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THE IMPACT OF ALCOHOL USE ON CONSTRUCTION SAFETY OUTCOMES: AN AGENT-BASED MODELING INVESTIGATION

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ABSTRACT

Construction is a notoriously hazardous industry and heavy alcohol use is common. This project created an agent-based modeling (ABM) simulation to explore the impact of alcohol on safety outcomes. Simulation modeling is useful in occupational safety research because it generates immediate results and bypasses ethical concerns. In this project, workers and foremen interacted on a virtual jobsite with hazards present, where positive blood alcohol concentration (BAC) decreased hazard awareness, reaction time, and foreman competency. Three scenarios of baseline, increased, and decreased alcohol consumption were analyzed for changes in near misses, injuries, and fatalities. Additional scenarios of improved training and engineering controls were explored also for comparison. Simulation results show that a decrease in alcohol consumption leads to a significant reduction in injuries by up to 12%, and an increase has the opposite effect. Neither of the scenarios significantly impact fatalities due to fatalities' low base rate. Safety training has a comparable impact but improving engineering controls outweighed both.

1 INTRODUCTION AND BACKGROUND

Construction consistently ranks as one of the deadliest occupations (BLS 2021a). Therefore, safety is a crucial concern in the industry. Alcohol and substance use is common in the industry and a known contributor to safety risks. Yet, it remains under-addressed. In general occupational safety practice is shifting focus towards human factors components of safety, since traditional approaches are reaching their limit in their ability to improve safety outcomes, and substance use is an important such human factors component. This project uses agent-based modeling (ABM) to study the impacts of alcohol use on construction safety outcomes, the first known study to do so. It is hoped that this project will draw more awareness to this sensitive issue, helping to change the culture surrounding substance use and contribute to the growing awareness of under-explored aspects of safety performance.

1.1 Alcohol Use in Construction

Heavy alcohol use as defined by the National Survey on Drug Use and Health (NSDUH) is more prevalent in the construction industry than any other industry besides mining (Bush and Lipari 2016). In a recent survey of construction workers in the United Kingdom, 35% said they noticed co-workers under the influence at work and 59% agreed that alcohol and substance misuse was a “huge problem” in the industry (Flannery et al. 2021). In a sample of construction workers in Australia, 66% reported harmful drinking patterns as characterized by the Alcohol Use Disorders Identification Test (AUDIT), with 36% reporting 10 or more drinks at a time “on a regular basis” (du Plessis et al. 2013). Reasons for heavy alcohol use in the industry may include stress from productivity demands, physical pain and discomfort, onerous and

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irregular schedules, a culture of machismo, and general acceptance of the behavior (Sarwicki and Szostak 2020; Roche et al. 2020).

Construction is one of the most dangerous industries, comprising 18% of occupational fatalities in the United States in 2021, second only to the transportation industry (BLS 2021b). In fact, of the fifteen “deadliest” jobs in the US, five are construction occupations (Hoff 2022). Yet despite comprehensive Occupational Safety and Health Administration (OSHA) laws and an abundance of research on the topic, improvement in construction safety has stalled. There have been no improvements in fatality rates over the past ten years (BLS 2021a) and total recordable incident rates have remained virtually unchanged since 2017 (BLS 2022). Safety practitioners have begun to identify cognitive states such as fatigue, rushing, and stress as important contributors to safety outcomes that have hitherto been neglected. Practitioners are starting to propose that such human factors components represent the “next safety frontier” (Robb 2020) including alcohol and substance use. Alcohol use results in disorientation, lack of caution, vision deterioration, high error rates, difficulty navigating, increased perceived mental workload, reduced attention and alertness, and impaired psychomotor performance (Kim et al. 2007; Newman 2004) all contributors to safety incidents (Gordon 1998). Furthermore, most people are not able to detect the degree of their performance impairment due to alcohol.

1.2 Agent-Based Modeling in Construction Safety Research

Agent-based modeling (AMB) and other modeling techniques have been used extensively in construction productivity and resource planning applications since the 1960s (Abdelmegid et al 2022). The industry has created its own simulation applications including CYCLONE, MicroCYCLONE, Simphony, RESQUE, INSIGHT, AP2-Earth, and CSD, and has also used discrete event simulation, finite element simulation, Monte-Carlo simulation, ABM, and system dynamics (SD). The utility in simulation for construction lies in its ability to generate immediate insights without having to wait for real-world data to accumulate, and in its ability to conduct controlled experiments, which can be extraordinarily difficult to do in a real construction environment. In the last decade interest has turned to applying simulation to construction safety research as well. Simulation is an especially powerful tool in occupational safety research. It allows researchers substantial leverage to manipulate a controlled environment, something that is exceedingly difficult to do in the field. Furthermore there are severe concerns with conducting controlled experiments in safety because it is unethical to knowingly put a worker in an unsafe or less safe situation. Therefore, researchers mostly rely on observational data instead. However, real-world observational data takes time to accumulate, time in which workers could be getting hurt. Modeling can help overcome the ethical issues surrounding safety research and meet the need for timely results.

Previous literature on ABM in construction safety has focused primarily on social and cognitive aspects of safety. It is widely recognized that safety culture plays a substantial role in improving safety outcomes but defining safety culture proves challenging and improving culture even more so (Bisbey et al. 2021). The interactive nature of ABM allows researchers to model the day-to-day social interactions and decisions that when aggregated comprise the worksite culture. In this context, social support (Ji et al. 2019), management interactions (Choi and Lee 2017), behavioral norms (Ye et al. 2020), influence of attitudes on behavior (Xu et al. 2023), and management practices (Zhang et al. 2019) have been investigated. Hybrid approaches combining ABM with SD have also been used (Nasirzadeh et al 2018; Liang et al. 2018). In addition, the impact of interventions such as increases in fines and insurance premiums (Awwad 2017) and cash investments in safety (Lu et al. 2016) have also been studied. The team that created the first and simplest ABM in construction safety (Sawhney et al. 2003; Palaniappan et al. 2007) suggested that ABM could be used to account for the human factors such as fatigue, poor sleep, stress, and skill that will constitute the next advancements in safety. They further suggested that ABM would be appropriate for study the impacts of alcohol use on safety outcomes, yet no ABM study has yet done so – until now. To the best of our knowledge, this study will be the first to model the sociocognitive aspects of alcohol use in construction safety.

The model will simulate a work environment that contains a certain degree of fall hazards on each grid. Worker and foremen agents will have the attributes of hazard awareness and reaction time, and foremen will additionally have the attribute competence. All factors may be impacted by blood alcohol concentration (BAC). Outcomes of near misses, OSHA recordables (injuries), and fatalities will be examined in different distributions of BAC, using a baseline distribution found in the literature as the control condition. All other parameters will be directly taken from or estimated based on the academic literature as well.

2 METHODS

2.1 Environment

This project recreates a worksite employing structural steel workers. The steel trade was chosen because it is the deadliest construction trade behind roofers (BLS 2021b), and because the worksite, type of work, and hazards encountered are fairly homogeneous, meaning that simplifying assumptions can be made in model development without compromising the model's external validity. The hazards represented by this model are fall hazards because fall hazards are overwhelmingly the primary hazard in this trade and because they are present to the same or a very similar degree at each story of a multi-story project. The model is a 150m-by-200m grid representing the total square footage of steel to frame in a large 4-story building. The environment was simplified to a single-story model because the fall hazards and amount of work encountered in the ironwork trade are consistent story to story. Each $1m^2$ grid contains a work score representing the amount of steel to be placed in that grid, a hazard score representing the degree of fall hazard, and a reaction time score representing the required time for the agent to safely navigate the hazard present on the grid. Hazard score is normally distributed with a mean of 40 and a standard deviation of 5, reaction time required is fixed at 1.5 seconds, and work score is fixed at 0.45 tons/m^2, the average density of steel per square meter (AISC 2014). Each simulation tick represents one hour of work and the model is run until all of the work on each grid in the environment is complete.

2.2 Agents and Attributes

There are 100 worker agents and 10 foremen agents, a commonly encountered ratio (Zhang et al. 2019). Worker and foremen attributes include work pace, reaction time, and hazard recognition, with foremen agents have an additional attribute of competency. Work pace is uniform at 0.15 tons/hr (AISC 2014). Initial reaction time is normally distributed with a mean of 1.5 seconds and a standard deviation of 0.18 seconds (Mulder et al. 2004). Initial hazard recognition is based on worker's ability to recognize gravity hazards in a controlled setting, which is 60.13% (Uddin et al. 2020). The standard deviation was reduced from 27.3% to 14% during calibration to bring more consistency to the model. Using findings that suggest that the ratio of safe to unsafe behavior is about 0.34, the grid hazard score was set with a mean that resulted in agent's hazard awareness falling below the hazard present (and triggering unsafe behavior) about 34% of the time (Ye et al. 2020, Choi and Lee 2018). For foremen, initial competency was set with a mean of 4.2 and a standard deviation of 1.12. These values are based on findings of competency ratings for construction foremen on a 7-point Likert scale among various domains such as attentiveness, managing conflict, and social awareness (Maqbool et al. 2017). The same study demonstrated an association between foreman competency and project success of 0.675. Since this project is interested in safety success, the range of influence foremen could have over worker's hazard awareness was set to 67.5%. Foremen indeed are the frontline leaders that create the safety climate in the workplace, which then directly impact worker's capability, willingness, and proclivity to behave safety (Goldenhar et al. 2019).

Blood alcohol content was randomly assigned to workers and foremen from a distribution based on a study of BAC tests given to 100 Portuguese construction workers in the afternoon (Arezes and Bizarro 2011). In the study, 33 workers registered a positive BAC ranging from 0.01 (very slightly impaired) to 0.08 (legally intoxicated in the United States). Of those 33 who tested positive, 20 had BAC in the range associated with hangovers (0.01-0.04) (PsychDB 2022; Verster et al. 2010). The BAC then influenced reaction time, hazard recognition, and competency. In the case of a BAC of 0.00 – 0.02, the initial values for these attributes were left in place. For a BAC above 0.02, reaction time was reduced by 2% for every 10% increase in BAC over 0.01 (Christoforou et al. 2013). For a BAC above 0.05, hazard recognition was reduced by 41% (Pihl et al. 2003). Foremen competency was reduced by 41% for BAC between 0.05 and 0.08 and by 65% for BAC over 0.08 (Pihl et al. 2003).

2.3 Movement and Rules

Worker and foremen agents work and move through the environment while encountering fall hazards. Foremen agents additionally supervise, impacting workers around them. At each tick, each agent conducts one unit of work at their constant work pace. When the work score of the grid the agent is on has decreased to 0.15, the worker finishes the work on the grid and then moves to a nearby grid which has a positive work score. No more than one agent can occupy one grid at a time, and all work is completed on each grid before moving on to the next one. At each tick, each foreman supervises the nearest 7 workers around them. The supervision has either a positive, neutral, or negative influence on the worker's hazard awareness based on the foreman's competency, and this influence lasts for 6 ticks before hazard awareness returns to normal. These values were assumed based on author experience in the field. The threshold for a negative influence is 4.0 and for positive influence is 4.4 and the magnitude of increase or decrease of surrounding workers ranges from -33% to 33%, encompassing the 67% influence described in Maqbool et al. (2017).

At each tick, worker and foremen agents encounter a hazard which is the value of the hazard score of the grid they begin the tick on. If the agent's hazard recognition level or reaction time are below the grid's hazard score, a potentially unsafe behavior is incurred and an incident probability function is triggered. The worker may suffer a fatality, an OSHA recordable incident (injury), a near miss, or nothing. If a near miss or nothing occurs, the worker continues on with work and the foreman continues on with work and supervising. If an OSHA recordable occurs, the agent is removed from the simulation for 9.4 days, the average amount of time spent away from work for a lost time recordable in the steel trade in 2020 (BLS 2021e). If a fatality occurs, the agent is removed from the simulation. In the case of recordables and near misses, the agent experiences a permanent increase in hazard recognition. The permanent increase for a recordable is 23% and the permanent increase for a near miss is 16% based on a study of personal injury impact on safety attitude (Beus et al. 2010). At each tick, a separate incident function is triggered regardless of the agent's hazard awareness level or reaction time. This function represents hazards from the environment that are beyond the worker's control and are present to the same degree for every worker. The probability of incurring an adverse outcome from the background incident function is much smaller than that of the unsafe behavior function – traditionally only about 2% of all accidents have been attributed to inevitability and considered unavoidable (Heinrich 1941). Furthermore, when an agent incurs a fatality, recordable, or near miss, the nearest 3 agents in the vicinity also trigger a secondary incident function to represent the likelihood that other agents may be impacted by the accident. Approximately 24% of incidents occur as the result of a different worker's actions (Winge et al. 2019).

NetLogo version 6.3.0 was used for the modeling (Wilensky 1999). After completion of each simulated project, agent attributes were reallocated based on a new random distribution and a new project automatically commenced. After 10 replications of project generation, a new series of ten projects was generated for a total of 50 simulations per experiment.

2.4 Calibration

The model was calibrated by adjusting the probabilities in each of the incident functions to generate fatality, recordable, and near miss rates that correspond with well-established surveillance data. In the steel trade, there were 0.361 fatalities per 100 full-time equivalent (FTE) employees (BLS 2021c). There were 3.0 OSHA recordables per 100 FTE in the same year (BLS 2021d). The ratio of near misses to recordables has been determined to be approximately 100 to 1 (Ye et al. 2020, Choi and Lee 2018). These rates were converted into expected incidents per tick (hour) on the 110-person worksite in Table 1, which lists the calibration results. In addition, the ratio of secondary (caused by a nearby worker's unsafe behavior) to primary (incurred by the worker performing the unsafe behavior themselves) were compared to those in Winge et al. (2019), as well as the ratio of incidents deemed to be preventable versus background inevitable incidents. These comparisons were performed to ensure that, in addition to the probabilities generating an overall accurate incident profile, the relative probabilities present for each of the three incident function types were also consistent with observed data.

Table 1: Calibration results.

Outcome	**Literature**	**Model μ**	**Model σ^2**	**Units**
Fatality Rate	0.00002	0.00008	0.00006	Per tick
Recordable Rate	0.0017	0.0074	0.0005	Per tick
Near Miss Rate	0.165	0.176	0.004	Per tick
Secondary Incidents	33	32.1	0.9	% of Direct
Background Incidents	2.0	1.4	0.2	% of Total

2.5 Proposed Experiments

Interventions to reduce alcohol and other substance use in construction have centered primarily on educational initiatives and promotions (Yuvaraj et al. 2019; Ames and Bennett 2011). Instituting random drug and alcohol testing is also a popular intervention but it has mixed evidence of effectiveness (Els et al. 2020) due to methodological inconsistencies such as instituting both random testing and a promotional campaign at the same time (Gomez-Recasens 2018). Unfortunately, the evidence of effectiveness of interventions has been reported in terms of accident reductions (Pidd and Roche 2014) rather than in terms of reduction of actual substance use. Given the lack of reliable data on the impact of interventions on actual use, this project will model interventions in terms of theoretical reductions in alcohol use: a reduction in the total number of workers testing positive for BAC and a reduction in the severity of BAC. The first will eliminate by half the number of workers who tested positive for BAC at each concentration level in the sample distribution (Arezes and Szostak 2020) and the second will reduce by half the measured BAC at each concentration level in the sample distribution. In each, the distribution of these new sample values will be obtained and agents in the simulation will be assigned a random BAC based on the new distributions. A zero-alcohol use condition will also be tested. In addition, increase in alcohol use will be tested by first increasing the severity of BAC by doubling the measured BAC at each concentration level, and then doubling measured BAC at each concentration level in the sample distribution. A condition featuring both increases will also be tested. Furthermore, the effectiveness of two other interventions will be considered: safety training and engineering controls. Safety training will be modeled via increases in agent's baseline hazard awareness and reaction time, and engineering controls will be modeled via first a decrease in hazard probabilities in each hazard function and then a decrease in each grid's hazard score. Examples of engineering controls for fall hazards can include schedule and design strategies to ensure that full flooring framing is installed before next story work begins, erecting scaffolding or guardrails, or the use of man buckets. These interventions will be run using the baseline BAC distribution from the literature. The purpose of testing the other interventions is to compare their effectiveness to the intervention of reducing alcohol use. The outcomes compared will be near miss rate, OSHA recordable rate, and fatality rate. Table 2 describes the baseline BAC distribution and Table 3 summarizes the experiments.

Table 2: Initial BAC distribution (Arezes and Bizarro 2011).

BAC	Number of Workers	Approximate Impact
0.00	67	None
0.01	7	Slight
0.02	4	
0.03	6	
0.04	3	End of hangover range
0.05	6	1+ drinks, mildly impaired
0.06	3	
0.07	3	
0.08	1	Intoxicated, DUI/DWI threshold

Table 3: Experimental scenarios.

Scenario	Description
Baseline	No change to initial BAC distribution
Decrease Number	Half the number of workers at each BAC
Decrease Severity	Half the magnitude of each BAC
Zero Alcohol	All BAC = 0.00
Increase Number	Double the number of workers at each BAC
Increase Severity	Double the magnitude of each BAC
Increase Both	Double both the number and magnitude of each BAC
Safety Training	Improve agent's hazard recognition by 10, competency by 1.0, reaction time by 0.10 sec
Engineering Controls: Hazard Probability	Reduce underlying probabilities in each incident function by 33%
Engineering Controls: Environmental	Reduce each grid's hazard score by 5 and increase reaction time required by 0.70 sec

3 RESULTS

3.1 Impact of Change in BAC Distribution

Of the three scenarios modeling decreases in alcohol use, all three scenarios – the decrease in number of positive BAC, decrease in severity of positive BAC, and the zero-alcohol condition – yielded statistically significant decreases in OSHA recordable rates at the 95% confidence level, incurring on average 1.0, 0.7, and 2.1 fewer incidents respectively per year for the model worksite. All three scenarios resulted in statistically significant decreases in near misses, and no statistically significant decrease in fatalities. Table 4 presents the results for the decrease in use scenarios.

Of the three scenarios modeling increases in alcohol use, all three scenarios – increase in number of positive BAC, increase in severity of positive BAC, and both – resulted in statistically significant increases in OSHA recordable rates, incurring on average 1.1, 1.2 and 3.5 excess incidents respectively per year for the model worksite. All three scenarios resulted in statistically significant increases in near misses, and no statistically significant increases in fatalities. Table 5 presents the results for the increase in use scenarios. Although the increase in number scenario yielded outcomes in the opposite direction as expected, the p-values were not significant and indeed higher than the p-values for the other scenarios, implying no true change from the baseline scenario.

Table 6 describes the change to percentage of agents incurring an adverse outcome who have a positive BAC, the change in percentage of incidents involving supervisory influence, and change to percentage of adverse outcomes incurred by someone nearby the agent exhibiting unsafe behavior. This number excludes unpreventable incidents. In the zero-alcohol scenario, both supervisor-related incidents and secondary incidents were statistically significantly lower than the baseline scenario, and in the increased use scenario both aspects were statistically significantly higher.

Table 4: Results for decrease in BAC.

	Fatalities			Recordable Incidents			Near Misses		
	p-value	**Average Rate[a]**	**Average/ Year[b]**	**p-value**	**Average Rate[a]**	**Average/ Year[b]**	**p-value**	**Average Rate[a]**	**Average/ Year[b]**
Baseline		$5.9x10^{-4}$	0.15		0.0070	17.5		0.151	378
Dec. Number	0.258	$5.1x10^{-4}$	0.13	0.024	0.0066	16.5	0.001	0.146	365
Dec. Severity	0.303	$5.3x10^{-4}$	0.13	0.079	0.0067	16.8	0.004	0.147	368
Zero BAC	0.386	$5.5x10^{-4}$	0.14	0.015	0.0061	15.4	0.000	0.137	342

[a] per tick; [b] average incidents per year for the modeled worksite

Table 5: Results for increase in BAC.

	Fatalities			Recordable Incidents			Near Misses		
	p-value	**Average Rate[a]**	**Average/ Year[b]**	**p-value**	**Average Rate[a]**	**Average/ Year[b]**	**p-value**	**Average Rate[a]**	**Average/ Year[b]**
Baseline		$5.9x10^{-4}$	0.15		0.0070	17.5		0.151	378
Inc. Number	0.186	$4.6x10^{-4}$	0.11	0.010	0.0074	18.6	0.000	0.161	401
Inc. Severity	0.136	$7.6x10^{-4}$	0.19	0.017	0.0075	18.7	0.000	0.162	405
Inc. Both	0.161	$7.9x10^{-4}$	0.20	0.000	0.0084	21.0	0.000	0.180	450

[a] per tick; [b] average incidents per year for the modeled worksite

Table 6: Changes to scenarios.

	Outcomes Positive[a]	**p-value**	**Supervisory[b]**	**p-value**	**Secondary Rate[c]**	**p-value**
Baseline	30.3%		14.1%		0.058	
Zero BAC	0.0%	0.000	10.6%	0.000	0.051	0.000
Inc. Both	68.2%	0.000	18.6%	0.000	0.068	0.011

[a] fatalities, incidents, or near misses incurring a positive BAC; [b] incidents where supervision was a factor; [c] incidents rate per tick of fatalities, incidents, or near misses on surrounding workers

3.2 Impact of Improving Attributes – Safety Training

Safety training was modeled by improving agent attributes of competency, reaction time, and hazard awareness. Foremen competency was increased at the baseline by 1.0, and the impact of positive BAC on the deterioration of competency was reduced by 0.80 at each level. Worker reaction time was decreased by 0.10 seconds in baseline and in each change with BAC level. Baseline hazard recognition was increased by 10. The results were statistically significant for OSHA recordables and near misses, and approached significance to a greater degree than the alcohol scenarios for fatalities. The magnitude of decrease in recordables was comparable to that of the zero-alcohol scenario, but the magnitude of the decrease in fatalities was greater. Table 7 presents the results.

Table 7: Results for improving agent attributes – safety training.

	Fatalities			**Recordable Incidents**			**Near Misses**		
	p-value	**Average Rate[a]**	**Average/ Year[b]**	**p-value**	**Average Rate[a]**	**Average/ Year[b]**	**p-value**	**Average Rate[a]**	**Average/ Year[b]**
Baseline		$5.9\text{x}10^{-4}$	0.15		0.0070	17.5		0.151	378
Base Rate Dec.	0.061	$3.0\text{x}10^{-4}$	0.075	0.000	0.0061	15.3	0.000	0.130	325

[a] per tick; [b] average incidents per year for the modeled worksite

3.3 Impact of Base Rate Changes – Engineering Controls

A change due to engineering controls was approximated by reducing the underlying adverse outcome probabilities. To this end, the probabilities imbedded in each hazard function (unsafe work, secondary incident, and environmental incident) were all reduced by 33%. Table 8 shows that the magnitude of decrease in fatalities, OSHA recordables, and near misses was greater than for all other scenarios testing in this project, and the only scenario resulting in statistically significant decrease in fatalities.

Table 8: Results for baseline probability improvements.

	Fatalities			**Recordable Incidents**			**Near Misses**		
	p-value	**Average Rate[a]**	**Average/ Year[b]**	**p-value**	**Average Rate[a]**	**Average/ Year[b]**	**p-value**	**Average Rate[a]**	**Average/ Year[b]**
Baseline		$5.9\text{x}10^{-4}$	0.15		0.0070	17.5		0.151	378
Base Rate Dec.	0.020	$2.2\text{x}10^{-4}$	0.06	0.000	0.0043	10.8	0.000	0.092	229

[a] per tick; [b] average incidents per year for the modeled worksite

3.4 Impact of Environmental Changes – Engineering Controls

Finally, the grid properties were improved to represent a change in environment. The patch hazard score was reduced to 35 and the reaction required was increased to 2.2 seconds. Table 9 shows that both OSHA recordables and near misses decreased by a statistically significant amount, and fatalities declined as well. The degree of decline was greater than for the decrease in alcohol use scenarios but not as great for the change in base rate probability scenario.

Table 9: Results for environmental improvements.

	Fatalities			Recordable Incidents			Near Misses		
	p-value	**Average Rate[a]**	**Average/ Year[b]**	**p-value**	**Average Rate[a]**	**Average/ Year[b]**	**p-value**	**Average Ratea**	**Average/ Year[b]**
Baseline		5.9×10^{-4}	0.15		0.0070	17.5		0.151	378
Env. Impr.	0.159	3.8×10^{-4}	0.10	0.000	0.0054	13.5	0.000	0.124	311

[a] per tick; [b] average incidents per year for the modeled worksite

3.5 Discussion

Reducing the frequency of alcohol consumption and eliminating alcohol consumption in this model reduced OSHA recordable incidents and near misses at the 95% confidence level, and reducing the severity reduced both at the 90% confidence level. Increasing consumption had the opposite impact. The magnitude of the decrease due to less alcohol consumption was in the range of 1-2 fewer OSHA recordables per year or about 6-12%. The magnitude of the increase due to more alcohol consumptions was in the range 1-3 greater OSHA recordables per year or about 6-20%. The impact of improving agent attributes of competency, hazard awareness, and reaction time, intended to approximate safety training, had an almost identical impact on OSHA recordables and a greater impact on fatalities (although the p-value was 0.061) as reducing alcohol consumption. However, changes in the inherent hazards present due to engineering controls, modeled as improvements in grid properties or reductions in base rates, had a greater reduction in adverse outcomes than reducing alcohol consumption or training. This suggests that engineering improvements to the actual work environment may be more helpful than changes to the human behavioral components, and that eliminating alcohol consumption from the worksite is as impactful as safety training.

Neither increasing nor decreasing alcohol consumption had a significant impact on fatalities, although the direction of change in fatalities was in the expected direction in every scenario but one. The difficulty in impacting fatalities is the result of their very low frequency compared to the other outcomes. This reflects the phenomenon observed in reality, where despite many improvements in worksite safety fatality rates have barely budged in the past ten years. Of the three non-alcohol interventions tested, only one resulted in statistically significant decrease in fatalities. This suggests that to improve fatalities, substantial and multi-faceted interventions are warranted, and more scenarios should be explored.

The study entails several limitations. As a simulation it of course represents an approximation to reality. While parameters were carefully selected from peer-reviewed evidence, any compromise in external validity in any of the studies utilized or any compromise entailed by combining studies necessarily compromises the external validity of the model. The impact of specific interventions to reduce alcohol consumption could not be modeled due to lack of data on how these interventions change actual use as measured by BAC at work. Therefore the impact of safety training and engineering interventions is approximate since the magnitude of the changes was based on estimation rather than data from the literature. The calibration, rules, and environment design were intended to obtain results approximately correlated to the steel framing trade, but any deviations render specific results, such as the 12% reduction in OSHA recordables, as estimates and specific to the hypothetical project modeled. In addition, the model was only able to capture whether or not an injury occurred. It did not capture the severity of the injury. Finally, the study did not capture the hangover effect, which is intertwined with yet distinct from BAC. The hangover effect persists after alcohol has left the bloodstream and entails fatigue, reduced physical ability and poor concentration (Verster et al. 2010). If the model was able to capture the hangover effect in addition to simple BAC, the magnitude of the changes in safety outcomes would likely be greater. The levels of BAC found in the sample from the literature suggest that most of the workers who tested for a positive BAC were likely impacted by the hangover effect.

4 CONCLUSIONS

An agent-based simulation model was constructed to explore the impact of alcohol consumption on construction safety outcomes. A model worksite intended to represent steel framing construction of a large building contained fall hazards which worker and foremen agents navigated as they worked. Blood alcohol concentration impacted the agent's hazard awareness and reaction time, and impacted competency for foremen. Foremen with exceptional competency increased the hazard recognition of workers around them, and foremen with poor competency had the opposite impact. If hazard recognition or reaction time fell below that required to navigate the fall hazard, the probability of an adverse outcome was triggered, with additional probability of impacting agents in the immediate area and a small unavoidable hazard probability was encountered every tick as well. Decreasing the number of agents impacted by alcohol, decreasing the severity of BAC, and having zero alcohol all improved OSHA recordable and near miss rates, including adverse outcomes for surrounding workers. Increasing alcohol consumption had the opposite impact, and in addition increased adverse outcomes even for surrounding workers who were not using alcohol. The influence of foremen interactions on these changes was significant, suggesting that supervision plays a significant role as a mechanism for the impact of alcohol use. Increasing agent's baseline hazard recognition and hazard awareness levels, intended to approximate safety training, had a similar impact on OSHA recordables as reducing alcohol consumption. However, improving the environment itself in the form of less severe hazards and less severe probabilities of adverse outcomes had the greatest impact, suggesting that engineering controls can play a crucial role in improving safety and should be deployed as much as possible in conjunction with the human behavioral interventions.

It is hoped that this analysis will draw attention to the issue of alcohol consumption in the construction industry and illustrate that eliminating alcohol from the worksite is significantly beneficial according to this model. In fact, eliminating alcohol from the worksite proved as beneficial as safety training in reducing injuries. It is also hoped that the revelations about the importance of hazard management from an engineering perspective will prompt renewed commitment to design, scheduling, and procedural considerations that can reduce inherent hazards. Finally, the difficulty of reducing fatalities due to their low base rate is highlighted, suggesting that to move beyond the industry's stagnation in fatality reductions more multi-faceted and aggressive measures are warranted. Future research should incorporate the effect of hangover in addition to the direct effect of alcohol. Future work could also model the interaction of alcohol on various hazard types, and could incorporate alcohol's impact on more variables such as social interactions or pace of work. Finally, field research should obtain more samples of BAC among construction workers at work and refine results regarding the effectiveness of drug and alcohol testing on use and outcomes.

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