# Modeling and Visualizing Workers' Behaviors for Safer Construction





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發展局
Development Bureau

CONSTRUCTION INDUSTRY COUNCIL
建造業議會

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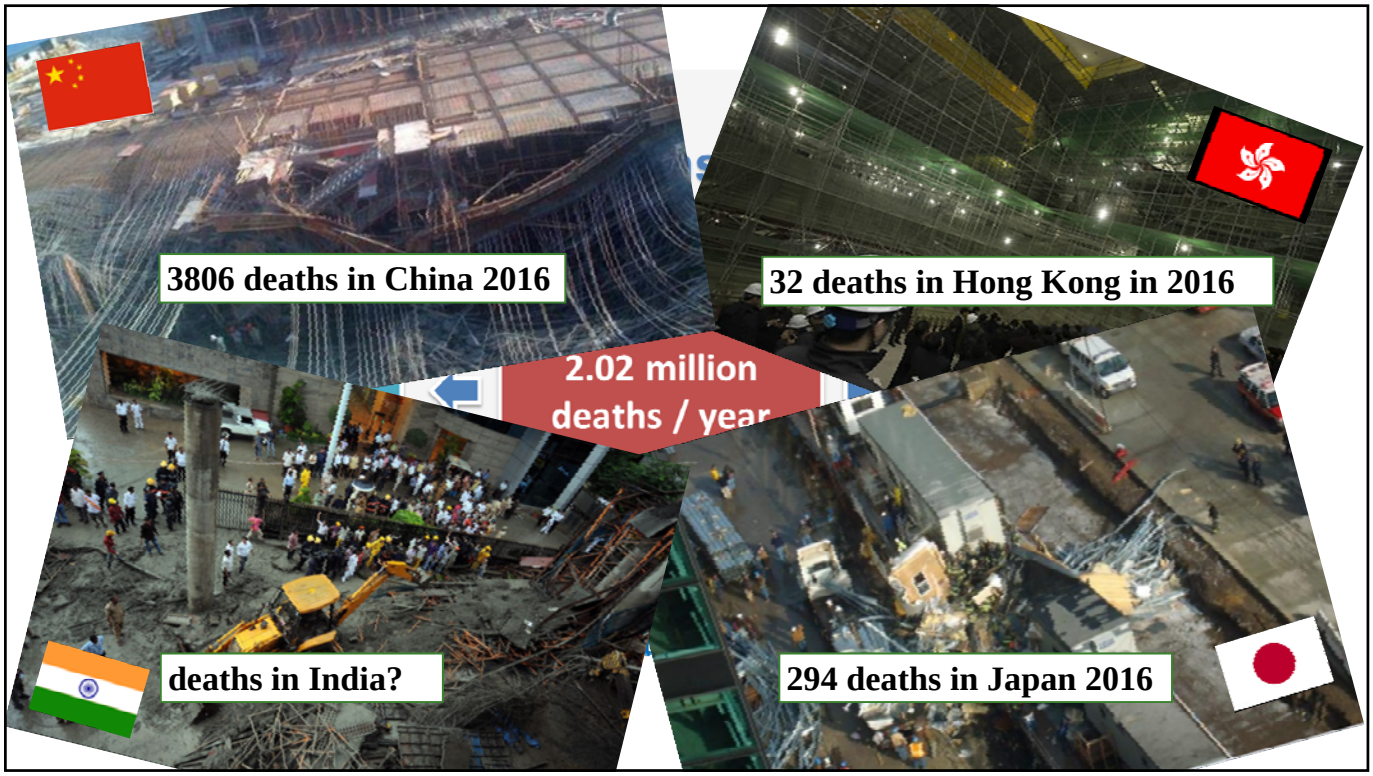
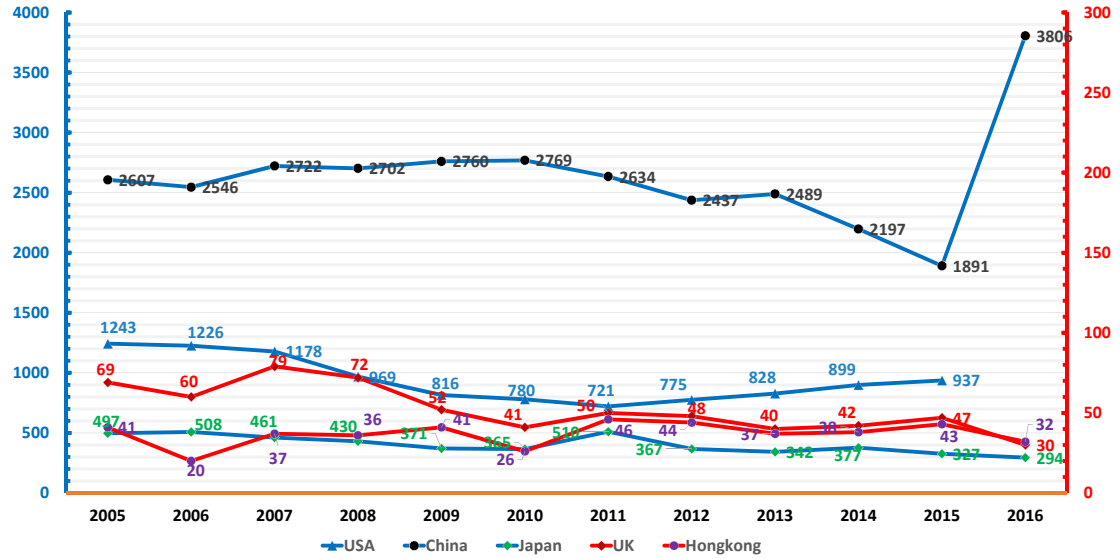
Construction Safety Week — Conference



## Construction Fatalities (2005-2016)




USA China Japan UK Hongkong

Source: USA: http://www.bls.gov/iif/oshwc/cfoi; Japan: http://www.mhlw.go.jp/bunya/roudoukijun/anzeneisei11/rousai-hassei/index.html
Hong Kong: http://www.labour.gov.hk/chs/osh/content10b.htm ; UK: http://www.hse.gov.uk/statistics/tables/index.htm#riddor
China: http://www.chinasafety.gov.cn/newpage/Contents/Channel_6210/2016/0229/265356/content_265356.htm

## Accidents & Unsafe behaviors


Accident

Unsafe Behaviors

## Accident Caused by Unsafe Behaviors

Immediate questions:

- How could it happen?
- Did he see the hole?
- If he saw, did he think it is dangerous?
- If he thought so, what did he think and do?

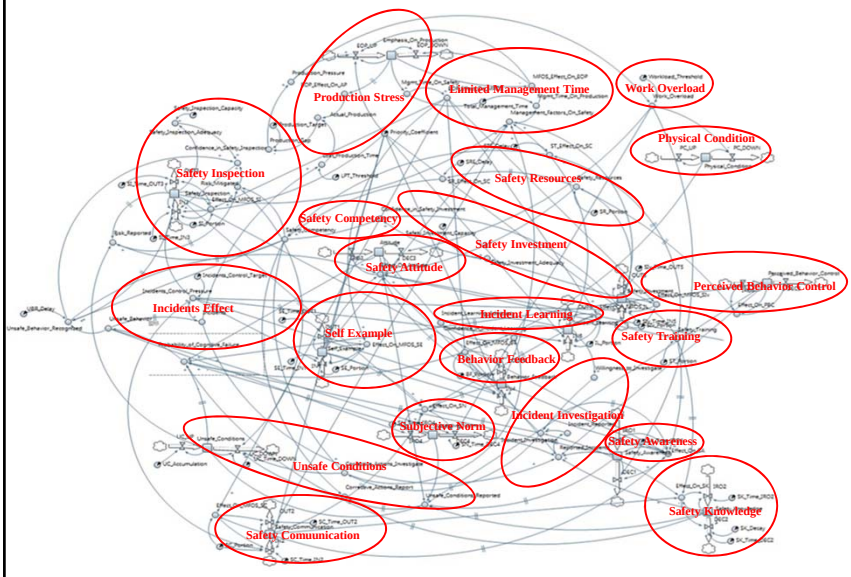
Source：Zhulong.com, http://down6.zhulong.com/tech/detailprof773977AQ.htm

## Research Questions

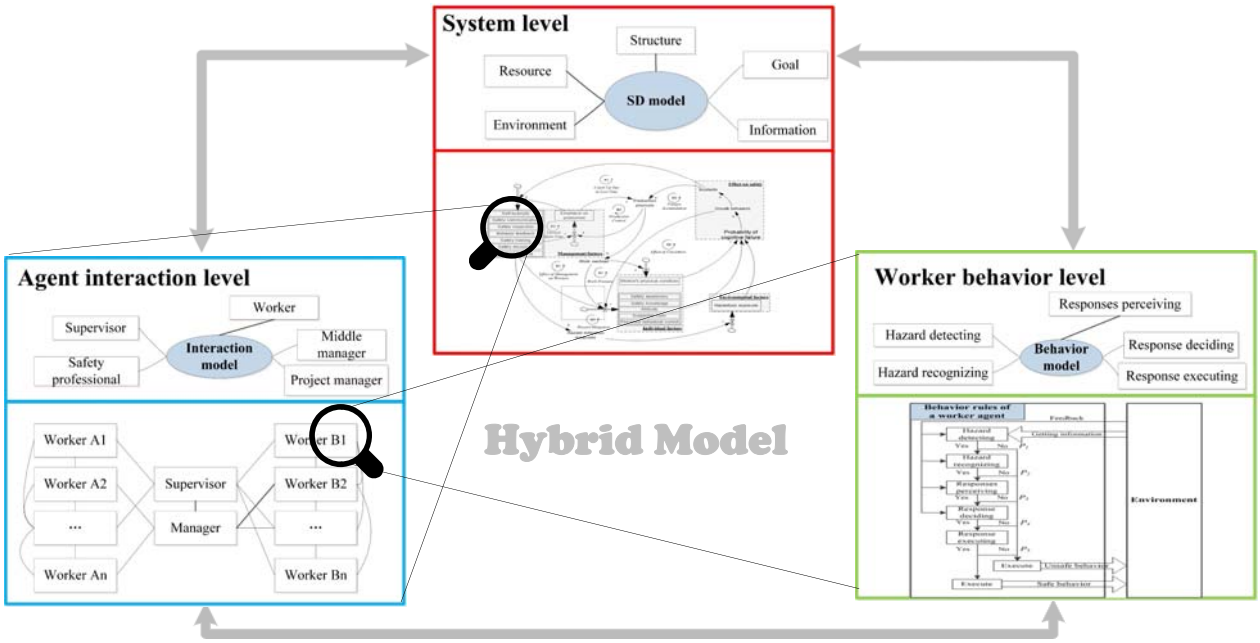
- What are the factors that cause unsafe behaviors on construction sites and how do they interact with each others?
- How do these factors affect construction workers and eventually lead to workers' unsafe behaviors and accidents?
- Can we model workers' behaviors and the site environment by considering both management and individual factors?
- Can we simulate, visualize and predict how unsafe behaviors occur?

## Factors that Cause Unsafe Behaviors

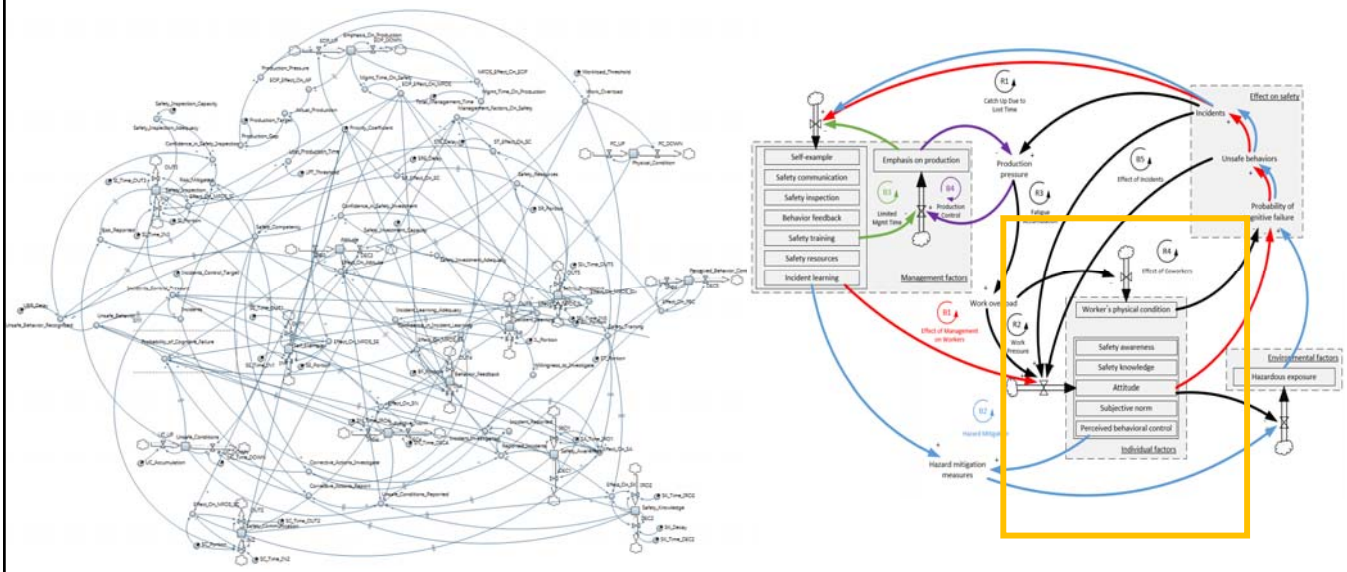

## Factors that Cause Unsafe Behaviors




## Hybrid Model for construction site environment and individuals

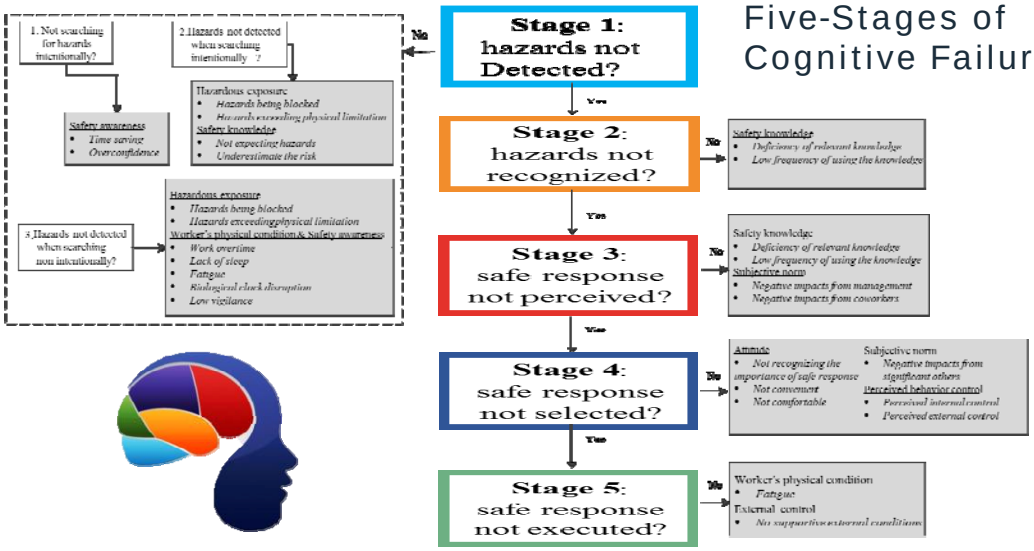



## System Dynamics Model




Source: Jiang Z, Fang D, Zhang M. Understanding the Causation of Construction Workers' Unsafe Behaviors on System Dynamics Modeling. Journal of Management in Engineering. 2015; 31(6). 10.1061/(ASCE)ME.1943-5479.0000350

## Cognitive Model of Unsafe Behaviors



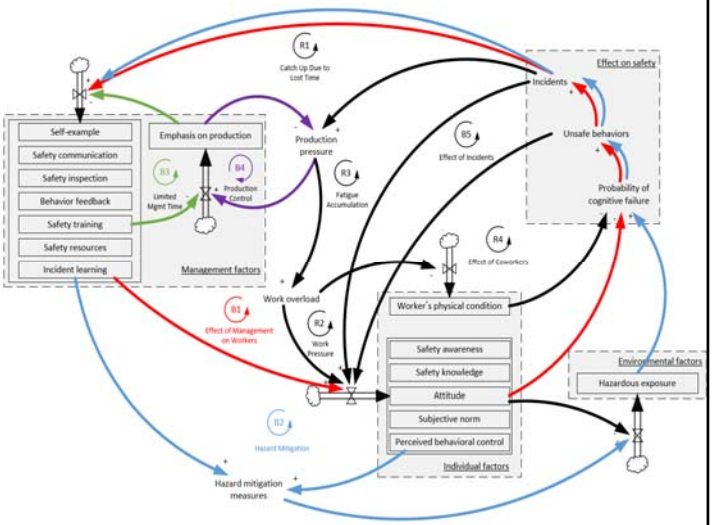

Five-Stages of Cognitive Failure

Source:
Fang D, Zhao C, Zhang M. A Cognitive Model of Construction Workers' Unsafe Behaviors. Journal of Construction Engineering and Management. 2016. Online Published. 10.1061/(ASCE)CO.1943-7862.0001118.
Zhang M, Fang D. A cognitive analysis of why Chinese scaffolders do not use safety harnesses in construction. Construction Management and Economics. 2013; 31(3):207-222.

## Loops of System Dynamics Model

Regulation Loop B1: Effect of Management on Workers
Regulation Loop B2: Hazard Mitigation
Regulation Loop B3: Limited Management
Regulation Loop B4: Production Control
Regulation Loop B5: Impact of Events

Enhancement Loop R1: Rush after Loss of Man-Hours
Enhancement Loop R2: Work Stress
Enhancement Loop R3: Fatigue Accumulation
Enhancement Loop R4: Influences of Co-Workers

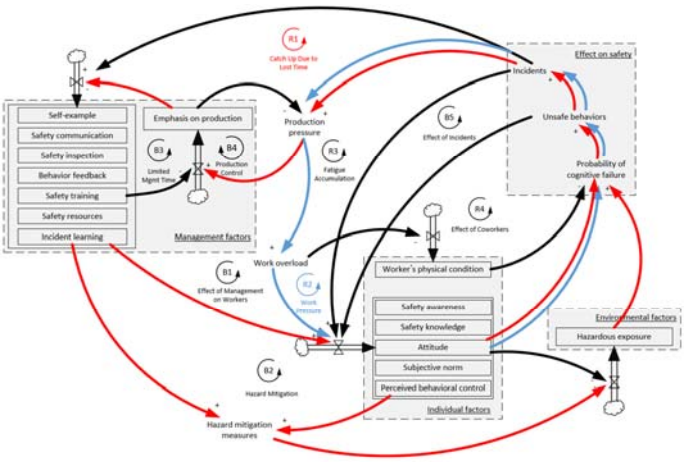



Source: Jiang Z, Fang D, Zhang M. Understanding the Causation of Construction Workers' Unsafe Behaviors on System Dynamics Modeling. Journal of Management in Engineering. 2015; 31(6). 10.1061/(ASCE)ME.1943-5479.0000350

## Main Loops of System Dynamics Model

Regulation Loop B1: Effect of Management on Workers
Regulation Loop B2: Hazard Mitigation
Regulation Loop B3: Limited Management
Regulation Loop B4: Production Control
Regulation Loop B5: Impact of Events

Enhancement Loop R1: Rush after Loss of Man-Hours
Enhancement Loop R2: Work Stress
Enhancement Loop R3: Fatigue Accumulation
Enhancement Loop R4: Influences of Co-Workers




Source: Jiang Z, Fang D, Zhang M. Understanding the Causation of Construction Workers' Unsafe Behaviors on System Dynamics Modeling. Journal of Management in Engineering. 2015; 31(6). 10.1061/(ASCE)ME.1943-5479.0000350

## Multi-Agent Models

### The senior manager agent's variables

| Variable | Definition |
|---|---|
| Visibility ($V_{SM}$) | The percentage of safety activities the senior manager agent attends. |
| Production goal (PG) | The number of tasks expected to be completed on each workday. |
| Safety goal (SG) | The upper bound number of daily incidents tolerable. |
| Production performance control (PPC) | From value 0 to 5 means that the senior manager agent has actually no/little/slight/some/strong/very strong control over production performance. |
| Safety performance control (SPC) | From value 0 to 5 means that the senior manager agent has actually no/little/slight/some/strong/very strong control over safety performance. |

### The safety official agent's variables

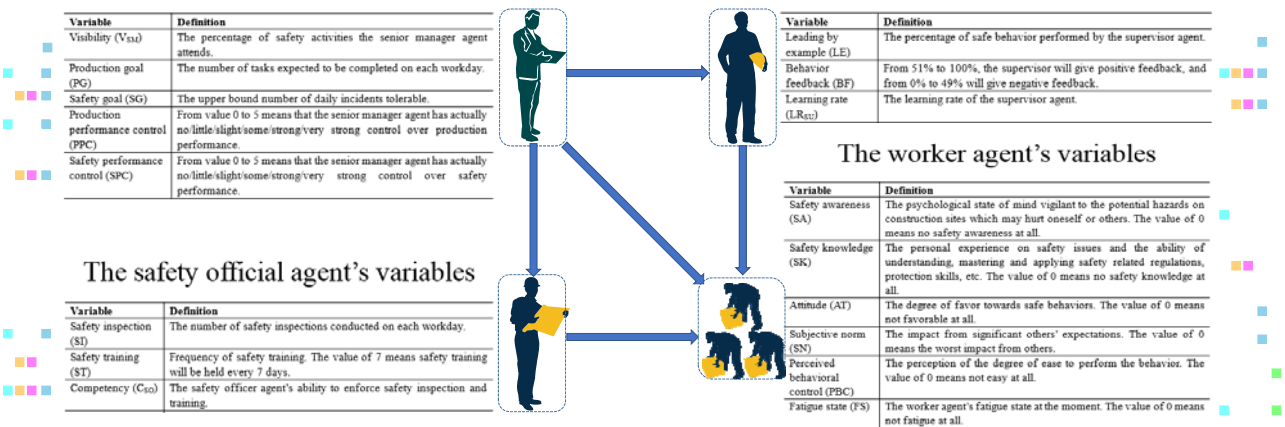
| Variable | Definition |
|---|---|
| Safety inspection (SI) | The number of safety inspections conducted on each workday. |
| Safety training (ST) | Frequency of safety training. The value of 7 means safety training will be held every 7 days. |
| Competency ($C_{SO}$) | The safety officer agent's ability to enforce safety inspection and training. |

### The supervisor agent's variables

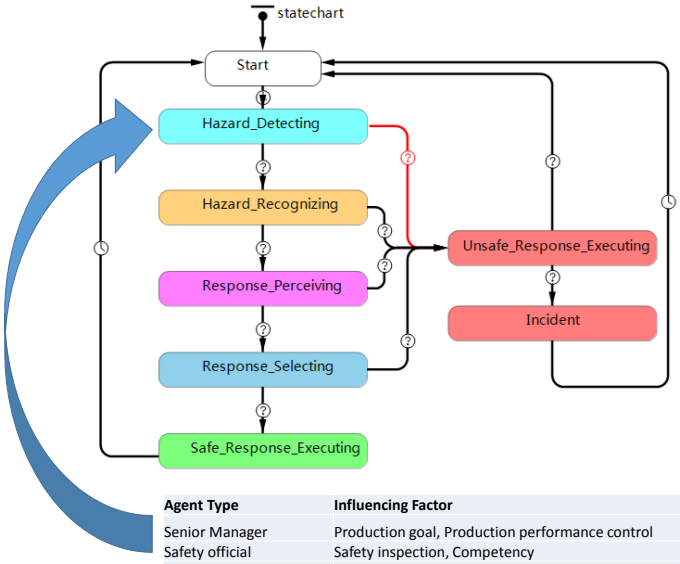
| Variable | Definition |
|---|---|
| Leading by example (LE) | The percentage of safe behavior performed by the supervisor agent. |
| Behavior feedback (BF) | From 51% to 100%, the supervisor will give positive feedback, and from 0% to 49% will give negative feedback. |
| Learning rate ($LR_{SU}$) | The learning rate of the supervisor agent. |

### The worker agent's variables

| Variable | Definition |
|---|---|
| Safety awareness (SA) | The psychological state of mind vigilant to the potential hazards on construction sites which may hurt oneself or others. The value of 0 means no safety awareness at all. |
| Safety knowledge (SK) | The personal experience on safety issues and the ability of understanding, mastering and applying safety related regulations, protection skills, etc. The value of 0 means no safety knowledge at all. |
| Attitude (AT) | The degree of favor towards safe behaviors. The value of 0 means not favorable at all. |
| Subjective norm (SN) | The impact from significant others' expectations. The value of 0 means the worst impact from others. |
| Perceived behavioral control (PBC) | The perception of the degree of ease to perform the behavior. The value of 0 means not easy at all. |
| Fatigue state (FS) | The worker agent's fatigue state at the moment. The value of 0 means not fatigue at all. |
| Learning rate ($LR_{WO}$) | The learning rate of the worker agent. |

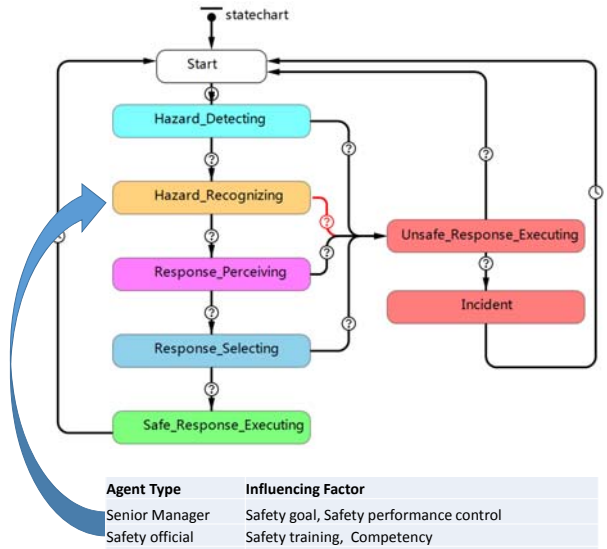


## Cognitive Failure at Stage 1



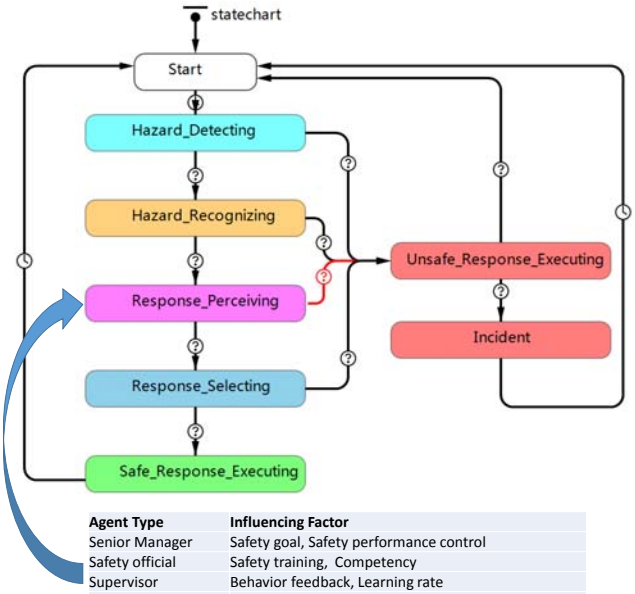

| Agent Type | Influencing Factor |
|---|---|
| Senior Manager | Production goal, Production performance control |
| Safety official | Safety inspection, Competency |
| Supervisor | Behavior feedback |
| Worker | Safety awareness, Fatigue state |

## Cognitive Failure at Stage 2



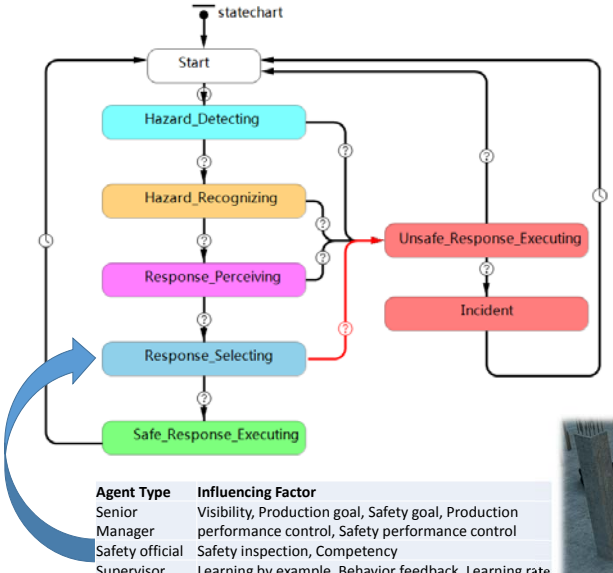

| Agent Type | Influencing Factor |
|---|---|
| Senior Manager | Safety goal, Safety performance control |
| Safety official | Safety training, Competency |
| Supervisor | Behavior feedback, Learning rate |
| Worker | Safety knowledge, Learning rate |

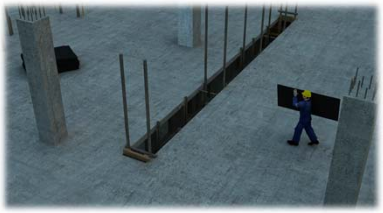
## Cognitive Failure at Stage 3




| Agent Type | Influencing Factor |
|---|---|
| Senior Manager | Safety goal, Safety performance control |
| Safety official | Safety training, Competency |
| Supervisor | Behavior feedback, Learning rate |
| Worker | Safety knowledge, Learning rate |

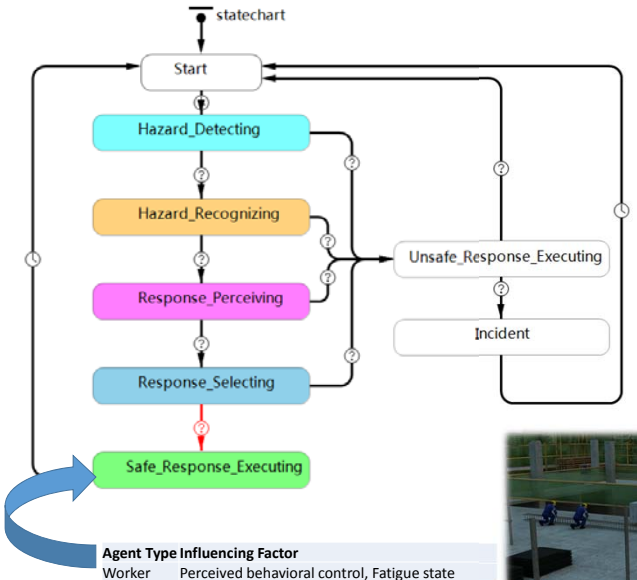
## Cognitive Failure at Stage 4



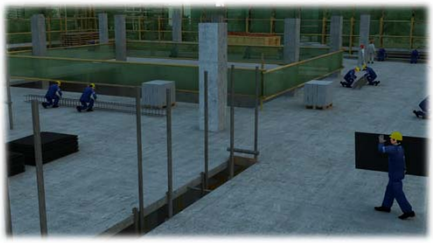



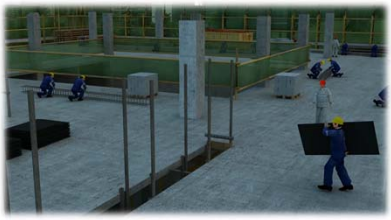
| Agent Type | Influencing Factor |
|---|---|
| Senior Manager | Visibility, Production goal, Safety goal, Production performance control, Safety performance control |
| Safety official | Safety inspection, Competency |
| Supervisor | Learning by example, Behavior feedback, Learning rate |
| Worker | Attitude, Subjective norm |

## No cognitive failure in all five stages

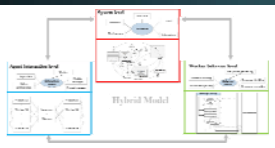



| Agent Type | Influencing Factor |
|---|---|
| Worker | Perceived behavioral control, Fatigue state |

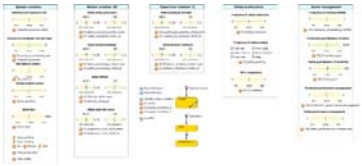




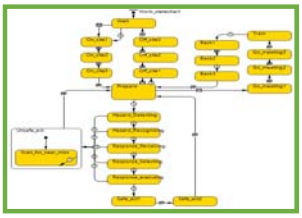
## Hybrid Model in AnyLogic



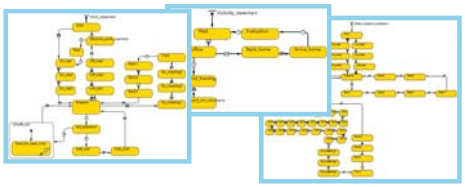
System Dynamic Model of Management Factors



Variables Initialization Interface

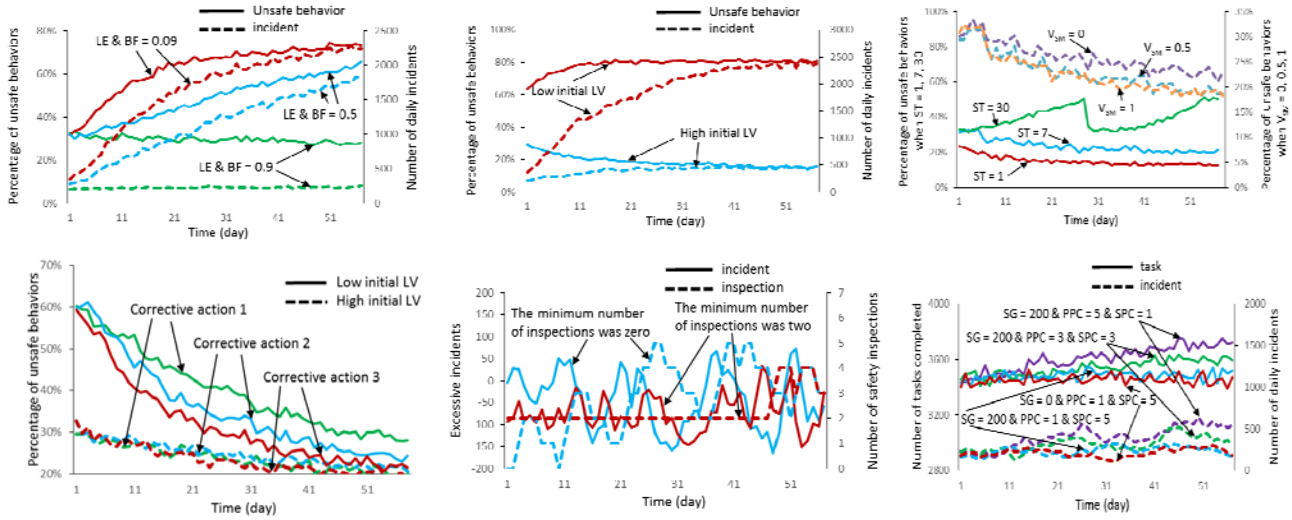


Agents Model of Workers (Group)



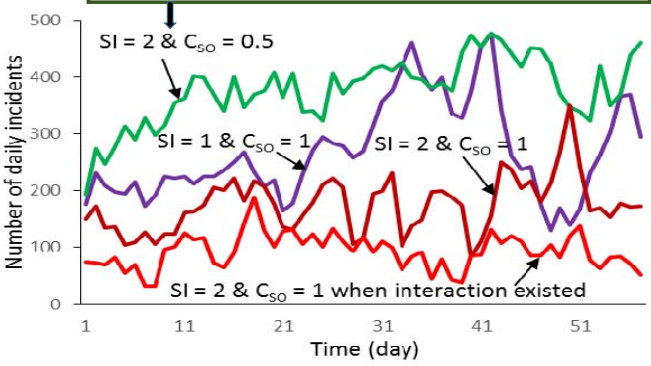
Agent Models of Supervisors, Safety Officials, and Senior Managers

## Scenario Comparison and Analysis




## Scenario 1 : Safety Inspection

High safety inspection frequency – SI = 2 times a day
Low safety inspection capability – $C_{SO}$ = half as required




**1#(Green Line)** When the safety officers conduct safety inspection **twice a day with limited ability** to remove hazards **(SI = 2 & $C_{SO}$ = 0.5)** .

**2#(Purple Line)** When the safety officers conduct safety inspection **once a day with completely ability** to remove hazards **(SI = 1 & $C_{SO}$ = 1)** .

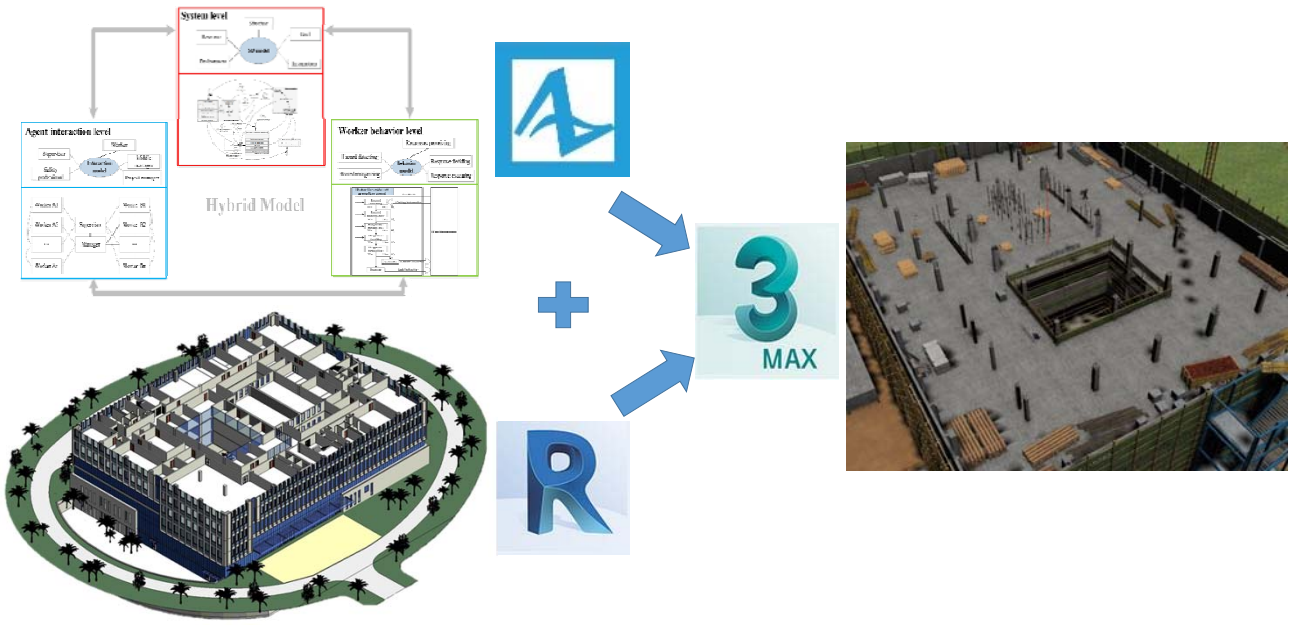
**3#(Dark Red Line)** When the safety officers conduct safety inspection **twice a day with completely ability** to remove hazards **(SI = 2 & $C_{SO}$ = 1)** .

**4#(Red Line)** When the **safety officers interacted with workers while inspecting (SI = 2 & $C_{SO}$ = 1, interactions existed)** .

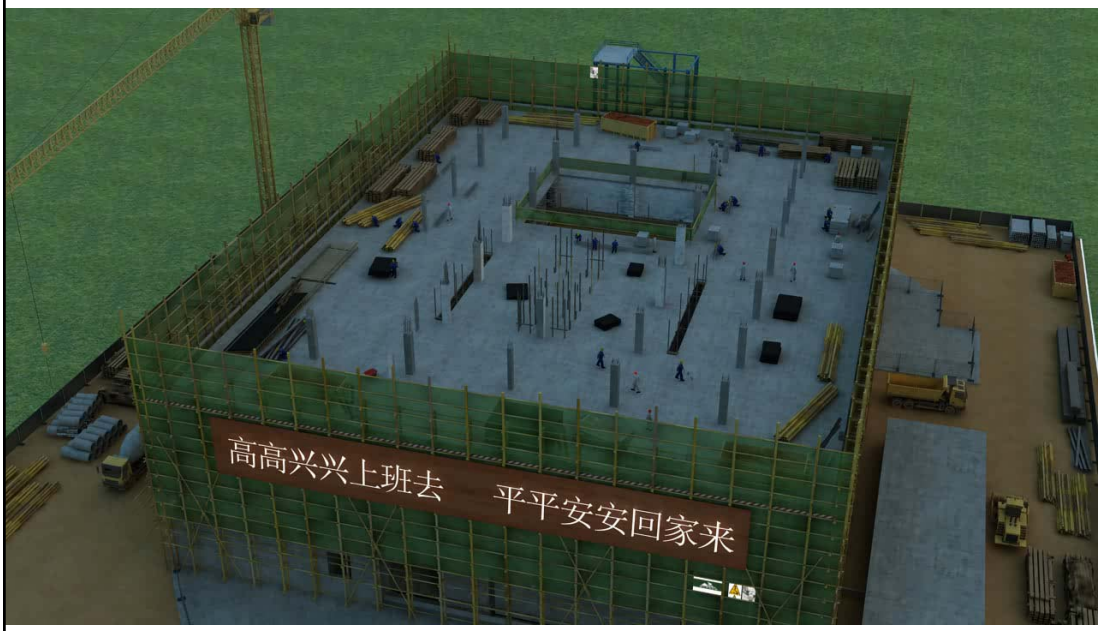
**Implications to safety management :**

- Improving the safety inspection capability of safety officers could be more effective than simply increasing the frequency of safety inspections.
- Improving the communications amongst individuals ( including managers, superintendents and workers) could be an effective approach to decrease incidents.

## Integration for visualization




## Integrating for visualization




**(Glodon Building II)**

## Ideas for model improvement

Physics-Driven Modelling

+

Data-Driven Modelling (sensor based)

## Ideas for model improvement

Worker-Vehicle Collision Risks Monitoring and Warning System Based on Binocular Vision System

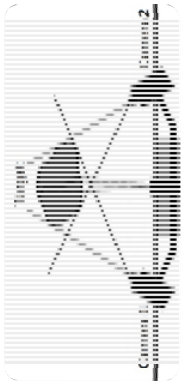
| Drivers | Workers |
|---|---|
| **Neglecting the workers in blind spots** | **Being unaware of the vehicles approaching** |
| **Overconfidence in driving skills** | **Misjudgment on vehicles moving** |
| Bad driving habits | Failure to find safe zones |
| **Risk-taking decisions** | **Risk-taking decisions** |
| Losing control of the vehicles | Failure to escape |

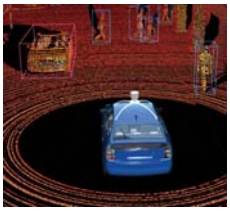
## Ideas for model improvement

### Worker-Vehicle Collision Risks Monitoring and Warning System Based on Binocular Vision System

Worker Detection and Warning System (Driver)


Warning System (Worker)



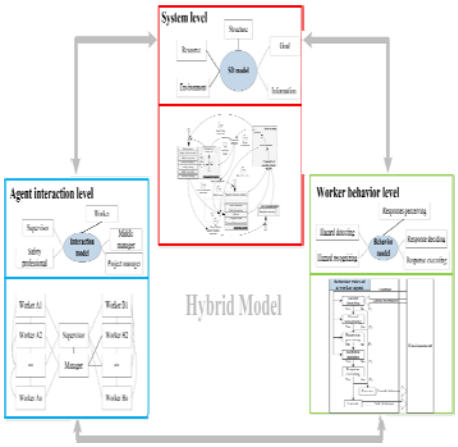



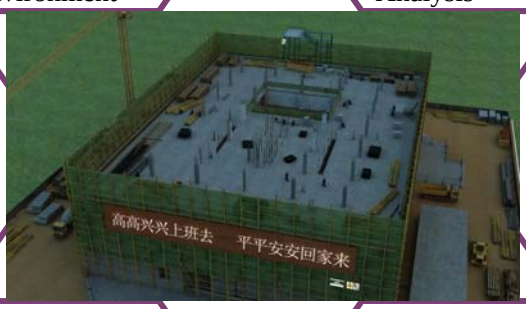
## Application Prospects

II: Simulating & Visualizing Site Scenarios

I: Modelling Worker Behaviors and Site Environment

III: Integrating Site Data for Real Time Analysis



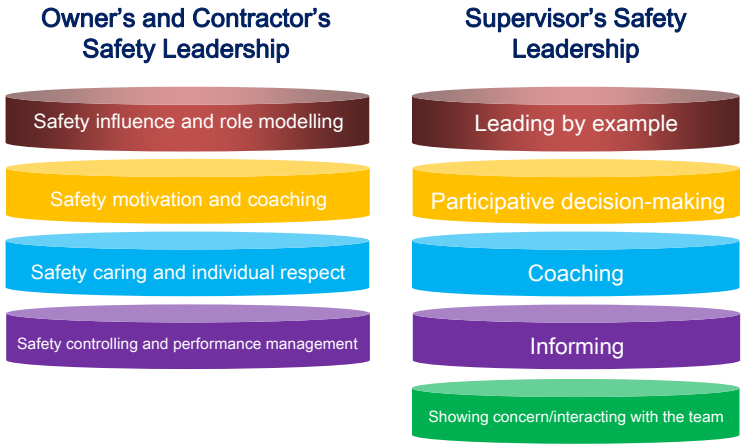

VI: Future: AI and Deep Learning

IV: Predicting Risks and Supporting Decision Making

V: Optimizing Management Strategy and Plan

# Worker's behavior vs Safety leadership

Safety leadership model for construction

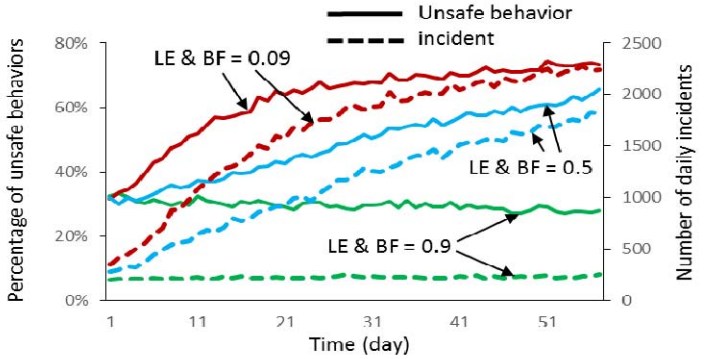

Safety leadership matrix

# Thank You !

**Prof. Dongping FANG**
**Tsinghua University**

清华-金门建筑安全研究中心
Tsinghua-Gammon Construction Safety Research Center

## Simulation: Supervisor's Intervention




**LE:** Leading by Examples, stands for the percentage of safe behavior performed by the supervisors themselves. LE∈[0,1].
**BF:** Behavior Feedback, stands for the percentage of positive feedback that the supervisors give to the workers. BF ∈[0,1]. 1 means supervisors usually remind and encourage workers towards safety 0 means supervisors usually condemn and punish workers.

**1#(Green Lines)** When most of the supervisor agents' behaviors were safe (LE = 0.9) and their feedback towards worker agents' behaviors were positive (BF = 0.9), worker agents tended to behave more safely than there was no intervention by the supervisor agents. The percentage of unsafe behaviors reduced from 32.5% to 27.9%, and the number of daily incidents were maintained at around 220.

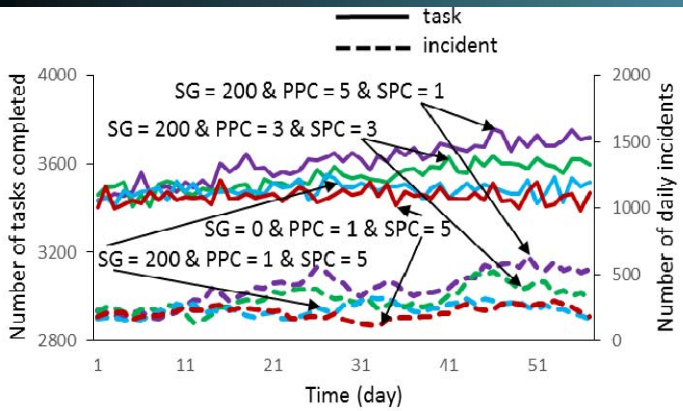
**2#(Red Lines)** When the means of both LE and BF were 0.09, the percentage of unsafe behaviors increased from 31.5% to 73.1%, and the number of daily incidents increased from 348 to 2241.

**3#(Blue Lines)** When the means of both LE and BF were 0.5, the percentage of unsafe behaviors increased from 31.9% to 65.6%, and the number of daily incidents increased from 275 to 1814.

**Implications to safety management :**

- Supervisors who not only acts as a bad example, but also complains that the safety outcomes cause losses of productivity.
- The management team should make more effort on the cultivation of positive and correct leadership role among the supervisors.

## Simulation: Safety Management Strategy




**SG:** Safety Goal, the upper bound number of daily incidents tolerable for managers.
**SPC & PPC:** Safety Performance Control & Production Performance Control. From value 1 to 5 means that the senior managers have actually little/slight/some/strong/very strong control over safety performance or production performance. Due to limited management capacity, there is a balance between these two variables. The sum of them is 6.

**1#** When managers cared more about the production goal (Purple Lines), the number of tasks completed were increased from 3434 to 3719 a day, but the number of daily incidents also increased from 226 to 533.

**2#** On the contrary, when cared more about safety (Blue Lines), the number of daily incidents were maintained at a low level, with an average of 236, while the number of tasks completed was also stabilized at around 3483 a day.

**3#** When the safety goal was tightened from 200 to 0 (Red Lines), indicating that the senior manager agent would never be satisfied with safety performance, the number of daily incidents was reduced by another 9.0%, with an average of 213, while the number of tasks completed was stabilized at around 3453 a day.

**Implications to safety management :**

- Managers should have the ability to balance the productivity and safety while making decisions, and need to make more efforts on achieving these goal.
- "Zero-Harm" is very effective on improving of safety performance.