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PRODUCTIVITY SIMULATION WITH PROMODEL FOR AN AUTOMOTIVE ASSEMBLY WORKSTATION INVOLVING A LIFT ASSIST DEVICE

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ABSTRACT

With advances in computer technology and digital human modeling methodology, it is possible to predict risks of potential injuries during manufacturing design prior to production, and make proactive ergonomic design for manufacturing assembly workstations involving human-machine interfaces. However, the productivity of manufacturing systems may be decreased, and this negative impact is difficult to evaluate in experimental and manufacturing environments. This research focuses on productivity issue for an automotive assembly workstation involving a lift assist device. To evaluate the productivity of the assembly workstation interfered by proactive ergonomic design, a prescriptive model of the automotive assembly system is developed and simulated with ProModel. This model and its simulation can not only evaluate the productivity, but also determine the maximum conveyor speed. Furthermore, this methodology using ProModel simulation to evaluate productivity and utilization described in this paper can be extended to evaluating other human-machine systems with dynamic, stochastic, and discrete-event characteristics.

1 INTRODUCTION

Traditional production assembly or workstation design related to human factors starts by diagnosing the system and identifying deficiencies in the existing human-system interactions, followed by implementation of a solution through design, training, and selection (Wickens, 1997). Design, including equipment design, task design, and environment design, is a critical step that requires a great amount of effort since the redesign procedure usually leads to loss of significant amount of money and time. With advances in computer technology and development of digital human modelling methodology, it is possible to predict risks of potential injuries during manufacturing design prior to production, and make proactive ergonomic design for manufacturing assembly workstations or work-cells involving human-machine interfaces.

Perhaps the most important criteria to be used in workstation design are derived from a fundamental understanding of the intended end user's expectation (Chaffin, 1997). For automobile assembly workstation design, higher productivity is primarily expected. As recent research on human factors engineering shows, in industry the two most prevalent musculoskeletal problems are low back pain (LBP) and upper extremity cumulative trauma disorders (UECTDs), especially in automobile industry (Chaffin, 1997). Thus reduction in worker injury, complaints, and/or absenteeism/turnover is another design objective. Therefore productivity and safety related to LBP risk are two main objectives for design of automobile assembly workstation involving lift assist devices. However, these two objectives may conflict. For instance, while proactive ergonomic design can benefit in reduction of potential LBP risk through modifying workstation layout, introducing a material handling device (MHD), improving worker's posture/movement, and so forth, it may also decrease productivity due to more time spent for tasks, as well as increase expenditure. Design engineers should evaluate these two objectives in the same unit (such as monetary unit) and make a trade off to achieve the maximum profit.

The safety issue related to LBP risk can be simulated and measured through virtual build method and EMG method (Duffy, 2004). However, the negative impact of ergonomic design on productivity is difficult or at least costly to evaluate or measure in both laboratory experimental environment and actual manufacturing environment, and becomes the main focus of this research.

2 AUTOMOBILE ASSEMBLY WORKSTATIONS INVOLVING LIFT ASSIST DEVICES

2.1 Manual Installation of Panoramic Glasses

This research studies the task of installing panoramic glasses for vehicles in an auto assembly line. This task can be conducted either manually or by using a lifting assist device (LAD). When conducting the installation task manually, the workers spend a time to complete the task. The time consists of time t_g for using a suction hand cup to grasp and hold the panoramic glass, time t_i for inspecting its quality (check for obvious defects on the surrounding rubber rim), time t_c for walking and carrying it to a vehicle on a slowly moving conveyor, time t_l for putting it accurately into the rectangular sunroof space, and time t_p for pushing it to make sure the seal is tight (Duffy 2005). The installing time can be expressed as

$$t_m = t_g + t_i + t_c + t_l + t_p \quad (1)$$

Figure 1 shows a kind of commercial suction hand cup.

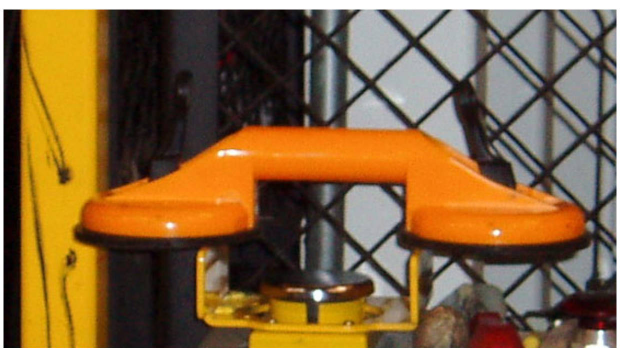

Figure 1: Suction Hand Cups

2.2 Installation of Panoramic Glasses with LAD

Due to the potential risk of LBP, some automotive companies encourage the workers to use an LAD. The LAD is located in the overhead rails. The installation task with LADs requires the worker to push a button to turn on the servo-motor to drag the LAD along the overhead rails to the top of panoramic glasses (time t_{mi}), pull down the suction cups into the surface of the glass (time t_d), grasp and hold the glass with suction cups (time t_g), inspect its quality (time t_i), settle and lift the glass to the bracket of the LAD (time t_s), drive the LAD by using the servo-motor to a vehicle on the slowly moving conveyor (time t_c), pull down the glass and install it accurately into the rectangular sunroof space (time t_l), relieve the suction cups from the glass (time t_r), and push the glass to the vehicle to make sure the seal is tight (time t_p). The installing time can be expressed as

$$t_{LAD} = t_d + t_g + t_i + t_s + t_c + t_l + t_r + t_p \quad (2)$$

It should be noticed that the installing time does not include the time t_{mi} because the worker can perform other jobs during that time.

2.3 Task Time Comparison

From Equation 1 and 2, it can be seen that the installing time t_M and t_{LAD} include a common set of times, t_g, t_i, t_c, t_l, and t_p. However, t_g, t_c, and t_l in t_{LAD} will be larger than their counterparts in t_M. Also the installing time t_{LAD} consists of some extra terms, such as t_d, t_s, and t_r, comparing to the installing time t_M. Thus the workers will spend more time to install the panoramic glass with LADs than manual installation.

The LAD can decrease the potential risk of LBP but decreases productivity as well. In practice, many workers choose not to use a lift assist device because its negative impact on the productivity is immediate while the reduction of LBP risk is not obvious until after a relatively long time period. Therefore, most workers and even their line managers choose not to use the LAD. Thus, a good workstation design involving lift assist devices should know the effect of LAD on productivity and consider this tradeoff between safety (potential LBP risk) and productivity.

3 PRESCRIPTIVE MODEL DEVELOPMENT AND SIMULATION WITH PROMODEL

3.1 ProModel Overview

"ProModel is designed to model manufacturing systems ranging from small job shops and machining cells to large mass production, flexible manufacturing systems, and supply chain systems" (Harrell & Price, 2003).

The basic modeling elements in ProModel are locations, entities, arrivals, and processing (Harrell and *et al*, 2004).

Locations represent fixed places in the system where entities are routed for processing, delay, storage, decision making, or some other activity. We need some type of receiving locations to hold incoming entities, and processing locations where entities have value added to them. Anything that a model can process is called an entity. Some examples are parts or widgets in a factory, patients in a hospital, customers in a bank or a grocery store, and travelers calling in for airline reservations. The mechanism for defining how entities enter the system is called arrivals. Entities can arrive singly or in batches. The number of entities arriving at a time is called the batch size. The time between the arrivals of successive entities is called interarrival time. Processing describes the operations that take place at a location, such as the amount of time an entity spends there, the resources it needs to complete processing, and anything else that happens at the location, including selecting an entity's next destination.

In addition to these basic elements, ProModel also includes other elements, such as path network, attribute, resource, variable, etc.

ProModel concentrates on resource utilization, production capacity, productivity, inventory levels, bottlenecks, throughput times, and other performance measures. ProModel is capable of modeling even the most complex systems.

3.2 Prescriptive Model

This automotive assembly subsystem consists of four parts, the cars (with sunroof and without sunroof), a conveyor, two workstations, and workers (one operator and one supervisor). The prescriptive model can be abstracted from the real world as following:

- The cars with sunroof and without sunroof are distributed on the conveyor in random order and with even, fixed spacing. During two hours of period, eight cars with sunroof and thirty-two cars without sunroof have passed the workstation.
- The conveyor is a kind of non-accumulating, fixed spacing conveyors with finite capacity (thirty-two). Here it is assumed that the conveyor speed is solely determined by operator's task finishing time.
- In one workstation, an operator takes a time to finish roof rack and other parts installation for cars without sunroof, and panoramic glass, roof rack and other parts installation for cars with sunroof. For cars without sunroof, the time is U(2.0, 0.3). For cars with sunroof, the time is either U(2.4, 0.3) for manual installation, or U(3.0, 0.3) for installation with an LAD.
- There are two workstations. One operator performs most of installation jobs in one workstation. In case the operator working pace becomes slower than the conveyor speed and will cause conveyor block, a supervisor will perform the installation job for an incoming car in another workstation. However, the supervisor's utilization will not be over 25%.

3.3 Model Implementation with ProModel

The prescriptive model can be implemented in ProModel environment. This model consists of three entities, Chassis, Car_Sunroof, and Car_NoSunroof. The Chassis arrives at the Chassis_Q with arrival rate at p/min. The worker integrates the Chassis into either the Car_Sunroof or Car_NoSunroof, with the ratio of 0.25. Then the conveyor transports the cars through the workstations. Assume the conveyor is L ft in length and n in capacity, moving with q ft/min. To ensure the fixed-spacing conveyor, Chassis arrival rate and conveyor speed should maintain the following relationship:

$$p = \frac{L}{nq} \tag{2}$$

The operator installs roof rack and other parts into the entity Car_NoSunroof with a time U(2.0,0.3), or panoramic glass, roof rack, and other parts into the entity Car_Sunroof manually with a time U(2.4,0.3). If the operator works with an LAD, the time will be U(3.0,0.3). In case the operator working pace can not catch up with the conveyor speed and will cause conveyor block, a supervisor will perform the installation job for an incoming car in another workstation. However, the supervisor's utilization will not be over 25%. The model layout are listed in Figure 2.

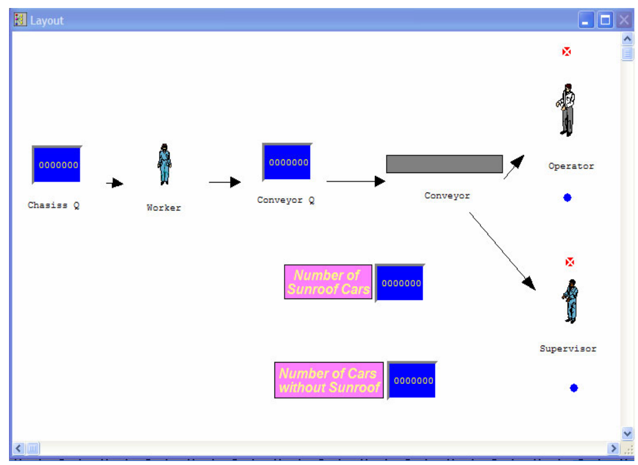

Figure 2: The Prescriptive Model Layout

3.4 Subsection Headings

Given the time for installation of panoramic glass, roof rack, and other parts, we simulate the model for one month (12hours/day, 5days/week, and 4weeks/month), with the conveyor speed as an input.

Simulation results show that, when the conveyor speed is 10.93 ft/min, the utilization of the supervisor reaches 25% for installation with an LAD. For manual installation, the conveyor speed is 11.085 ft/min when reaching the same utilization. It means that the maximum conveyor speed is 10.93 ft/min for installation with an LAD, and 11.085 ft/min for manual installation. These results are summarized in Table 1.

Table 1: Utilizations and the Number of Cars at the Maximum Conveyor Speed

	LAD	Manual
Conveyor Speed	10.93	11.085
Supervisor Utilization	25.0%	25.0%
Operator Utilization	74.7%	70.6%
Conveyor Utilization	69.1%	69.1%
Sunroof Car	1299	1319
NoSunroof Car	5227	5300
Productivity	6526	6619

Utilizations of the operator, supervisor, and conveyor versus the conveyor speed for installation with an LAD and manual installation are plotted in Figure 3 and 4 respectively.

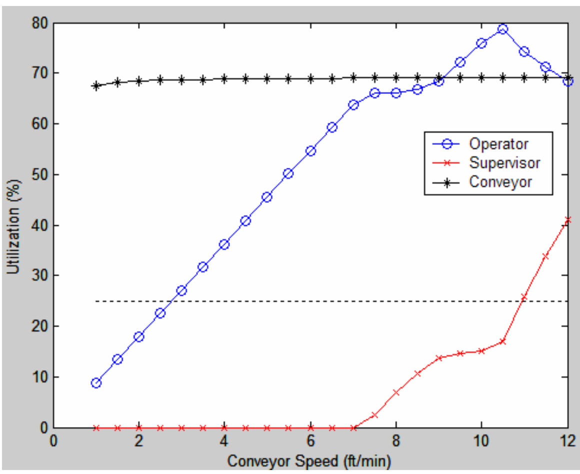

Figure 3: Utilization vs. Conveyor Speed (LAD)

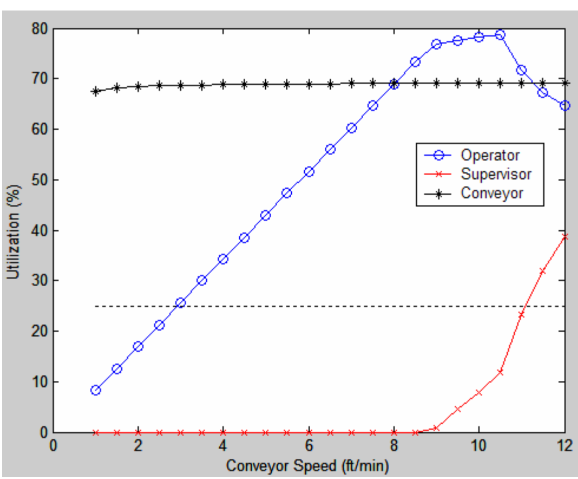

Figure 4: Utilization vs. Conveyor Speed (manual)

The states of the operator and supervisor for installation with LAD at the maximum conveyor speed are shown in Figure 5.

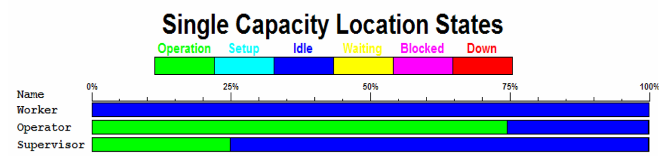

Figure 5: Single Capacity Location States at the Maximum Conveyor Speed (LAD)

The productivity (number of cars produced per month) versus the conveyor speed is plotted in Figure 6. While the relationship between the utilization and the conveyor speed is non-linear, the relationship between the productivity and the conveyor speed is linear.

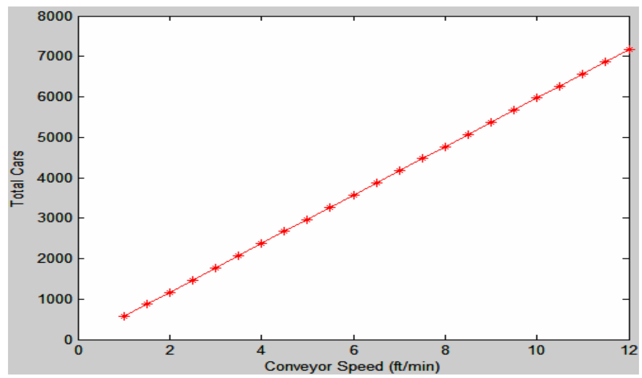

Figure 6: The Productivity vs. the Conveyor Speed

Simulation results show that, for installation with an LAD, the potential maximum productivity is 6526/month, which is 93 fewer than 6619/month of the maximum productivity for manual installation.

4 DISCUSSION AND FUTURE WORK

Given the processing time for both manual installation and installation with an LAD, this model can be simulated with ProModel to determine potential maximum conveyor speed and related productivity. The model is simple and easy to simulate. However, the most difficulty is to abstract the prescriptive model from the real world based on observations and appropriate assumptions. In this model the location Worker is used only to produce the specified ratio of cars with sunroof to cars without sunroof, and its processing time is ignored. It should be mentioned that here the conveyor speed is assumed to depend solely on operator's installation time.

This methodology using ProModel simulation software to evaluate productivity and utilization can be extended to evaluating other human-machine systems which are dynamic, stochastic, and discrete-event systems in nature, such as manufacturing systems, material handling systems, and service systems.

This research only focuses on the productivity estimation, How to make trade-off between productivity and safety will be the future work.

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