Modeling and Visualizing Workers’ Behaviors for Safer Construction

Prof. Dongping FANG, School of Civil Engineering, Tsinghua University

建造业安全周 — 研讨会 21.9.2017
Construction Safety Week — Conference

3806 deaths in China 2016
32 deaths in Hong Kong in 2016
202 million deaths / year
294 deaths in Japan 2016

deaths in India?
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?

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

- Production Stress
- Limited Management Time
- Work Overload
- Physical Conditions

- Safety Competency
- Safety Investment
- Perceived Behavior Control

- Safety Communication
- Safety Attitude

- Unsafe Conditions
- Self Example

- Safety Inspection
- Safety Resources

- Safety Investment
- Safety Training

- Limited Management Time
- Safety Competency

- Work Overload
- Safety Communication

- Physical Conditions
- Safety Training

- Incident Investigation
- Subjective Norm

- Safety Awareness
- Behavior Feedback

- Perceived Behavior Control
- Safety Knowledge

- Incident Learning
- Safety Training

- Subjective Norm
- Safety Training

- Incident Investigation
- Subjective Norm

- Safety Awareness
- Behavior Feedback
Hybrid Model for construction site environment and individuals

System Dynamics Model

Cognitive Model of Unsafe Behaviors

Five-Stages of Cognitive Failure

1. Not seeing hazards

- Fatigue
- Overload
- Overconfidence

2. Not seeing hazards

- Fatigue
- Overload
- Overconfidence

3. Hazards are detected

- Hazards being blocked
- Hazards remaining unrecognised

Stage 1: hazards not detected?

Stage 2: hazards not recognized?

- Fatigue
- Overload
- Overconfidence

Stage 3: safe response not perceived?

- Not seeing
- Not being able to respond

Stage 4: safe response not selected?

- Fatigue
- Overload
- Overconfidence

Stage 5: safe response not executed?

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:

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

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


Multi-Agent Models

The senior manager agent's variables

- Visibility (V)
  - Percentage of safety activities for senior manager agents

- Production goal (PG)
  - Number of tasks expected to be completed each workday

- Safety goal (SG)
  - Upper bound number of daily accidents tolerable

- Performance control (PCC)
  - From 0.5 to 1.0 signifies how well a manager actually enforces management rules versus production performance

- Safety performance control (SPCC)
  - From 0 to 1 signifies how much the senior manager actually enforces management rules versus safety performance

- Systemic Pressure (SP)
  - The psychological state of mind regarding the potential hazards, on construction sites which may harm oneself or others. The value of 0 means no systemic pressure at all.

- Safety knowledge (SK)
  - The personal experience on safety issues and the ability of understanding, managing, and operating safer related equipment, protective skills, etc. The value of 0 means no safety knowledge at all.

- Fatigue level (FL)
  - The degree of fatigue or tiredness of the worker. The value of 5 means very tired or still.

- Stress level (SL)
  - The mental state of a worker. The value of 5 means very stressed or still.

- Safety training (ST)
  - Frequency of safety training. The value of 0 means safety training will not be held within 6 mo.

- Competency (C)
  - The safety officer agent's ability to enforce safety training and inspection

The supervisor agent's variables

- Leadership (L)
  - The percentage of safe behavior performed by the supervisor agent

- Behavioral feedback (BF)
  - From 0% to 100%, the supervisor will give positive feedback, and from -5% to 10% will give negative feedback.

- Learning rate (LR)
  - The learning rate of the agent the agent

The worker agent's variables

- Safety awareness (SA)
  - The psychological state of mind regarding the potential hazards, on construction sites which may harm oneself or others. The value of 0 means no systemic pressure at all.

- Safety knowledge (SK)
  - The personal experience on safety issues and the ability of understanding, managing, and operating safer related equipment, protective skills, etc. The value of 0 means no safety knowledge at all.

- Fatigue level (FL)
  - The degree of fatigue or tiredness of the worker. The value of 5 means very tired or still.

- Stress level (SL)
  - The mental state of a worker. The value of 5 means very stressed or still.

- Safety training (ST)
  - Frequency of safety training. The value of 0 means safety training will not be held within 6 mo.

- Competency (C)
  - The safety officer agent's ability to enforce safety training and inspection

- Systemic Pressure (SP)
  - The psychological state of mind regarding the potential hazards, on construction sites which may harm oneself or others. The value of 0 means no systemic pressure at all.

First stage
- Hazard Detecting
- Hazard Recognizing

Second stage
- Response Perceiving
- Response Selecting

Third stage
- Safe Response Executing
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

<table>
<thead>
<tr>
<th>Agent Type</th>
<th>Influencing Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Senior Manager</td>
<td>Safety goal, Safety performance control</td>
</tr>
<tr>
<td>Safety official</td>
<td>Safety training, Competency</td>
</tr>
<tr>
<td>Supervisor</td>
<td>Behavior feedback, Learning rate</td>
</tr>
<tr>
<td>Worker</td>
<td>Safety knowledge, Learning rate</td>
</tr>
</tbody>
</table>

Cognitive Failure at Stage 4

<table>
<thead>
<tr>
<th>Agent Type</th>
<th>Influencing Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Senior Manager</td>
<td>Visibility, Production goal, Safety goal, Production performance control, Safety performance control</td>
</tr>
<tr>
<td>Safety official</td>
<td>Safety inspection, Competency</td>
</tr>
<tr>
<td>Supervisor</td>
<td>Learning by example, Behavior feedback, Learning rate</td>
</tr>
<tr>
<td>Worker</td>
<td>Attitude, Subjective norm</td>
</tr>
</tbody>
</table>
No cognitive failure in all five stages

System Dynamic Model of Management Factors

Agent Models of Supervisors, Safety Officials, and Senior Managers

Variables Initialization Interface

Agents Model of Workers (Group)

Hybrid Model in AnyLogic

Agent Type Influencing Factor
Worker: Perceived behavioral control, Fatigue state
Scenario Comparison and Analysis

1# (Green Line) When the safety officers conduct safety inspection twice a day with limited ability to remove hazards (SI = 2 & CSO = 0.5).

2# (Purple Line) When the safety officers conduct safety inspection once a day with completely ability to remove hazards (SI = 1 & CSO = 1).

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

4# (Red Line) When the safety officers interacted with workers while inspecting (SI = 2 & CSO = 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)
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

<table>
<thead>
<tr>
<th>Drivers</th>
<th>Workers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neglecting the workers in blind spots</td>
<td>Being unaware of the vehicles approaching</td>
</tr>
<tr>
<td>Overconfidence in driving skills</td>
<td>Misjudgment on vehicles moving</td>
</tr>
<tr>
<td>Bad driving habits</td>
<td>Failure to find safe zones</td>
</tr>
<tr>
<td>Risk-taking decisions</td>
<td>Risk-taking decisions</td>
</tr>
<tr>
<td>Losing control of the vehicles</td>
<td>Failure to escape</td>
</tr>
</tbody>
</table>
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**

- I: Modelling Worker Behaviors and Site Environment
- II: Simulating & Visualizing Site Scenarios
- III: Integrating Site Data for Real Time Analysis
- IV: Predicting Risks and Supporting Decision Making
- V: Optimizing Management Strategy and Plan
- VI: Future: AI and Deep Learning
### Worker’s behavior vs Safety leadership

#### Safety leadership model for construction
- **Safety Leadership**
- **Safety Culture**
- **Safety Performance**: (1) Leading by example; (2) Participative decision-making; (3) Safety influence and role modelling; (4) Safety motivation and coaching; (5) Safety caring and individual respect; (6) Safety controlling and performance management; (7) Showing concern/interacting with the team.

#### Owner's and Contractor's Safety Leadership
- Leading by example
- Participative decision-making
- Coaching
- Informing
- Showing concern/interacting with the team

#### Supervisor's Safety Leadership
- Safety influence and role modelling
- Safety motivation and coaching
- Safety caring and individual respect
- Safety controlling and performance management

---

**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**

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**

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.