Abstract—This study introduces a simple agent-based model of stress in the workplace. Agents are described by time allocation to a base job, a special project, and time spent resting. Agent training is the inaccurate imitation of high productivity colleagues. The relative worth of the base job and special project vary stochastically, representing shifting management priorities. Stress is accumulated by working long days and has a negative impact on productivity. The impact of covert drug use, implemented as abnormally high stress tolerance, is investigated as a form of proactive management encouraging workers to work longer hours. It is found that choosing the training cohort for low-performing and new workers to be other than the highest performers reduces overall productivity but also ameliorates the impact of having drug users training non-drug users toward unrealistic performance levels. Proactive management is found to have a small impact on productivity but sharply increases the number of low-performance related firings.

I. INTRODUCTION

STRESS and stress-related productivity loss is a significant problem in the workplace. The welfare of individual employees impacts the performance of the employer company and the overall development of the employees country [10]. The hypotheses developed and features encoded in this study are partially informed by previous quantitative and qualitative research that sought to understand the relationship between a healthy work-life balance and the overall economic benefit to a given corporation. The Organization for Economic Co-operation and Developments Work-Life Balance Index, available at http://www.oecdbetterlifeindex.org/topics/work-life-balance/ for example, considered the amount of time spent at work an "important aspect of work-life balance... ...as evidence suggests that long work hours may impair personal health, jeopardize safety and increase stress". Qualitative research on work performance has also found that rest, namely relief from stress, can enable greater productivity and problem solving[7]. Scientific research on an individuals stress levels while at work is relatively new as well as attempts to quantify the economic costs to an organization and country of low employee well being [13].

This study uses simple agents to model individuals early in their careers. The agents represented as a string that specifies the agent’s behavior as in [12], although the fitness evaluation used for the worker agents is more complex. Other studies using this type of technology appear in [9], [14], [11], [6]. An individual in this situation will often attempt to mimic the behavior of successful individuals they encounter. The goal of this mimetic behavior is to advance their career through recognition of their achievements, namely their work, by senior leaders in the organization. To do so often requires additional time working and in the most extreme cases can lead to physical illness due to the onset of stress from long hours worked [8]. As there is a finite amount of time in a day to complete tasks, an employee must adopt not only a good work ethic but one that enables the individual to establish a sustainable work-life balance. In this paper we examine the imitation of high-status individuals as a possible indirect source of stress in the workplace.

The agent model used in this study is one in which agents divide their time in a month, hour by hour, into time spent in low stress activities, working on their base task, or working on a special project. The model encodes a number of features:

1) Quality of work declines as stress exceeds an acceptable minimum.
2) There is a minimum level of productivity on an agent’s base task that is required not to be fired.
3) An agent’s status in the company is proportional to their productivity on their base task and their productivity on special products, subject to not having already been fired.
4) Agents in the lower tier of status are assigned to re-training to enhance their productivity.
5) Agents that are fired are replaced by new agents.
6) Agents assigned to re-training and new agents are trained by a mentor assigned from a given status tier. The impact of the technique for selecting mentors is one of the phenomena this study is intended to address.
7) The relative importance of special projects varies randomly week-to-week. In this case randomness is used to simulate effects like variation in the importance of the special project and the degree to which company performance impacts the need to do your standard assigned duties well.

The model is used to test several hypotheses. First, the choice of status tier for mentors has an impact on overall productivity of the agent. Second, people using artificial aids to enhance their stress tolerance can indirectly cause substantial damage when acting as mentors because their performance is not reasonably replicable. Third, the variability of the importance of special projects and base tasks impacts corporate performance.

II. MODEL SPECIFICATION

Agents are assessed one month at a time. We regularize a month to contain four weeks with five twelve-hour days...
and two weekend days. This does not mean that the agent must stay at work for twelve hours each weekday, rather it means that they cannot stay more than twelve hours. The agent representation thus determines hour by hour if they are resting, working on their main job, or working on a special project. The agent’s chromosomes have the structure shown above in Figure 1.

**A. Agent Representations**

The agents are represented as a string of 240 ($4 \times 5 \times 12$) numbers from the set $\{0, 1, 2\}$. Each loci in the string designates an hour of time in the month shown in Figure 1. The designation 0 represents rest which could include time at home, taking a break, eating lunch, or engaging in low-stress conversation with co-workers. The designation 1 represents time spent working on the agent’s base task within the company, typically the one appearing in a job description. The designation 2 represents time spent on special projects that are outside the agent’s base job but which may advance the company.

New agents are generated from old ones by simply copying the old agent and then modifying their chromosome by changing some of the loci[1]. The per-loci rate at which new loci are produced, $\mu$, is the mutation rate for new agents.

**B. The Adaptive Algorithm**

The adaptive algorithm used to model agent learning is given in Figure 2. The key features that must be specified are performance evaluation, including base task performance, and training.

1) **Performance Evaluation**: The agent is evaluated on base and special projects performance each week and the weekly figures are added to get a monthly figure used by the algorithm for updating the agent population. The steps for generating the weekly figure are:

**Generate original population of agents**

**Repeat**

- **Evaluate agent performance**
- **Fire under-performing base task agents**
- **Sort remaining agents by performance**
- **New and low-performing agents trained**

**Until Done**

1) The total number of loci not of type 0 are computed for each day. If the total is eight or less, the daily score is one, otherwise the daily score is the number of hours above eight spent on non-0 tasks in the day.

2) The daily totals for the five days of the work week are multiplied to obtain a total stress number $t$ in the range 1-1024.

3) The stress factor for the week is computed from $t$ as

\[ S(t) = \beta + (1 - \beta) \frac{1}{1 + (\alpha t)^2} \]

4) The agent’s performance on their base job is the number of hours spent on that job in the week times the stress factor. We denote this for agent $A$ by $N_A$.

5) The agent’s performance on special projects is the number of hours spent on special projects times the stress factor. We denote this for agent $A$ by $S_A$.

The parameters $\alpha$ and $\beta$ establish the stress response curve. The parameter $\beta$ is the floor - the level of performance a maximally stressed agent will engage in. The parameter $\alpha$ represents the rate at which stress impacts the agent’s performance. Smaller values of $\alpha$ represent greater stress tolerance by agents. Note that a stress factor is 1.0 for no stress and near $\beta$ when there is maximum stress.
If the agent’s total performance on their base job for the month falls below an acceptable minimum $M$, the agent is fired and a new agent is hired to replace them. Agents $A$ not fired get a performance evaluation $P_A$ given by:

$$P_A = \delta N_A + (1 - \delta)S_A$$

(1)

where the coefficient $0 \leq \delta \leq 1$ represents upper management’s perception of the relative worth of special projects that month. This parameter introduces the stochasticity involved in guessing what your manager might want in any given month.

C. Training

We adopt a simple training model for the agents: imitation. Agents not being trained are ranked by their performance status in the company. A block of these in the rank order are assigned as mentors. Each trainee then inaccurately copies the time assignment of their mentor. The parameter $\mu$ is the probability that an agent will adopt their mentor’s value at a given location in the gene.

D. Drug Use

The model is also used to explore the effect of having a certain number of covert drug users in the population. Drug use is modeled by giving the individuals using drugs a different stress response parameter $\alpha_d$ representing a higher tolerance for stress. Drug-using agents are in all other ways the same as standard agents. This model fails to incorporate long term effects of drug use. Drugs are perceived as helpful for dealing with stress in the short term, taking their toll when use is prolonged. In spite of this, even short term drug use to deal with stress can have an impact on corporate welfare, a hypothesis we test in this study.

E. Proactive Management

A final feature added to the model is proactive management. A number of workers $N_m$ are targeted for increased productivity. It is assumed that management is using the productivity metric “hours spent working”. Proactive Management is implemented in the model by having management urge the least stressed workers to work a little harder. The workers are sorted by stress factor and the $N_p$ with the lowest stress levels change one of their 0 loci to a one or two. This represents a tiny incremental increase in time spent at work.

III. DESIGN OF EXPERIMENTS

This study represents the initial presentation of the model and so a parameter study is needed. The baseline study uses the following parameters: population of 120 agents was evolved for 120 months (ten year) using the parameters $\alpha = 0.05$, $\beta = 0.2$, $0.4 \leq \delta \leq 0.6$ with a uniform distribution. Base per month productivity to avoid firing was set to 60. Recall this base productivity is $\text{stress factor} \times \text{hours on base task}$. The default range of individuals used for training is 0.0-0.1, representing the top 10% of performers in the company. Each experiment in the parameter study uses ten replicates.
Individual parameters were varied from the baseline as follows. The minimum base productivity factor was varied beginning at 45 and increasing at intervals of 15 to a maximum of 105. The underlying hypothesis for this test was that as the base requirement for work increased, the base productivity of the individual must adapt to match the changing requirement. Furthermore, the individual would have less time to focus on special projects as they must spend more of their time completing their base work. Moreover, it was expected that as the factor increased, the number of individuals fired would increase as the low performing individuals would not meet the base productivity requirement. The stress drop-off parameter $\alpha$ was then varied to establish its impact on performance. For this parameter study, the values were set at $\alpha = 0.05, 0.03, 0.01, 0.005, 0.002$ and 0.0001 with the underlying assumption that individuals with a lower ability to adapt to stress will have a higher total average of stress quantified by the stress factor $S(t)$. The management perception of relative value of the base job and special project was varied with the lower bound of $\delta = 0, 0.2, 0.4, 0.6, 0.8$ with a range of 0.2. The hypothesis for this test was that as management places higher importance on special projects that the overall status of the evolved individuals would be higher as more recognition is awarded. The ranges for which a mentor could be chosen from were also varied. Mentor ranges are established as a pair of decimal numbers specifying a range in the unit interval; the highest performing members of the population are at zero, the lowest at one. The ranges for mentor selection tested were 0-0.1, 0.1-0.2, 0.1-0.3, 0-0.2 and finally 0-0.5. The overall expectation from implementing the variation was that the larger the mentor selection group the more likely base productivity increases as there is a larger pool of candidates from which to re-train individuals. The stochasticity of the parameter $\delta$ means that a narrow training pool will over-learn managements current preferences. The replacement fraction of low-performing individuals was then varied with the expectation that the larger the group being replaced, the more optimal overall base productivity would be. For this, the values were set to be 0.1, 0.2, 0.3, 0.5 and 0.7.

A. Experiments with Drug Users

A second set of experiments introduced a number of drug users into the problem with the same initial parameters outlined above however, the drug users were set to have a different tolerance to stress that was significantly greater than that of the non-drug taking agents. For this simulation, the number of drug users were assigned as 5, 10, 15, 25 and 50 out of the population of 120 individuals. The goal of this was to establish whether when a drug user was chosen as a mentor, an agent could replicate the behavior without the addition of a performance enhancing substance. The hypothesis for this scenario was that the non-drug users would be unable to replicate the behavior and that more stochasticity would be introduced into the performance of the model. Finally, the parameter for the drug user’s stress was varied with $\alpha_d = 0.01, 0.0025$ and 0.001 compared to the tolerance of the non-drug using individuals whose stress drop-off was set as $\alpha = 0.05$. In this instance the expectation was that as the drug users could tolerate increasing levels of stress, that the mimetic behavior of non-drug taking agents would result in higher stress levels overall. We also conjecture that having drug users in the cohort of mentors will create a source of stress by training non-drug users to emulate drug users behavior without the enhanced stress tolerance granted by the drug use.

The relatively small number of replicates in the first two sets of experiments makes it difficult to quantify the impact of drug use. A third experiment using four sets of simulations was performed. This experiment used the baseline parameters except that the number of drug user set to zero and ten and the training cohort set to the top ten percent and the second ten percent. This study is intended to quantify the effect of drug use’s interaction with training. Instead of ten replicates, 400 were performed. These experiments used the baseline parameters with $\alpha_d = 0.005$ for those parameters not varied.

B. Experiments with Proactive Management

The four sets of runs used in the third experiment was repeated with the addition of proactive management with $N_p = 30$. This means the 30 least stressed workers were persuaded to work one more hour per month in each training cycle.

IV. RESULTS AND DISCUSSION

Over the course of numerous simulations, running the model with a variety of parameter combinations, the model exhibited behavior as was predicted by the stated hypotheses with only a few exceptions. In varying the minimum productivity required to avoid firing, the base productivity increased to a maximum average of 84.67$\pm$1.54. This maximum occurred when the minimum productivity was set to 90. In addition to the base productivity increasing, the number of firings concurrently rose. Figure 4 shows how the number of monthly firings responds to the change in the required base productivity. Of note, once the threshold for minimum productivity increased past 100, there was a drastic drop in performance resulting in a complete firing and re-training of the population due to the inability of agents to meet the unrealistic expectation for base work.

Examining Figure 4 we see that the model has a sort of burn in period. For base productivity requirements of 60 and 75 the amount of firing drops to near zero in a smooth, nearly linear fashion. The slope of these curves, which show the learning algorithm training the agents to meet their base workload, are mediated by the mutation rate and could probably be accelerated by increasing it. When the base workload is at 90 the burn-in period to learn to meet base workload is longer than the duration of the simulation for seven of ten replicates. This represents either an unreasonable base workload or evidence that the mutation rate could profitably be raised.

With the addition of 5 drug users into the population and the minimum productivity requirement set to 60, the
model exhibited a much higher level of stochasticity that that observes in the simulations without drug users. This can be seen in the productivity plots shown in Figures 5 and 6. The effect is likely caused by drug users training people to unreasonable expectations.

Fig. 4. Number of monthly firings as a function of time for the experiments in the parameter study with minimum productivity set to 60, 75, and 90. Ten replicates are shown for each performance level.

Fig. 5. Response of 10 simulations with no drug users in a population of 120 with initial $\alpha=0.05$, $\beta=0.2$, and minimum productivity set at 60.

Fig. 6. Response of 10 simulations to the addition of 5 drug users into a population of 120 with initial $\alpha=0.05$, $\alpha_d=0.01$, and minimum productivity set at 60.

The greatest effect on stress occurred in the variation of the stress drop-off parameter ($\alpha$). In general, as the rate at which stress drop-off decreased, the overall stress of the agents increased in conjunction with the number of hours worked. The maximum mean number of hours worked per day reached 8.76 and in several instances the maximum stress value reached the highest possible value of 1 (no stress) when the threshold for the stress drop-off was $\alpha = 0.0001$. This makes sense as meeting high productivity goals is not difficult when agents have favorable stress response.

In the instances where management’s recognition of special projects was varied more, the overall status of the
employee increased when the values for $\delta$ were higher. Not surprisingly, this had the greatest effect on the awarding of recognition and the status outcome from the special project.

When the replacement fraction of the population was varied, there was little impact to the model and very little fluctuation in the stress, base productivity and status of the individual agents. This was not the result the researchers expected. The fraction of individuals assigned to retraining may matter more in simulations run against companies with smaller numbers of workers, a matter we slate for future investigation.

When increasing the number of drug users in the simulations, as a general result the maximum values attained for the stress factor continually peaked higher than 0.99 and the overall base productivity average was, in most cases, lower than non-drug user simulations. This however corresponds with a higher firing average in general than the non-drug user simulations. Furthermore, it is interesting to note that when manipulating the training tier with drug users involved, a more stable result is achieved when the training tier is set lower. This result can be seen by comparing Figure 6 and Figure 7. Since drug users are often high performers, this result is probably explained by having fewer drug users in the cohort.

It is worth noting that the parameter $\beta$ has very little impact on the simulation. Most agents stay far over on the left side of the stress response curve. This means that no-one gets near the floor of the curve and so all effects can be modeled by varying alpha unless much smaller values of alpha are tested.

Figures 5-7 all have a similar shape. There is an initial sharp rise in productivity followed by a slow climb. The initial rapid climb represents the removal of patently absurd time allocations from the population. These include both those who do not work and those that work themselves to un-supportable stress levels. The continuing upward progression suggests that ten years (120 months) is not enough time for the system to come to equilibrium. The baseline experiment was re-run with the length of the simulation increased from ten years to one hundred years. The resulting productivity curves are shown in Figure 8. This is an unreasonably long simulated duration, but it shows that small amounts of improvement occur for a very long time. Coincidentally, there is a knee in the productivity curve near 120 months - suggesting that the simulation lengths chosen show the most vigorous period of adaptation of the system.

A. Results for Large Replicate Study

Table I summarizes the results for the third experiment. This experiment compared using the top performing 10% of the workforce as mentors with using the second 10%. These comparisons were made in a drug free company and in a company with 10% of the workforce covertly using drugs. These experiments support the following conclusions:

- When no drug users are present, using the highest performing workers as mentors pays a significant bonus in productivity, exactly as one would expect.
- When drug users are present and the mentors are chosen from the top 10% of performers (in all probability including many drug users), there is no significant productivity advantage to using the higher performers in the training cohort. There is a substantial disadvantage to using the best performers as trainers: the number of...
firings increases sharply.

- Comparing the experiments where the training cohorts are drawn from the second 10% of performers, there is a small but statistically significant decrease in the number of firings when drug users are present. Since a few drug users have a high probability of being in the training cohort in this situation, this is most likely an interaction effect.

The hypothesis that choosing a lower performing cohort for trainers would grant immunity to the negative effects of drug use is verified by these experiments, but we note that no drug use still results in the highest overall productivity, in spite of the fact that drug use enhances the productivity of the users in the short term. Training of non-drug users to unrealistic expectations by drug users has a significant effect.

### B. Results with Proactive Management

Table II summarizes the results of the fourth experiment testing the impact of proactive management. The notable effect of these results is that proactive management increases low-performance related firing. This suggests that the net effect of proactive management is to push workers into high work (high stress) time allocations which lead to stress related degradation of performance.

The relative effects of drug use and choice of training cohort remain fairly similar. This is slightly unexpected as proactive management should push the relatively low stress drug users to take on absurd workloads at which point one would expect the experiment in which the drug users are dense in the training cohort to have a much larger effect from training to unrealistic expectation. The most probable explanation is that management always proactively urges the drug users to take on more work until they also fall off the stress cliff. In a sense the higher rate of firing ends up affecting the drug users as well as the non-users so that proactive management somewhat ameliorates the effects of the presence of drug users.

### V. Conclusions and Next Steps

This study demonstrates a simple agent-based model of stress in the workplace and shows how to incorporate covert drug use and a policy change (proactive management) into the model. It should be clear that there are many other sorts of situations that can be explored within the model. The most interesting results are in the experiments that explore the interaction of the presence or absence of drug use with the choice of training cohort. A substantial interaction appears in which the major impact of drug use is to increase the number of firings of non-drug users.

The model is very simple and thus easy to modify and generalize. There is a good deal of room to explore more with the existing model. Performing a parameter study on the number of drug users and the $\alpha_d$ parameter that governs the performance advantage of drug use is an early priority for further research. We also have not explored the effect of changing the size of the workforce. Larger companies will have more “inertia” caused by having a larger and hence more diverse population of workers. Smaller companies will experience greater variability. It would also be interesting to see how much interaction there is between drug use and the $\delta$ parameter. Larger variability in management expectations might amplify the effect of drug use.

### A. Modifications and generalizations

There are a number of points where the model can be generalized to improve plausibility or range of effects that can be modeled power. We list a few of these here:

- In the present model stress is simply reset over the weekend. A more plausible situation would involve the weekend reducing stress by a certain amount so that very high stress individuals arrive at work Monday morning with residual stress from the previous week.
- The parameter $\alpha$ is a one-size-fits all model feature. If workers had individual $\alpha$ values drawn from a distribution then the model would implement variable stress tolerance - something that is plausibly a part of the workplace.
- The parameters of the model are fixed for its entire duration. New management might change the corporate culture and so change the value of $\alpha$ or $\delta$. Intentionally changing the values of parameters at fixed times within the simulation can be used to model the impact of such changes in corporate culture.
- The current simulation uses a fixed proportion of drug users. A simple generalization is to make drug use contagious in the form of a fixed probability that a mentor will train their proteges to imitate their drug use. This would make the prevalence of drug use a trackable statistic in the simulation.
- The company represented by the current simulation is drug tolerant. Having periodic campaigns in which drug use is discovered (probabilistically discovered and punished) could be simulated. The optimal spacing and duration of anti-drug campaigns could be explored.
- At present there is a single type of drug that has only short term beneficial effects to the individual. First of all, a productivity loss tied to sustained use of drugs would permit a more realistic modeling of their impact. Second, once the long term drug use feature is added to the model, it is possible to compare the impact of the
presence of different drug usage. These could include relatively harmless stimulants like coffee.

- The simulation could be extended to model management efforts at encouraging wellness. These could include management intervention to reduce number of hours worked in high stress individuals, investment (that is charged against total productivity) in providing a lower stress workplace which is modeled as a lower value for $\alpha$ when such stress reduction measures are in effect.

- The current simulation completely ignores the effects of social networks. A worker who is a personal friend of someone in upper management might have very different minimum base productivity requirements and might be assigned as mentors in spite of their actual productivity. This new model feature permits the modeling of nepotism.

- More complex social interactions could also be studied. Rather than having a single mentor, a worker might have a main mentor and a network of social contacts that transmit information about their work preferences influencing the agent’s work pattern.

- A natural generalization is to increase the number of types of special projects from one to several. At this point a minimum investment by an individual in a project is required to get a payoff.

- Workers can be divided into teams that both train one another and share fitness. This permits the modeling of a standard feature of modern corporate life. Moreover, the corporation modeled in this study has, implicitly, a single division. Modeling a corporation with multiple divisions with different stress levels would permit modeling of a broader variety of corporate environments.

B. More complex agent representations

The agent representation in this study is a simple string specifying the agent’s behavior. More complex agents that generate behavior adaptively based on knowledge of their own current stress level, hour worked on each task, and possibly management expectation would generate more complex and, if well designed, more plausible agent behaviors. In [5], [4] a technique was developed to give agents emotions in the form of an artificial hormonal system. The agents with an emotional system were found to have a substantial competitive advantage. This emotional system could easily be adapted to manage the agent’s stress response and even model effects like depression induced by working too hard. Another possible agent representation could be adapted from those used in [3], finite state machines with transitions driven by Boolean tests on inputs. Incorporating a $\lambda$-transition, that generates no action, into these binary decision automata permits them to make complex decisions based on multiple data items.

The use of more complex agent representations provides more entry points for modeling additional phenomena. Use of binary decision automata with access to an emotional system would permit modeling, for example, of the impact of the work environment on the agents non-work life. While such models would require careful normalization against behavioral data to avoid representational sensitivity effects [2], we are approaching the point where this type of complex system can be profitably modeled.

REFERENCES