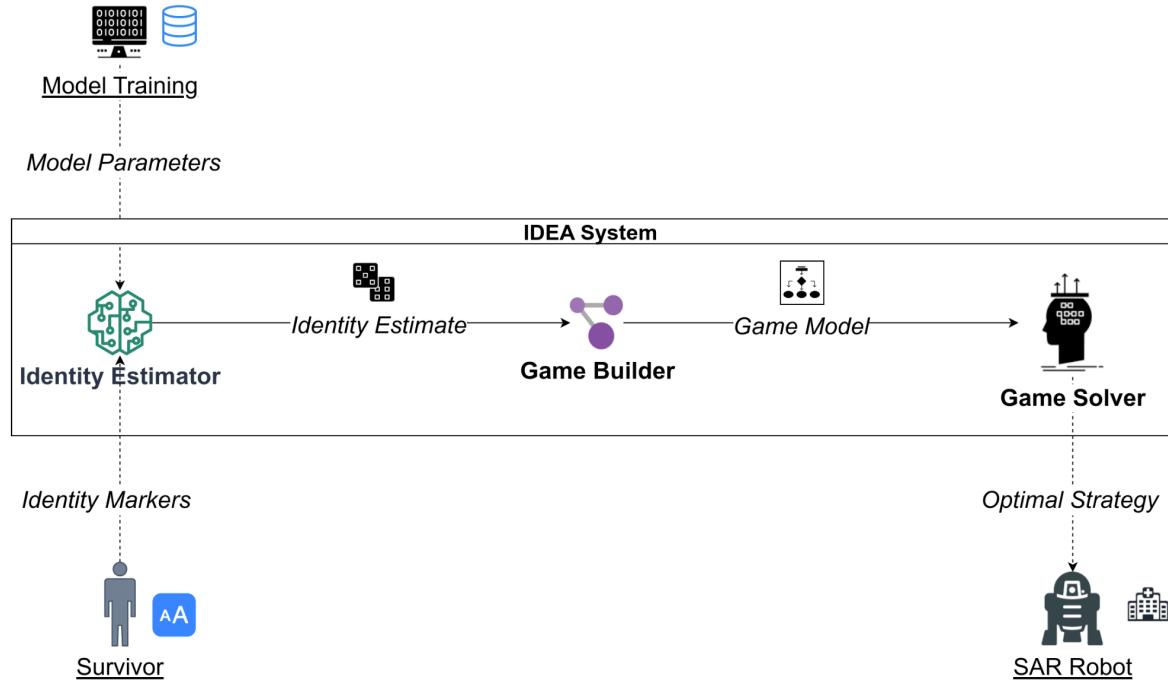




POLITECNICO
MILANO 1863

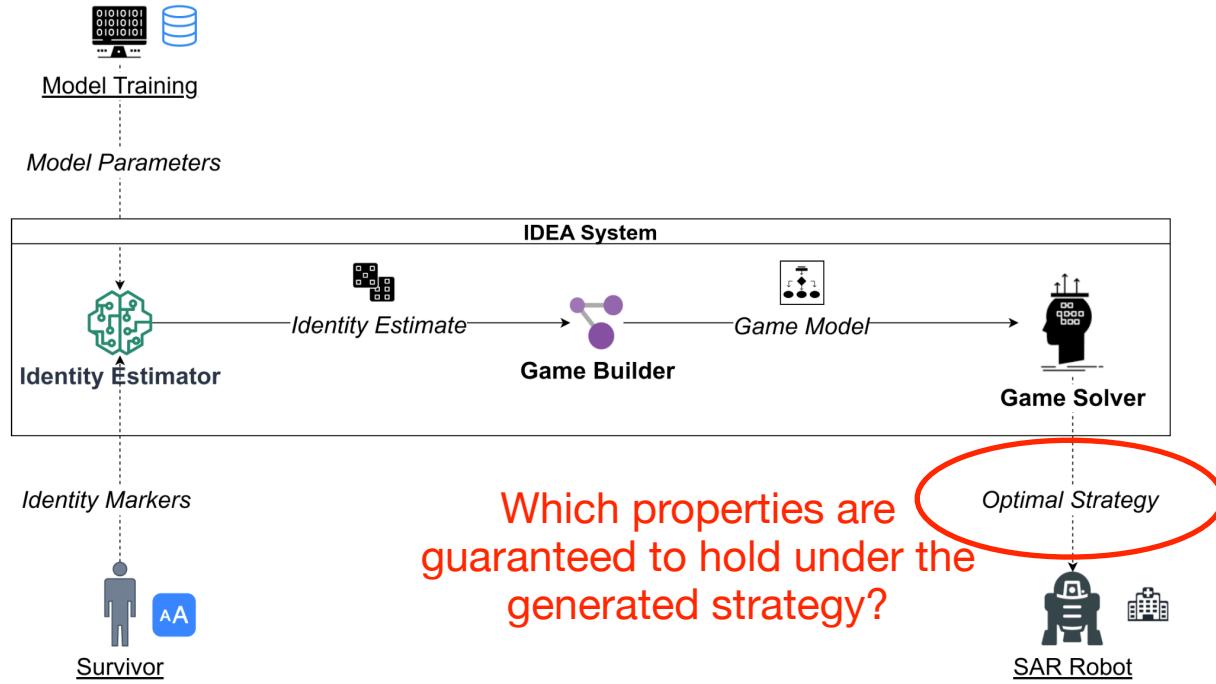
FormIdeAble: A Formally Verified Identity-Aware Autonomous Systems

The IDEA Framework [1]



[1] Gavidia-Calderon, C., Kordoni, A., Bennaceur, A., Levine, M., & Nuseibeh, B. The IDEA of Us: An Identity-Aware Architecture for Autonomous Systems. Submitted to TOSEM.

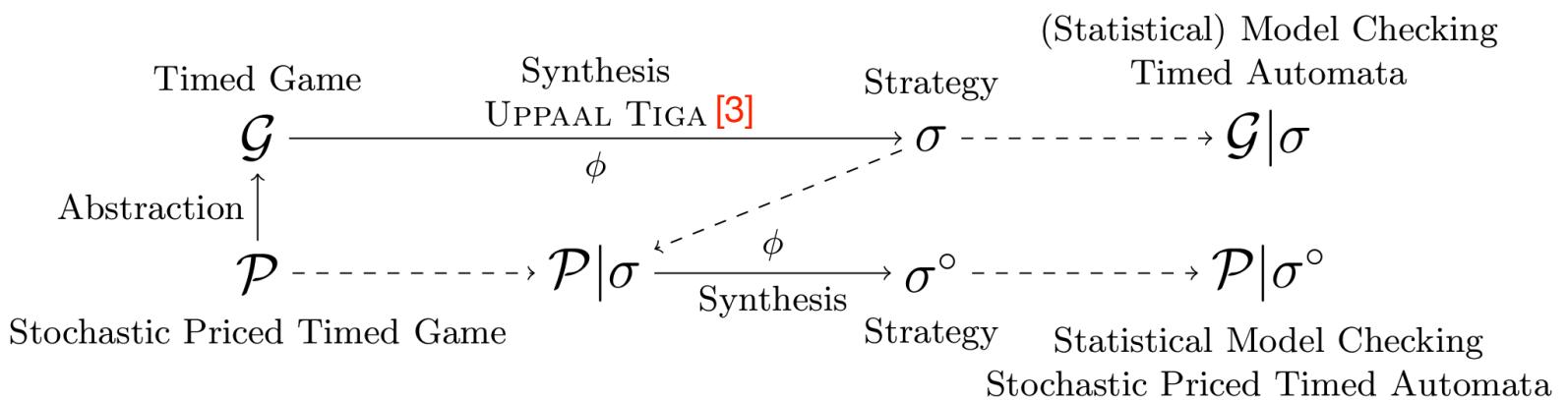
The IDEA Framework [1]



Which properties are
guaranteed to hold under the
generated strategy?

[1] Gavidia-Calderon, C., Kordoni, A., Bennaceur, A., Levine, M., & Nuseibeh, B. The IDEA of Us: An Identity-Aware Architecture for Autonomous Systems. Submitted to TOSEM.

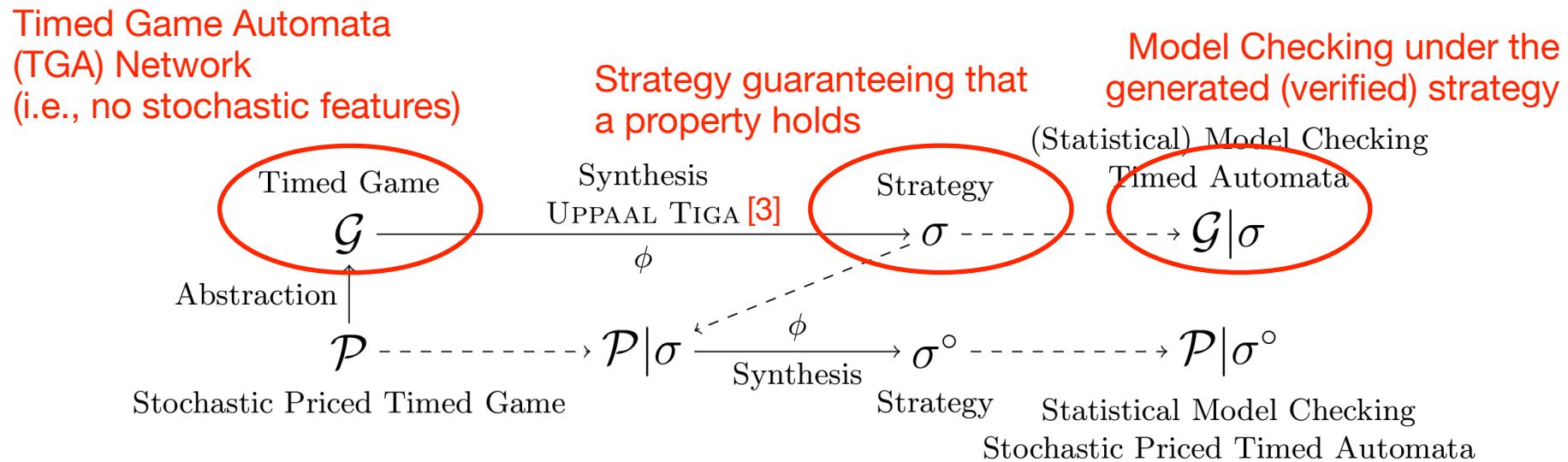
Uppaal Stratego [2]



[2] David, A., Jensen, P. G., Larsen, K. G., Mikučionis, M., & Taankvist, J. H. (2015). Uppaal stratego. In TACAS 2015, Proceedings 21 (pp. 206-211). Springer Berlin Heidelberg.

[3] Behrmann, G., Cougnard, A., David, A., Fleury, E., Larsen, K. G., & Lime, D. (2007). UPPAAL-Tiga: Time for Playing Games! (Tool Paper). In CAV 2007. Proceedings 19 (pp. 121-125). Springer Berlin Heidelberg.

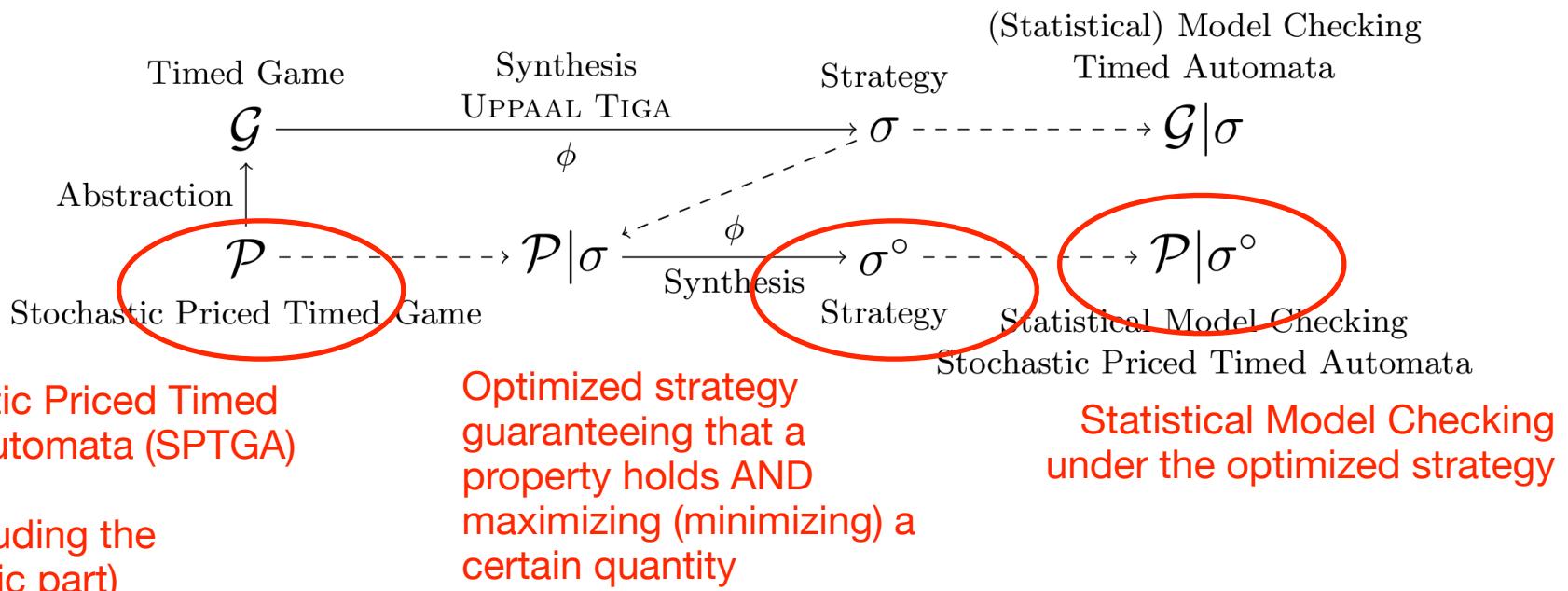
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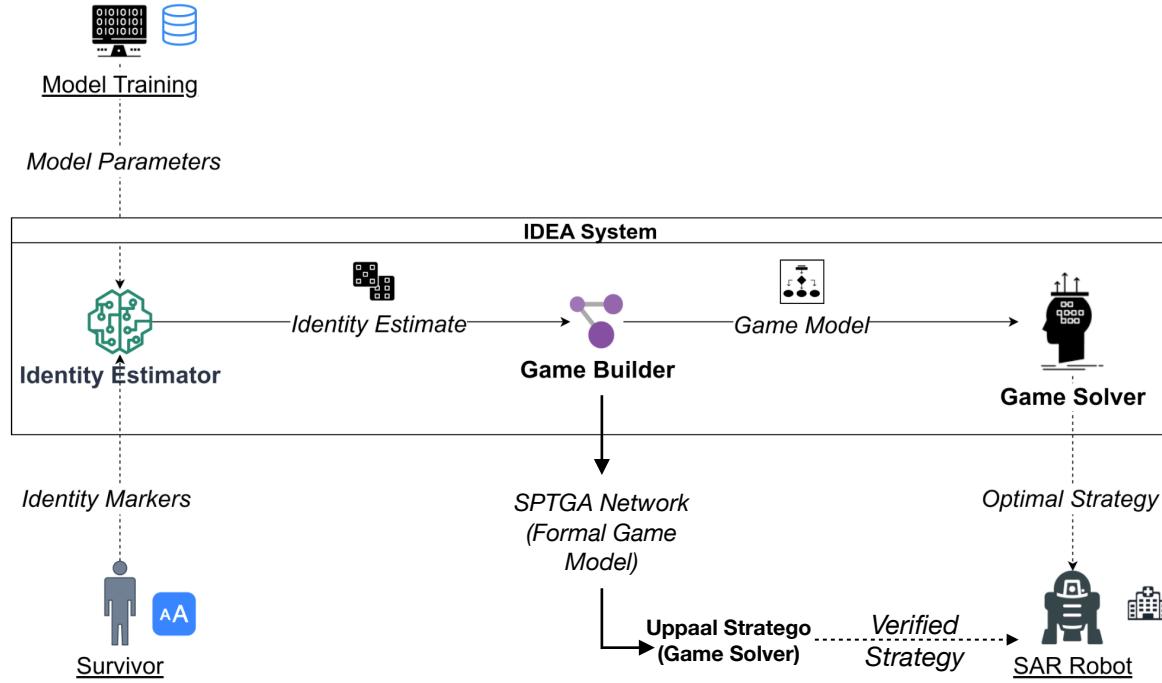
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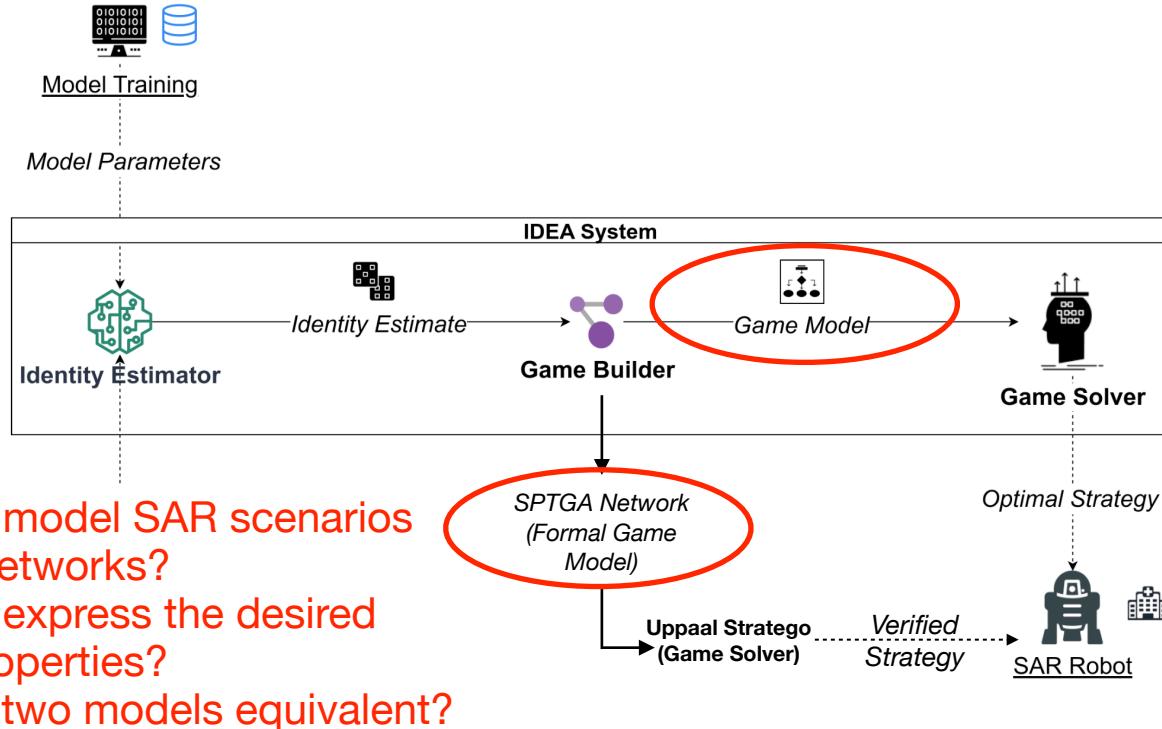
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The IDEA Framework [1] + Formal Verification



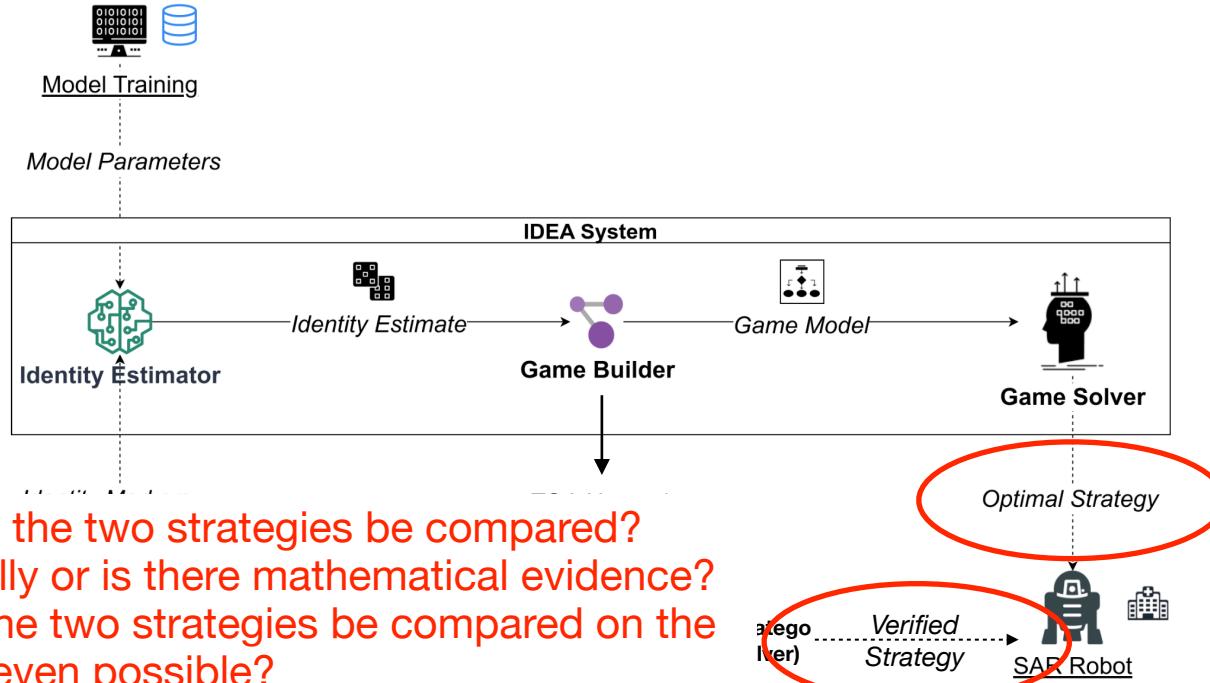
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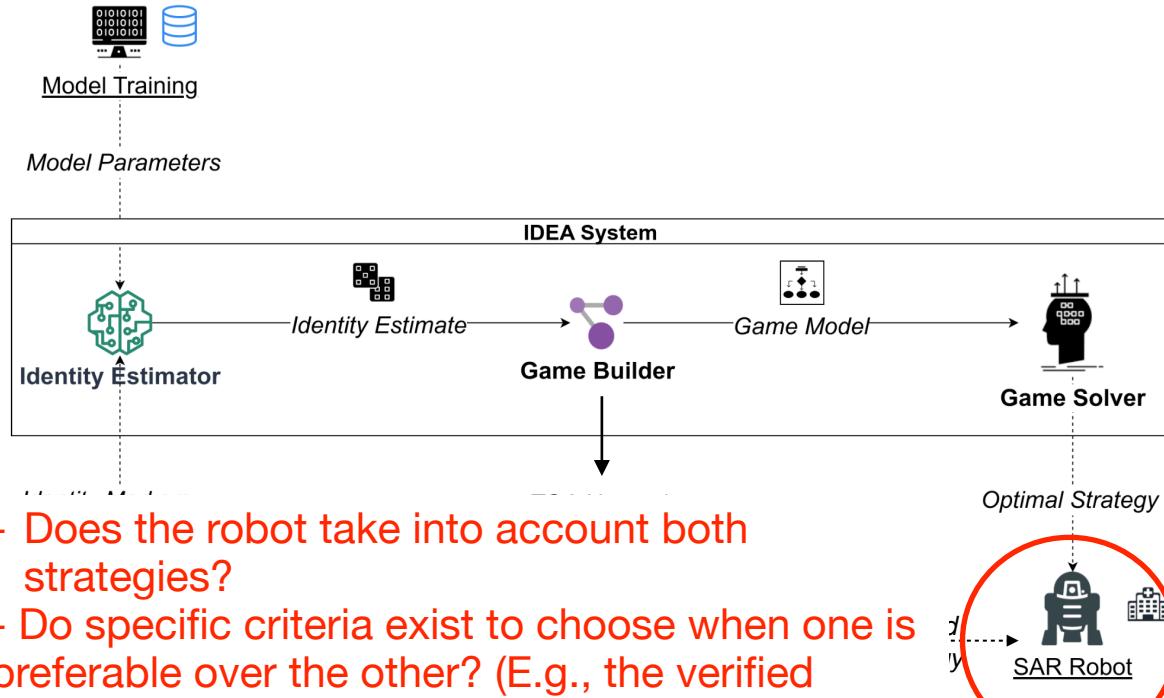
The IDEA Framework [1] + Formal Verification



- How can the two strategies be compared? Empirically or is there mathematical evidence?
- Should the two strategies be compared on the fly? Is it even possible?
- Can the formally verified strategy realistically be computed at runtime?

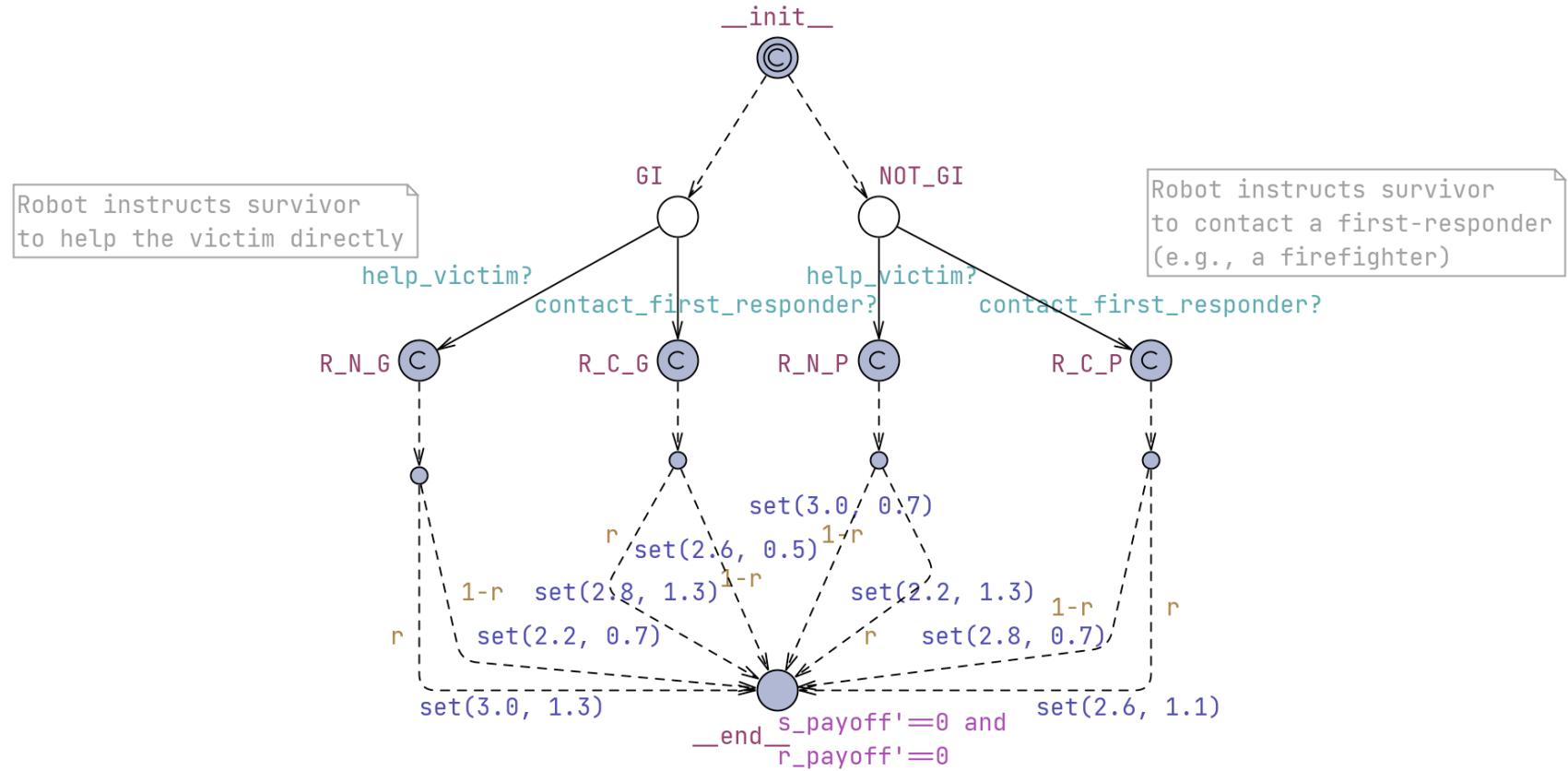
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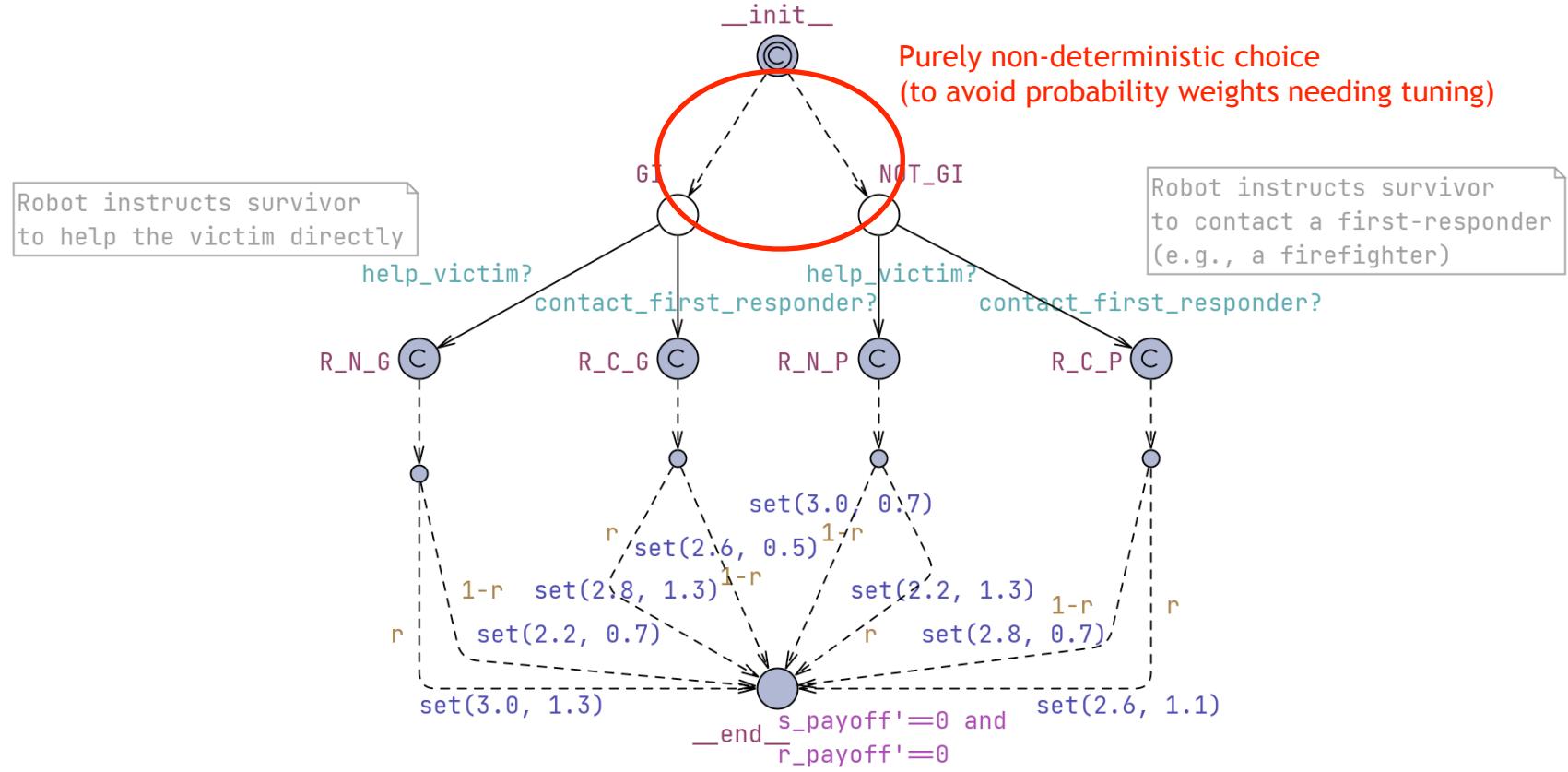


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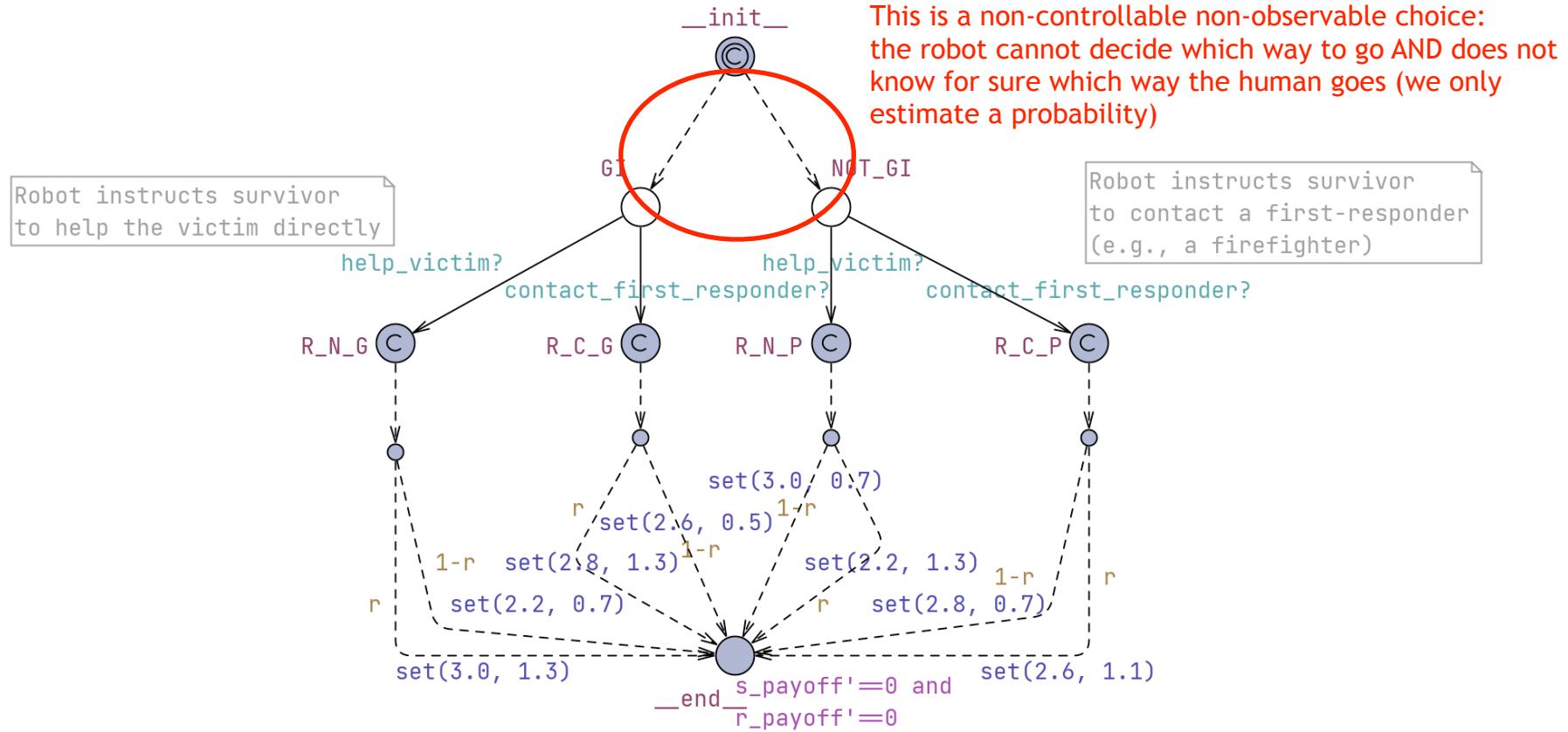
Formal Model



Formal Model



Formal Model



Synthesized controller: Payoffs?

The robot has two possible choices: $A_s = \{\text{contact-staff, do-help}\}$

Uppaal Stratego synthesizes a controller for the robot indicating the expected payoff value when choice act $\in A_s$ is selected in GI or NOT_GI, indicated as $U(\text{GI}, \text{act})$ and $U(\text{NOT_GI}, \text{act})$, respectively.

Uppaal optimizes the system's payoff value assuming a certain degree of rationality on the human's side, i.e., parameter r.

For example:

If $r = 1.0$ (the human is perfectly rational), they developed a shared identity (GI), and the robot instructs them to help, they will help with probability 1 since $1.3 > 0.7$.

Synthesized controller: Payoffs?

!! At runtime (when applying the controller), the robot does not know whether the human is in location GI or NOT_GI !!

We have an estimate (e.g., through a NN) of $P(\text{GI})$, $P(\text{NOT_GI}) = 1 - P(\text{GI})$.

Formal Model: How to deal with uncontrollable actions affected by uncertainty?

Re-calibrate the expected payoff value to account for the probability to reach the corresponding state (where act is either call-staff or do-help):

$$u_S(\text{GI}, \text{act}) = U(\text{GI}, \text{act}) \times P(\text{GI})$$

$$u_S(\text{NOT_GI}, \text{act}) = U(\text{NOT_GI}, \text{act}) \times (1 - P(\text{GI}))$$

Extracted from Uppaal strategy Estimated (at runtime)

Formal Model: How to deal with uncontrollable actions affected by uncertainty?

Re-calibrate the expected payoff value to account for the probability to reach the corresponding state (where act is either call-staff or do-help):

$$u_S(\text{GI}, \text{act}) = U(\text{GI}, \text{act}) \times P(\text{GI})$$

$$u_S(\text{NOT_GI}, \text{act}) = U(\text{NOT_GI}, \text{act}) \times (1 - P(\text{GI}))$$

	contact-staff	do-help
GI	2.8	3.0
NOT_GI	2.6	2.2

Formal Model: How to deal with uncontrollable actions affected by uncertainty?

Re-calibrate the expected payoff value to account for the probability to reach the corresponding state (where act is either call-staff or do-help):

$$u_S(\text{GI}, \text{act}) = U(\text{GI}, \text{act}) \times P(\text{GI})$$

$$u_S(\text{NOT_GI}, \text{act}) = U(\text{NOT_GI}, \text{act}) \times (1 - P(\text{GI}))$$

P(GI) = 0.8	contact-staff	do-help
GI	2.8*0.8=2.24	3.0*0.8=2.4
NOT_GI	2.6*0.2=0.52	2.2*0.2=0.44

Formal Model: How to deal with uncontrollable actions affected by uncertainty?

Re-calibrate the expected payoff value to account for the probability to reach the corresponding state (where act is either call-staff or do-help):

$$u_S(\text{GI}, \text{act}) = U(\text{GI}, \text{act}) \times P(\text{GI})$$

$$u_S(\text{NOT_GI}, \text{act}) = U(\text{NOT_GI}, \text{act}) \times (1 - P(\text{GI}))$$

$P(\text{GI}) = 0.8$	contact-staff	do-help	
GI	$2.8 * 0.8 = 2.24$	$3.0 * 0.8 = 2.4$	
NOT_GI	$2.6 * 0.2 = 0.52$	$2.2 * 0.2 = 0.44$	
	2.76	<	2.84
	(do-help is preferable)		

Formal Model: How to deal with uncontrollable actions affected by uncertainty?

Re-calibrate the expected payoff value to account for the probability to reach the corresponding state (where act is either call-staff or do-help):

$$u_S(\text{GI}, \text{act}) = U(\text{GI}, \text{act}) \times P(\text{GI})$$

$$u_S(\text{NOT_GI}, \text{act}) = U(\text{NOT_GI}, \text{act}) \times (1 - P(\text{GI}))$$

$P(\text{GI}) = 0.12$	contact-staff	do-help
GI	$2.8 * 0.12 = 0.33$	$3.0 * 0.12 = 0.36$
NOT_GI	$2.6 * 0.88 = 2.28$	$2.2 * 0.88 = 1.93$

Formal Model: How to deal with uncontrollable actions affected by uncertainty?

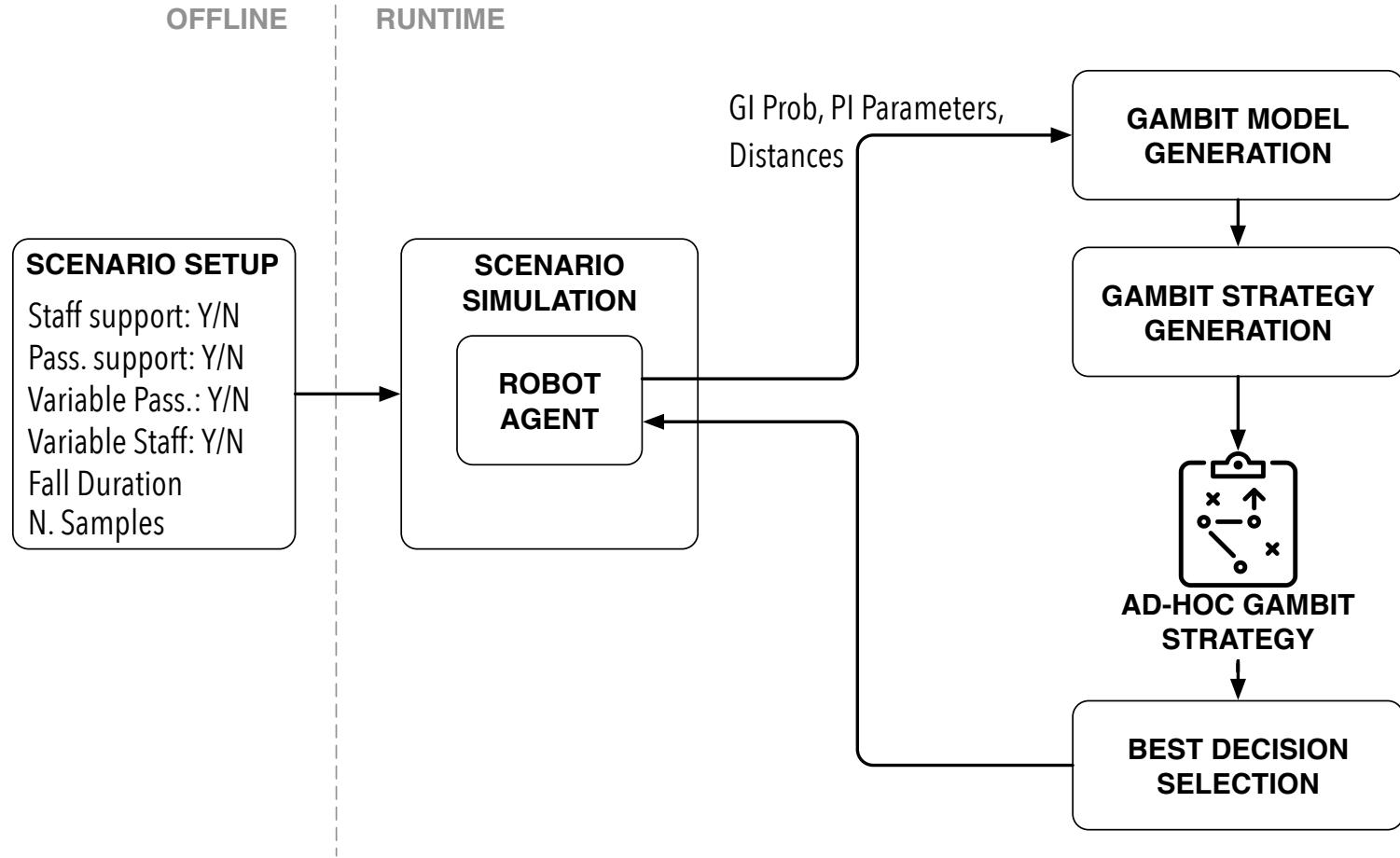
Re-calibrate the expected payoff value to account for the probability to reach the corresponding state (where act is either call-staff or do-help):

$$u_S(\text{GI}, \text{act}) = U(\text{GI}, \text{act}) \times P(\text{GI})$$

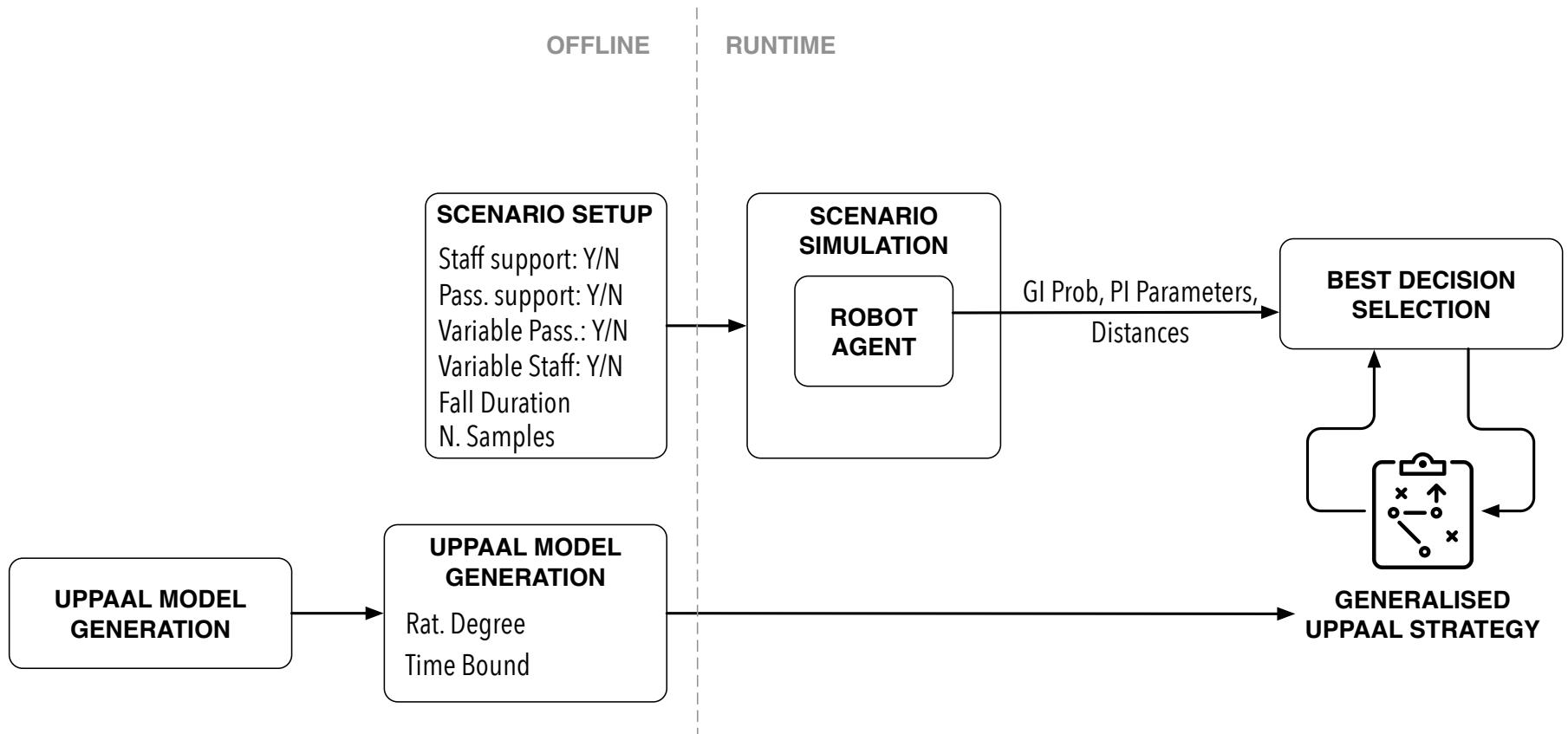
$$u_S(\text{NOT_GI}, \text{act}) = U(\text{NOT_GI}, \text{act}) \times (1 - P(\text{GI}))$$

$P(\text{GI}) = 0.12$	contact-staff	do-help	
GI	$2.8 * 0.12 = 0.33$	$3.0 * 0.12 = 0.36$	
NOT_GI	$2.6 * 0.88 = 2.28$	$2.2 * 0.88 = 1.93$	
	2.61	>	2.29
	(contact-staff is preferable)		

IMPACT+ Framework IDEA agents: Game-theoretic Model

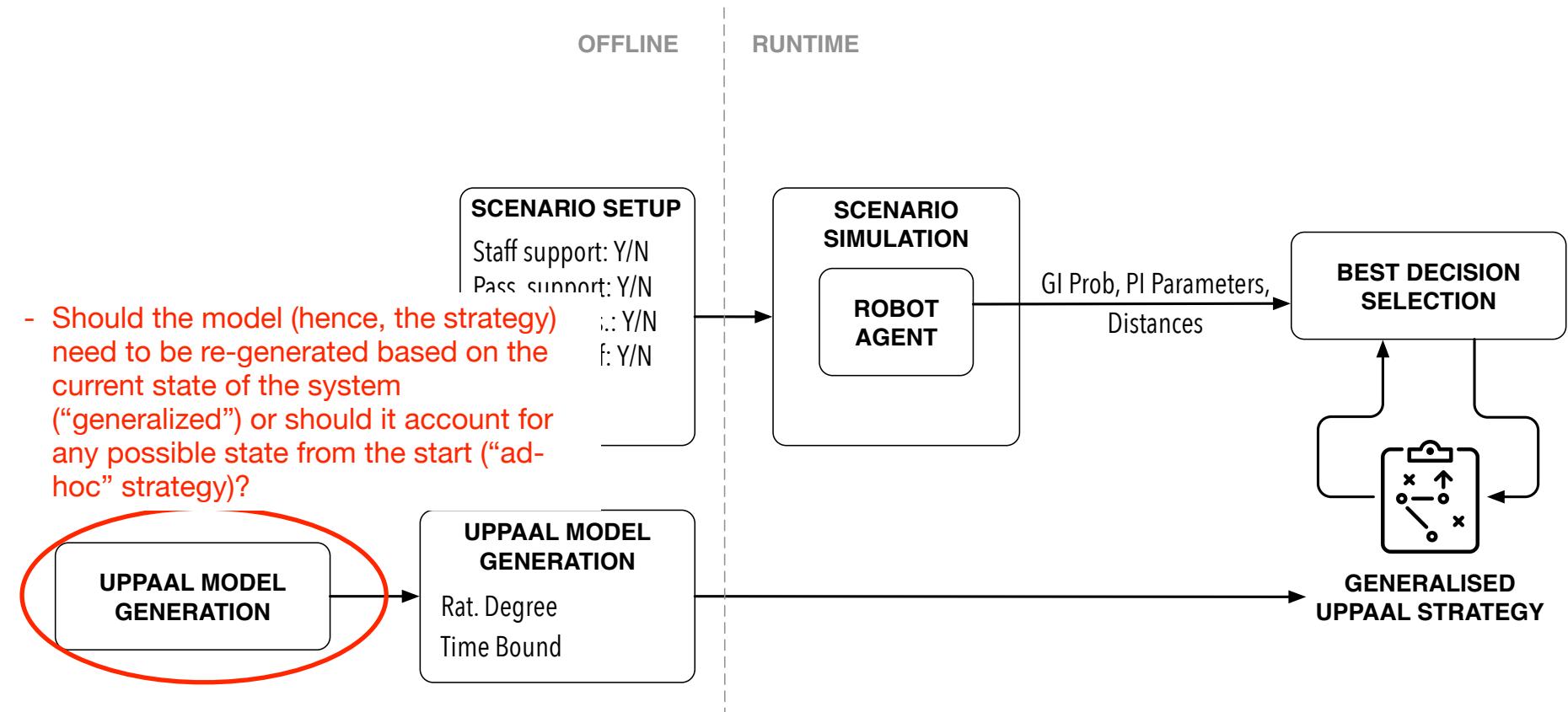


IMPACT+ Framework for Formalised IDEA agents: Generalised Strategy



IMPACT+ Framework for Formalised IDEA agents: Generalised Strategy

- Should the model (hence, the strategy) need to be re-generated based on the current state of the system ("generalized") or should it account for any possible state from the start ("ad-hoc" strategy)?



Experiment Settings:

- **Generalized** Strategy
- **Fixed** (462, 6%) vs. **variable** (150-700, 1-10%) Passengers/Staff Members
- **Time Bound** 20/50 s
- **Rationality Degree** 1.0/0.5
- **Fall length** 30-600

X

Configuration with best evacuation time median
considering **all sim. seeds**

X

Configuration with best evacuation time median
considering **only sim. seeds where robot makes
at least 3 decisions**

Generalized Strategy, fixed Passengers/Staff Members, TB 20, RAT 1.0

Fall Length	No-support	Staff-support	Passenger-support	Adaptive-support
30	275.0	274.0	271.5	269.0
60	290.5	268.5	279.0	273.5
90	274.0	271.0	277.0	273.0
120	275.5	269.5	271.0	274.0
150	280.5	271.0	273.5	274.5
180	274.0	276.0	276.0	266.0
210	275.5	271.5	273.0	272.0
240	273.5	272.0	278.5	265.0
270	275.0	273.0	271.0	271.5
300	276.5	265.0	275.0	268.5
330	275.0	277.0	274.5	276.0
360	273.5	271.5	274.0	265.0
390	279.0	269.0	272.0	269.5
420	268.0	268.5	275.0	283.0
450	276.5	273.0	276.5	267.0
480	275.0	282.0	274.0	277.0
510	280.0	272.5	273.5	275.0
540	277.0	278.0	274.0	279.0
570	279.0	265.0	278.0	272.5
600	280.0	267.0	275.0	265.5

Generalized Strategy, variable Passengers/Staff Members, TB 20, RAT 1.0

Fall Length	No-support	Staff-support	Passenger-support	Adaptive-support
30	265.5	260.0	259.5	261.0
60	273.5	290.0	272.5	266.0
90	262.5	270.0	276.0	269.0
120	269.0	262.5	263.0	260.0
150	281.5	270.0	269.5	264.0
180	276.0	273.0	266.5	267.0
210	267.5	303.5	280.0	264.0
240	294.0	261.5	267.5	280.0
270	288.0	267.5	270.5	261.0
300	282.5	263.5	267.5	268.0
330	275.0	260.0	267.5	264.5
360	268.5	266.0	278.0	263.5
390	264.5	265.5	268.5	262.0
420	275.0	296.0	278.0	271.5
450	276.0	266.0	271.5	270.5
480	273.5	260.0	266.0	261.0
510	264.0	267.5	263.5	261.0
540	273.5	272.5	270.5	278.5
570	267.0	259.0	269.0	260.5
600	266.0	266.0	262.5	267.0

Generalized Strategy, variable Passengers/Staff Members, TB 20, RAT 1.0

Fall Length	No-support	Staff-support	Passenger-support	Adaptive-support
30	306.0	266.5	276.5	273.5
60	271.0	297.0	280.0	288.0
90	275.0	271.0	277.0	271.0
120	293.0	270.0	271.0	276.0
150	273.5	275.0	269.5	283.0
180	290.0	281.0	269.0	271.0
210	271.0	311.0	280.0	264.0
240	293.0	265.0	279.0	278.0
270	289.0	289.0	260.5	265.0
300	310.0	276.0	272.0	289.0
330	275.0	259.0	274.0	268.0
360	296.5	271.0	291.5	261.0
390	277.5	274.5	281.5	263.0
420	309.0	323.0	303.0	278.0
450	285.5	268.5	295.0	273.5
480	289.0	273.0	276.0	267.0
510	273.0	275.0	267.0	264.0
540	275.5	313.5	273.5	295.0
570	280.0	267.0	270.0	260.0
600	264.0	263.0	270.0	260.0

Generalized Strategy, fixed Passengers/Staff Members, TB 20, RAT 0.5

Fall Length	No-support	Staff-support	Passenger-support	Adaptive-support
30	282.5	265.0	268.5	268.0
60	298.5	263.5	267.0	263.5
90	275.5	274.5	273.0	273.5
120	274.5	269.0	289.5	282.0
150	286.0	270.0	275.0	297.0
180	272.5	269.0	274.0	272.0
210	272.0	278.5	269.0	295.0
240	286.0	267.5	276.5	274.0
270	267.0	270.0	280.5	265.0
300	277.5	270.5	271.5	270.5
330	287.0	272.5	290.0	263.0
360	290.5	268.5	271.0	270.0
390	268.0	276.0	286.5	285.0
420	276.0	267.0	276.5	267.0
450	268.5	289.5	269.0	268.5
480	278.0	277.5	273.0	273.5
510	270.0	280.0	267.0	264.5
540	279.0	267.5	271.0	276.5
570	289.5	292.5	270.5	265.5
600	266.5	262.0	267.0	296.0

Generalized Strategy, fixed Passengers/Staff Members, TB 20, RAT 0.5

Fall Length	No-support	Staff-support	Passenger-support	Adaptive-support
30	274.0	262.0	294.0	261.0
60	315.5	316.5	267.0	275.5
90	288.0	271.0	274.5	259.0
120	297.0	266.0	297.0	259.0
150	345.0	286.5	314.0	321.5
180	267.5	266.5	268.5	269.5
210	283.0	279.0	288.0	291.0
240	280.0	315.0	278.0	282.0
270	313.0	269.0	269.0	261.0
300	267.0	265.0	270.0	273.0
330	271.0	283.0	305.5	261.0
360	272.0	266.0	270.0	269.0
390	267.0	284.0	280.0	291.0
420	275.0	281.0	276.0	259.0
450	272.0	314.0	316.5	262.0
480	282.0	275.0	300.0	257.0
510	294.0	285.0	271.5	263.5
540	269.0	264.5	267.5	282.5
570	291.0	273.0	261.0	282.0
600	261.5	268.0	276.0	312.5

Generalized Strategy, variable Passengers/Staff Members, TB 20, RAT 0.5

Fall Length	No-support	Staff-support	Passenger-support	Adaptive-support
30	277.0	269.0	273.5	269.5
60	280.0	266.0	277.5	266.0
90	271.0	259.5	269.0	264.5
120	272.5	284.5	281.5	273.5
150	269.0	266.0	268.0	265.0
180	273.5	272.0	269.5	266.5
210	268.0	268.0	271.0	263.0
240	282.5	269.5	268.5	275.5
270	271.0	286.5	264.5	262.5
300	266.5	258.0	270.5	262.0
330	279.0	272.0	268.5	271.5
360	269.0	260.5	267.0	261.5
390	267.5	285.0	279.0	279.0
420	265.5	266.5	263.5	268.0
450	282.5	271.5	278.5	270.0
480	269.0	287.0	269.5	269.0
510	270.0	263.0	272.5	265.5
540	272.5	268.5	276.5	263.5
570	268.5	261.5	267.0	265.0
600	271.5	264.5	269.5	272.5

Generalized Strategy, variable Passengers/Staff Members, TB 20, RAT 0.5

Fall Length	No-support	Staff-support	Passenger-support	Adaptive-support
30	288.0	271.0	281.0	269.0
60	294.0	266.0	306.0	268.5
90	277.5	272.5	277.5	275.0
120	274.0	314.0	268.0	264.0
150	288.0	276.0	273.0	280.0
180	295.0	275.0	272.0	280.0
210	298.0	274.0	280.0	261.0
240	329.0	305.0	285.0	275.0
270	285.0	264.0	296.0	268.0
300	292.0	260.0	284.5	261.5
330	299.5	324.0	276.5	298.5
360	368.0	260.5	282.0	280.5
390	274.0	320.5	300.0	314.5
420	296.0	282.0	285.5	303.0
450	296.0	282.0	283.5	275.5
480	283.0	305.0	274.5	270.0
510	311.0	262.0	286.0	268.0
540	276.0	295.0	315.0	315.0
570	275.0	267.0	289.0	291.0
600	273.5	261.0	296.0	276.5

Generalized Strategy, fixed Passengers/Staff Members, TB 50, RAT 1.0

Fall Length	No-support	Staff-support	Passenger-support	Adaptive-support
30	286.5	272.0	269.0	278.0
60	265.0	269.0	272.5	270.0
90	272.0	271.5	276.5	268.5
120	289.0	266.5	272.0	272.0
150	278.5	266.5	268.0	266.0
180	270.0	262.5	271.5	265.0
210	270.0	273.5	280.0	273.0
240	271.0	272.0	266.0	269.0
270	271.0	272.5	282.0	277.0
300	271.5	272.0	270.5	268.5
330	286.0	275.0	270.0	268.5
360	270.0	279.0	278.5	277.5
390	277.0	265.5	286.0	273.5
420	264.0	267.0	266.5	265.0
450	284.5	277.0	285.5	286.0
480	268.5	268.0	274.0	273.0
510	280.0	275.5	279.5	279.0
540	271.0	265.5	271.0	268.0
570	273.0	273.5	275.5	275.5
600	306.5	264.5	283.5	267.5

Generalized Strategy, variable Passengers/Staff Members, TB 50, RAT 1.0

Fall Length	No-support	Staff-support	Passenger-support	Adaptive-support
30	272.5	275.0	264.0	266.5
60	278.5	270.0	268.5	266.0
90	268.5	267.5	270.0	265.5
120	279.0	279.5	282.0	270.5
150	273.5	266.0	267.5	263.5
180	279.5	257.0	265.0	263.5
210	280.5	268.0	273.5	264.0
240	280.0	265.0	286.5	264.5
270	275.0	269.5	262.5	262.0
300	296.0	287.5	270.5	266.5
330	281.0	272.0	273.0	264.5
360	285.0	265.5	271.0	271.5
390	274.5	274.0	275.0	274.5
420	274.0	262.0	276.0	274.5
450	271.5	260.0	269.0	261.5
480	269.0	270.5	273.5	267.5
510	273.0	261.0	264.5	271.5
540	266.5	262.5	263.5	262.0
570	280.5	272.0	273.0	270.0
600	275.5	266.5	266.0	271.5

Generalized Strategy, variable Passengers/Staff Members, TB 50, RAT 1.0

Fall Length	No-support	Staff-support	Passenger-support	Adaptive-support
30	288.5	317.0	271.5	269.0
60	278.5	276.0	271.5	279.5
90	306.5	274.5	313.5	270.0
120	291.0	313.0	277.0	269.0
150	294.0	262.0	269.0	265.0
180	288.5	265.0	271.0	266.0
210	287.0	272.0	276.0	265.0
240	275.0	266.0	285.0	267.0
270	317.0	294.0	275.0	266.0
300	316.0	286.0	276.0	276.0
330	315.0	265.0	273.0	283.0
360	320.0	260.0	270.0	275.0
390	269.0	301.5	285.0	286.5
420	317.0	259.0	280.0	283.0
450	279.5	271.0	293.0	261.5
480	296.0	284.0	285.0	267.0
510	278.0	267.0	274.0	276.0
540	306.0	279.0	318.0	280.0
570	317.0	283.0	278.0	271.0
600	290.0	269.0	272.0	276.0

Generalized Strategy, fixed Passengers/Staff Members, TB 50, RAT 0.5

Fall Length	No-support	Staff-support	Passenger-support	Adaptive-support
30	270.5	271.5	283.0	276.5
60	281.5	266.5	269.0	265.5
90	277.0	270.0	266.5	266.0
120	274.0	262.5	271.5	263.0
150	267.0	270.0	281.0	264.0
180	280.0	268.0	276.5	271.0
210	273.5	264.0	279.5	264.0
240	275.5	268.5	289.0	277.5
270	274.0	276.5	264.0	273.5
300	268.5	263.5	273.0	271.0
330	271.5	269.0	283.5	265.0
360	285.0	288.5	285.0	276.0
390	287.0	273.0	265.0	272.5
420	284.5	305.5	273.5	274.0
450	278.0	263.0	276.0	267.5
480	281.0	276.5	286.5	283.5
510	277.5	265.0	275.5	281.5
540	271.0	277.5	287.0	268.0
570	268.0	264.5	278.5	277.0
600	277.5	274.5	279.0	276.0

Generalized Strategy, fixed Passengers/Staff Members, TB 50, RAT 0.5

Fall Length	No-support	Staff-support	Passenger-support	Adaptive-support
30	267.0	272.0	271.0	286.0
60	279.0	261.0	289.0	261.0
90	273.0	267.0	263.0	266.0
120	266.0	260.0	270.0	262.5
150	270.0	278.0	285.0	269.0
180	277.0	263.0	280.0	270.5
210	271.0	265.5	272.0	264.0
240	268.0	280.5	292.0	271.5
270	271.0	299.0	272.0	265.0
300	268.0	272.0	273.0	263.0
330	269.5	270.5	288.5	272.5
360	286.0	286.0	278.0	276.0
390	283.5	258.5	266.0	268.0
420	285.0	286.0	269.0	268.5
450	277.0	262.5	273.0	266.5
480	268.0	276.0	304.0	284.0
510	281.0	265.0	277.0	288.5
540	270.0	280.0	279.0	290.0
570	267.5	260.5	282.0	299.5
600	274.0	268.0	273.0	286.0

Generalized Strategy, variable Passengers/Staff Members, TB 50, RAT 0.5

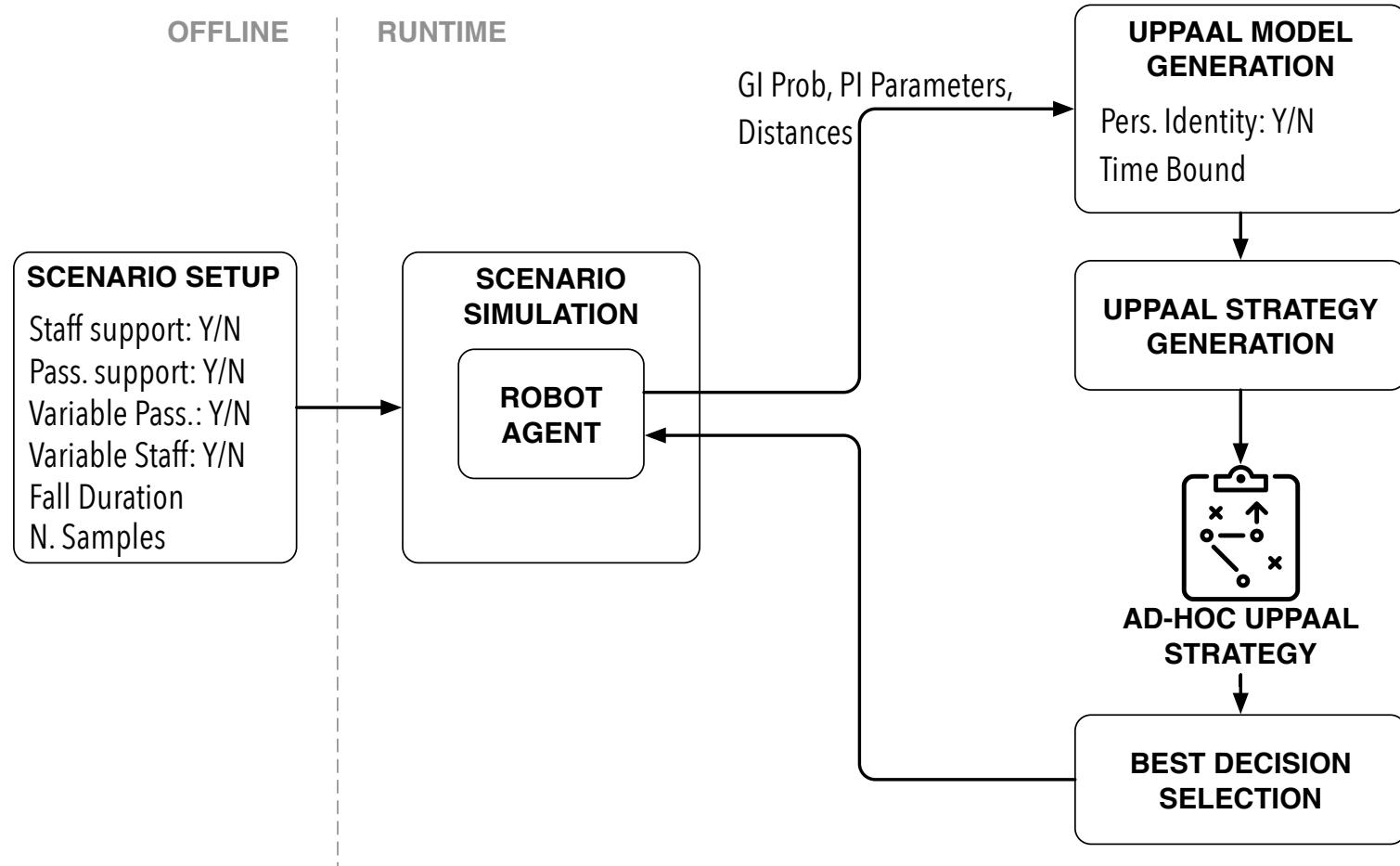
Fall Length	No-support	Staff-support	Passenger-support	Uppaal-support	Gambit-support
30	269.0	274.0	260.5	263.0	275.0
60	272.5	262.5	264.0	261.5	318.5
90	278.0	260.5	259.0	260.5	320.0
120	287.5	266.0	276.5	261.0	320.5
150	270.0	271.5	273.5	267.5	308.5
180	269.0	260.5	265.0	263.5	321.5
210	281.0	265.0	265.5	265.0	307.0
240	271.5	272.5	269.0	276.0	315.0
270	270.0	260.5	274.0	262.5	318.0
300	267.0	265.0	267.5	259.5	312.5
330	273.0	260.5	272.0	278.5	280.0
360	265.0	263.0	274.5	263.0	304.5
390	270.0	274.0	271.0	264.0	316.5
420	290.0	283.0	277.0	261.0	312.0
450	282.5	278.5	279.0	276.0	319.0
480	267.0	260.5	269.5	262.5	357.0
510	267.5	269.0	277.5	263.0	318.5
540	271.0	271.5	262.5	262.0	314.0
570	284.0	258.5	279.5	265.5	327.0
600	280.5	260.0	260.0	264.5	309.0

Generalized Strategy, variable Passengers/Staff Members, TB 50, RAT 0.5

Best Performance.
(outperforms
14/20 times)

Fall Length	No-support	Staff-support	Passenger-support	Uppaal-support	Gambit-support
30	270.0	313.0	273.5	267.5	274.5
60	292.0	264.0	292.0	262.0	332.0
90	318.0	271.0	311.0	263.0	357.0
120	313.0	279.0	276.0	264.0	287.0
150	323.5	269.0	268.0	263.5	300.0
180	305.0	261.0	264.5	260.5	339.0
210	278.0	303.5	302.0	272.5	315.0
240	284.0	293.0	304.5	284.5	352.5
270	276.5	313.0	272.5	267.5	337.0
300	281.0	266.0	275.0	255.0	315.0
330	278.0	265.5	285.0	291.5	304.5
360	273.0	267.0	323.0	260.0	317.0
390	273.0	286.5	292.5	258.5	324.5
420	301.5	328.5	283.5	262.0	308.5
450	288.0	306.0	299.5	274.0	312.0
480	295.0	259.0	267.0	270.0	379.0
510	271.0	273.5	290.0	270.5	312.5
540	307.5	295.0	274.5	282.0	321.5
570	290.0	261.0	295.0	266.0	327.0
600	298.0	262.5	271.0	282.5	290.0

IMPACT+ Framework for Formalised IDEA agents: Ad-hoc strategy



Experiment Settings:

- **Ad-hoc** Strategy
- **Fixed** (462, 6%) vs. **variable** (150-700, 1-10%) Passengers/Staff Members
- **Time Bound** 20/50/200 s
- **Rationality Degree** 1.0/PI ($0.33 \times \text{same gender} + 0.33 \times \text{same age} + 0.33 \times \text{same culture}$)
- **Fall length** 30-600

Ad-hoc Strategy, no PI, fixed Passengers/Staff Members, TB 20, RAT 1.0

Fall Length	No-support	Staff-support	Passenger-support	Adaptive-support
30	279.0	267.0	266.0	264.5
60	278.0	269.0	270.5	268.5
90	269.0	262.0	272.0	292.0
120	279.0	264.5	270.0	266.0
150	285.0	267.5	267.0	270.5
180	289.0	274.0	269.0	263.0
210	273.0	280.5	270.0	266.5
240	295.5	268.5	275.5	275.5
270	275.0	265.5	271.0	266.5
300	270.0	277.0	269.5	263.5
330	275.0	315.5	282.0	279.0
360	275.0	287.5	289.5	269.5
390	280.0	268.0	277.5	271.5
420	272.0	262.0	274.0	263.0
450	268.5	265.5	270.0	269.5
480	283.5	283.0	271.5	272.0
510	272.0	281.5	270.0	269.5
540	274.0	265.5	273.0	285.5
570	273.5	269.0	268.0	268.0
600	282.0	273.5	272.0	266.0

Ad-hoc Strategy, no PI, fixed Passengers/Staff Members, TB 20, RAT 1.0

Fall Length	No-support	Staff-support	Passenger-support	Adaptive-support
30				
60	267.5	276.0	274.5	265.0
90	264.0	267.0	272.0	292.0
120	307.0	262.5	277.5	268.0
150	270.0	273.0	276.0	263.0
180	312.0	276.0	262.0	262.0
210				
240	291.0	266.0	270.0	269.0
270	298.5	261.0	268.0	265.0
300				
330	278.5	323.0	292.5	274.0
360	303.0	289.0	295.0	262.0
390	267.0	270.0	315.0	279.0
420	274.0	311.0	274.0	260.0
450	266.5	262.5	289.5	263.0
480	268.5	273.5	309.0	297.5
510				
540	267.5	271.5	290.0	277.5
570	267.5	269.0	277.0	267.0
600	283.0	277.0	268.0	285.0

Ad-hoc Strategy, no PI, variable Passengers/Staff Members, TB 20, RAT 1.0

Fall Length	No-support	Staff-support	Passenger-support	Adaptive-support
30	287.0	262.5	268.5	271.0
60	272.5	267.0	281.5	268.0
90	280.5	279.5	274.0	273.0
120	276.5	265.0	264.0	267.5
150	282.5	276.5	267.5	278.5
180	270.5	277.5	277.5	281.5
210	295.5	285.5	266.0	266.0
240	272.5	268.0	272.0	262.0
270	276.5	263.0	264.5	260.5
300	285.5	269.0	287.0	271.5
330	278.5	271.5	273.5	268.5
360	271.5	270.5	276.0	290.0
390	287.0	283.0	263.5	266.0
420	275.5	266.0	268.5	265.5
450	272.5	270.0	265.5	266.0
480	270.0	272.5	274.0	297.5
510	276.0	258.5	269.5	268.0
540	278.0	276.5	268.0	269.0
570	282.0	273.0	268.0	275.5
600	271.0	285.0	294.5	271.5

Ad-hoc Strategy, no PI, variable Passengers/Staff Members, TB 20, RAT 1.0

Fall Length	No-support	Staff-support	Passenger-support	Adaptive-support
30	297.0	261.5	302.5	286.0
60	281.0	276.0	297.0	273.0
90	308.5	281.0	277.5	262.5
120	305.5	302.0	280.5	288.5
150	313.0	289.0	267.0	283.0
180	292.0	283.0	273.0	285.0
210	327.0	310.0	306.0	287.0
240	365.0	292.0	315.0	267.0
270	278.0	265.5	265.5	259.5
300	311.0	307.5	289.0	284.0
330	277.0	278.0	271.0	268.0
360	275.5	303.5	279.0	301.5
390	287.0	306.5	299.0	295.5
420	334.0	267.0	271.0	264.0
450	269.0	271.0	275.0	268.0
480	280.0	275.0	265.0	290.0
510	279.0	259.5	273.5	282.0
540	288.0	309.0	318.0	284.0
570	293.0	279.0	272.5	281.0
600	280.5	274.0	308.5	271.5

Ad-hoc Strategy, no PI, fixed Passengers/Staff Members, TB 200, RAT 1.0

Fall Length	No-support	Staff-support	Passenger-support	Adaptive-support
30	273.0	279.5	273.0	265.0
60	285.0	272.5	266.5	271.5
90	299.0	261.0	274.5	266.5
120	274.5	270.0	274.0	273.0
150	313.5	270.0	276.5	267.5
180	271.0	288.0	284.5	273.5
210	280.0	275.5	272.0	270.0
240	271.0	276.5	274.5	281.5
270	279.5	274.0	276.5	267.0
300	267.0	266.0	284.5	266.0
330	276.5	270.0	266.5	299.0
360	289.5	269.5	277.0	266.5
390	274.5	276.0	272.0	273.5
420	277.0	268.0	269.5	265.0
450	279.0	263.0	267.0	264.0
480	274.0	288.0	295.0	295.5
510	271.5	274.0	273.5	266.0
540	270.5	264.5	270.5	268.0
570	274.5	279.0	268.0	265.5
600	283.5	266.0	279.5	265.0

Ad-hoc Strategy, no PI, fixed Passengers/Staff Members, TB 200, RAT 1.0

Fall Length	No-support	Staff-support	Passenger-support	Adaptive-support
30	273.0	274.5	275.5	258.5
60	281.5	259.0	286.0	275.0
90	305.5	256.5	269.5	260.5
120				
150	323.5	266.5	283.0	267.5
180	271.0	315.0	313.0	273.0
210				
240	292.5	267.5	277.0	269.0
270	265.0	277.0	265.0	267.0
300	270.5	271.0	294.0	259.0
330	288.0	272.5	263.0	308.5
360	279.0	277.0	276.0	264.0
390	293.0	288.0	263.0	306.0
420				
450	267.0	255.0	267.0	268.0
480	275.5	284.5	288.5	267.0
510	272.0	273.0	269.0	261.0
540	270.5	260.0	269.5	259.5
570	277.5	292.5	267.5	261.0
600	270.0	259.0	289.0	262.0

Ad-hoc Strategy, no PI, variable Passengers/Staff Members, TB 200, RAT 1.0

Fall Length	No-support	Staff-support	Passenger-support	Adaptive-support
30	273.0	261.0	261.0	276.5
60	268.5	261.0	263.5	266.5
90	278.0	267.0	267.0	265.5
120	273.5	261.5	264.5	260.0
150	269.5	274.5	268.5	275.0
180	282.5	267.5	264.5	263.5
210	272.5	281.0	276.0	263.5
240	264.0	265.5	263.0	261.5
270	290.0	262.5	262.0	262.5
300	278.5	267.5	268.0	259.5
330	265.5	260.0	266.0	266.0
360	276.5	265.0	267.0	264.0
390	269.5	264.0	271.0	277.5
420	290.5	259.0	269.0	260.5
450	276.5	260.0	265.0	262.0
480	276.5	258.0	263.0	259.0
510	315.0	271.0	279.0	274.5
540	263.0	269.5	272.5	266.5
570	267.0	268.5	272.0	270.5
600	285.5	275.0	261.0	270.0

Ad-hoc Strategy, no PI, variable Passengers/Staff Members, TB 200, RAT 1.0

Fall Length	No-support	Staff-support	Passenger-support	Adaptive-support
30	288.0	275.0	260.0	312.0
60	325.5	263.0	282.0	272.0
90	300.0	278.0	267.0	277.0
120	285.0	273.0	317.0	280.0
150	300.0	270.0	274.0	267.0
180	278.5	269.0	272.5	316.0
210	290.5	306.0	285.0	274.0
240	271.0	311.0	274.0	264.0
270	329.0	303.0	288.0	259.0
300	401.0	273.0	279.5	260.5
330	271.0	274.0	272.0	285.0
360	287.0	293.0	289.0	313.0
390	286.5	267.5	301.0	301.0
420	301.5	259.5	295.5	257.5
450	278.0	271.0	290.0	268.0
480	309.5	273.5	293.5	262.0
510	316.0	275.0	274.0	266.5
540	310.5	262.5	297.5	267.0
570	287.0	283.5	309.0	288.5
600	294.0	262.5	265.5	281.5

Ad-hoc Strategy, with PI, fixed Passengers/Staff Members, TB 20

Fall Length	No-support	Staff-support	Passenger-support	Adaptive-support
30	268.5	292.5	276.0	271.0
60	280.0	280.5	268.5	275.0
90	281.5	273.0	273.5	272.0
120	273.5	271.0	272.5	277.0
150	299.5	265.0	267.5	268.5
180	283.5	261.5	275.5	268.5
210	265.5	263.5	268.5	273.0
240	269.5	275.0	280.0	275.5
270	275.5	262.0	272.5	295.5
300	272.5	261.5	275.0	261.5
330	277.5	262.5	267.5	261.5
360	282.5	267.0	274.0	267.0
390	272.0	279.0	275.0	274.0
420	277.5	263.0	264.5	265.0
450	269.0	266.5	277.5	265.5
480	269.0	273.0	272.0	286.5
510	275.5	266.5	268.5	268.0
540	274.5	269.5	286.0	281.5
570	270.5	269.0	309.5	275.5
600	288.5	273.5	272.0	273.0

Ad-hoc Strategy, with PI, fixed Passengers/Staff Members, TB 20

Fall Length	No-support	Staff-support	Passenger-support	Adaptive-support
30	288.0	285.5	276.0	278.0
60	277.0	282.5	272.0	280.0
90	287.0	263.5	272.0	270.0
120	271.5	266.5	273.5	268.5
150	277.0	276.0	286.5	278.5
180	307.0	261.0	274.0	281.0
210	263.0	273.0	271.0	273.0
240	269.5	278.5	288.5	275.5
270	269.0	260.0	265.5	295.5
300	274.0	261.5	275.0	267.0
330	275.0	260.0	264.0	264.0
360	277.0	283.0	274.0	267.0
390	269.0	284.0	288.0	282.0
420	288.0	267.0	275.0	265.0
450	266.0	270.0	283.0	264.0
480	268.0	265.0	272.0	302.0
510	277.5	258.5	267.5	270.0
540	272.5	260.5	273.0	303.0
570	269.0	269.0	312.0	275.0
600	283.0	269.0	265.0	272.0

Ad-hoc Strategy, with PI, variable Passengers/Staff Members, TB 20

Fall Length	No-support	Staff-support	Passenger-support	Adaptive-support
30	282.5	271.5	272.5	269.0
60	277.5	268.5	268.0	262.0
90	266.5	267.5	266.5	272.5
120	277.5	257.0	263.5	260.0
150	268.5	275.0	281.0	271.5
180	276.5	262.0	271.0	271.0
210	295.5	271.5	270.5	263.5
240	275.0	261.5	270.5	268.0
270	270.5	260.0	278.0	264.0
300	280.5	266.0	264.0	267.0
330	276.5	264.5	271.5	274.0
360	269.0	265.5	265.0	267.0
390	274.5	262.5	267.0	263.0
420	302.0	266.5	266.5	265.0
450	265.0	264.0	266.0	271.5
480	283.5	273.0	268.0	263.0
510	273.5	265.5	269.0	260.0
540	279.5	264.5	266.0	259.5
570	263.0	263.0	265.5	260.0
600	274.0	270.0	265.0	264.0

Ad-hoc Strategy, with PI, variable Passengers/Staff Members, TB 20

Fall Length	No-support	Staff-support	Passenger-support	Adaptive-support
30	303.0	273.0	281.0	280.0
60	280.0	287.0	279.0	264.0
90	310.0	263.0	272.0	273.0
120	311.0	255.5	263.5	267.0
150	285.5	290.0	282.5	269.5
180	306.5	275.5	273.0	275.0
210	276.0	296.0	311.0	267.0
240	318.0	261.0	278.0	277.0
270	279.0	264.0	275.0	271.0
300	283.0	273.0	264.0	269.0
330	280.0	279.0	275.0	289.0
360	281.0	273.0	260.0	273.0
390	281.0	267.0	269.0	269.5
420	311.0	266.5	273.0	271.0
450	280.0	275.0	275.0	275.0
480	283.5	294.0	293.0	269.0
510	273.5	312.5	274.5	272.5
540	286.5	266.5	277.5	262.5
570	271.0	268.0	266.0	261.0
600	291.0	314.5	261.5	271.0

Ad-hoc Strategy, with PI, fixed Passengers/Staff Members, TB 50

Fall Length	No-support	Staff-support	Passenger-support	Adaptive-support
30	272.0	267.0	267.5	264.0
60	269.5	276.5	281.0	263.5
90	268.5	267.5	267.0	263.0
120	275.5	268.0	285.5	272.5
150	280.0	264.5	272.0	271.5
180	276.5	272.0	281.0	269.0
210	283.5	263.0	267.0	261.0
240	280.0	270.5	271.0	264.5
270	271.5	276.5	270.5	290.0
300	266.0	269.0	266.0	261.0
330	283.0	281.0	262.5	277.5
360	280.0	272.0	277.0	271.5
390	280.5	267.0	286.0	273.0
420	264.0	269.5	276.5	267.5
450	277.0	260.0	262.5	263.5
480	282.5	273.0	268.5	267.0
510	275.0	268.0	279.0	263.5
540	280.5	280.0	270.0	265.0
570	307.0	267.5	275.0	263.5
600	291.0	267.5	274.0	270.0

Ad-hoc Strategy, with PI, fixed Passengers/Staff Members, TB 50

Fall Length	No-support	Staff-support	Passenger-support	Adaptive-support
30	270.0	259.0	262.0	260.0
60	267.0	277.0	304.0	263.0
90	289.0	292.0	278.0	267.0
120	277.0	270.0	303.5	285.0
150	274.5	276.5	272.0	266.5
180	297.0	272.0	280.0	286.0
210	287.0	271.5	279.5	277.5
240	277.0	265.0	261.0	261.0
270	263.0	285.0	262.0	276.0
300	272.0	261.0	266.0	262.0
330	270.0	269.0	260.0	277.5
360	261.5	292.5	315.5	266.5
390	282.5	266.5	319.5	312.0
420	279.0	290.0	284.5	278.5
450	278.5	261.5	266.0	259.0
480	306.0	274.0	278.0	303.0
510	292.0	274.0	295.0	261.0
540	274.0	282.0	269.0	301.0
570	306.0	308.0	274.0	265.0
600	318.0	269.0	268.5	277.0

Ad-hoc Strategy, with PI, variable Passengers/Staff Members, TB 50

Fall Length	No-support	Staff-support	Passenger-support	Adaptive-support
30	266.0	269.5	287.0	276.0
60	278.0	257.0	261.0	262.0
90	269.0	258.0	265.5	265.0
120	267.0	269.5	268.5	261.5
150	281.5	267.5	265.5	266.5
180	268.0	269.5	273.0	270.5
210	302.0	279.0	270.5	267.0
240	265.5	262.5	273.5	263.0
270	276.5	267.5	266.5	262.0
300	278.0	262.0	264.0	267.0
330	283.5	266.0	291.0	269.0
360	264.0	263.5	267.5	259.5
390	274.0	265.5	267.5	271.5
420	273.0	260.5	270.5	268.5
450	306.5	262.5	268.0	266.0
480	264.0	264.5	276.5	284.5
510	272.5	263.5	265.5	261.0
540	269.5	271.0	274.5	271.0
570	287.0	269.0	282.5	266.0
600	274.0	269.0	267.0	263.0

Ad-hoc Strategy, with PI, variable Passengers/Staff Members, TB 50

Fall Length	No-support	Staff-support	Passenger-support	Adaptive-support
30	314.0	264.0	288.0	299.0
60	335.0	259.0	270.0	314.0
90	283.5	285.0	281.5	278.0
120	281.0	288.0	269.0	260.0
150	297.0	273.0	268.0	285.0
180	279.0	265.0	273.0	277.0
210	283.0	266.5	295.0	267.0
240	280.5	258.5	296.5	268.0
270	292.0	270.0	271.0	259.0
300	281.0	265.0	274.0	282.0
330	295.0	264.0	315.0	285.0
360	277.0	274.0	275.0	274.0
390	294.5	257.5	277.5	271.5
420	276.0	262.0	282.0	292.0
450	327.0	266.0	280.0	271.0
480	283.0	281.0	275.0	300.0
510	276.0	271.0	279.0	260.0
540	300.5	289.0	281.5	308.0
570	288.0	307.0	327.0	264.0
600	280.0	278.0	274.0	300.5

Ad-hoc Strategy, with PI, fixed Passengers/Staff Members, TB 200

Fall Length	No-support	Staff-support	Passenger-support	Adaptive-support
30	272.0	263.0	275.5	266.0
60	269.5	284.5	278.5	313.5
90	282.0	268.0	267.0	259.0
120	278.0	276.0	271.0	278.0
150	269.0	283.0	264.5	269.5
180	276.0	268.0	293.5	271.5
210	271.5	265.0	264.5	269.5
240	272.5	269.5	263.0	264.0
270	271.5	273.0	261.5	272.5
300	287.0	263.5	272.5	265.0
330	279.0	272.5	282.0	269.5
360	287.5	271.5	276.0	275.0
390	273.5	263.0	275.0	298.0
420	273.5	268.0	279.0	262.5
450	267.0	276.0	282.5	272.5
480	270.5	273.5	269.0	280.5
510	272.0	274.5	270.0	268.0
540	288.0	280.0	270.0	258.0
570	312.0	272.0	278.0	276.0
600	276.0	262.5	266.0	264.5

Ad-hoc Strategy, with PI, fixed Passengers/Staff Members, TB 200

Fall Length	No-support	Staff-support	Passenger-support	Adaptive-support
30	264.0	260.0	268.0	290.0
60	271.0	294.0	275.0	318.0
90	287.0	268.0	262.0	257.0
120	270.0	295.0	266.0	277.0
150	272.0	272.0	268.0	313.0
180	285.0	262.5	280.0	261.0
210	270.0	264.0	264.0	277.0
240	286.0	260.0	260.0	274.0
270	297.0	279.5	267.0	274.5
300	309.0	263.0	282.0	256.0
330	275.0	264.5	277.0	276.0
360	262.0	267.0	268.0	263.0
390	270.0	263.0	276.0	275.0
420	264.5	290.0	284.0	266.5
450	268.5	289.0	298.5	259.5
480	270.5	261.0	265.5	275.5
510	272.0	268.0	277.0	266.0
540	297.0	269.0	270.0	257.0
570	313.0	273.0	273.0	287.0
600	279.0	258.0	271.0	264.0

Ad-hoc Strategy, with PI, variable Passengers/Staff Members, TB 200

Fall Length	No-support	Staff-support	Passenger-support	Adaptive-support
30	284.0	260.0	269.0	264.5
60	277.5	271.0	265.0	268.0
90	264.5	264.5	270.5	261.5
120	277.5	261.0	276.0	268.0
150	275.0	262.5	284.0	271.0
180	267.5	275.0	272.0	275.5
210	277.0	273.5	272.5	280.5
240	270.5	263.0	267.5	269.0
270	266.5	267.0	271.0	269.0
300	283.0	263.0	269.0	264.5
330	275.5	265.0	262.0	266.0
360	273.5	290.5	276.0	268.0
390	277.0	263.0	265.5	262.5
420	267.5	272.5	271.5	278.5
450	267.0	261.5	274.0	266.0
480	269.5	264.5	267.5	273.5
510	270.0	259.5	272.5	264.5
540	286.5	274.5	272.5	269.5
570	267.5	277.0	272.0	267.0
600	281.5	266.5	278.0	265.0

Ad-hoc Strategy, with PI, variable Passengers/Staff Members, TB 200

Fall Length	No-support	Staff-support	Passenger-support	Adaptive-support
30	307.0	260.0	278.0	263.0
60	295.0	313.0	265.5	267.5
90	273.0	284.0	321.0	263.0
120	297.0	259.0	270.5	285.5
150	292.0	269.5	279.0	271.5
180	263.0	274.0	272.0	262.0
210	284.5	295.5	282.0	314.5
240	275.0	280.0	273.0	266.0
270	298.5	278.5	281.5	302.0
300	300.0	265.0	281.0	290.0
330	282.0	283.0	282.0	269.0
360	291.0	320.0	302.0	297.0
390	266.0	262.0	265.5	276.5
420	283.0	275.0	286.0	276.0
450	364.0	283.0	278.0	287.0
480	275.5	277.0	326.5	276.5
510	272.5	258.5	301.0	302.0
540	291.0	272.5	272.5	267.5
570	278.0	283.5	279.5	265.5
600	283.5	263.5	294.5	294.5