



# Moving safety decisions upstream using risk analysis

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# Agenda

- Review safety risk quantification techniques
- Introduce a schedule-based safety risk management method
- Introduce a method of evaluating the impact of alternative means and methods of construction
- Discuss integration with preconstruction phases





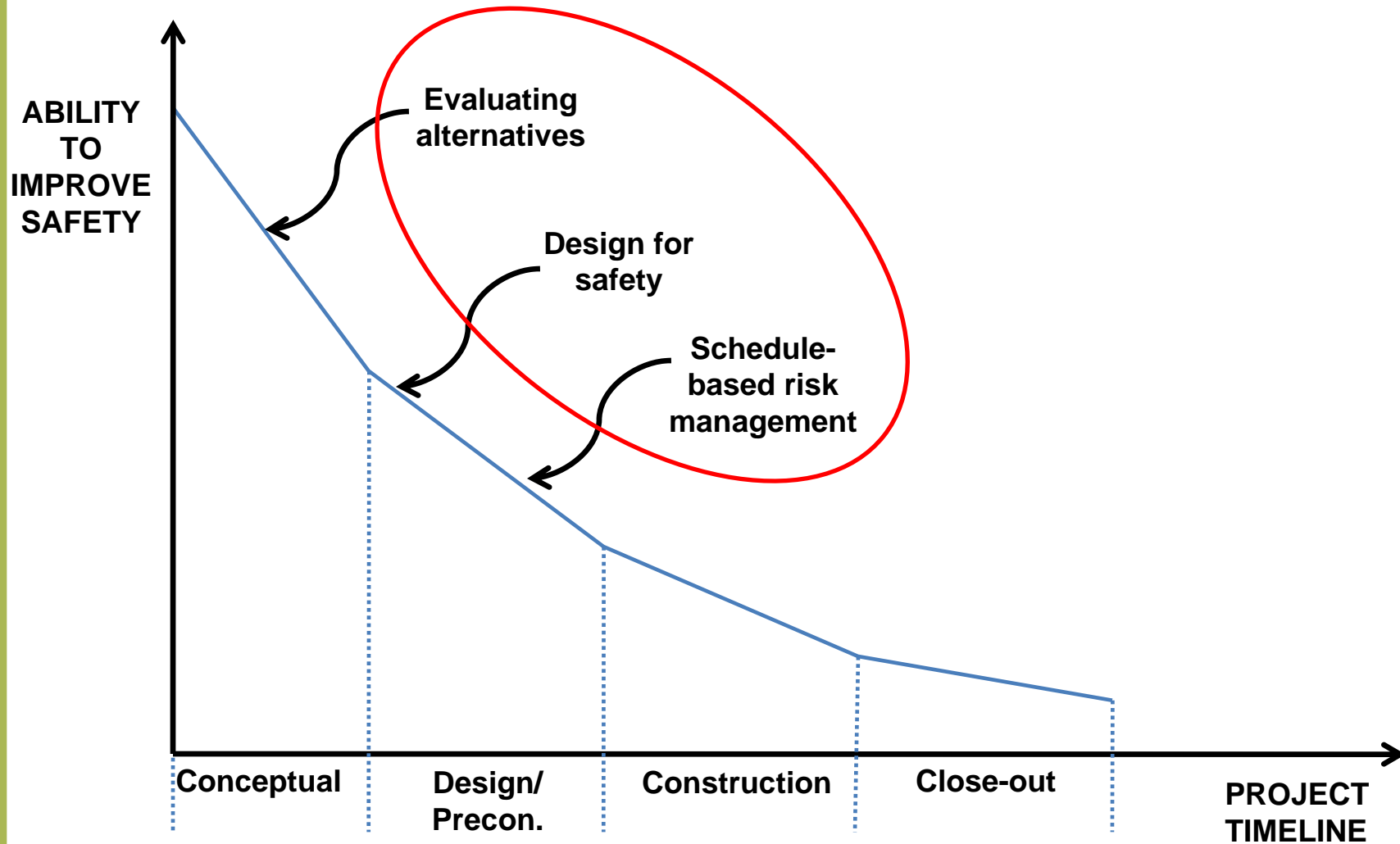
## The problem

- The highway construction sector has an injury rate nearly 10 times the all-industry average
- The number of fatal injuries on highway projects steadily increased between 1992 and 2000 despite the fact that the volume of construction work remained relatively constant (BLS 2001).
- Highest rate of struck-by injuries of all sectors





# Moving safety decisions upstream





# The theory

- Every construction process is associated with a specific degree of safety risk
- Risk is defined as the product of an element of chance (frequency) and an outcome (severity)
- If we can assign risk levels to specific processes or worker activities we better integrate safety with other preconstruction planning efforts





# Quantifying risk

- Unit risk = frequency x severity
  - Average frequency (# incidents/200,000 w-h)
  - Severity of that average injury (measured in impact to the worker or cost to the firm)
- Cumulative risk = frequency x severity x exposure
  - Exposure (task duration): measured in units of time
- Total process risk =  $\sum$  Activity risk
- Total project risk =  $\sum$  Process risk





# Severity scale

| <b>Subjective severity level</b> | <b>Severity Score</b> |
|----------------------------------|-----------------------|
| Negligible                       | 1                     |
| Temporary discomfort             | 2                     |
| Persistent discomfort            | 4                     |
| Temporary pain                   | 8                     |
| Persistent pain                  | 16                    |
| Minor first aid                  | 32                    |
| Major first aid                  | 64                    |
| Lost work time                   | 128                   |
| Medical case                     | 256                   |
| Permanent disablement            | 1024                  |
| Fatality                         | 26,214                |





# Example: Excavation

- Assume that:
  - The average incident results in a major first aid injury (e.g., laceration where no medical attention is required)
  - Severity score = 64 S
  - The average injury occurs once six times every 200,000 worker-hours
  - Frequency =  $6/200,000$  w-h
  - Unit risk score (S/w-h) =  $64 S \times 3/200,000$  w-h =  $0.0020$  S/w-h





## Risk-based schedule

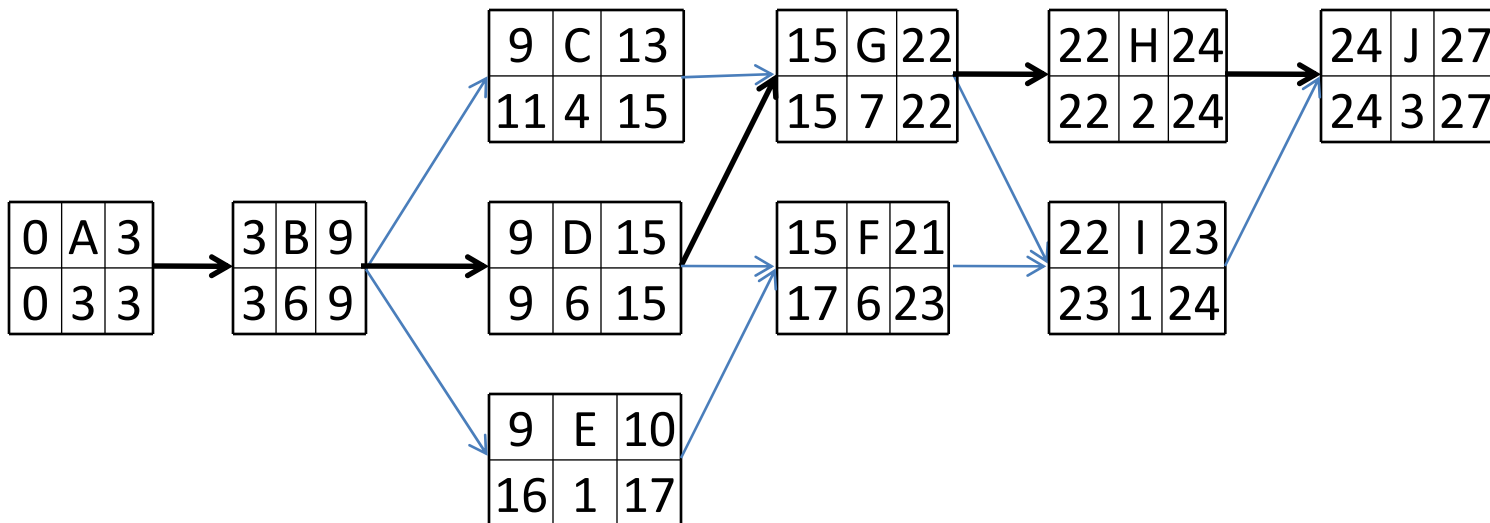
- Construction schedules are based upon the duration of major processes (e.g., excavation)
- Safety risk can be linked to schedule to produce a risk profile
  - Allows managers to identify high risk periods
  - Schedule alternatives that level risk
  - Focus safety programs
  - Better use of limited safety resources (CDOT)





| Activity                   | Activity Code | PIB | Duration | Safety Risk |
|----------------------------|---------------|-----|----------|-------------|
| Surveying                  | A             | --  | 3        | 7           |
| Mobilization               | B             | A   | 4        | 9           |
| Repair Subbase             | C             | B   | 4        | 4           |
| Rotomill Existing Pavement | D             | B   | 6        | 8           |
| Install Geosynthetics      | E             | B   | 1        | 16          |
| Install Culverts, Drainage | F             | D,E | 6        | 11          |
| Lay Asphalt                | G             | C,D | 7        | 9           |
| Striping                   | H             | G   | 2        | 7           |
| Signage                    | I             | G,F | 1        | 5           |
| Lanscaping                 | J             | H,I | 3        | 2           |







| Activity  | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 |   |   |
|-----------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|---|---|
| A (B)     | 7 | 7 | 7 |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |   |   |
| B (C,D,E) |   |   |   | 9 | 9 | 9 | 9 | 9 | 9 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |   |   |
| C (G)     |   |   |   |   |   |   |   |   |   | 4  | 4  | 4  | 4  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |   |   |
| D (G,F)   |   |   |   |   |   |   |   |   |   | 8  | 8  | 8  | 8  | 8  | 8  |    |    |    |    |    |    |    |    |    |    |    |    |   |   |
| E (F)     |   |   |   |   |   |   |   |   |   | 16 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |   |   |
| F (I)     |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    | 11 | 11 | 11 | 11 | 11 | 11 | 11 |    |    |    |    |    |   |   |
| G (H,I)   |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    | 9  | 9  | 9  | 9  | 9  | 9  | 9  | 9  |    |    |    |    |   |   |
| H (J)     |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 7  | 7  |    |    |   |   |
| I (J)     |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 5  |    |    |    |   |   |
| J         |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 2  | 2 | 2 |



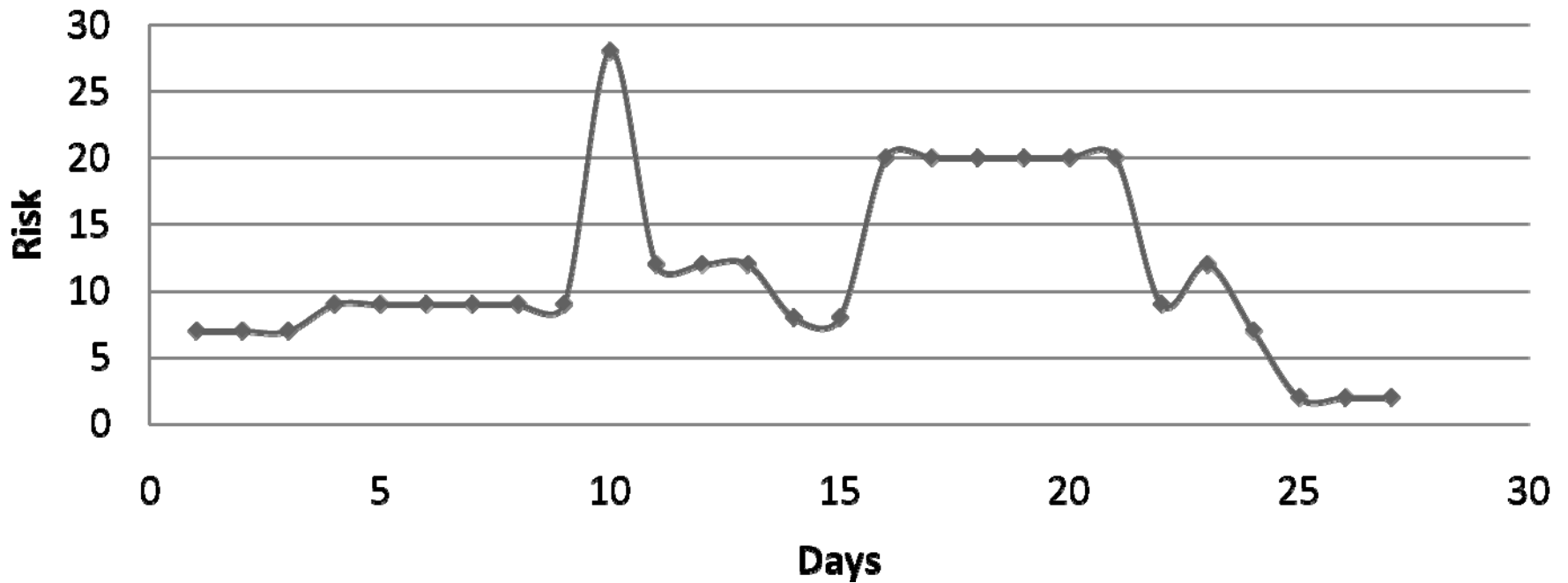


| Activity  | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 |   |   |
|-----------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|---|---|
| A (B)     | 7 | 7 | 7 |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |   |   |
| B (C,D,E) |   |   |   | 9 | 9 | 9 | 9 | 9 | 9 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |   |   |
| C (G)     |   |   |   |   |   |   |   |   |   | 4  | 4  | 4  | 4  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |   |   |
| D (G,F)   |   |   |   |   |   |   |   |   |   | 8  | 8  | 8  | 8  | 8  | 8  |    |    |    |    |    |    |    |    |    |    |    |    |   |   |
| E (F)     |   |   |   |   |   |   |   |   |   | 16 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |   |   |
| F (I)     |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    | 11 | 11 | 11 | 11 | 11 | 11 | 11 |    |    |    |    |   |   |
| G (H,I)   |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    | 9  | 9  | 9  | 9  | 9  | 9  | 9  |    |    |    |    |   |   |
| H (J)     |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 7  | 7  |    |    |   |   |
| I (J)     |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 5  |    |    |    |   |   |
| J         |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 2  | 2 | 2 |
| As Is     | 7 | 7 | 7 | 9 | 9 | 9 | 9 | 9 | 9 | 28 | 12 | 12 | 12 | 8  | 8  | 20 | 20 | 20 | 20 | 20 | 20 | 9  | 12 | 7  | 2  | 2  | 2  |   |   |





### Safety risk over time (original sequence)





| Activity  | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 |   |   |
|-----------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|---|---|
| A (B)     | 7 | 7 | 7 |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |   |   |
| B (C,D,E) |   |   |   | 9 | 9 | 9 | 9 | 9 | 9 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |   |   |
| C (G)     |   |   |   |   |   |   |   |   |   | 4  | 4  | 4  | 4  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |   |   |
| D (G,F)   |   |   |   |   |   |   |   |   |   | 8  | 8  | 8  | 8  | 8  | 8  |    |    |    |    |    |    |    |    |    |    |    |    |   |   |
| E (F)     |   |   |   |   |   |   |   |   |   | 16 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |   |   |
| F (I)     |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    | 11 | 11 | 11 | 11 | 11 | 11 | 11 |    |    |    |    |   |   |
| G (H,I)   |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    | 9  | 9  | 9  | 9  | 9  | 9  | 9  |    |    |    |    |   |   |
| H (J)     |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 7  | 7  |    |    |   |   |
| I (J)     |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 5  |    |    |    |   |   |
| J         |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 2  | 2 | 2 |
| As Is     | 7 | 7 | 7 | 9 | 9 | 9 | 9 | 9 | 9 | 28 | 12 | 12 | 12 | 8  | 8  | 20 | 20 | 20 | 20 | 20 | 20 | 9  | 12 | 7  | 2  | 2  | 2  |   |   |



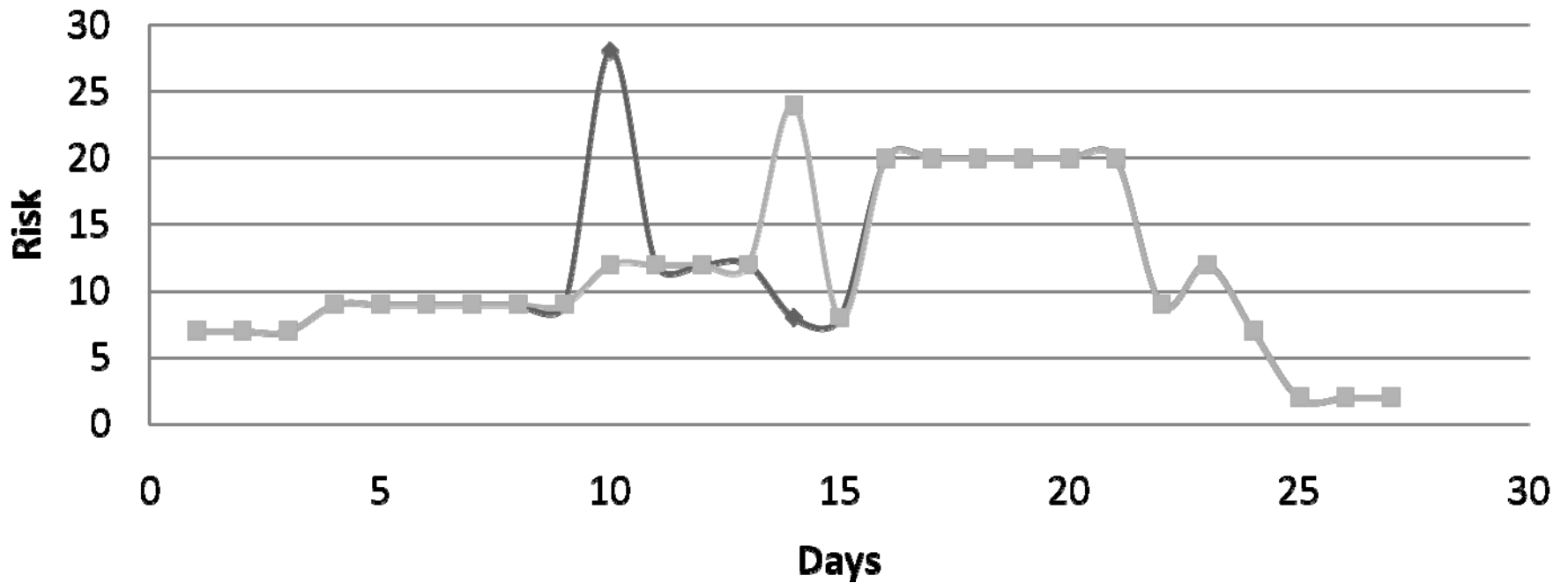


| Activity  | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 |   |  |
|-----------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|---|--|
| A (B)     | 7 | 7 | 7 |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |   |  |
| B (C,D,E) |   |   |   | 9 | 9 | 9 | 9 | 9 | 9 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |   |  |
| C (G)     |   |   |   |   |   |   |   |   |   | 4  | 4  | 4  | 4  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |   |  |
| D (G,F)   |   |   |   |   |   |   |   |   |   | 8  | 8  | 8  | 8  | 8  | 8  |    |    |    |    |    |    |    |    |    |    |    |    |   |  |
| E (F)     |   |   |   |   |   |   |   |   |   |    |    |    | 16 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |   |  |
| F (I)     |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    | 11 | 11 | 11 | 11 | 11 | 11 | 11 |    |    |    |    |    |   |  |
| G (H,I)   |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    | 9  | 9  | 9  | 9  | 9  | 9  | 9  |    |    |    |    |    |   |  |
| H (J)     |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    | 7  | 7  |    |    |    |   |  |
| I (J)     |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    | 5  |    |    |    |    |   |  |
| J         |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 2  | 2  | 2 |  |
| As Is     | 7 | 7 | 7 | 9 | 9 | 9 | 9 | 9 | 9 | 28 | 12 | 12 | 12 | 8  | 8  | 20 | 20 | 20 | 20 | 20 | 20 | 9  | 12 | 7  | 2  | 2  | 2  |   |  |
| Best Case | 7 | 7 | 7 | 9 | 9 | 9 | 9 | 9 | 9 | 12 | 12 | 12 | 12 | 24 | 8  | 20 | 20 | 20 | 20 | 20 | 20 | 9  | 12 | 7  | 2  | 2  | 2  |   |  |





### Safety risk over time (original vs. best case)





| Activity  | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 |   |
|-----------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|---|
| A (B)     | 7 | 7 | 7 |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |   |
| B (C,D,E) |   |   |   | 9 | 9 | 9 | 9 | 9 | 9 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |   |
| C (G)     |   |   |   |   |   |   |   |   |   | 4  | 4  | 4  | 4  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |   |
| D (G,F)   |   |   |   |   |   |   |   |   |   | 8  | 8  | 8  | 8  | 8  | 8  |    |    |    |    |    |    |    |    |    |    |    |    |   |
| E (F)     |   |   |   |   |   |   |   |   |   |    |    |    | 16 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |   |
| F (I)     |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    | 11 | 11 | 11 | 11 | 11 | 11 | 11 |    |    |    |    |    |   |
| G (H,I)   |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    | 9  | 9  | 9  | 9  | 9  | 9  | 9  |    |    |    |    |    |   |
| H (J)     |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    | 7  | 7  |    |    |    |   |
| I (J)     |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    | 5  |    |    |    |    |   |
| J         |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 2  | 2  | 2 |
| As Is     | 7 | 7 | 7 | 9 | 9 | 9 | 9 | 9 | 9 | 28 | 12 | 12 | 12 | 8  | 8  | 20 | 20 | 20 | 20 | 20 | 20 | 9  | 12 | 7  | 2  | 2  | 2  |   |
| Best Case | 7 | 7 | 7 | 9 | 9 | 9 | 9 | 9 | 9 | 12 | 12 | 12 | 12 | 24 | 8  | 20 | 20 | 20 | 20 | 20 | 20 | 9  | 12 | 7  | 2  | 2  | 2  |   |





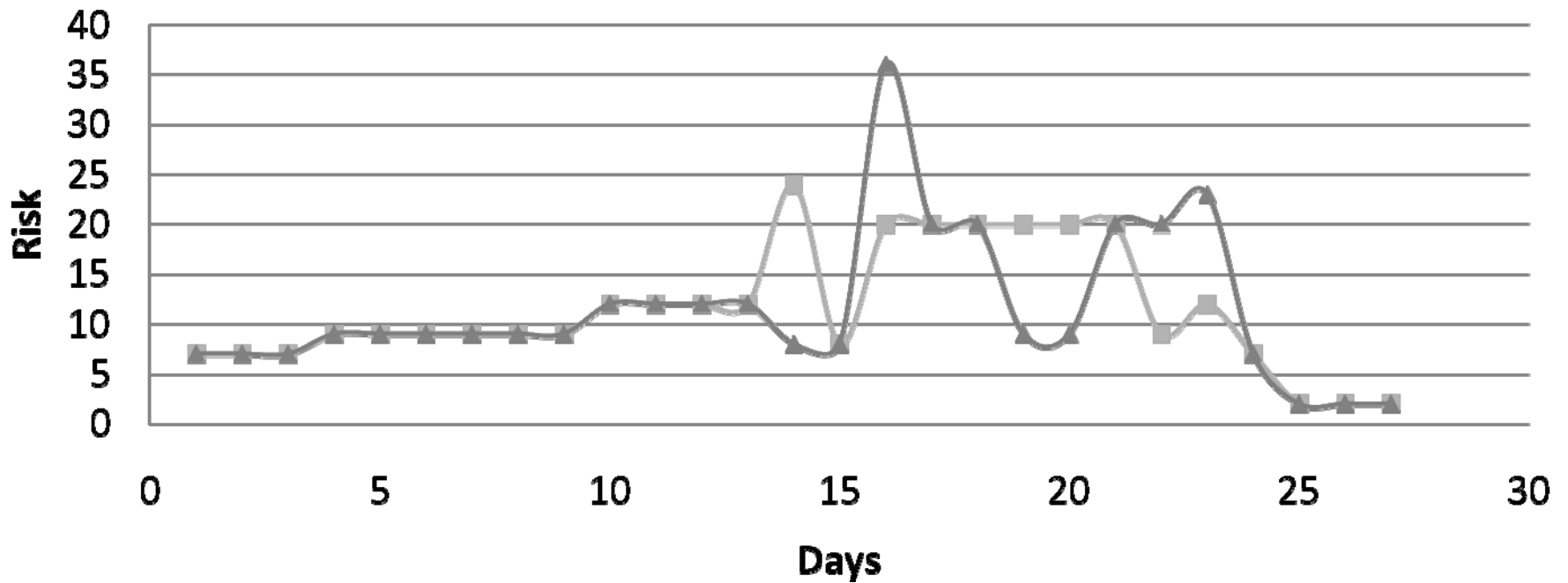
| Activity  | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 |   |
|-----------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|---|
| A (B)     | 7 | 7 | 7 |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |   |
| B (C,D,E) |   |   |   | 9 | 9 | 9 | 9 | 9 | 9 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |   |
| C (G)     |   |   |   |   |   |   |   |   |   | 4  | 4  | 4  | 4  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |   |
| D (G,F)   |   |   |   |   |   |   |   |   |   | 8  | 8  | 8  | 8  | 8  | 8  |    |    |    |    |    |    |    |    |    |    |    |    |   |
| E (F)     |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    | 16 |    |    |    |    |    |    |    |    |    |    |    |   |
| F (I)     |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    | 11 | 11 |    |    |    | 11 | 11 | 11 | 11 |    |    |    |   |
| G (H,I)   |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    | 9  | 9  | 9  | 9  | 9  | 9  | 9  |    |    |    |    |    |   |
| H (J)     |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    | 7  | 7  |    |    |    |   |
| I (J)     |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    | 5  |    |    |    |    |   |
| J         |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | 2  | 2  | 2 |

|            |   |   |   |   |   |   |   |   |   |    |    |    |    |    |   |    |    |    |    |    |    |    |    |   |   |   |   |
|------------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|---|----|----|----|----|----|----|----|----|---|---|---|---|
| As Is      | 7 | 7 | 7 | 9 | 9 | 9 | 9 | 9 | 9 | 28 | 12 | 12 | 12 | 8  | 8 | 20 | 20 | 20 | 20 | 20 | 20 | 9  | 12 | 7 | 2 | 2 | 2 |
| Best Case  | 7 | 7 | 7 | 9 | 9 | 9 | 9 | 9 | 9 | 12 | 12 | 12 | 12 | 24 | 8 | 20 | 20 | 20 | 20 | 20 | 20 | 9  | 12 | 7 | 2 | 2 | 2 |
| Worst Case | 7 | 7 | 7 | 9 | 9 | 9 | 9 | 9 | 9 | 12 | 12 | 12 | 12 | 8  | 8 | 36 | 20 | 20 | 9  | 9  | 20 | 20 | 23 | 7 | 2 | 2 | 2 |





### Safety risk over time (best case vs. worst case)





# Benefits of this method

- Sequences can be adjusted without compromising the end date of the project
- High risk periods can be identified before construction begins and communicated to the workforce
- Safety programs can be focused based on this info



# Comparing alternatives

- Risks must be defined at the process level (i.e., excavation, landscaping) to integrate with schedules
- To make comparisons of means and methods of construction, tasks must be defined at the activity level (crane materials, cut materials)





# Example: Formwork construction

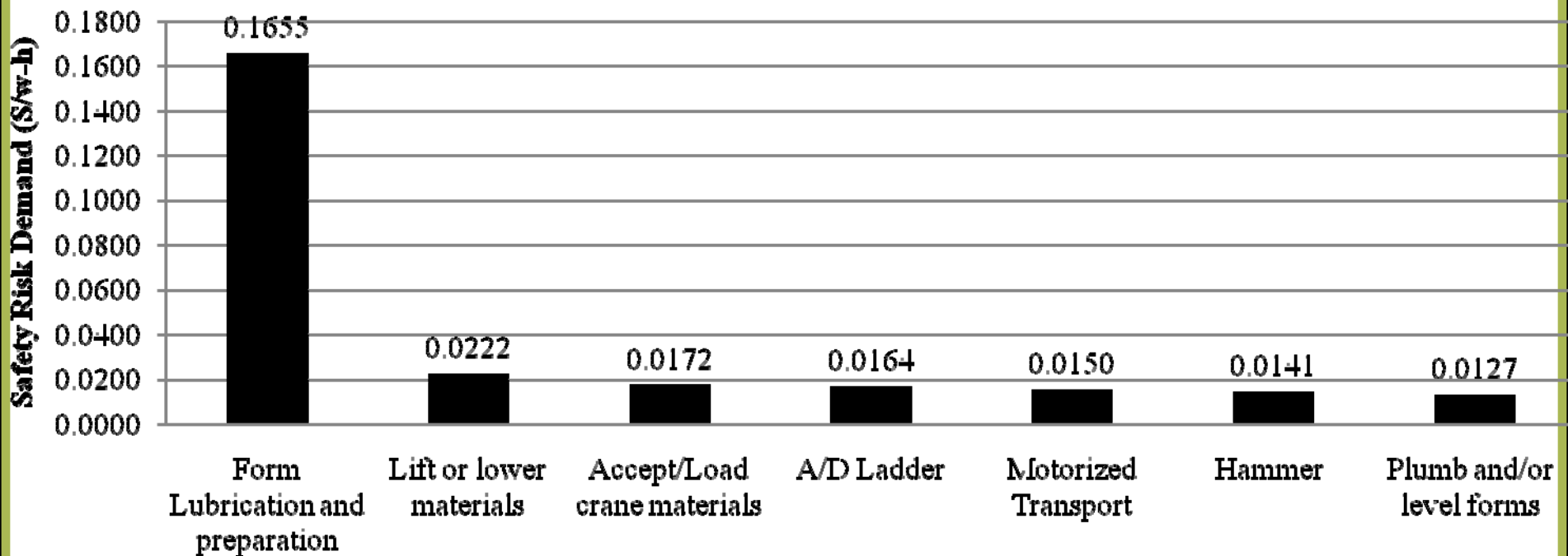
- 13 major work activities were identified (e.g., cut materials, ascend/descend ladder)
- 10 all-inclusive, mutually exclusive risk classifications (e.g., fall from height, struck-by)
- The average frequency and severity defined for each risk and for each activity
- Research method: Delphi





# Unit risk values

## Highest Risk Formwork Activities





# The question: what method of constructing formwork is safest?

- Methods of formwork construction examined:
  - Traditional hand-built forms
  - Slip forms
  - Panelized forms
- These types vary in task, duration, quality, and safety risk



| <b>Formwork Construction Activity</b>     | <b>Unit Risk (S/w-h)</b> |
|---|--------------------------|
| Form lubrication                          | 18.67172                 |
| A/D ladder                                | 1.86208                  |
| Crane materials                           | 0.51349                  |
| Motorized transport                       | 0.47512                  |
| Hammer w/ sledgehammer, etc.              | 0.24728                  |
| Lift or lower materials, etc.             | 0.19398                  |
| Excavation                                | 0.11231                  |
| Plumb and/or level forms                  | 0.10647                  |
| Cut materials using circular or table saw | 0.05018                  |
| Transport materials w/o motorized assist. | 0.03613                  |
| Nail/Screw/Drill                          | 0.03235                  |
| Static Lift                               | 0.02758                  |
| Inspect forms and planning                | 0.00618                  |
|   | Total                    |





| Formwork Construction Activity            | Unit Risk (S/w-h) | Traditional Formwork Construction |          | Panelized formwork |          | Slip forming |          |
|---|-------------------|-----------------------------------|----------|--------------------|----------|--------------|----------|
|   |                   | worker-days                       | Risk (S) | worker-days        | Risk (S) | worker-days  | Risk (S) |
| Form lubrication                          | 18.67172          | 2                                 |          | 4                  |          | 5            |          |
| A/D ladder                                | 1.86208           | 20                                |          | 20                 |          | 20           |          |
| Crane materials                           | 0.51349           | 10                                |          | 80                 |          | 100          |          |
| Motorized transport                       | 0.47512           | 60                                |          | 20                 |          | 20           |          |
| Hammer w/ sledgehammer, etc.              | 0.24728           | 40                                |          | 20                 |          | 20           |          |
| Lift or lower materials, etc.             | 0.19398           | 80                                |          | 60                 |          | 60           |          |
| Excavation                                | 0.11231           | 40                                |          | 40                 |          | 40           |          |
| Plumb and/or level forms                  | 0.10647           | 30                                |          | 50                 |          | 50           |          |
| Cut materials using circular or table saw | 0.05018           | 60                                |          | 10                 |          | 10           |          |
| Transport materials w/o motorized assist. | 0.03613           | 60                                |          | 10                 |          | 20           |          |
| Nail/Screw/Drill                          | 0.03235           | 100                               |          | 60                 |          | 60           |          |
| Static Lift                               | 0.02758           | 40                                |          | 60                 |          | 50           |          |
| Inspect forms and planning                | 0.00618           | 80                                |          | 60                 |          | 60           |          |
| <b>Total</b>                              |                   | <b>622</b>                        |          | <b>494</b>         |          | <b>515</b>   |          |





| Formwork Construction Activity            | Unit Risk (S/w-h) | Traditional Formwork Construction |             | Panelized formwork |          | Slip forming |          |
|---|-------------------|-----------------------------------|-------------|--------------------|----------|--------------|----------|
|   |                   | worker-days                       | Risk (S)    | worker-days        | Risk (S) | worker-days  | Risk (S) |
| Form lubrication                          | 18.67172          | 2                                 | 299         | 4                  |          | 5            |          |
| A/D ladder                                | 1.86208           | 20                                | 298         | 20                 |          | 20           |          |
| Crane materials                           | 0.51349           | 10                                | 41          | 80                 |          | 100          |          |
| Motorized transport                       | 0.47512           | 60                                | 228         | 20                 |          | 20           |          |
| Hammer w/ sledgehammer, etc.              | 0.24728           | 40                                | 79          | 20                 |          | 20           |          |
| Lift or lower materials, etc.             | 0.19398           | 80                                | 124         | 60                 |          | 60           |          |
| Excavation                                | 0.11231           | 40                                | 36          | 40                 |          | 40           |          |
| Plumb and/or level forms                  | 0.10647           | 30                                | 26          | 50                 |          | 50           |          |
| Cut materials using circular or table saw | 0.05018           | 60                                | 24          | 10                 |          | 10           |          |
| Transport materials w/o motorized assist. | 0.03613           | 60                                | 17          | 10                 |          | 20           |          |
| Nail/Screw/Drill                          | 0.03235           | 100                               | 26          | 60                 |          | 60           |          |
| Static Lift                               | 0.02758           | 40                                | 9           | 60                 |          | 50           |          |
| Inspect forms and planning                | 0.00618           | 80                                | 4           | 60                 |          | 60           |          |
| <b>Total</b>                              |                   | <b>622</b>                        | <b>1211</b> | <b>494</b>         |          | <b>515</b>   |          |





| Formwork Construction Activity            | Unit Risk (S/w-h) | Traditional Formwork Construction |             | Panelized formwork |             | Slip forming |          |
|---|-------------------|-----------------------------------|-------------|--------------------|-------------|--------------|----------|
|   |                   | worker-days                       | Risk (S)    | worker-days        | Risk (S)    | worker-days  | Risk (S) |
| Form lubrication                          | 18.67172          | 2                                 | 299         | 4                  | 597         | 5            |          |
| A/D ladder                                | 1.86208           | 20                                | 298         | 20                 | 298         | 20           |          |
| Crane materials                           | 0.51349           | 10                                | 41          | 80                 | 329         | 100          |          |
| Motorized transport                       | 0.47512           | 60                                | 228         | 20                 | 76          | 20           |          |
| Hammer w/ sledgehammer, etc.              | 0.24728           | 40                                | 79          | 20                 | 40          | 20           |          |
| Lift or lower materials, etc.             | 0.19398           | 80                                | 124         | 60                 | 93          | 60           |          |
| Excavation                                | 0.11231           | 40                                | 36          | 40                 | 36          | 40           |          |
| Plumb and/or level forms                  | 0.10647           | 30                                | 26          | 50                 | 43          | 50           |          |
| Cut materials using circular or table saw | 0.05018           | 60                                | 24          | 10                 | 4           | 10           |          |
| Transport materials w/o motorized assist. | 0.03613           | 60                                | 17          | 10                 | 3           | 20           |          |
| Nail/Screw/Drill                          | 0.03235           | 100                               | 26          | 60                 | 16          | 60           |          |
| Static Lift                               | 0.02758           | 40                                | 9           | 60                 | 13          | 50           |          |
| Inspect forms and planning                | 0.00618           | 80                                | 4           | 60                 | 3           | 60           |          |
| <b>Total</b>                              |                   | <b>622</b>                        | <b>1211</b> | <b>494</b>         | <b>1550</b> | <b>515</b>   |          |





| Formwork Construction Activity            | Unit Risk (S/w-h) | Traditional Formwork Construction |             | Panelized formwork |             | Slip forming |             |
|---|-------------------|-----------------------------------|-------------|--------------------|-------------|--------------|-------------|
|   |                   | worker-days                       | Risk (S)    | worker-days        | Risk (S)    | worker-days  | Risk (S)    |
| Form lubrication                          | 18.67172          | 2                                 | 299         | 4                  | 597         | 5            | 747         |
| A/D ladder                                | 1.86208           | 20                                | 298         | 20                 | 298         | 20           | 298         |
| Crane materials                           | 0.51349           | 10                                | 41          | 80                 | 329         | 100          | 411         |
| Motorized transport                       | 0.47512           | 60                                | 228         | 20                 | 76          | 20           | 76          |
| Hammer w/ sledgehammer, etc.              | 0.24728           | 40                                | 79          | 20                 | 40          | 20           | 40          |
| Lift or lower materials, etc.             | 0.19398           | 80                                | 124         | 60                 | 93          | 60           | 93          |
| Excavation                                | 0.11231           | 40                                | 36          | 40                 | 36          | 40           | 36          |
| Plumb and/or level forms                  | 0.10647           | 30                                | 26          | 50                 | 43          | 50           | 43          |
| Cut materials using circular or table saw | 0.05018           | 60                                | 24          | 10                 | 4           | 10           | 4           |
| Transport materials w/o motorized assist. | 0.03613           | 60                                | 17          | 10                 | 3           | 20           | 6           |
| Nail/Screw/Drill                          | 0.03235           | 100                               | 26          | 60                 | 16          | 60           | 16          |
| Static Lift                               | 0.02758           | 40                                | 9           | 60                 | 13          | 50           | 11          |
| Inspect forms and planning                | 0.00618           | 80                                | 4           | 60                 | 3           | 60           | 3           |
| <b>Total</b>                              |                   | <b>622</b>                        | <b>1211</b> | <b>494</b>         | <b>1550</b> | <b>515</b>   | <b>1782</b> |





# How can we use this information to improve decision making?

- Multi-criteria decision analyses (MCDA)
- Alternatives
  - Methods of formwork construction
- Criteria (e.g., duration, quality, cost, and safety)
  - Traditional (1211 S); Panelized (1550 S); Slip Forming (1782 S/w-h)
- Weights
  - Relative importance of the criteria

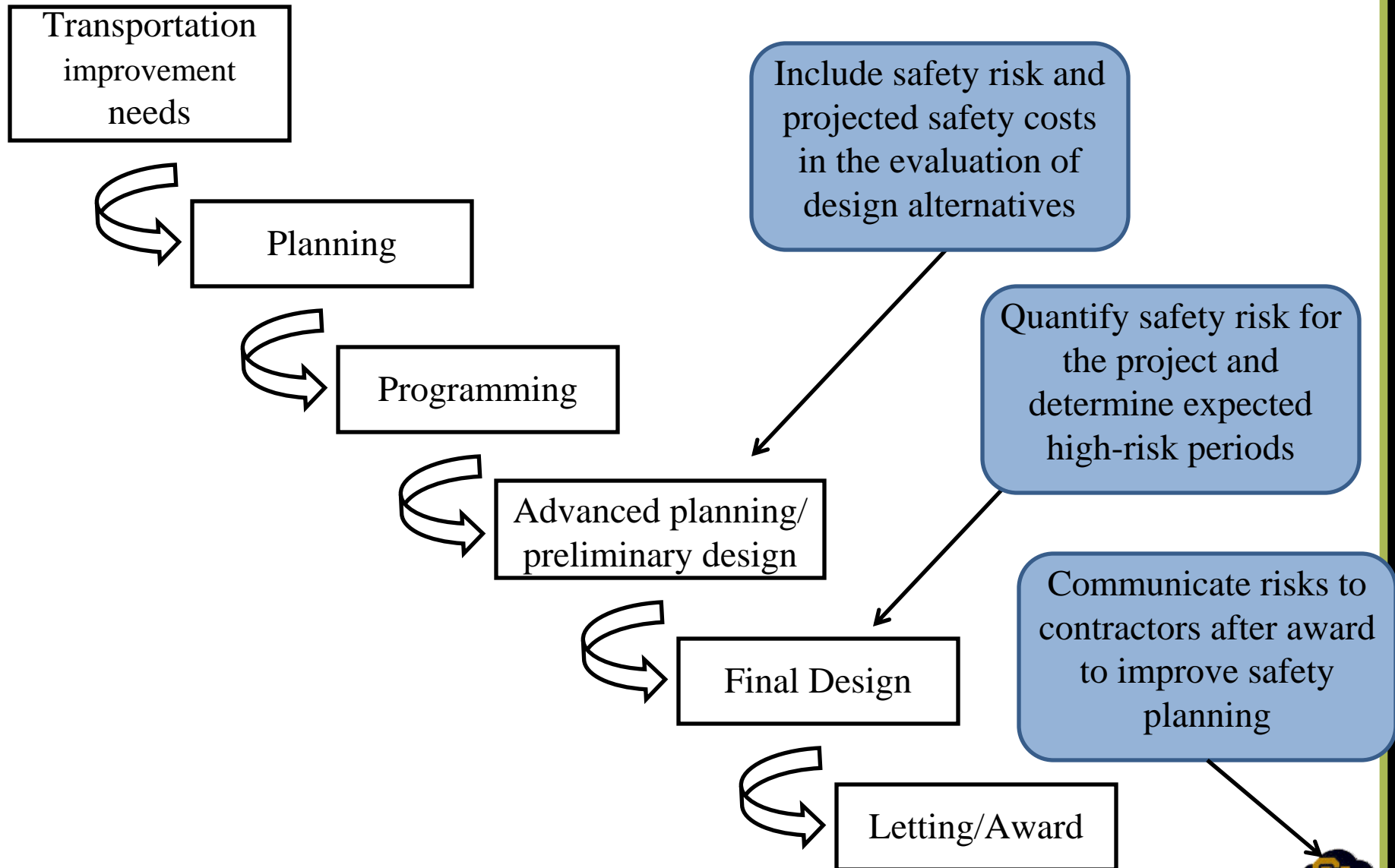




# Why highway construction safety?

- Potential for a large impact
- Highway construction processes are:
  - Well-defined
  - Few in numbers
  - Relatively standard
  - Linked to archival safety data
  - Common to most contractors and geographical regions







## In conclusion...

- Quantifying safety risk associated with construction processes allows managers to:
  - Estimate safety-related costs
  - Include objective safety data in evaluating design alternatives
  - Track safety risks through the construction timeline
  - Focus safety programs to target high risk processes and periods of exceptionally high risk





# Thank you

- Questions?
- If you are interested in the ideas presented, I would love to speak with you.

