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PRODUCT-MIX ANALYSIS WITH DISCRETE EVENT SIMULATION

Raid Al-Aomar

Classic Advanced Development Systems, Inc.
Troy, MI 48083, U.S.A.

ABSTRACT

Discrete Event Simulation (DES) has been used as a design and validation tool in various production and business applications. DES can also be utilized for analyzing the product-mix for production planning and scheduling. Product-mix decisions using analytical methods such as Linear Programming (LP) are usually made so that the market demand is met and the firm profit is maximized. However, the complexity and stochastic and dynamic nature of real-world production and business systems may lead to production levels that are different from those determined by analytical methods. Also, coping with the dynamic changes in the product-mix usually requires enhancing system parameters and/or process configuration. Therefore, its in some cases essential to conduct the product-mix analysis using a DES model that accounts for the complexity and stochastic and dynamic behavior of real-world systems. Utilizing DES to measure the system response to potential changes in product-mix is necessary to arrive at a flexible system configuration that is adaptable to dynamic changes in the product-mix. Therefore, the primary goals of this paper are to highlight the importance of analyzing the product-mix with DES, present a methodology for performing the analysis, and provide a case study to clarify the methodology.

1 INTRODUCTION

Production and business systems are key building blocks in the structure of modern industrial societies. Different human activities and the prosperity of whole nations are highly dependent on the performance of production and business systems. Companies and industrial firms, through which production and business operations are usually performed, represent the major sector of today's global economy. Therefore, in the last decade, companies have made the continuous improvement of production and business systems a milestone in their strategic planning for the new millennium. To remain competitive, companies have to maintain a high-level of performance by maintaining high quality, low cost, low manufacturing lead times, and high customer satisfaction. It is usually asserted that production and business operations have the potential to strengthen or weaken a company's competitive ability. Therefore, and as a result of fierce competition and decreasing business safety margins, efficient and robust production and business operations become a necessity for survival in the marketplace.

Because of this, improving the performance of production and business systems has been the primary interest of decision-makers and engineers. Indeed, Industrial Engineering (IE), as a profession and a science, plays a central role in the efforts towards improvement in these systems. Many industrial engineering subjects such as Operations Research, Quality Control, and Systems Modeling offer robust and efficient design and problem-solving tools with the ultimate aim of performance enhancement. Examples of this performance can be the throughput of a factory, the quality and reliability of a product, or the profit of an organization.

Discrete Event Simulation (DES), as an IE tool for system design and improvement, has undergone a tremendous development in the last decade. This development can be pictured through the growing capabilities of simulation software tools and the application of simulation solutions to a variety of real-world problems in different business arenas. With the aid of DES, companies were able to design efficient production and business systems, validate and tradeoff proposed design solution alternatives, troubleshoot potential problems, improve systems performance metrics, and, consequently, cut cost, meet targets, and boost sales and profits. Examples of DES applications are utilizing DES as a system design tool (Al-Aomar (1997)), modeling at the machine control-level (Al-Aomar and Cook (1998)), designing manufacturing processes (Law (1991)), and planning business operations (Pedgen (1994)).

Designing flexibility into production and business systems is, therefore, a key matter for success and survival in today's market. Businesses have inevitable obligation to deal with supply and demand fluctuations, changes in work scope, and trend dynamics of the market. Therefore, lean production and business systems demand continual improvement of delivery times, operating costs, capacities, material utilization, and information flow. DES has helped companies design and maintain the flexibility of their key production and business operations and, therefore, remain competitive. Adapting to changes in the product-mix is one aspect of this flexibility. Dynamic changes in demand, supply, and manufacturing strategies force companies to make continuous changes to the product-mix. Making such changes gracefully and effectively can be only accomplished when systems design is based on flexible production and business operations. The issue becomes even more challenging when the frequency of product-mix change increases. Therefore, under such conditions, determining the optimum product-mix and analyzing its implications as an integral part of the design process become essential for achieving robust and flexible production and business systems.

2 PRODUCT-MIX DECISIONS

An organization's product-mix is the percentage of total output devoted to each product (Vonderembse and White (1994)). For example, an agency that sells life, house, and automobile insurance might have a product-mix of 20%, 30%, and 50% for the three services respectively. In production, for example, an automobile manufacturer might have a product-mix of 50%, 25%, and 25% for cars, pick-up trucks, and sport utility vehicles (SUVs). Product mix analysis focuses on determining the optimum product-mix and highlights the implications of varying the percentage of each product on different production and business activities. Since different products have different production rates, the capacity requirements for each mix of products may, in some cases, drastically change. For example, increasing the proportion of a certain product in a production schedule may require duplicating a certain machine tool to cope with the rate of production which may eventually lead to adding a parallel processing line and a new line of products to make use of the added capacity. Therefore, product-mix analysis aims at answering the question "How does product-mix changes affect system capacity?" System capacity can be defined in terms of buffer sizes and manufacturing resources types, set-up, utilization, and availability.

Product-mix decisions are usually influenced by the product selection decision. When a firm has a current market for two or more products, a decision is usually taken to introduce more than one product to the market in an effort to increase market share and profitability. Deciding to produce more than one product type or to provide more than one-service leads to the issue of product-mix selection. Product selection decision is usually based on the organization goals, environment, and the organization's production, marketing, and financing strategies.

Once product types are selected, decisions must again be made within each product line with respect to which mix of products to produce and which production processes to use in view of cost, capacity, and the "theory of constraints". Product-mix decisions are typically dependent on market research and marketing strategies. Therefore, the product-mix in a production plan is not usually fixed. The mix may change dynamically at different time periods. Figure 1 shows examples of product-mix changes in different time periods. As the frequency of product-mix changes increase, the flexibility in the structure of the organization and production system should be also increased in order to adapt with these changes without impacting business targets and customer satisfaction.

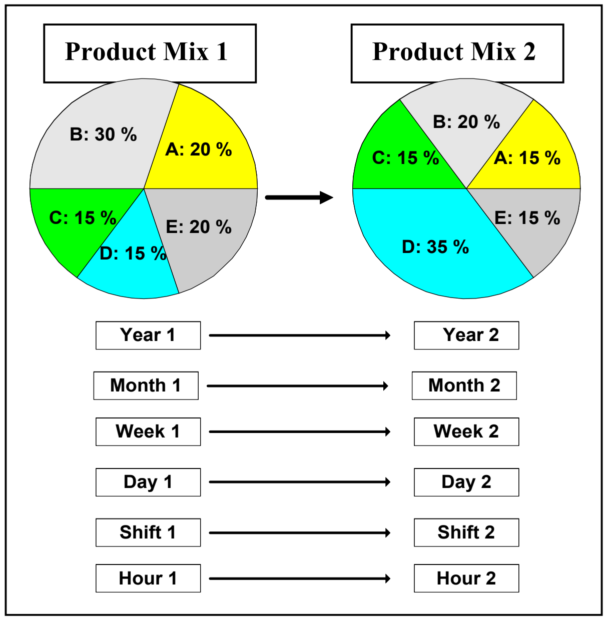

Figure 1: Product-Mix Dynamic Changes

3 PRODUCT-MIX DETERMINATION

For some firms, determining the product-mix is one of the most important decisions relating to production planning. Such decision implies utilizing limited resources to maximize the net value of the output from the production facilities. The quantity produced from each product in a certain time period results in utilizing certain resources for that time, consuming certain amount of raw materials, using certain labor skills and various production centers, and so on. The objective of the product-mix decision in the overall production plan is to find the product mix and the production program that maximizes the total contribution to profit/throughput subject to constraints imposed by resource limitations, market demand, and sales forecast. According to Johnson and Montgomery (1974), the following features characterize a product-mix determination problem:

1. Maximization of contribution to profit and overhead.
2. Constraints resulting from resource limitations.
3. Bound constraints on planned production.

Product-mix determination under such characteristics is usually approached using a traditional Linear Programming (LP) model. The LP model is formulated so that the solution eventually leads to the amount that should be produced from each product type in a production batch so that the overall profit is maximized.

Product-mix decisions can be then validated using a DES model of the underlying system. Using DES, the product-mix can be analyzed and the system design can be adapted to different changes in product-mix.

3.1 Product-Mix Decisions via LP

LP is a quantitative method of product-mix analysis with extensive applications in the production and business arenas. Many firms have found that Linear Programming (LP) methods are useful techniques for assisting in the product-mix decisions. LP is an analytical approach that is utilized to determine the optimum product-mix so that a certain criterion is met. Using LP an objective function is maximized or minimized subject to a certain set of constraints. In most cases, the least costly mix of products is obtained from the solution of the LP problem.

Other LP applications beside product-mix determination include capital budgeting, financial planning, work scheduling, and line balancing (Winston (1994)). Therefore, product-mix determination can be considered as one application of LP for short-term scheduling. LP problems can be solved using graphical method or using simplex method (see Winston (1994)).

Most large-scale problems nowadays are solved using software tools by the computer. However, it is always essential to gain at least a basic understanding of the solution methodology along with the knowledge of how to formulate and set up the problem, interpret the results, and draw the right inferences.

Johnson and Montgomery (1974) presented a mathematical formulation for the product-mix problem as a constrained LP model. They also illustrated two approaches for dealing with uncertainty in demand. Applying the LP model requires the following information:

1. Revenue obtained from selling one unit of each product type.
2. Unit variable cost of producing a unit of each product type.
3. Required minimum production level of each product type in the planning period.
4. Maximum potential sales of each product type in the planning period.
5. Number of units of each resource that are required to produce one unit of each product type.
6. Amount of each resource available during the planning period.

3.2 Product-Mix Analysis via DES

The LP as an analytical approach assumes that production and business processes involved in the production plan are capable of meeting the production requirements within the planning period. However, because of the stochastic variability in real-world processes, the limitations caused by control logic on the floor, along with the dynamic nature of demand and sales, a LP model may result in a product-mix that cannot be actually obtained from the current design of production and business processes. Variability impacts the availability of production resources, control logic may result in process lock-ups and delays, and dynamic demand and sales may lead to frequent changes in the production plan. Therefore, in.

DES model can be involved in the product-mix analysis in two ways, as a part of the system design stage to build flexibility in the system design that accounts for projected product-mixes, and as a part of the production implementation stage in order to adapt the production system to dynamic changes in the product-mix. An illustration of involving DES in the system design stage is shown in Figure 2.

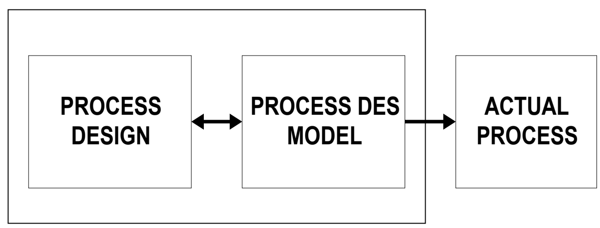

Figure 2: Utilizing DES in the System Design Stage

In this approach, the process design is enhanced before implementing the actual process in order to establish the flexibility required for handling different product mixes. This may include designing flexibility in buffer capacities, resource rates and availability, and logical design. Further, designing the system includes designing the supply chain that provides the necessary parts for assembly operations.

An illustration of involving DES in the system implementation stage is shown in Figure 3. In this approach, the actual process design is enhanced based on the actual dynamic changes in product mixes as decided by market demand and products sales. This may include

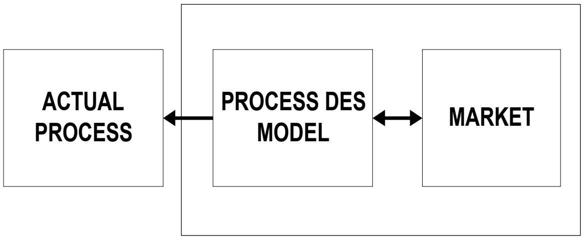

Figure 3: Utilizing DES in the Process Implementation

enhancing the design of buffer capacities, resource rates and availability, and process logic. Further, the supply chain design may also be enhanced so that parts required for assembly operations are available on time.

4 ADAPTING SYSTEMS TO PRODUCT-MIX CHANGES

System adaptation to product-mix changes occurs in response to two primary actions, adjusting current product-mix and adding a new product to the mix. Eliminating a product from the current mix is considered as an adjustment of the eliminated product percentage from its current value to zero and an increment to the percentage of one or more of other products in the mix accordingly so that product percentages sum to 100. Adapting systems for both types of change in product-mix can be approached in two ways, system parametric design and system non-parametric (structural) design. In some cases, system adaptation requires performing both parametric and non-parametric designs. Examples of parameters that can be adjusted in the model are buffer sizes, cycle times, and resources availability. Examples of structural changes are layout changes, adding elements and resources, and enhancing the system controls.

Adjusting system parameters to produce the new product-mix without altering its structure can be achieved using the system DES model. System parametric design with DES involves varying model parameters and selecting the combination of these parameters that leads the best performance and meets product-mix requirements. On the other hand, altering the system structure (in terms of elements, configuration, and interrelationships) requires building and analyzing several system DES models to implement these structural changes.

Using DES, adapting systems to product-mix changes can be performed at two levels in the organization, a micro-level design at the production system level and a macro-level design at the enterprise level. The ultimate objective of both levels of analysis is to build flexibility into the production and business operations of the firm so that it can adapt to dynamic changes in the product-mix. Analyzing product-mix at the production system level involves bottleneck analysis, buffer analysis, and downtime analysis. As shown in Figure 4, adaptation analyses are conducted at the production line level to cope with product-mix changes received from the sales department in the organization.

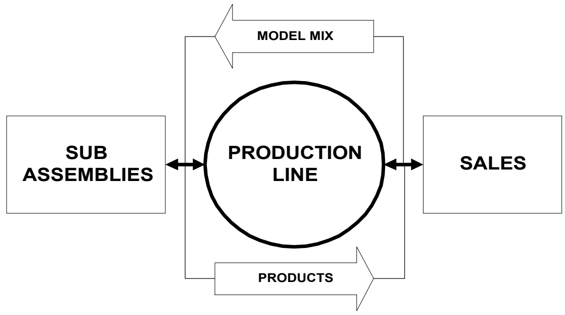

Figure 4: Micro-Level System Adaptation

This implies designing the parameters of the production line and adjusting the flow of products from sub-assemblies building and feeding subs to the production line and from the production line to the sales department.

On the other hand, analyzing the product mix at the enterprise level, as shown in Figure 5, involves supply chain analysis and logistics design. At this macro-level, the flow of goods, service, and information from supply chain to the enterprise and from the enterprise to the market is enhanced to meet the demand and cash flow targets coming from the marketplace.

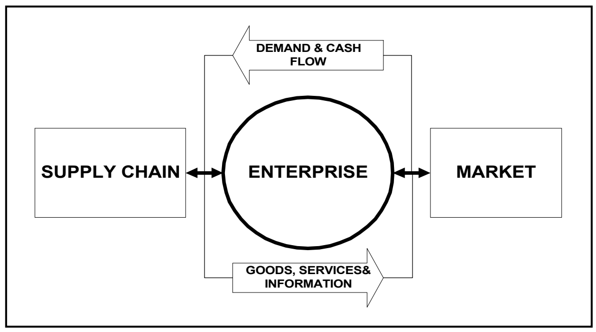

Figure 5: Macro-Level System Adaptation

5 CASE STUDY

The objective of this case study is to highlight the importance of conducting product-mix analysis via DES, clarify the adaptation of a production system to product-mix decisions, and analyze the product-mix at the production system level. The case study represents a hypothetical production line in a certain company that produces car toys. The process flow of the underlying production system is shown in Figure 6. Bodies of car toys enter the production line from another department. Several parts are then assembled to the toy body in the production process flow in order to build the car toy. Three types of sub-assemblies are used to feed the line with parts (A_1, B, and A_2). Assembly and processing operations take place through 10 sequential stations. A description of these operations is shown in Table 1. Upon completion, finished car toys depart from the system to a warehouse to be ready for shipping. The line was originally designed to produce

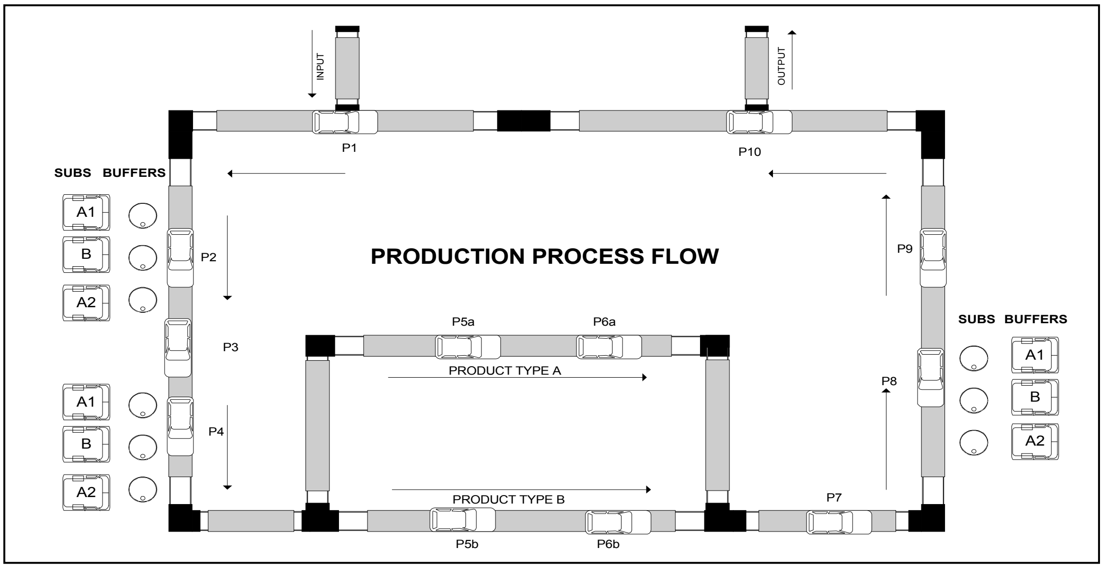

Figure 6: Process Flow of Car Toy Production Line

Table 1: Description of Production Processes in the Toy Production Line

Production Process	Description	Dedication
P1	Checking input body of car toy	All product types
P2	Inserting the car interior	All product types
P3	Fixing the car interior into the car body	All product types
P4	Loading body closures	All product types
P5a	Adhering Hood & Deck-lid closures	Product type A
P5b	Adhering Hood & Deck-id closures	Product type B
P6a	Adhering doors-closures	Product type A
P6b	Adhering doors-closures	Product type B
P7	Overall quality check	All product types
P8	Installing car wheels	All product types
P9	Packaging the car toy	All product types
P10	Labeling output packages	All product types

two types of car toys (A_1 and A_2). However, based on a recommendation of a recent market research, the company decided to introduce a new product type (B) of the car toy to the market. The structure of the production process remains the same. However, new sub-assemblies are added to feed the line with the parts dedicated to the new product and duplication of stations 5 and 6 was found necessary to keep up with the required production rates.

5.1 Product-Mix Decisions via LP

To determine the product-mix for the three products in the production plan, a Linear Programming (LP) model was developed based on the projected demand of the market research, the costs and unit prices recommended by the marketing, and the availability of sub-assemblies feeding subs and in-system production processes. The objective of the LP model is to determine the number of units produced per hour from each production type within the existing constraints so that profit is maximized. Throughput of each product type is measured in terms of net Job Per Hour (JPH). Table 2 presents the results of solving the LP model. To meet these production requirements of the LP model, the product-mix that should be implemented in the production plan is shown in Table 3.

5.2 Product-Mix Analysis via DES

A DES simulation model is built and validated to represent the production line of car toys. The model considers production rates, buffering, tool failures, and the availability of sub-assemblies operations. The simulation model is built in order to meet the following goals:

1. Determine the system net throughput capability using the product-mix requirement determined by the LP model.

2. Utilize the DES model to adapt the production line to the required product-mix.
3. Provide a full-blown product mix analysis that represents system capability at a sweep of product mixes.

In the DES model, the rates shown in Table 4 were used at the feeding subs for each product type and the buffer size and availability of each feeding sub are shown in Table 5.

The simulation results based on run controls of 24 hours warm-up period and a run-time of a month of 3-shift production schedule lead to the net throughput capability values shown in Table 6. Comparing the system net throughput capability obtained from the DES model to that obtained from the LP model leads to the conclusion that the system (in its actual performance) cannot meet net throughput requirement for the proposed product-mix. This is because the system DES model considers the dynamic and stochastic variability of real-world processes in its estimation for net throughput capability.

Since mainline operations were proven to meet requirements, three parameters are altered using the DES model in order to adapt the system to the required Product-mix:

1. The rates of the sub-assemblies feeding subs.
2. The Stand Alone Availability (SAA) of the feeding subs.
3. The buffer sizes between the feeding subs and the mainline operations.

Using the DES model, the new rates of the feeding subs are adjusted as shown in Table 7. Also, using the DES model, the new SAA and buffer sizes of the feeding subs are adjusted as shown in Table 8. After adapting the system to the proposed product-mix requirements, the new net throughput capability obtained from the DES model is shown in Table 9. The results of the DES model imply that the system net throughput capability (70.4 JPH) is met for the proposed product-mix (75% of type B, 12.5% of type A_1, and 12.5% of type A_2). Further the DES model is utilized to provide a full-blown product-mix analysis to determine system net throughput capability at a sweep of product-mixes. The results of product-mix analysis with DES are summarized in Table 10.

Table 2: System Net Throughput Requirements

Product Type	*Product B*	*Product A1*	*Product A2*	*Total JPH*
Net Throughput	52.8 JPH	8.8 JPH	8.8 JPH	70.4 JPH

Table 3: System Product-Mix Requirements

Product Type	*Product B*	*Product A1*	*Product A2*	*Total*
Percentage	75.0%	12.5%	12.5%	100.0%

Table 4: Rates of Production Line Feeding Subs

Sub-Assembly	Product B	Product A1	Product A2
Interior	63.5 JPH	75.0 JPH	75.0 JPH
Closures	60.0 JPH	88.0 JPH	88.0 JPH
Wheels	60.0 JPH	58.0 JPH	50.0 JPH

Table 5: SAA and Buffer Sizes for System Feeding Subs

Sub-Assembly	Buffer Size	Sub Stand Alone Availability
Interior	7	85%
Closures	6	85%
Wheels	7	85%

Table 6: Simulation Results of System Capability

Product Type	*Product B*	*Product A1*	*Product A2*	*Total JPH*
Net Throughput	50.8 JPH	8.4 JPH	8.6 JPH	67.8 JPH

Table 7: Adjusted Rates of the Feeding Subs

Sub-Assembly	Product B	Product A1	Product A2
Interior	60.9 JPH	75.0 JPH	75.0 JPH
Closures	60.1 JPH	88.0 JPH	88.0 JPH
Wheels	65.0 JPH	58.0 JPH	50.0 JPH

Table 8: Adjusted SAA and Buffer Sizes of the Feeding Subs

Sub-Assembly	Buffer Size	Stand Alone Availability
Interior	15	90%
Closures	14	90%
Wheels	7	90%

Table 9: System Capability after Adaptation

Product Type	*Product B*	*Product A1*	*Product A2*	*Total JPH*
Net Throughput	53.2 JPH	8.7 JPH	8.9 JPH	70.8 JPH

Table 10: Full-blown Product-Mix Analysis with DES

Product-Mix			*Product Net Throughput (JPH)*			*System Net JPH*
B	A1	A2	B	A1	**5.2.1 A2**	
100.0%	0.0%	0.0%	54.1	0.0	0.0	54.1
90.0%	5.0%	5.0%	53.9	2.8	3.0	59.7
80.0%	10.0%	10.0%	53.6	6.3	6.4	66.3
75.0%	12.5%	12.5%	53.2	8.7	8.9	70.8
70.0%	15.0%	15.0%	48.6	11.2	11.6	71.4
60.0%	20.0%	20.0%	44.3	14.8	14.6	73.7
50.0%	25.0%	25.0%	37.3	18.6	18.6	74.5
40.0%	30.0%	30.0%	30.2	24.9	21.9	77.0
30.0%	35.0%	35.0%	22.2	26.1	26.2	74.5
20.0%	40.0%	40.0%	14.4	28.8	28.7	71.9
10.0%	45.0%	45.0%	7.0	31.1	31.1	69.2
0.0%	50.0%	50.0%	0.0	35.7	33.2	67.0
0.0%	100.0%	00.0%	0.0	51.3	0.0	51.3
0.0%	0.0%	100.0%	0.0	0.0	45.0	45.0

6 CONCLUSION

The paper presented a practical approach for conducting product-mix analysis with Discrete Event Simulation (DES). The approach suggests starting the analysis with a traditional Linear Programming (LP) model to determine the optimum product-mix that meets the business targets. A DES model is then utilized to check the actual system performance at the optimum product-mix. If the simulation results match the results of the LP model, the decision-maker's confidence increases and the DES model is used to validate the system design. Otherwise, the DES model is utilized to enhance system parameter settings and process configuration so that the optimum product-mix is reached. Finally, the DES model is used to adapt the system design to most possible combinations of the product-mix. This approach can be implemented at the production system micro-level as well as the enterprise macro-level.

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AUTHOR BIOGRAPHY

RAID AL-AOMAR is a senior Project Engineer at Classic Advanced Development Systems, Inc. in Troy, Michigan. He is responsible for applying state-of-the-art DES simulation tools in designing manufacturing processes for the Auto industry. He received a B.S. in Industrial Engineering from the University of Jordan in Amman-Jordan and a M.S. in Manufacturing Engineering and a Ph.D. in Industrial Engineering from Wayne State University in Detroit-Michigan. His interests include work-cell and material handling systems design and analysis with DES, simulation-optimization methods, and artificial intelligence. His email address is `<Raid.AlAomar@Classic-co.com>`.