# Humanizing Labor Resource in a Discrete Event Manufacturing Simulation Software

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**Abstract.** Simulation is a decision making support tool very useful for the design and dimensioning of manufacturing plants. Although workmanship hand is largely employed in production systems, labor involved in the process is often modeled as an inanimate predictable resource (like machines, tools or equipment). In order to make simulation more realistic, this study applied ergonomics principles (circadian rhythm and rest pauses) to the labor resource of a software that is largely used in commercial applications. Results showed that this "humanization" impact the simulation results. Production outcomes from the circadian rhythm modeling were up to 7 % higher than the ones obtained with the standard PROMODEL modeling; the introduction of 5 min rest pauses increased productivity in less than 1 %. Overall, these results justify the development of computational routines able to represent "humans" and their interactions with the system in a more realistic manner.

**Keywords:** Simulation · Ergonomics · Circadian rhythm · Production systems

## 1 Introduction

Simulation is an important tool for virtually designing and evaluating products and process before its implementation. Manufacturing simulation software (such as ProModel, Arena, AweSim!, Extend, GPSS/H, MODSIM III, SES, Taylor II, WITNESS) allow for building virtual factories with different lay-outs, equipment, processes and labor alternatives so the one with best performance can be later implemented. Most simulations often use predictable production variables, such as quantity, type and physical distribution of machines, quantity of intermediate stocks, production times etc. Although workmanship hand is largely employed in most manufacturing systems, labor is often modeled as an essential, but inanimate predictable resource. However, workers capability and performance are less predictable than machines, equipment, products etc. Unlike machines, human beings do not keep the same production rhythm throughout the day, what directly affects productivity.

In spite of intra (people have different behavior during a journey) and inter (different people have different capabilities) human variability, simulation often assumes


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that workers are capable of performing the task as designed, with no mental, physical, social, environmental or time constraints. Besides, when labor is modeled as a machine, workers do not stop working anytime, do not take breaks and have to work to meet pre defined production goals that are often set with no ergonomics support. In most cases, there is no questioning either these goals are above or beyond workers capabilities. Possible reasons for not considering human factors in simulation is the complexity of the factors that influences human productivity, and the lack of ergonomists in most production planning. Nevertheless, human variation is the cause of a large percentage of the disparity between simulation predictions and real world performance [1].

Therefore, this study evaluated the impact of human factors on a manufacturing simulation software. The objective was not the integration of ergonomic assessment in the modeling, but to give some "life" and to turn "more real", the built in labor resource of the software. This was done by embedding rest pauses and circadian parameters that are independent either of the type of work (such as physical and mental demands, stress and fatigue) or type of people (such as age, gender, personality, level of training). Using the simulation software WITNESS, [1] incorporated circadian rhythm in the modeling of an automotive engine assembly line and found that circadian rhythm impacted production outcomes in 2 %. The circadian model was based on the study of [2] that took into account the time of day of work and time awaked on the performance of air traffic controllers and pilots. Assuming that workers in most manufacturing processes have more in common with construction workers than air traffic controllers and pilots, the study presented in this paper aims to add to this previous study, by using a daily productivity model proposed by [3], as described in the next section.

## 2 Ergonomic Parameters Used in the Study

Although human behavior and performance depends on environmental, physical and psychosocial factors, this study considered only rest break and circadian parameters that might affect productivity.

Human performance depends on physiological markers known as circadian rhythms, which vary during the day, despite the type of work or type of people. They are manifested as oscillations in biochemical, physiological and behavioral cycles of approximately 24 h as noted in body temperature, blood pressure, renal excretion of metabolites and circulating levels of hormones, which have a pattern of variation that is repeated day by day at the same day time. Humans have different endogenous circadian pacemakers which regulate homeostasis through various efferent neuroendocrine responses that interact with homeostatic processes (e.g. amount of hours since awake until the maximum alertness) [4], which end up defining whether one activity would be best performed in the morning, afternoon or evening. A study by [3] on daily productivity curve in the civil construction industry, showed that the rhythm of work adapts itself to the rhythm of the body, and productivity curves resemble physiological curves. Productivity increases in the morning, decreases before lunch and is lower in the afternoon.

Besides this circadian rhythm variation, humans take breaks during the day because nobody can work at the same pace without rest. The ergonomics literature reinforces the need for formal rest breaks during the journey, although there is no prescribed "best break": pause intervals and duration might vary depending on the work performed and individuals. Reference [5] recommends short breaks of 3–5 min every hour in case of machine-paced work. A study by [6] concluded that workers prefer a 10-min pause after each working hour than four 15-min pauses at longer intervals. Breaks might have a positive impact on productivity: 10-min pauses in the morning and afternoon could increase production by 5–12 % [7] or 10–20 % [8].

## 3 Method

Ergonomic parameters used for simulation were the daily productivity model as proposed by [3] and 5 min rest pauses after each hour of work. The selected simulation model was one demo available from PROMODEL, a discrete event simulation software largely used in the manufacturing industry, which is also the software adopted at the University.

The PROMODEL Mfg_cost.mod simulates a shop for machining, milling and assembly of gears, employing one, two or three workers. Evaluation can be done based on productivity or cost of each manufactured product according to the number of workers involved. Cost is calculated either as a function of human/h or machine.

The shop has two lathes (NC Lathe1 and NC Lathe2), a workbench and a place for product inspection. As the material arrives, the operator takes it to one of the lathes, place the material on the lathe and program it. The operation time distribution follows a normal distribution (mean time = 3 min; SD = 0.2 min). The next operation depends on the following system states:

1. one of the lathes is available, and will be used for processing a new gear part;
2. one of the lathes ended the operation. The gear part is taken from the lathe and placed on the bench for degreasing;
3. both lathes are busy, and there is a degreased gear part on the bench, waiting for inspection. After inspection, if it passes the test, it will be assembled with roller balls, conforming a gear.

Inspection time (mean time 3.2 min; SD = 0,3 min) as well as assembly time (mean time 1,5 min; SD = 0,2 min) follows a normal distribution The production of a correct gear takes a mean time of 7.7 min, while defective products take 6.2 min.

In this model, the rate of defective products is 30 %, but it can be adjusted. When this rate is less than 30 %, the number of manufactured products (good or defectives) in a certain time diminishes because it takes longer to process correct products than defective ones. The mean processing time of a gear is 34 min, a mean time of 7,25 min (21 % of the total time) corresponding to operations involving the workers.

The demo model is programmed for a 15 non-stop hours of operation, and can be set for operating during days, weeks or even years. However, considering a real life situation, the time was set for an 8 h shift. Three conditions were compared: (1) 5 working days of an 8 h non-stop shift (PROMODEL standard); (2) 5 working days of an 8 h shift with one hour for lunch break and considering the circadian rhythm performance and productivity curve; (3) 5 working days of an 8 h shift with one hour for lunch break, 5 min rest pauses at each hour, and considering the circadian rhythm performance and productivity curve. It was assumed a 10 % performance recovery after the 5 min break, because the workers could rest (i.e., performance increases because fatigue decreases). The expected performance and productivity curve resembles the one proposed by [3]. However, because this exact curve is not known, simulations were done considering curves with mean productivity amplitude variation of ± 5 % to ± 20 % during the day. Therefore, a 5 % variation means that productivity varies only 5 % during the day (tending to a standard flat curve) i.e., there is no much difference among workers capability/productivity during the day, while a 20 % variation means that this variation is higher during the day, approaching the capability/productivity circadian curve.

## 4 Results

Figures 1, 2, 3 and 4 present the obtained results for condition 2 (circadian rhythm) assuming 70 %, 80 %, 90 % and 100 % of correct products. Figures 5, 6, 7 and 8 present the results for condition 3 (circadian rhythm + rest pause) assuming 70 %, 80 %, 90 % and 100 % of correct products. Values on the y axis are the mean deviations in production (%) for ergonomic modeling involving 1, 2 and 3 workers, in comparison to condition 1 (standard PROMODEL). Values on the x axis displays the results assuming 5 %, 10 %, 15 % and 20 % variation from the capability/productivity curve during the day.

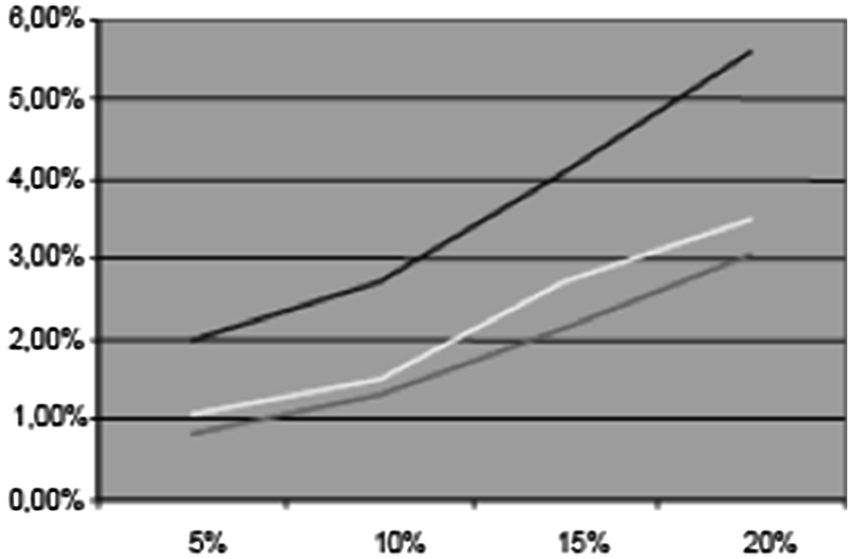


**Fig. 1.** Simulation results considering 70 % of correct gears produced by 1 worker (*black line*); 2 workers (*gray line*) and 3 workers (*white line*).

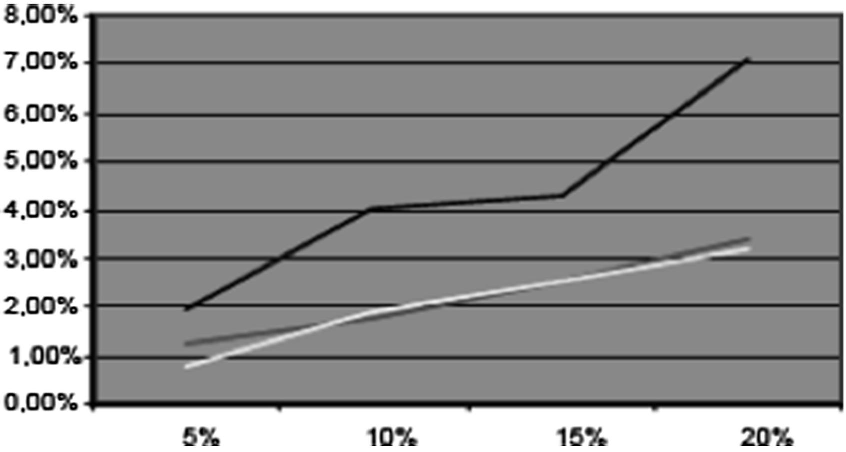


**Fig. 2.** Simulation results considering 80 % of correct gears produced by 1 worker (*black line*); 2 workers (*gray line*) and 3 workers (*white line*).

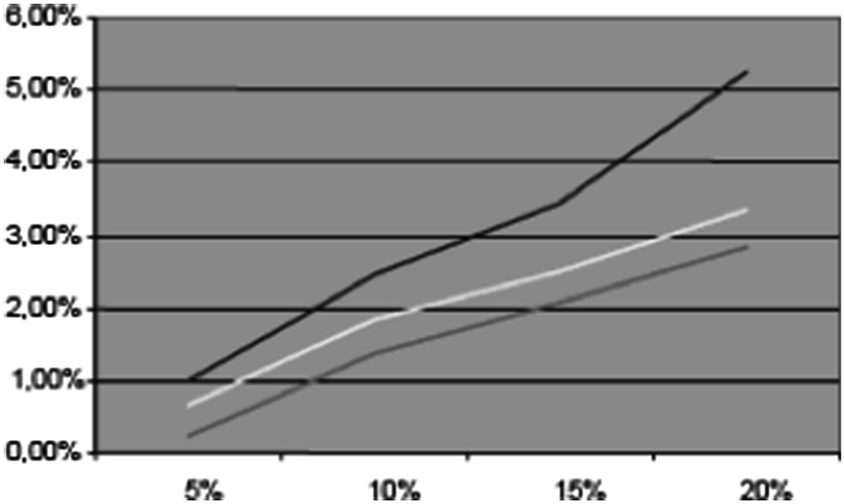


**Fig. 3.** Simulation results considering 90 % of correct gears produced by 1 worker (*black line*); 2 workers (*gray line*) and 3 workers (*white line*).

Figures 5, 6, 7 and 8 present the results for conditions with 5 min rest after each hour of work.

It is clear that performance, mainly when only one worker is involved, increases with the effect of circadian rhythm, i.e., tend to be higher for curves approaching circadian variations (20 %) during the day. Adjusting production goals to circadian rhythm increased productivity up to 7 %, what is a significant gain since labor represents only 20 % of the total manufacturing time. Larger productivity increase might

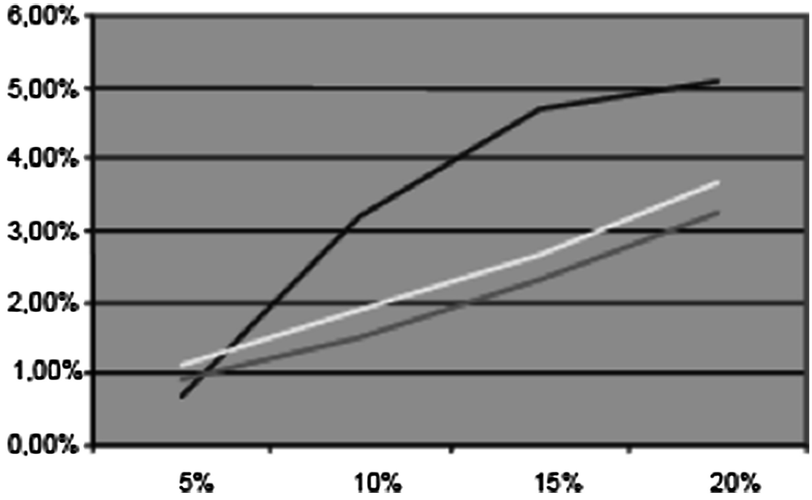


**Fig. 4.** Simulation results considering 100 % of correct gears produced by 1 worker (*black line*); 2 workers (*gray line*) and 3 workers (*white line*).

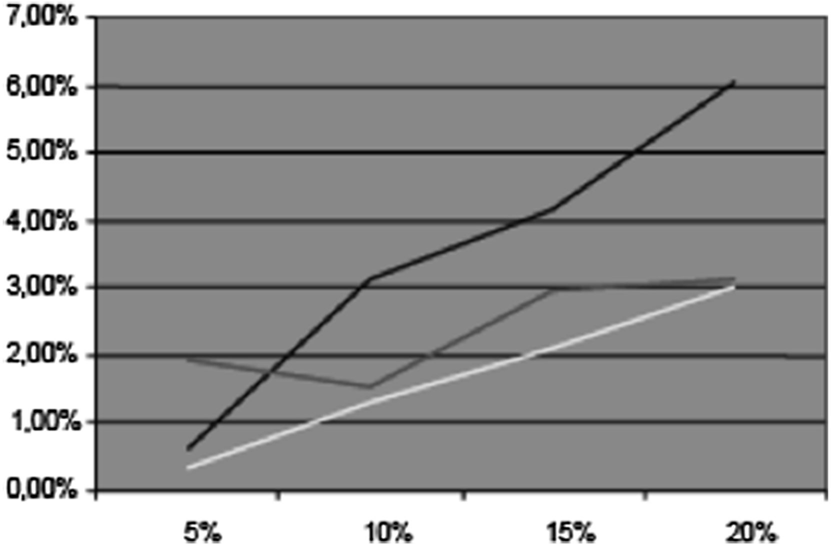


**Fig. 5.** Simulation results considering 70 % of correct gears produced by 1 worker (*black line*); 2 workers (*gray line*) and 3 workers (*white line*), with 5 min rest pause after 1 h of work.

be expected for conditions where human labor is more intense. The mean obtained gains are higher than the 2 % reported by [1], who used different productivity model and simulation software. Nevertheless, productivity rate is not the focus of the study but, rather, being able to demonstrate that it is possible to adjust production demands to

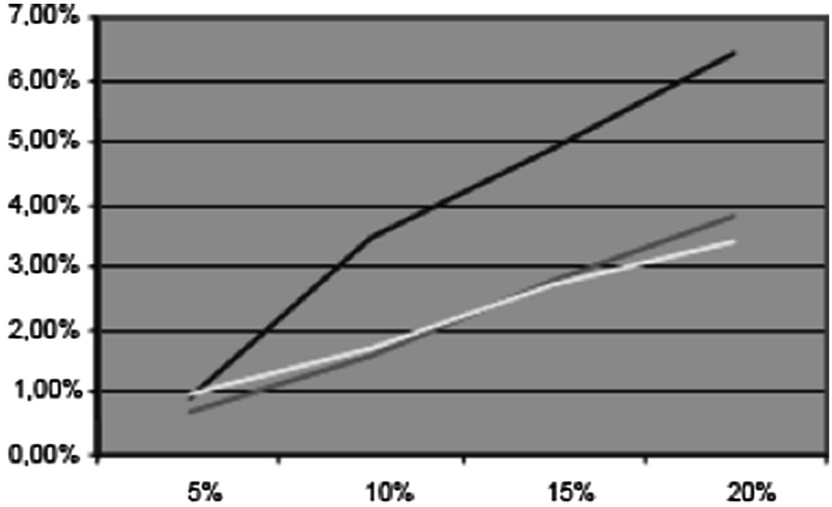


**Fig. 6.** Simulation results considering 80 % of correct gears produced by 1 worker (*black line*); 2 workers (*gray line*) and 3 workers (*white line*), with 5 min rest pause after 1 h of work.

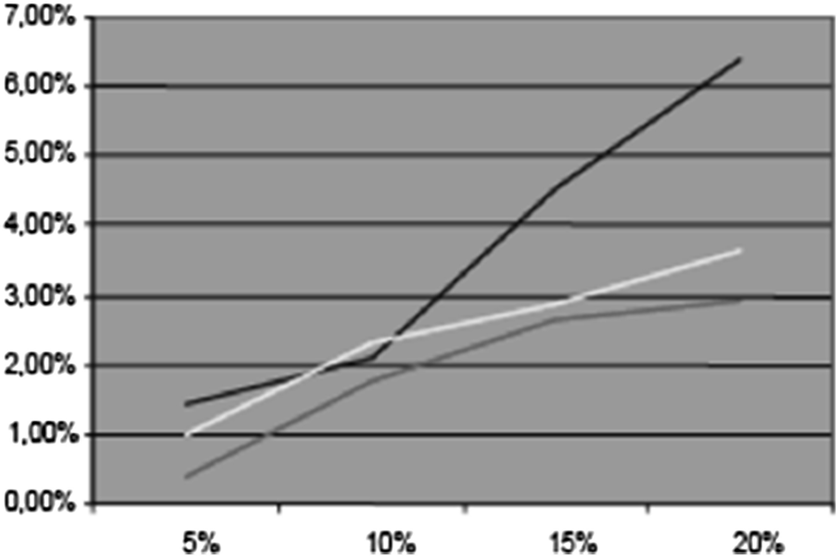


**Fig. 7.** Simulation results considering 90 % of correct gears produced by 1 worker (*black line*); 2 workers (*gray line*) and 3 workers (*white line*), with 5 min rest pause after 1 h of work.

human capabilities with no impact on the enterprise goals. Simulation is a tool for designing better production alternatives, and similar outcomes should be expected if human factors are used when implementing new work organizations. By assuming a

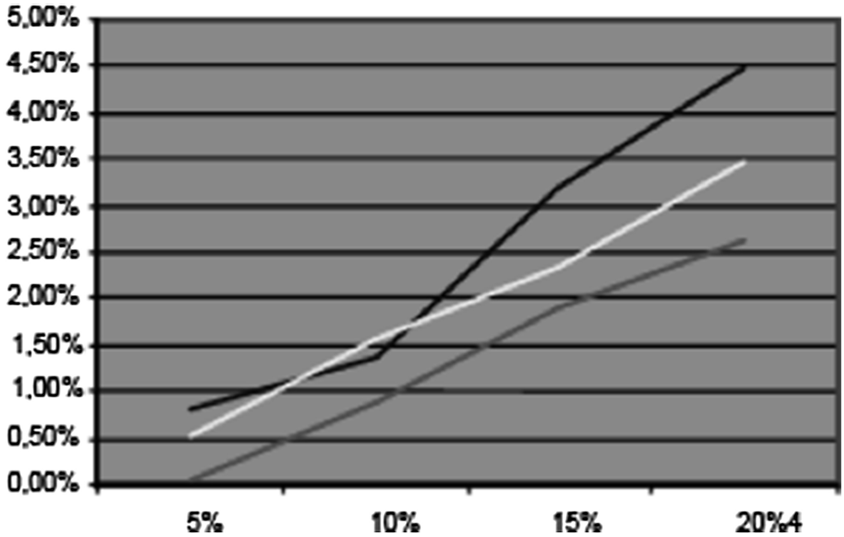


**Fig. 8.** Simulation results considering 100 % of correct gears produced by 1 worker (*black line*); 2 workers (*gray line*) and 3 workers (*white line*), with 5 min rest pause after 1 h of work.

constant productivity/day, as it happens in most production systems, workers have to work either above or below their capabilities depending on the hour of the day, what impacts both humans and production. On the other hand, when production set up fluctuates according the capability/productivity curve, productivity would increase with minimum stress on the worker.

Rest pauses showed to have little impact on productivity. For example, productivity curves of one worker, in Figs. 1 and 5, show that rest pause increased performance in <1 % (productivity increased from 5.5 % to 6 %), which is lower than the 5–20 % productivity increase reported in the literature. Assuming that these studies did not consider production pace and circadian rhythm, one explanation might be that fatigue is lower when production demand follows workers capability/productivity curve, reducing the need for recovery from rest pauses.

## 5 Conclusion

This article presented a study on the use of ergonomic parameters in manufacturing systems simulation. The goal was to "humanize" the labor resource of a commercial software and to evaluate whether incorporating human performance variation and rest pauses would alter productivity results. Production outcomes from the circadian rhythm modeling (productivity increasing in the morning, decreasing before lunch and lowering in the afternoon) were up to 7 % higher than the ones obtained with the standard modeling (a flat curve: same productivity rate all day). The addition of 5-min rest pauses to the circadian curves had little impact on performance, increasing productivity in less than 1 %. It is important to note that these results derived from simulation therefore they are not exact outcomes, from real life situations. However, they point out that it is possible, and desirable, to make simulations more real by incorporating human parameters to the software.

There are many variables impacting human performance, and many constraints that might be used in simulations, which were not used in this study. However, the goal was to show that it is possible and desirable to "humanize" the labor resource of simulation software in order to get more real results. Overall, the obtained results justify the development of computational routines able to represent "humans" and their interactions with the system in a more realistic manner. Labor is often represented as a machine, because it is difficult to mimic human complexity in a software. Although this might be true, there is no reason for avoiding the inclusion of human factors parameters in manufacturing modeling. Either production engineers must improve their knowledge in ergonomics, or ergonomists must be included in the engineer's team, or both.

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