Proceedings of the 1994 Winter Simulation Conference
ed. J. D. Tew, S. Manivannan, D. A. Sadowski, and A. F. Seila

CREATING A FOCUSED APPLICATION SIMULATOR WITH FLEXIBLE DECISION MAKING CAPABILITIES

Barbara Werner Mazziotti

Textile/Clothing Technology Corporation
211 Gregson Drive
Cary, North Carolina 27511, U.S.A.

F. Bradley Armstrong

Simulation Engineering Associates
7317 Laketree Drive
Raleigh, North Carolina 27615, U.S.A.

ABSTRACT

In attempting to reach a larger, less technical audience, one of the most debated topics in simulation has been how to effectively bridge the gap between the flexibility and detail available in general purposes simulation languages, and the ease of use, simplicity and more limited modeling skills required of data-driven simulators. Many vendors have promoted the concept of "templates", user-defined, reusable pieces of model code that are object or object-like building blocks. Building blocks are a great time saving concept, however, this leaves one large assumption unaddressed: that the template user can accurately define the logic to link the building blocks together. Trained analysts with time constraints can greatly benefit from modeling templates, but less technical users still have a huge risk of creating inaccurate models. If, instead of a template, a more focused, generic model (Focused Application Simulator & Trainer, FAST) is constructed, it is possible to build in additional levels of pre-defined logic and data consistency control. This paper will present a brief literature review of Dual Resource Constrained (DRC) systems and task assignment (movement decision) rules for cross-trained operators. These concepts have been incorporated into a FAST model that includes a non-programming way to define the decision making for production line balancing, and an interactive, simulation-based training method for teaching operators and supervisors the rules they are expected to follow.

Keywords and phrases

Operator movement rules, decision rules, scheduling rules, Dual Resource Constrained (DRC) systems, team manufacturing, cross-trained operators, generic models, Data-Driven Animation, Focused Application Simulator & Trainer (FAST), non-programming data entry, interactive training, The Line Balancing Decision Trainer (LBDT).

1 INTRODUCTION

1.1 Research Motivation

Team production systems with cross-trained operators have historically fallen under the general classification of Dual Resource Constrained Systems (DRC). These systems whose productivity is constrained because all machines are not fully staffed and, where operators can be transferred from one operation to another but movement is constrained by the operators' training. (Treleven, 1989). Previous analysis has assumed that there is a real-time control system that is aware of the current state of the entire system and can therefore dispatch workers to the best location within that system based on computationally intensive mathematical comparisons. Unfortunately, many team-based manufacturing operations do not have a real-time control system and therefore have a third constraint on productivity, the ability of human supervisors or operators to make effective line balancing (operator assignment) decisions. In this paper "line balancing" will be defined as: *the static and dynamic activities executed to: meet production demand, limit work-in-process (WIP), and control product throughput time.*

In virtually all of the DRC papers from the 1960s, 1970s, and most of the 1980s, the activity of moving operators from one task to another was referred to as a "labor transfer" that was decided and mechanically executed by a computer system or a management supervisor. In the environment of the late 1980s and 1990s self-directed work teams, team members are responsible for their own actions and therefore their own movement decisions. Since many GT or other team systems were devised to reduce the amount of WIP allowed in a production line, there is little time to react to imbalances and therefore it is also infeasible for a centralized production manager to make all of the decisions. In order for these "empowered" teams to be successful, decision training for operators and team leaders becomes a critical implementation issue.

While trying to facilitate an industry-wide changeover to team-oriented systems (in apparel manufacturing), this dramatic need for decision training was identified. [TC]^2, a non-profit research consortium, began a project to study the impact of movement rules on productivity and to devise an interactive, simulation-based training tool that could hopefully improve decision-making skills in production workers.

1.2 Operator "When" and "Where" Movement Rules

For people to make effective movement decisions, there must first be a policy that defines "When" a decision can be made. There are two general categories of decision points, time-based and situational. Once an operator gets to a decision point, there must be rules or methods that define how to select between a set of alternative destination stations -- these procedures will be defined as the "Where" movement rules because they determine where an operator will move to.

In the following literature review, the historical trend for "When" and "Where" rules will be discussed. In section 3 a new compact structure for generically describing both "When" and "Where" rules will be presented. The simplicity and power of this rule structure, (as a non-programming method to accept input for a FAST model) is described with an example in section 4. Section 5 discusses the issues of creating an interactive decision trainer with currently available simulation and animation tools and finally, section 6 suggests directions for future research.

2 LITERATURE REVIEW AND EVALUATION OF OPERATOR ASSIGNMENT RULES

2.1 Rule Definitions

The DRC literature is primarily concerned with job shop environments where workers complete orders for a variety of products that require various routings through process specific, not part specific machining centers/stations. There appeared to be equal or greater emphasis placed on the part dispatching rules as to the operator movement rules. Perhaps this can partially be attributed to dealing with theoretical rather than real systems. Treleven (1989) compared and charted the characteristics of 13 DRC studies of which only 4 modeled real systems. As stated in his Directions for Future Research, Treleven suggests that the most important [contribution] would be [defining] steps necessary to feasibly implement various rules. This paper is concerned with exactly that; first accurately modeling realistic team-managed flow shops and capturing the details of human balancing decisions, followed by devising a training method to aid in the implementation of new team systems.

Table 1 shows the "When" rules covered in the DRC studies. Rules 1-4 define system conditions that must be true before an operator can consider moving to another station. These are basically go/no go determinations. Rule 5 is time-based, suggesting that an operator must spend a minimum amount of time at a particular station before he/she is eligible to move to another station. Rule 6, like rules 1-4, involves checking a system condition but it is a secondary check or qualifier used in combination with a go/no go rule.

Table 1: "When" Movement Rules

1	Upon job completion
2	Move when idle
3	Maximum number of units remaining at current station before move
4	Can't leave if there is any work at current station
5	Minimum time before allowed to move
6	Must always check for available machine at destination station

Once it had been established that it was an appropriate time for an operator to move, Table 2 shows the computations that were used to select a new destination station for that operator. In some studies it was assumed that operators were completely cross-trained and capable of working at any station in the entire system. In others, the distinction of a division suggested a major seperation of the work force (physically different buildings or departments under different management control). Sometimes it was possible for operators to move to any station within a division but it was not possible to move between divisions. In the apparel industry complete cross-training is rare, usually operators are trained on 2 or 3 operations and generally not more than 5 unique tasks.

Table 2: "Where" Movement Rules

1	Max jobs in queue, (LNQ)
2	Station with shortest operation time (SOT)
3	Operator's max efficiency (MEFF)
4	Critical ratio (CRT)
5	Station with oldest job in queue (First In System First Served, FISFS)
6	Max queue time accumulated by jobs at a specific station
7	Station with job that has least slack per remaining number of operations (SPR)
8	Station with job in queue with highest priority

2.2 Feasibility of Rules Being Computed by Human Decision-Makers

In the apparel industry as in many others, cross-trained teams have been developed. Since there are no real-time, computer control systems, operator movement rules must be executed by people working on the production floor. Therefore, the previous list of "Where" rules must be examined and evaluated based on the feasibiity of operators being able to calculate the comparisons. As a reality check, it must be possible for an operator to make her assessment by: 1) visually inspecting the system, or 2) reading a simple digital display counter showing units or batches of WIP at a station, or 3) personal knowledge. Rules 4-8 require a database of information and many mathematical comparisons leaving only rules 1-3 as alternatives for human decision-makers. In contrast, all of the "When" rules are feasible for humans to assess.

2.3 Extension of Rules Considered

While the original list of 8 "Where" rules covers a wide variety of circumstances, the 3 human rules are very broad and cannot adequately cover as many situations. By interviewing managers, supervisors, and engineers at more than 20 sewn products manufacturers (including Russell Corp., Osh Kosh B'Gosh, Mattel Toys, and Milliken) it was determined that there is currently no prescribed method for assessing the system status or determining where operators should move. People learn from experience. However, there were many similarities in the characteristics of the decision making and there were additional factors beyond the rules listed above that were actually being evaluated by floor personnel. The authors are proposing the additional factors listed in Table 3 as new components of movement rules.

Table 3: Additional Factors to Be Considered in Movement Rules

1	Batches completed at current station
2	Total System WIP
3	Unskilled Tasks
4	Assembly Station has no component parts
5	2 person task currently has only 1 person

Factor 1 is an alternative "When" rule to rule 5. Instead of spending a minimum amount of clock time at a station, some companies put restrictions on the minimum number of batches completed at a station before an operator can move. Taking into account ergonomic concerns about repetitive motion disorders, some companies also set a maximum amount of time that a person can stay at a station. If this condition exists an operator must move to another task.

In contrast to job shop systems, it is possible to control and manage the time in system for batches in a flow shop by limiting the total WIP (factor 2) in a production line and by setting WIP limits at each processing station. These WIP limits become trigger points or indicators that the system is getting out of balance and will be used as the basis for many operator movement rules. In companies such as Russell and Osh Kosh B'Gosh there is a fixed number of carts assigned to a production line, each cart can hold 1 batch of garments. This provides a physical limitation to the total WIP.

Factors 3, 4 and 5 will be added to the list of "Where" rules. Unskilled tasks, those that do not require specific training, include items such as sorting parts, folding or packing boxes. Under normal, balanced circumstances these tasks are often low priority, but they are viable choices when an operator becomes idle ("When" rule 2). Factor 4 exploits the operator's knowledge of a specific process plan. If an operator notices an assembly station starved for parts, the person can/should move to a station that processes the required components. Unlike unskilled tasks, all other operations are assumed to require specific training, and if an operator is not trained on a station, it is not a possible destination.

Finally, factor 5 was described by companies that processed large, bulky items such as draperies, sleeping bags, and air bags. Some tasks actually require 2 operators; therefore it could be part of an operator's decision process or "Where" rule to check for any operation (that she is trained on) that requires 2 operators but currently only has one.

Section 3 describes how all of these rules and conditions can be expressed in a simplistic data structure and therefore modeled with a compact, extendable section of generic model code.

3 PROPOSED STRUCTURE FOR DATA-DRIVEN INPUT OF DECISION RULES

In attempting to compare the effectiveness of operator movement rules for team-based production systems, it was discovered that modeling a finite set of specific rules was a limiting and ineffective solution. The rules also need to be flexible (data-driven) so they can be adapted to the details of each specific production system that could be addressed with a FAST model. To create an extendable set of rules, a generic rule structure was devised. The logic of this process has been divided into two levels, the first will be referred to as the actual Movement Rules and the second will be called Movement Decisions.

A Movement rule consists of a set of sequential "Checks" of system conditions and comparisons resulting in one candidate destination station. A check can be read like an IF THEN statement (see Table 4). IF... the DATA option (a system condition such as WIP at a station), is compared to a system constant or specific numeric VALUE using the stated mathematical CONDITION, and the answer is true for any of the stations stated in the RANGE, THEN...that station becomes a candidate destination. Often, the first check in a Movement Rule is a "When" rule that simply has a true or false answer. If the check returns false, the rule is terminated with no resulting destination station. Each subsequent check can test a unique system characteristic or it can further filter the set of alternatives determined from the "Previous Check". Potentially, at the beginnning of the evaluation of a rule an operator could select any station in the system. The first check could limit the choices to only the stations the operator is specifically trained on. A second check could be used to eliminate any stations that do not have an available machine and a third check could pare it down to stations that are over their defined WIP limit. If the filtering process eliminates all possibilities, again the rule ends without a destination station. In order to arrive at a single station option it could be necessary to provide a tie breaking mechanism such as a MINimum or MAXimum CONDITION in addition to the mathematical operators.

Table 4: Basic Data Structure of a Movement Rule

DATA	CONDITION	VALUE	RANGE
System Status Variable	Mathematical comparison operator	The standard to which DATA is compared	Set of Stations or operators to evaluate

A Movement Decision consists of a series of prioritized "Choices" of Movement Rules. The decision process will sequentially evaluate the rules until one yields a valid station. This station becomes the operator's destination and all subsequent rules are ignored. A decision with multiple choices more closely models the human thinking process, especially as a way of dealing with exceptions and special case situations. For example, the general movement rule may be to select the station with the MAX WIP, but, if an assembly station is running out of component parts this special case would dictate following a different rule that selects one of the stations that feeds parts to the starved assembly station. This situation could easily be accomodated with a Movement Decision consisting of 2 choices; the first choice would be to evaluate the rule checking the assembly station, and the second choice would follow the MAX WIP rule.

Section 4 describes a specific example of incorporating this generic rule structure into a FAST model for sewn products production systems.

4 THE LINE BALANCING DECISION TRAINER (LBDT) & ITS DATA-DRIVEN RULE DEFINITIONS

The LBDT is a FAST model that was designed to provide a non-programming, user-friendly analysis and training environment for team based apparel production systems and textile machine tending systems. The product consists of: 1) a Windows application (written in C++) for data entry and static analysis, 2) a SIMAN V generic model, 3) a generic CINEMA V animation with C code to provide an interaction menu during runtime, and 4) a customized report generator contained within the SIMAN model. Such a simulator was devised so that managers or shop-floor personnel, with little or no computer skills, could effectively solve production problems with the aid of simulation yet without requiring modeling expertise.

One of the greatest challenges was devising a way to implement a flexible set of operator movement rules that could be customized by data input from a user. One important modeling choice was to implement operators as entities so they could execute decision logic. It was assumed that processing cycles cannot be preempted therefore decisions can only be made at the completion of an operation/delay ("When" rule 1). Operators are defined with a specific set of skills and are assigned to follow a defined Movement Decision. These decision processes can be the same for all operators or they can be customized for each individual.

In the data entry portion of the LBDT, users can define their own Movement Rules and Movement Decisions just as easily as they can define the number of machines at a station or the name of an operation.

4.1 Defining Movement Rules

Figure 1 shows the Movement Rule Definition screen in the data input environment for the LBDT. The user can quickly define his/her own rule by adding checks to the grid. Each category of the data structure contains a pull-down list of options that the user can select from. In the actual software there is a set of predefined generic rules that can be used as is or modified by the user. A generic rule is one that does not refer to a specific station or operator. Specific rules can also be devised, for example, to closely monitor the bottleneck station in a production line. Figure 2 shows an example of a specific rule that could only be defined after data for a particular system was entered.

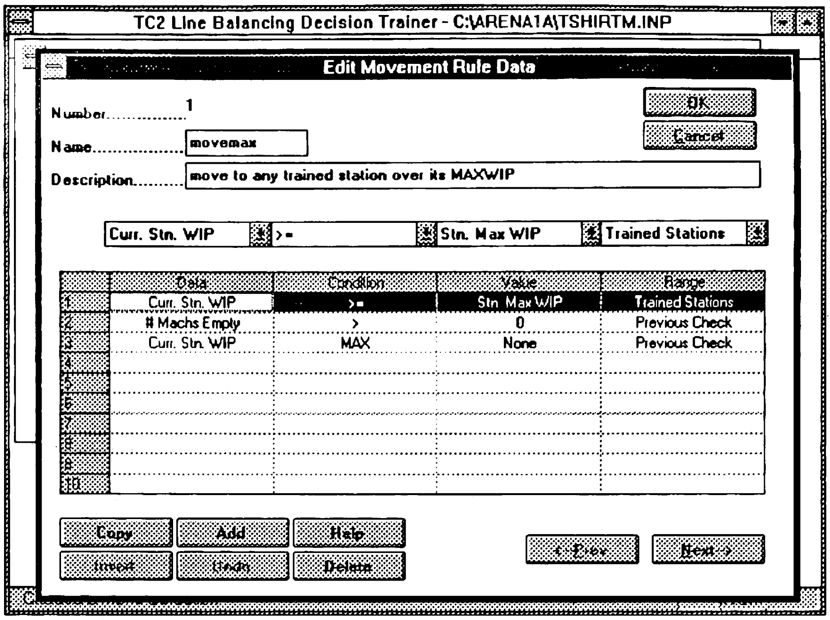

Figure 1: Movement Rule Definition Screen

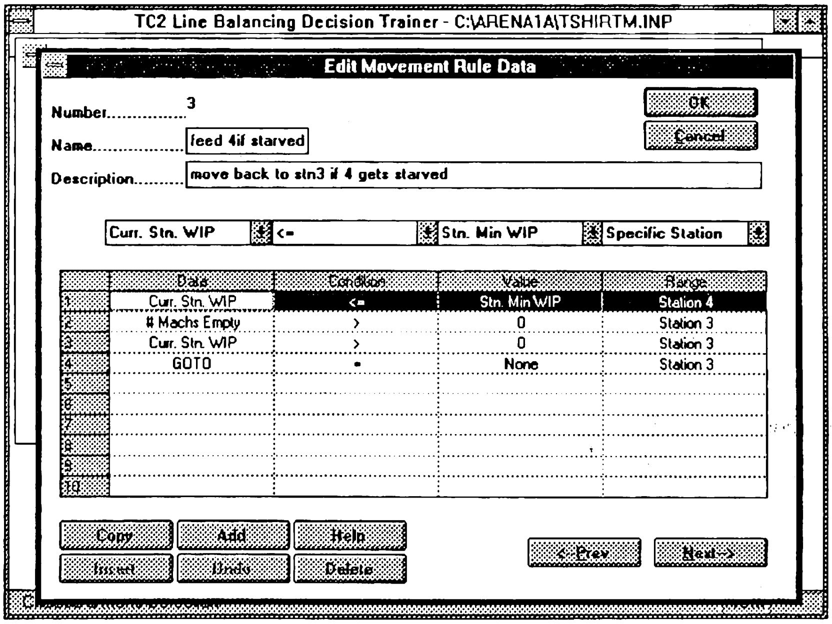

Figure 2: Movement Rule Example

4.2 Defining Movement Decisions

Defining a Movement Decision involves selecting the rule or set of rules that should be evaluated. This data entry screen (Figure 3) shows the list of defined rules and asks the user to identify the priority for each selected rule. Note that the pull-down menu contains the rules specifically defined by the user. After the decisions have been defined, they must be applied to the operators because it is assumed that operators cannot move unless they have a decision process to follow.

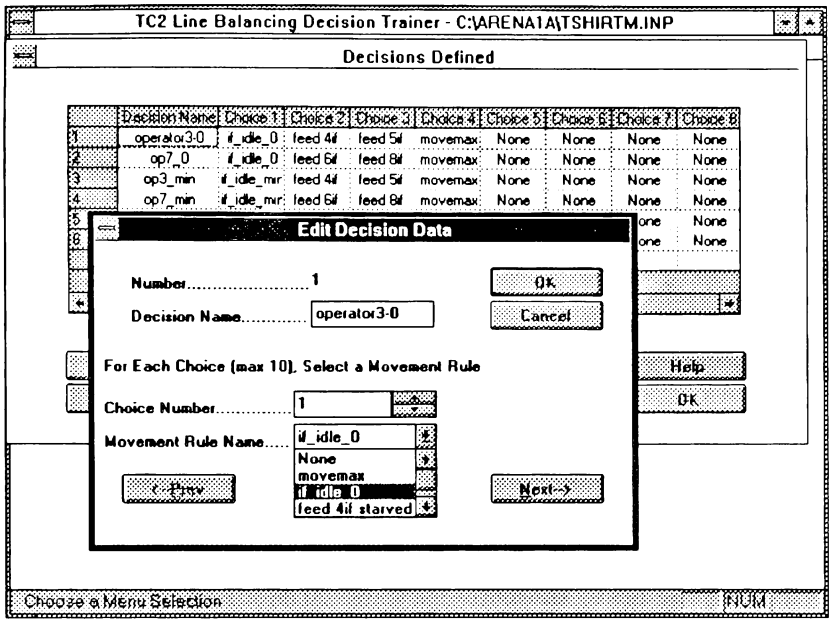

Figure 3: Movement Decision Definition Screen

4.3 Analysis and Comparison of Rules and Decisions

With this flexible rule structure that is customized by specific system characteristics and by user requirements, it is literally possible to define thousands of unique rule combinations. By keeping other features and parameters of a system the same, it is possible to isolate and analyze the effects of the movement rules on the system performance measures. This FAST model provides output statistics for batch throughput time, total units & batches produced, average units per hour, and both grouped and specific operator utilization measures.

As shown in Table 5, the DATA options for the LBDT Movement Rules are all ones that can be evaluated by a human decision maker, with the possible exception of WIP ratio. The WIP ratio calculation requires that each station's current WIP be compared to its stated maximum, resulting in a ratio that is usually between 0 and 2. If a few ratios are greater than 1.0 it is now possible to make a judgement as to which is in a worse relative position. The original "Where" rules 4-8 could also be added to the DATA options. This would also allow an analyst to compare the relative cost of using human rules versus rules that require computer calculations. A company could then quantitively estimate the marginal value of adding real-time capabilities. For example, based on statistical analysis the Station WIP Ratio does perform better than the count of Current Station WIP as a tie breaking mechanism.

Table 5: Movement Rule Options in the LBDT

DATA	CONDITION	VALUE	RANGE
Bundles Completed	=	Minimum Bundles	Current Operator
Time at Station	>	Maximum Bundes	Current Station
Total System WIP	>=	Minimum Time	All Trained Stations
Current Station WIP	<	Maximum Time	All Stations
Station WIP Ratio	<=	System MIN WIP	All Operators
Queue of Unskilled	NE	System MAX WIP	Previous Check
Machines Available	MIN	Zero	Specific Station (x)
# Waiting for 2nd Op	MAX	enter specific value	Specific Operator (x)
# Op Waiting for Parts		Station MIN WIP	
Trained Efficiency		Station MAX WIP	
GOTO		Station Alarm WIP	

5 INTERACTIVE METHOD TO TEACH DECISION MAKING SKILLS

In production systems with human decision makers, simulation analysis can only be a predictor of performance because actual performance directly depends on the ability of the people to execute the Movement Decisions and Rules that were used in the model. To better insure the probability of reality matching the simulated results, the same generic model used for analysis can be used as a training tool for the decision makers. The model must be animated and must be capable of being interrupted for users to interact with the system. The training is similar to a video game with a purpose. The decision makers watch the animation of their production line and interactively make all of the movement decision that would need to be made on the production floor. In order to act on the user's decisions, the simulation and animation must be able to run concurrently, (post processed animations are not acceptable) and must have a mechanism for accepting user input. The simulation would respond to the user input and the trainee would immediately see the consequences of his/her decision.

5.1 Lessons & Sphere of Control

In the LBDT mentioned above, a structured set of training lessons was created to introduce the concepts of Movement Rules and Decisions. As the lessons progressed, the user's sphere of control was increased and the amount of visual information/feedback was increased accordingly. Initially, a user was allowed to move only one operator. In subsequent lessons the user could control more and more operators. One exciting benefit of the generic model and Movement Decisions is that decision training can be customized for specific products and people by simple data entry. Lessons can also be created that simulate the system for different functional perspectives (i.e. an operator's view, a supervisor's view, or a production manager's view). To achieve this, some operators could be defined with movement decisions (which would cause them to move automatically), and others could be defined with multiple skills but no movement decision. The latter type of operator would require the trainee to make the movement decisions. If all operators except one had movement decisions, this would simulate the perspective of one operator's view of an entire team. She could control her own movements but the other people would just move on their own. This would also facilitate the creation of a supervisor or team leader training scenario. In such a case the operators may follow basic rules but the supervisor can still intervene to make decisions in special circumstances.

5.2 Self-adjusting, Data-Driven Animation

For both the credibility of the generic model and the quality and feasibility of using the model as a training tool, the accompanying animation must be data-driven just as the logic and scope of the system are. With current animation products this is virtually impossible to completely achieve, yet partial solutions have been created. Particularly for training, the user must be able to easily distinguish the unique identity of the operators and the stations in the system. This suggests a numbering or naming convention. Preferrably, the identifiers that were input by the user to define their production scenario would be used in the display.

5.3 Run-time User Interaction

In order for the user to tell the simulation he or she wants to make a decision it is necessary to be able to interrupt the run. At this time there must be an interaction mechanism for the user to tell the simulation what to do. In the LBDT program, SIMAN V was used which provided a text-based menu system that is accessible during runtime when the user hits function keys on the keyboard. The simulation and animation would be temporarily suspended and a small window would be displayed in the upper corner of the screen. The movement interaction asked two simple questions: 1) Who do you want to move, and 2) Where do you want to move the operator. Like the other animation features this interaction should be data-driven, based on the input to the generic model. If the user defined 5 stations and 3 operators these should be the only viable options. Customization with names would certainly add clarity and easy recognition to this activity.

6 CONCLUSIONS AND SUGGESTIONS FOR FUTURE RESEARCH

The generic structure for Movement Rules and Movement Decisions presented in this paper represents a breakthrough in the complexity of logic and control that can be represented in a non-programming data input system that supports a generic simulation model. Although the specific control of operator movements was discussed, the structure (and underlying coding) could be applied to general scheduling or part dispatching rules as well. When applying the historical DRC research to current issues for team-based manufacturing operations, it is important to consider rules that can be computed by human decision makers. By using the generic rule structure, statistical comparisons can be made, comparing human rules to each other and to more complex rules that require computer calculations.

In creating the FAST model for sewn products production systems, it was discovered that while generic modeling can be a powerful concept to provide problem solving tools to non-modelers, the supporting elements of a total solution are laging behind in capability. Specifically, animation packages that can be data-driven, methods of interaction to use animations for training systems (e.g. customizable buttons, menu interaction windows, etc.), and data control features in the simulation language/ animation (protecting data from certain users). These topics would be valuable research topics, particularly for the simulation software vendors.

ACKNOWLEDGEMENTS

The authors wish to entend their appreciation to Kenneth A. Powell, Jr. and D. Michelle Benjamin who were members of the project team for the commercialization of the LBDT and to the Department of Commerce for funding the [TC]^2 research work.

REFERENCES

Armstrong, F. Bradley, B. W. Mazziotti, D. M. Benjamin, and K. Powell, *"Focused Analysis and Training Environments"*, Proceedings of The Winter Simulation Conference 1994.

Benjamin, D. Michelle, B. W. Mazziotti, F. B. Armstrong, *"Issues and Requirements for Building a Generic Animation"*, Proceedings of The Winter Simulation Conference 1994.

Fryer, John S. *"Operating Policies in Multiechelon Dual-Constraint Job Shops"*, Management Science, Vol 19, No. 9, May 1973.

Fryer, John S. *" Labor Flexibility in Multiechelon Dual-Constraint Job Shops"*, Management Science, Vo 20, No. 7, March 1974.

LeGrande, Earl, *"The development of a factory simulation system using actual operating data"*, Management Technology, Vol. 3, No. 1, May 1963.

Mazziotti, Barbara Werner, F. Bradley Armstrong, Kenneth A. Powell, Jr., *"Teaching Production Line Balancing With an Interactive, Simulation-Based Training System"*, Proceedings of the Winter Simulation Conference, December 1993, Los Angeles, CA.

Ozdemire, Nur E., " *"Measuring The User acceptance of generic manufacturing simulation models by review of Modeling Assumptions"*, Proceedings of The Winter Simulation Conference 1991, Barry L. Nelson, W. David Kelton, Gordon M. Clark, Editors.

Rochette, Rene and Randall P. Sadowski, *"A Statistical Comparison of the performance of simple dispatching rules for a particular set of job shops"*, International Journal of Production Research, 1976, Vol. 14, No. 1, 63-75.

Treleven, Mark, *"A Literature Review of Dual Resource Constrained Systems"*, IIE Transactions, Sept. 1989, Volume 21, Number 3.

Weeks, James K. and John S. Fryer, *"A Simulation Study of operating policies in a hypothetical dual-constrained job shop"*, Management Science, Vol 22, No. 12, August 1976.

AUTHOR BIOGRAPHIES

BARBARA WERNER MAZZIOTTI is currently the Manager of Simulation Services at the Textile/Clothing Technology Corporation. For the past 4 years, Mrs. Mazziotti has been challenged with bringing the technology of process simulation to the apparel and textile industries. In this position she has focused on creating data-driven, flexible simulation models and animations for non-expert users. In addition to conducting seminars on simulation and production systems, she has completed consulting projects with more that 20 retail, apparel and textile companies. Prior to [TC]^2, Barbara was on the consulting staff at Systems Modeling Corporation, teaching SIMAN and CINEMA, managing projects and doing analysis for a variety of industries and applications. Barbara began her career at General Motors as a Simulation Project Engineer for a group of metal stamping and automotive assembly plants. Barbara has a B.S. in Operations Research and Industrial Engineering from Cornell University and is completing an M.S. in Industrial Engineering at North Carolina State University. She is a member of SCS and a senior member of IIE.

F. BRADLEY ARMSTRONG is a Fellow Engineer for Asea, Brown, Boveri in the Engineering and Manufacturing Productivity Center where he is an internal consultant for simulation and world class manufacturing methods. He also is the owner of Simulation Engineering Associates (SEA). Prior to forming his own company, he was a Senior Staff Engineer at Hughes Aircraft company where he worked as an internal simulation consultant. He also worked as a Senior Systems Analyst for Pritsker and Associates, and as an Operations Analyst for General Dynamics. He received a B.S. in Mechanical Engineering from the University of Texas at Austin in 1981, an M.S. degree in Industrial Engineering from Purdue University in 1986, and is completing an M.S. degree in Integrated Manufacturing and Systems Engineering. He is a professionally registered engineer in North Carolina, California, and Indiana. He is a member of IIE and SCS. His current interest is in using simulation, statistics, and GUI tools to build Focused Analysis and Training Environments.