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DEVELOPMENT OF A PRODUCT DESIGN SUPPORT TOOL USING MANUFACTURING CYCLE TIME

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ABSTRACT

Nowadays varieties of product are still continuously increasing in the market. To survive in their business, companies should be able develop new products. This means that for a company, product development is an important aspect for competing in the market. In this situation, a need for a design support tool to help product development team in the development activities is very urgent. This paper addresses the development of a design support tool based on mathematical model related to cycle time, modeling a multi-stage, multi-product production line system and it can process a variety of products in a batch production environment. Products are processed according to a predefined sequence. The tool used at earlier stages of product design to develop products in a shorter time.

KEYWORDS

Batch Production, Cycle Time, Mathematical Model, Multi-stage Production Line, Product Design

NOMENCLATURE

B_{i1L} =	batch size at the first workstation of production line L
$B_{i(out)(L-1)}$ =	batch size out at production line (L-1)
c_j^a =	the squared coefficient of variation (*SCV*) of interarrival times at the resource *j*
c_j^* =	*SCV* of modified aggregate process time
CT_j^* =	average manufacturing cycle time at the resource *j*
CT_i =	the average manufacturing cycle time of jobs of the product *i*
k =	batch size number
n_j =	the number of resources in the workstation *j*
R_i =	the number of workstations that the product *i* must visit
t_j^* =	modified aggregate process time at the workstation *j*
u_j =	the average resource utilization
V_j =	set of products that visit the workstation
x_i =	release rate of product *i* (jobs per hour)

1 INTRODUCTION

Developing successful new products requires ability to predict life cycle impact of design decisions at the early stage of product development. Downstream life cycle issues include considerations on processing manufacturing, shipping, installation, usage, service, and retire or recycle. Ignoring downstream issues leads to poor product design that may cause unforeseen problems and excessive costs (Cooper et al., 2004). Unfortunately, downstream life cycle are difficult to predict accurately during the early design phases. To overcome this problem, many researchers presented results of their study using the concurrent engineering approach during product design. The Development of Design for X (DFX) method is an important effort to actualize the application of concurrent engineering (Gatenby and Foo, 1990).

Newly developed products need production resources process raw material to finished goods. On the other hand, the procurement of these machines and resources requires a substantial amount as well as time from design to production. Procurement, manufacture and marketing of a new product require longer time to market. This affects presence of products in the market and easy entry by competitors. Therefore, it is very important to use the existing manufacturing system to produce new products, or in the other words, the existing manufacturing system should have capability to process product mix i.e. existing products and new products.

Based on DFX approach and product mix concept, in this paper the development of a tool that supports product development activities which relate to the manufacturing cycle time is discussed. In order to quickly analyze, parameters such as such as cycle time, throughput, batch size, capacity or utilization, cost, inventory, and product mix are used. A Visual Basic® program used to develop user-interface of the tool. This is used on multi-stage product mix concept.

2 RELATED WORKS

Successful product development requires definition of various measures of performance for different phases of the product life cycle and methods to predict these performances. Accurately predicting these performances enables the product development team to develop product “right first time” thereby avoiding or minimizing development costs and product redesign. Such performance measures are numerous and influence various aspects of the development cycle, from concept to product delivery (Chincholkar, 2002)

Magrab (1997) described a set of techniques mentioned as IP2D2 methodology which could also be applied to facilitate the use of concurrent engineering. The proposed IP2D2 method broadly indicates the overlapping, interacting, and iterative nature of all the aspects that impact product realization process.

Govil (1999) suggested an approach relating product design and throughput in order to reduce time-to-market products. This strategy was conducted during the concept design phase of products. First, designer should input data relating to the products and its process information into a tree structure. The system will make inference and evaluation to find out the production rate that conforms to time-to-market requirement. Next, product and components of critical production system can be identified based on this certain production rate. Therefore, many alternatives for improving production rates can be tried and the best alternative selected.

Taylor et al (1994) used a capacity analysis model to determine the maximum product quantity at electronic assembling facilities. The analysis was conducted on a set of product that consists of existing products mixed with design of new products. In case maximum production quantity is not enough, the design of the new products should be changed to avoid production process at critical or bottleneck resources. By this action, production quantity would be increased to an acceptable level. However, this capacity analysis model does not consider the manufacturing cycle time of the system.

Bermon et al. (1995) have studied capacity analysis model at a production line producing various products. The approach made was focused not only on product design but also on decision support that enables quick analysis. They defined available capacity as the number of operations that can be accomplished by the equipment in a day. When information was available about equipment, products, and required operation are known, equipment capacities that conform to both required throughput and existing limitations are allocated. Cycle time data and capacity are allocated at level below the existing available capacity. The differences between the available capacity and allocated capacity are referred to as contingency factor. A good contingency factor will prevent the queuing time of average equipment group from exceeding the processing time determined before. The queuing model approach was used to model the relationship between utilization and queuing time. By using this approach, hat can verify the capacity of manufacturing system in terms of capability to achieve the required throughput for a reasonable manufacturing cycle time.

A few researchers described capacity planning approach as a part of planning and control systems of traditional manufacturing (Hopp et al., 1996;

Vollmann et al., 1997). These approaches identify how many times, when, what, and where manufacturing system should increase its capacity in order to obtain the required throughput. Therefore its general objective was to minimize equipment costs, inventories, and cycle time. There are many models that are not very significant and also less accurate. Furthermore, these models do not include applications for multi-stage manufacturing system.

Candadai et al (1995, 1996) noted that in agile manufacturing, a manufacturing firm should form partnerships with other manufacturers in order to design and manufacture a product quickly in response to a market. In order to form a successful partnership, the firm needs to create a superior design and select the potential partners to best fit the partnership's scope. There are two approaches for predicting manufacturing cycle time in relation to the agile manufacturing which are the variant approach and generative approach. In the case of known detail product design, the variant approach will be started by looking at the Group Technology codes that comprehensively describe product attributes. Next, the approach will try to find out the existing products made by potential partner and identify the products that have almost similar code with the new products. The manufacturing cycle time of existing products that have similarities with the new products used as a guide for predicting manufacturing cycle time of the new products.

The generative approach (Herrmann and Chincholkar, 2000; Minis et al., 1996) lists set of possible specific process planning of a potential partner. If the process for the new product design already listed, the cycle time for each stage in process planning of that new product design can be calculated. In the case of known production quantity or production size, the generative approach calculate the processing time needed for the specified production size, and combine this processing time to both average value of setup time and queue time at related resource. These setup time and queue time are known based on historical data. The next step of the generative approach was to sum up all the time at each stage of each process planning, which gives an indication on the effect of different potential partner selection to determine manufacturing cycle time. However, this approach did not consider the available capacity. When the utilization increased, the queue time was not conducted.

Soundar and Bao (1994) presented a planning that relates product design effects to manufacturing system. They suggested that the use of mathematical model and simulation to predict various performance parameters including manufacturing cycle time. The approach was however very general and no example was discussed in their paper.

Johnson and Montgomery (Aomar, 2000) presented a mathematical formulation for the product-mix problem as a constrained LP (Linear Programming) model. They found that many firms have benefited from the use of this LP model especially in making product-mix decision. In order to apply the LP model, many input data from the industry was required such as the minimum production level of each product type in the planning period, number of units of each resource that are required to produce one unit of each product, and the amount of each resource available during the planning period.

Walid Abdul Kader (2006) presented a study on certain parameters of modern production lines having variety of product processes in a batch production environment, which was in relation to capacity estimation. These parameters include set-up time, product mix, and reliability of the stations composing the systems.

The design of the product, among other things, affects the performance of the manufacturing system. Concurrent engineering research in this area has been focused on testing the manufacturability of a product at the initial design stage. The concurrent design of products and performance of manufacturing systems required to manufacture the product has been largely ignored. It is therefore necessary to integrate product design and manufacturing system.

Based on discussion above, it can be stated that previous studies have shown the importance of developing a tool that supports product development activities which relates to the manufacturing cycle time. The tool should help to quickly analysis using a mathematical model that consider parameters as mentioned in the DFX approach However, these studies do not address the application in a multi-stage process which is the current trend in modern production lines. Previous studies also do not mention specifically the type of user-interface to be used for a design support tool. User-interface is a very important component of the design support tool as it determines the ability of the design support tool to perform a quick analysis.

3 PROPOSED DESIGN SUPPORT TOOL

For the purpose of developing the design support tool the following tasks were carried out:

a) Development of a manufacturing system model: estimate the manufacturing system performance, a model of manufacturing system based on queuing network was developed. This model was used to analyze the manufacturing system processing different product sets. Data needed by the model was mainly related to manufacturing cycle time. This model can also be used as a design support tool in product development.

b) Acquisition of real data from industrial partner: To implement the manufacturing system model, the type of data collected from the industrial partner are as follows:
   - For each workstation
     - The number of resources available
     - Mean time to failure for a resource
     - Mean time to repair the resource
   - For each existing product and the new product
     - The job size (number of parts)
     - Desired throughput (number of parts per hour of factory operation)
     - Sequence of workstations that each job must visit
   - For each product-resource combination
     - Mean setup time (per job) at each workstation and its variance
     - Mean processing time (per part) at each workstation and its variance

c) Validation of the manufacturing system model: ARENA© software was used to validate the developed manufacturing system model based on the same input data acquired from the industrial partner. The output parameters of the model are then compared to the same output parameters resulted from ARENA©.

d) Designing user interface: Visual Basic® was used as an interface to the manufacturing system model for ease of application of the design support tool.

Figure 1 shows the flowchart for the operation of a design support tool as proposed by Herrmann and Chincholkar (2000). The original model consists of simply user interface along with a process planning module, an aggregation module, an approximation algorithm, and an analysis module. The study was based on a production line consisting of nine workstations for printed circuit boards.

Based on the study, the above model was improved by incorporating a multi-stage process, reliability factors of the manufacturing system and developing a Visual Basic® interface along with the WIP cost. These additions are shown in Figure 2.

The importance of having a model for multi-stage processes in today's industry is outlined as follows:

- Multi-stage production line systems are realistic representations of most production systems. This system includes modern high technology manufacturing systems, such as those in the electronics, semiconductor, aerospace and automotive industries.

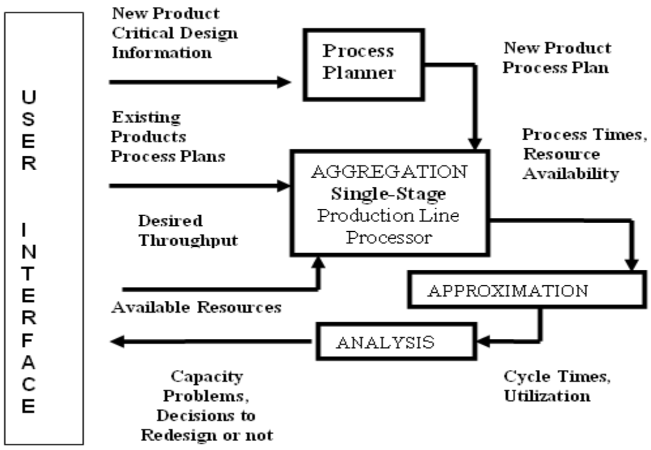

Figure 1 Flowchart of the Design Support Tool as proposed by Herrmann & Chincholkar (2000)

- There is a unique challenge brought by multi-

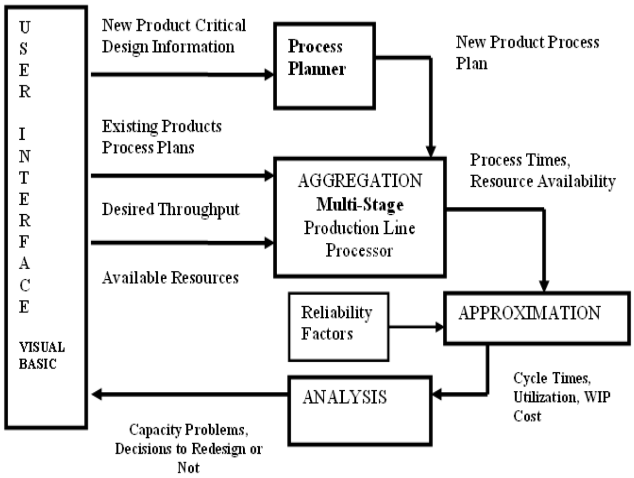

Figure 2 Flowchart of the proposed Design Support Tool

stage production line system, which is a system level model to characterize the variation propagation in the entire process.

The user interface allows the user to input the product design and the key characteristics for the products being processed in the manufacturing system. The process planning module uses the product design information to obtain the processing time for the product and its components at the various resources that form a part of the product processing sequence.

The queuing network approximations used in the tool offers several advantages as well as some limitations. Compared to simulation models, these approximations are less accurate, especially for very complex systems. However, they require less data and less computational effort than the simulation models. Therefore, they are more appropriate for situations in which a decision-maker needs to compare many scenarios quickly. The approximation aggregate the products and calculate the average manufacturing cycle time at each workstation. For each product, the aggregation module calculated the mean processing time for each job at each workstation. It also calculate for each workstation, the average processing time, weighted by each product's arrival rate. Finally, it modifies the aggregate processing time by adjusting the resource availability.

To describe the predicted performance of each workstation in the manufacturing system, the tool estimates the resource utilization and manufacturing cycle time. Resource utilization defines percentage of total time in workstation for processing of parts. This in turn influences waiting at workstation before it can be processed. The utilization was a function of arrival rate and the processing time of the product at the workstation.

$$u_j = \frac{t_j^*}{n_j} \sum_{i \in V_j} x_i \quad (1)$$

The batch size in this multi-stage production can be approximated by:

$$B_{i1L} = \min(B_{i(out)(L-1)})_k \qquad \text{for k= 1,2,3, ..n} \quad (2)$$

The manufacturing cycle time for each workstation contributes to the total manufacturing cycle time for the product. The tool uses the following manufacturing cycle time approximation, which is a formula used extensively by Wei and Thornton (2002) and Wei (2001):

$$CT_j^* = \frac{1}{2}(c_j^a + c_j^*) \frac{u_j^{(\sqrt{2n_j+2}-1)}}{n_j(1-u_j)} t_j^* + t_j^* \quad (3)$$

The manufacturing cycle time for a product is the sum of the average manufacturing cycle times for the workstations that constitute the product's processing sequence. Thus,

$$CT_i = \sum_{j=1}^{R_i} CT_j^* \quad (4)$$

The outputs for this design support tool are in the form of:

- Suggestions for addition of workstation if there is a need.
- Suggestions for consolidation of resources to over utilized workstations.
- Assist the designer in making appropriate change to utilize production resources to optimum level
- Graphs indicating the following parameters :
  a) Output variable (such as utilization, cost or manufacturing cycle time) for resource processing versus input parameter (such as throughput)
  b) Output variable (such as manufacturing cycle time, cost) for product versus input parameter (such as throughput)

4 APPLICATION OF THE TOOL

The next phase was to apply the model and for this purpose M/S Ingress Precision Sdn. Bhd., a company manufacturing automotive car parts was selected based on the specified criteria. Roll-formed metal automotive door sash and related components that form the essential part of a car chassis frame are the key automotive component products fabricated by M/S Ingress Precision Sdn. Bhd. The existing products selected for this study are front door-sash and rear door-sash for Proton Wira. For the new product, the front door-sash for Proton Waja was selected. There are three products mix that need to be produced at the existing manufacturing system, namely the front door-sash Proton Wira, rear door-sash Proton Wira, and front door-sash Proton Waja. This company has facilities that include roll forming line (44 steps) with seam welding, roll forming line (20 steps), automatic progressive press, cell-type sub-assembly line, and robotized assembly line. To produce product mix as mentioned above, all these

facilities are grouped into six multi-stage production lines. In sequence these production lines are RF1-D1, RF-C, RBN, E, D2, and A. Figure 3 and Figure 4 show the assembly line and the car door product of the company.
Table 1 describes the values of both throughput and batch sizes for each product in the mixed production based on the company data.

Table 1 Throughput and batch size for each product in the mixed production

Product *i*	**Front Wira**	**Rear Wira**	**Front Waja**
Throughput T_i (parts/hr)	15	15	15
Batch Size B_i (parts/batch)	80	80	80

Table 2 shows the utilization for each workstation on production line RF1-D1 which resulted from the input data in Table 1 and calculated by using

Figure 3 Assembly lines at M/S Ingress Precision Sdn. Bhd.

Figure 4 The car-door product of the company

equations (1) and (2).

Table 2 Utilization at work station based on throughput and batch size in Table 1

Workstation in production line RF1-D1	***J***	n_i	Utilization			
			Two Products Mix			**Three Products Mix**
			Front Wira + Rear Wira	Front Wira + Front Waja	Rear Wira + Front Waja	Front Wira + Rear Wira + Front Waja
RF	1	3	0.052	0.052	0.052	0.077
Insp_1	2	3	0.034	0.040	0.034	0.054
KU Notching	3	3	0.047	0.045	0.047	0.070
Lower Cutting	4	3	0.019	0.019	0.019	0.028
Lower Cutting II	5	1	0.000	0.010	0.010	0.010
Side Cutting	6	3	0.019	0/019	0.019	0.028
Insp_2	7	3	0.034	0.039	0.034	0.054

Table 3 presents the cycle time for each workstation of RF1-D1 line which was also based on input data in Table 1 and calculated by using equations (1), (2), (3) and (4).

Table 3 Cycle time at work station based on throughput and batch size in Table 1

Workstation in production line RF1-D1	***J***	n_i	Cycle time (seconds)			
			Two Products Mix			**Three Products Mix**
			Front Wira + Rear Wira	Front Wira + Front Waja	Rear Wira + Front Waja	Front Wira + Rear Wira + Front Waja
RF	1	3	368.4	373.3	373.4	376.2
Insp_1	2	3	243.3	281.8	247.4	259.4
KU Notching	3	3	307.2	288.4	291.2	304.6
Lower Cutting	4	3	124.3	117.4	117.4	122.5
Lower Cutting II	5	1	0.000	117.1	117.1	117.1
Side Cutting	6	3	121.9	115.1	114.9	120.1
Insp_2	7	3	225.1	243.3	213.7	234.1

Data as shown in Table 3 is cycle time at each workstation for production line RF1-D1. The longest processing time was at workstation RF with duration of 368.4, 373.3, 373.4, and 376.2 seconds for product mix of front Wira-rear Wira, front Wira-front Waja, rear Wira-front Waja, and front Wira-rear Wira-front Waja, respectively.

Table 4 summarized the maximum utilization values for each production line, starting from the first line (RF1-D1) followed by the next sequence of line (RF1-C1) until the last line (A).

Table 4 Maximum utilization at each production line based on throughput and batch size in Table 1

PRODUC-TION LINE (In Sequence)	The maximum value of utilization			
	Two products mix			Three products mix
	Front Wira + Rear Wira (at station)	Front Wira + Front Waja (at station)	Rear Wira + Front Waja (at station)	Front Wira +Rear Wira + Front Waja (at station)
RF1-D1 (see Table 2)	0.052 (RF)	0.052 (RF)	0.052 (RF)	0.077 (RF)
RF1-C	0.122 (KU Crimping)	0.061 (KU Crimping)	0.122 (KU Crimping)	0.033 (RF)
RBN	0.263 (RBN)	0.132 (RBN)	0.282 (RBN)	0.052 (RF)
E	0.150 (Press 200T)	0.074 (Press 200T)	0.074 (Press 200T)	0.074 (Press 200T)
D2	0.055 (CO2 welding)	0.064 (Deformation)	0.064 (spot Welding)	0.064 (deformation)
A	0.666 (Anti Rust)	0.333 (Anti Rust)	0.666 (Anti Rust)	0.333 (Anti Rust)

Referring to the data shown in Table 4, it can be stated that:

a) For two products mix ‘front Wira and rear Wira’, with batch size and throughput as in Table 1 (each 80 and 15), the maximum utilization of existing manufacturing system is 0.666 at workstation Anti Rust on production line A.
b) For two products mix ‘front Wira and front Waja’, with batch size and throughput as in Table 1 (each 80 and 15), the maximum utilization of existing manufacturing system is 0.333 at workstation Anti Rust on production line A.
c) For two products mix ‘rear Wira and front Waja’, with batch size and throughput as in Table 1 (each 80 and 15), the maximum utilization of existing manufacturing system is 0.666 at workstation Anti Rust on production line A.
d) For three products mix ‘front Wira, rear Wira, and front Waja’, with batch size and throughput as in Table 1 (each 80 and 15), the maximum utilization of existing manufacturing system was 0.333 at workstation Anti Rust on production line A.

5 CONCLUSION

From the study, it was concluded that by using a throughput quantity of 15 and a batch size at 80 of products as shown in Table 1, the utilization of a manufacturing system was not maximized because the highest utilization for all type of products mix only 0.666 or 66.6% at the workstation Anti Rust on production line A. Therefore in order to obtain an utilization value of 100%, the amount of both throughput and batch size has to be changed by using optimization method by trial & error method. It was also clear that by knowing the cycle time at each production line, the manufacturing cycle time for a product can be calculated by summing up the cycle time of all the production lines. The method to calculate manufacturing cycle time presented in this paper was very useful in predicting availability of product while using this manufacturing system. The design tool is currently undergoing verification and improvements.

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REFERENCES

Ahmadi, R., and Wang, R.H. (1999), “Managing The Development Risk in Product Design Process”, Operations Research 47(2): pp 235-246

Aomar, R. (2000), “Product-mix Analysis with Discrete Event Simulation.”, Proceedings 2000 Winter Simulation Conference, USA.

Balachandra, R. (1991). “Some Strategic Aspects of Faster New Product Introduction.”, Engineering Management Conference, USA.

Bermon, S., Feigin, G., and Hood, S. (1995),. “Capacity Analysis of Complex Manufacturing Facilities.” Proceedings 34th Conference on Decision and Control. New Orleans, Lousiana - USA.

Bralla, J.G. (1996), Design for Excellence., McGraw-Hill Inc., USA

Burhanuddin, S. and Randhawa, S.U. (1992), “A Framework for Integrating Manufacturing Process Design and Analysis.”, Computers and Industrial Engineering 23(1-4): pp 27-30

Candadai, A., Herrmann, J.W., and Minis, I. (1995), “A Group Technology-Based Variant Approach for Agile Manufacturing, Concurrent Product and Process Engineering”,. International Mechanical Engineering Congress and Exposition. San Francisco: California.

Candadai, A., Herrmann, J.W., and Minis, I. (1996),. “Applications of Group Technology in Distributed Manufacturing”, Journal Intelligent Manufacturing pp 271-291.

Gatenby, D.A. and Foo, G. (1990), “Design for X (DFX): Key to Competitive, Profitable Products.”, AT&T Technical Journal May/June 1990, pp 2 -13.

Govil, M. (1999)., “Integrating Product Design and Production: Designing for Time-To-Market”, .PhD Thesis. University of Maryland, College Park, USA.

Herrmann, J.W., and Chincholkar, M. (2000),. “Design for production: A tool for reducing manufacturing cycle time”, DETC2000/DFM-14002 in CD-ROM Proceedings DETC 2000, ASME Design Engineering Technical Conference, Baltimore.

Herrmann, J.W., Cooper, J., Hayes, C.S., Gupta, S., Ishii, K., Sandborn, P.A., Wood, W.H., Kazmer, D. (2004),. “New Directions in Design for Manufacturing.”,. Proceeding DETC 2004, ASME Design Engineering Technical Conference and Computers and Information in Engineering Conference, Utah.

Hopp, W. J., and Mark L. S. (1996), Factory Physics, Irwin/McGraw Hill, Boston.

Magrab, E. B. (1997),. “Integrated Product and Process Design and Development”, The Product Realization Process, CRC Press, Boca Raton – Florida.

Minis, I., Herrmann, J.W., and Lam, G. (1996), “A Generative Approach for Design Evaluation and Partner Selection for Agile Manufacturing”, Technical Report 96-81, Institute for Systems Research. College Park, University of Maryland.

Soundar, P., and Han P. B. (1994), “Concurrent Design of Products for Manufacturing System Performance”,. Proceedings IEEE International Engineering Management Conference. Ohio, Dayton.

Taylor, D.G., English, J.R., and Graves, R.J. (1994).,”Designing New Products: Compatibility with Existing Product Facilities and Anticipated Product Mix”,. Integrated Manufacturing Systems 5(4/5) pp 13-21.

Vollmann, T.E., Berry, W.L., and Whybark D.C. (1997),. Manufacturing Planning and Control Systems,.4th Edition, Irwin/McGraw-Hill, New York.

Walid Abdul Kader. (2006), “Capacity Improvement of An Unreliable Production Line – An Analytical Approach”, Computer & Operations Research 33, pp 1695 – 1712.

Yu-Feng, W. and Thornton, A.C. (2002), “Concurrent Design for Optimal Production Performance”, Paper DETC2002/DFM-34163 in CD-ROM Proceedings 2002 ASME Design Engineering Technical Conference, Montreal, Canada.

Yu-Feng, W. (2001), Concurrent Design for Optimal Quality and cycle time, PhD thesis, Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts.