ACCIDENTS, HIGH RISK TASKS AND ERROR PROOFING OPPORTUNITIES IN RESIDENTIAL FRAMING

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ABSTRACT

This study analyzes the high-risk tasks in residential framing and identifies areas for error-proofing the production process that can reduce the probability of accident occurrence. The research consisted of a cognitive approach to safety and focused on the task demands that contribute to errors and accidents. To understand the errors involved in framing accidents, 177 recordable injuries were examined that were sustained in a large framing company in 2005. The analysis first examined the frequency and severity of the different accident events. Falls during truss installation, falls during roof plywood installation, and saw cuts were the three most severe accident events and together accounted for 58% of the total workers' compensation costs. Nail gun injuries and falls from same level were also identified as significant incidents. Incident analysis and interviews with safety and production personnel were then used to identify the 'high risk' tasks (that is, activities and tasks with high frequency and/or high severity of accidents), and to understand the task features and errors that contribute to accidents during these tasks. Based on the findings, the study identified directions for error-proofing of the high risk tasks that can reduce the errors and accidents.

Keywords: Residential accidents, Framing, High risk tasks, Errors, Error proofing.

1. INTRODUCTION

Construction injuries remain a significant problem. In Arizona, the recent growth in construction activity has exacerbated the safety problem, as this growth was accompanied by a disproportionate increase in injuries in many trades. Table 1 summarizes employment and injury data for selected specialty trades in Arizona. According to the Industrial Commission of Arizona and the Bureau of Labor Statistics, the number of injury/illnesses for specialty trade contractors involved in Foundation, Structure, and Exterior Buildings jumped from 3,300 in 2004 to 5,700 incidents in 2005, representing a 73 percent increase. For framing contractors, the average employment in 2005 increased by 34%, while the number of injuries increased by 120%. Framing contractors have the

highest incident rate among specialty trade contractors with a rate of 22 (equivalent to 22 injuries per 100 full time workers per year).

This study focused on residential framing operations. The goal of this study was to identify error-proofing interventions that can reduce the frequency and severity of accidents in residential framing. The focus of the study was on preventing the 'errors' or conditions that lead to loss of control and accidents, rather than improving the protective measures (such as personal protective equipment) that minimize the consequences of accidents. For example, the goal of the study was to prevent falls, rather than to develop fall protection system.

Error proofing techniques do not control the root causes of mistakes, such as human and environmental factors (fatigue, distractions, noise, lighting, etc.), but independent of the cause, they block or provide a warning about undesired outcomes at a point in the process where the consequences can be minimized. Error proofing has been used in the Toyota production system as the primary strategy for prevention of defects.

This study explored error-proofing as a possible direction for construction accident prevention. Identifying effective error proofing interventions requires a deeper understanding of the errors that lead to loss of control and the 'mechanisms' of accidents. Furthermore, the same accident event may be triggered by different causes. For example, a fall from a roof may be triggered either by overextending at the edge of the roof, or slipping on plywood. These involve different error mechanisms and reasons, and may be addressed with different interventions.

Table 1. Incident rates for selected building trades in AZ.

	2004		2005		% Change[3,4]		2005
INDUSTRY	Employment [1,2]	Total Cases [1]	Employment [1,2]	Total Cases [1]	Employment	Total Cases	Incident rate
Foundation, Structure, Exter Bldg Trade Contractors[5]	40.8	3.3	48.2	5.7	18%	73%	12.6
Framing Contractors	**11.7**	**1.5**	**15.7**	**3.3**	**34%**	**120%**	**22**
Masonry Contractors	9.4	0.3	10.8	0.7	15%	133%	6.8
Poured Foundation & Struct. Contactors	8.5	0.6	9.2	0.6	8%	0%	7.6
Structural Steel & Precast Conc. Contractors	2.6	0.2	2.9	0.3	12%	50%	10.7
Roofing Contractors	5.7	0.4	6.5	0.6	14%	50%	10.3

2. METHODOLOGY

To develop a deeper understanding of the accidents in residential framing, and the related errors the researchers analyzed 177 recordable accidents that occurred in a large residential framing company in 2005. This paper reports the initial findings of the study—it analyzes the frequency and severity of different accident events, it examines the tasks during which the accidents happened, and it investigates the errors and conditions that led to the most severe accidents.

Incident Data and Analysis

In 2005, the participating company recorded 177 recordable incidents. First-aid accidents with zero workers' comp costs were excluded from the analysis. In 2005 the company employed an average of 86 framing crews, worked 1.5 million labor hours, and framed over 2,800 houses. The incident records provided the following information:

- Date of incident
- Injured worker's position: foreman, carpenter, apprentice or laborer (incomplete records)
- Length of employment: months with the company
- Description of the incident (usually brief with little information).
- Workers' comp cost (actual or estimated). Indirect costs, such as production loss, etc. were not accounted for.

The analysis of the data included the following steps:

- Classified and analyzed the incidents based on the type of event.
- Classified and analyzed the incidents according to the activity and task that the worker was performing at the time of the incident.
- For the higher severity incident types, we investigated the errors that led to the incident event. Analyzed etiology with experienced personnel.

Incident Events.

Based on the injury descriptions, the researchers classified the incidents under the following 'Event' categories:

- **Falls** include falls to lower level, falls at same level, and falls from ladder.
- **Contact with tool/equipment/material** includes sawcuts, cuts on gussets, stepping on nails with static nail (e.g., stepped on nail), splinters
- **Struck by tool/equipment/material** includes injuries from nail guns, hammers, material falling from above, dropping materials during transport, dropping wall panels during lifting, debris in eye, etc.
- **Overexertion** includes injuries such as sprains and strains caused during walking, lifting, moving, etc.

Incidents and Main Activities.

Classified and analyzed the incidents according to the activity and task that the worker was performing at the time of the incident. After discussions with company personnel, we developed the following list of main activities and tasks included in each:

- **Site:** load/unload material and equipment, cleanup site, remove nails.
- **Walls:** (first or second floor) include layout, material handling of wall material, framing, lifting in place, installing blocking, installing shear walls, installing top plate.
- **Trusses:** (floor and roof trusses) include setting the truss, installing blocking and bracing, and sheeting, installing fascia, cutting tails, etc.)

- **Roof:** sheeting includes setting plywood on the roof

Each task includes transporting material, measuring, cutting, and nailing.

Incidents and Errors

For the incident events with the highest severity, the researchers examined the task errors that contributed to the particular events. This was done first through examination of the causes from the incident records. However, in most cases, the information provided in the incident description was too limited and did not identify the error involved. For the higher cost incidents, the researchers gathered additional information from the safety director and the quality control (QC) manager who had been involved in the incident investigation. The safety director and QC manager also identified the most common incident-related errors based on their experience. This part of the analysis identified errors related to particular work activities, and provided the basis for discussion regarding possible interventions for error prevention.

3. ANALYSIS OF INCIDENT EVENTS

Table 2 summarizes the frequency and severity of the various incident events. The frequency is indicated by the number of occurrences and % of cases, while the severity is expressed in terms of workers' compensation cost.

Table 2. Frequency and severity of incidents by event

EVENT	# of cases	$ cost	Frequency (% cases)	Severity (% cost)
Fall from trusses	10	293,432	6%	31%
Sawcuts	11	128,793	6%	14%
Falls from roof	5	123,812	3%	13%
Falls at same level (trip)	16	84,866	9%	9%
Nail gun	30	72,266	17%	8%
Overexertion	20	65,324	11%	7%
Hammer	5	53,145	3%	6%
Splinter	7	32,789	4%	4%
Fall from ladder	6	23,211	3%	2%
Dropped material	5	16,664	3%	2%
Cut on gussets	9	16,309	5%	2%
Nail (stepped on/contact)	15	5,266	8%	1%
Struck by wall panel	9	5,039	5%	1%
Struck by falling material	6	4,678	3%	1%
Debris in eye	8	1,535	5%	0%
Other	15	5,626	8%	1%
ALL ACCIDENTS	**177**	**932,755**	**100%**	**100%**

Figure 1 illustrates the relative frequency and severity of the different incident events, and indicates the five incident events with the highest severity. These are: (1) Falls during truss installation, (2) Saw cuts, (3) Falls during roof sheeting, (4) Falls from same level, and (5) Nail gun injuries. The top three incident events account for 58% of the workers' comp costs in 2005.

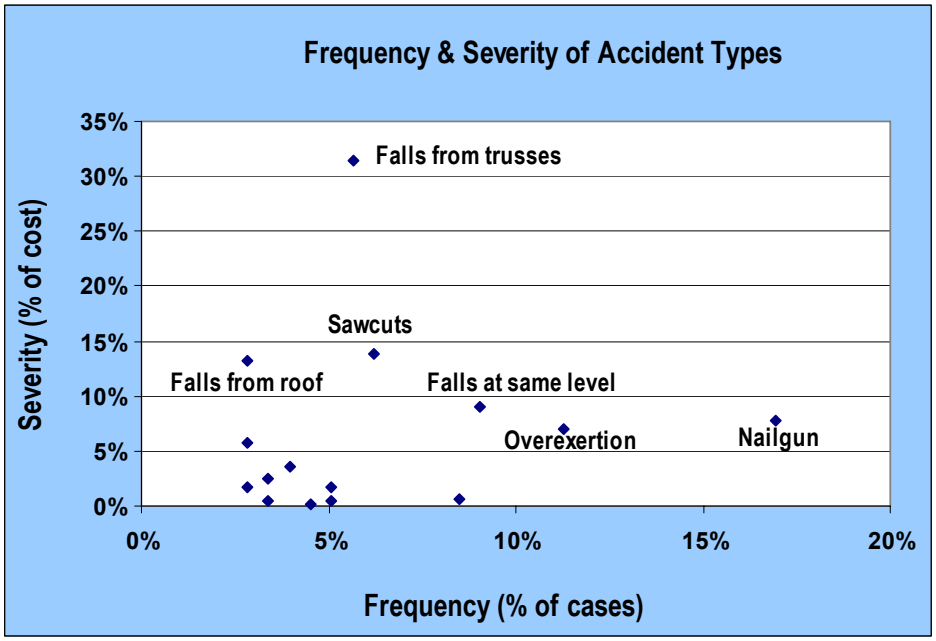

Figure 1. Frequency and severity of incident events.

Falls are 20% of the total incidents and account for 56% of the total workers' compensation costs. Falls during truss installation are only 6% of the total, but account for 31% of the total costs. Falls during roof sheeting are also severe, although less frequent. The 16 'falls at same level' include 10 falls on the ground, 4 falls on truss, and 2 falls on the roof.

Contact with Tool/Equipment/Material accounts for about 26% of all incidents. Of these, saw cuts have the highest total cost. The causes of saw cuts are examined in a later section. While splinters are an everyday occurrence, only seven cases were recordable incidents. In general, splinter incidents were of low severity, with the exception of one high cost case due to infection. Cuts on sharp edges (primarily gussets) accounted for 9 incidents and involved relatively low severity. Stepping on or inadvertently bumping into protruding nails was the cause of 15 recordable incidents, with low severity.

Struck by Tool/Equipment/Material accounts for 38% of the incidents and 17% of the workers' compensation costs. Nail gun injuries are the most common injuries (30 incidents), although not the most severe. For example, 26 of the 30 nailgun injuries cost less than $1,000, and only two incidents were more than $10,000. This category includes incidents such as hit by hammer (5 incidents, 2 of high cost), struck by material falling from higher level (6), material that the worker(s) dropped while handling (5), or wall panels dropped while lifting walls in place (9 incidents).

Overexertion (11 incidents) accounts for 15% of the incidents and 7% of the costs. They include sprains (mostly ankles and knees) and muscle strains (mostly back), primarily from material handling.

Figure 2 shows the distribution of incidents by cost category. As evidenced in the figure, 127 incidents had a cost less than $1,000 each (97 of them cost less than $500). In 2005, there were only two incidents over $50,000 (one fall from trusses, and one fall from roof).

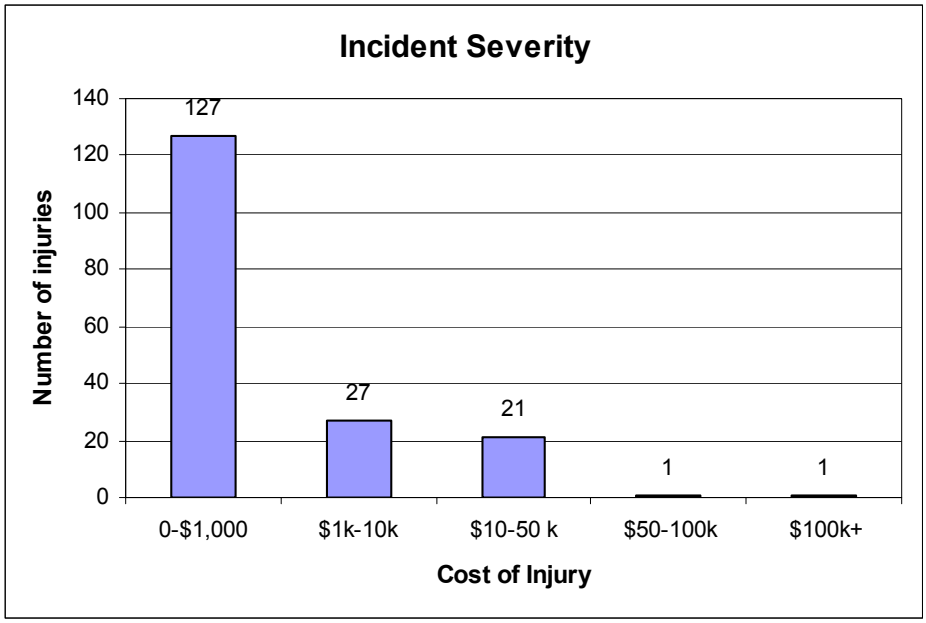

Figure 2. Distribution of incidents by severity (cost).

The first 5% of injuries (8 incidents) accounts for 49% of the costs. The second 5% accounts for 26% of the costs. Thus, the top 10% of the incidents (18 incidents) accounts for about $696,000, that is 75% of the total workers' compensation costs. The top 10% of the incidents (18 incidents) includes: 5 falls installing trusses, 2 falls during roof plywood installation, 3 saw cuts, 2 falls at same level, 2 'struck by hammer' injuries, one nail gun injury, one splinter, one overexertion and one fall from ladder.
The above analysis identifies the incidents with the highest cost, but in most cases not the specific activities related to the incidents. The following section examines the activities when incidents occur.

4. ANALYSIS OF INCIDENT BY ACTIVITY

The second step of the analysis examined the work activities during which incidents take place. Each incident was classified under the main activity and related task. For 39 incidents, the records did not identify the activity but only a subtask, for example, "nailing plywood" without specifying if it was for wall shear or roof sheathing. As listed previously, incidents were classified under five main activities:

- Site: load/unload material and equipment, cleanup site, remove nails.
- Walls (first or second floor) include framing, blocks, lifting, shear, top plate.
- Floor trusses (in case of a house more than 1 floors) include truss set up and sheeting
- Roof truss includes erecting the truss and framing the roof (install blocks, bracing, fascia, cut tails, etc.)
- Roof sheeting involves installing roof plywood.

Tables 3a and 3b summarize the number and severity of the incident events by main activity. Similar incident events occur during different activities. For example falls to lower level occur during truss and roof activities. However, the 'mechanism' of the incidents and the errors that lead to the loss of control are not necessarily the same—for example, some falls are a result of a worker stepping on an unsupported truss component, while others may result from slipping on the roof plywood. Furthermore, even very similar incidents (e.g., nail gun injuries) may have very different causes. In order to identify potential intervention that can prevent the incidents from occurring (rather than minimizing the consequences through protective equipment), the researchers examined the mechanisms and errors that contributed to the incidents.

Table 3.a Number of incidents by incident event and main activity.

MAIN ACTIVITY	Falls to lower level	Falls to same level	Falls from ladder	Saw cuts	Nail gun	Overexertion	Hammer	Splinter	Struck by material	Cut on gussets, etc	Nails	Struck by wall panel	Other	# of incidents
Site	-	4	-	-	-	2	2	-	6	-	2	-	-	16
Walls	-	2	2	2	16	14	2	3	2	2	3	8	2	58
Floor trusses	2	-	-	-	-	-	-	-	-	3	2	-	-	7
Frame Roof Trusses	8	4	1	2	4	5	1	2	2	5	1	-	-	35
Plywood roof	5	2	-	1	1	1	-	-	3	-	1	-	-	14
Activity not specified	-	3	3	6	8	5	-	2	1	1	6		8	43
Other		1			1					2				4
TOTAL	15	16	6	11	30	27	5	7	14	13	15	8	10	

Table 3.b. Cost of incidents by incident event and main activity (in $1,000)

	Type of Incident													
MAIN ACTIVITY	Falls to lowe level	Falls to sam level	Falls from ladder	Saw cuts	Nail gun	Overexertior	Hammer	Splinter	Struck by Material	Cut by gussets, etc	Nails	Struck by W panel	Other	Total $
Site	-	62.6	-	-	-	<1	1.4	-	16.7	-	<1	-	-	82
Walls	-	7.2	19.5	19.3	12	36	52	25	1.2	<1	<1	4.7	<1	177.7
Floor trusses	<1	-	-	-	-	-	-	-	-	1.3	1.4	-	-	3.4
Frame Roof Trusses	292.6	3.6	<1	22.4	1.7	2.6	<1	6.9	2	14.8	<1	-	-	346.2
Plywood roof	123.8	1.5	-	38.1	<1	<1	-	-	1.7	-	<1	-	-	166.2
Activity not specified	-	9.5	3.5	49	57	28	-	<1	2.1	1	2.4		1.7	154.7
Other		<1			1					1.2				2.7
TOTAL $	417.2	84.9	23.2	129	72	68	53	33	22.6	18.4	5.3	4.7	2	933

5. ERRORS AND ERROR PROOFING DIRECTIONS

The third part of the analysis investigated the most common errors and conditions that increase the likelihood of occurrence of incidents during the different framing tasks. The investigation was based on the incident records, and interviews with the safety director and QC manager. The errors related to the most severe injuries are discussed below.

Falls from trusses

The incident analysis indicated 14 falls from trusses: 10 falls to the ground, and 4 falls to the same level. The task with the highest fall risk was truss installation and the most common errors related to such falls are the following:

Truss erection/positioning the truss. This task requires dynamic coordination of a heavy component (pulling-pushing and directing the truss). Excessive pulling by any member of the crew may pull the truss off the support, and cause the workers to be off balance. Furthermore, the truss design influences the difficulty of the task—for example, 'bullnose' trusses require more careful handling and coordination.

Overextending is an error that can lead to a fall during truss erection, or other tasks. Installing fascia is a task that requires coordination (two crew members), and handling a heavy beam over the edge of the roof.

Cutting tails (protruding parts of the truss) is another activity with increased risk of falling, as it involves work at the edge of the trusses and the use of a power tool. A common error is stepping on an unsecured component. This task also poses increased risk of a saw cut injury due to the awkward position of the worker when performing the task.

Unsecured components. Stepping on unsecured truss components (along with failure to realize that the truss component is not secured) are a common cause of falls. In one fall, the hanger supporting a truss came off, while in another incident, the brace on the ridge (where the lead worker was sitting) came off.

Naturally, the likelihood of these mistakes increases with rushing and inexperience. Typically, these tasks are performed by the more experienced crew members.
Error proofing interventions should focus on:

- reduce the difficulties of positioning the trusses,
- prevent stepping on unsecured components, and
- prevent workers from overextending when working near the edge of the roof.

Falls from roof (during sheeting)

The incident descriptions indicated that 'tripping' was involved in all cases, but did not provide any more information. According to the experts, overextension, slipping on the roof and stepping or tripping on unsecured plywood are three common errors associated with falls from roofs.

Wind can also lead to loss of control while carrying plywood. Installing the first row of plywood near the edge of the roof is quite risky—some foremen allow only their

most experienced carpenters to work on this task. Material handling also involves significant risks, due to reduced visibility and increased slipping hazards.

Cutting the plywood on the roof generates saw dust that creates slippery conditions. Wearing shoes that minimize the likelihood of slipping is important, and that is why framers typically wear snickers rather than work boots.

Rushing while handling large pieces of plywood on a sloped roof increases the likelihood of errors.

Potential error proofing interventions can target the following:

- prevent loose plywood (or stepping on loose plywood) on the roof.
- reduce cutting on the roof to avoid creating more slippery conditions
- provide warnings regarding slippery conditions

Saw cuts

Tasks that involve cutting in awkward positions have greater potential for error. Such tasks include cutting notches on studs, cutting truss tails, ripping boards and cutting plywood. In these activities, it is more difficult to maintain control of the tool, and more likely that the saw may bind and kick back. Using a dull blade increases the possibility of the saw kicking back. Another error is placing hands too close to the saw, where a small slip or loss of control can bring the body part in contact with the blade. Six of the 11 saw cut injuries resulted from the saw kicking back (the other 5 cases did not provide sufficient information for analysis). The power of the saw makes it difficult to control when it kicks back.

Potential intervention to prevent saw cuts may include:

- minimize the amount of cuttig at awkward positions and locations
- reduce the power of the saw to increase the ability to maintain control when it kicks back.
- use sensors and automatic shutoffs when a dull blade is used.
- use sensors and automatic shutoffs when the saw kicks back.

Nail gun injuries

Nail gun injuries are typically of low cost, but relatively frequent. From the list of incidents and the interviews, the researchers identified the following different errors.

- Nail bounces on hard material (knot, another nail, metal strap)
- Accidental discharge due to tool operation: e.g., shooting a second nail on the re-load
- Accidental discharge caused by the worker, e.g., walking with the finger on the trigger
- Nailing errors: nail is fired in the wrong direction, in combination with hand position. Sometimes nails break through the wood and puncture the worker who might be positioning the wood with the free hand.

Ten of the 30 nail gun injuries occurred within the first 3 months of employment, and 22 of the 30 injuries happened within 1 year of employment.

Error-proofing intervention should focus on the following:

- prevent accidental discharge.

- prevent accidental triggering of the nail gun.
- avoid nailing on hard surfaces

Falls at same level

This category includes10 falls at ground level, 2 falls on a roof, and 4 on a truss. The most common error in falls at ground level is tripping. In 5 of the 10 cases, a load was being carried when the worker tripped. Tripping is also the main cause for sprains. Of the 11 injuries involving sprains (mostly ankle and knee), 9 cases were caused by tripping.

The falls at ground level indicate a failure in the interaction between worker and work area and they are influenced by two major factors: (1) the condition of the work area, and (2) the worker's awareness, which is often reduced due to the task (handling material) or rushing. The worker's experience appears to make a difference: 6 of the 16 falls at the same level occurred within the first 3 months of employment, and 11 of the 16 incidents were sustained by workers with less than 1 year of employment. Prevention of falls at the same level requires reducing the tripping hazards or increasing each worker's ability to detect the hazards, e.g., make the material handling task less difficult).

6. SUMMARY AND CONCLUSIONS

The goal of this research was to identify specific errors that lead to incidents in residential framing. The examination of the 177 incidents found that the incidents with the highest severity are falls from trusses, falls from roof, saw cuts, nail gun incidents and falls at same level. The analysis of each type of accident identified the tasks where such events occur and the most common errors that produce them, as well as some task characteristics and conditions that increased the likelihood of errors. The identification of the errors points out directions for interventions to prevent these accidents. Finally, the study proposes an improved system of collecting information about accidents, one that tracks the production tasks and errors that lead to the accidents. The next phase of this research will include the following:

- Analysis of more framing accidents, as this study has only considered the injuries experienced by the employees of one company in one year.
- Collection of input from production personnel (foremen) to understand in more depth the errors and the task conditions affecting the likelihood of errors, and to understand strategies that crews use to reduce the risks on particularly high-risk tasks.
- Identification and evaluation of potential interventions to prevent accidents. Error-proofing interventions can aim at the following issues:
    - reduce the complexity of the product, or work process or
    - block or detect the errors at a point in the process where they are easier to be blocked or detected

Finally, another long-term goal of this research path is the development of a typology of errors that will assist with systematic identification of interventions that can prevent the occurrence of errors.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

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