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SIMULATION-BASED ASSESSMENT OF CHANGE PROPAGATION EFFECT IN AN AIRCRAFT DESIGN PROCESS

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ABSTRACT

In the current work, a simulation-based approach is proposed to assess the change propagation effect in an aircraft design process. To this end, three extensions are made to the conventional approach using design structure matrix to model change propagation effect. They are: 1) logistics factor associated with the component supplies of aircraft; 2) manufacturing system flexibility factor; 3) uncertainty in design change parameters. Then the effects of change propagation are simulated using a discrete-event simulation model in Arena involving detailed design process of totally eight components of a real aircraft. Finally, what-if analyses are performed by varying logistics and flexibility factors under uncertainty in design change parameters to assess the change propagation effect. An optimization problem is also solved using OptQuest to determine the change propagation path that minimizes the total risk of design change. Future work is discussed for extending the proposed approach to other related areas.

1 INTRODUCTION

During the life cycle of a product from product design, process planning, to production and maintenance, product design changes often occur with respect to its shape, dimensions, functionality, or material of one or more of its components. These design changes are necessary for manufacturing companies to respond to major changes in the customer demands or the availability of manufacturing resources over time. However, the companies incur additional costs and experience increase in lead-time of the product due to design changes. Therefore, they must take an important decision on whether to perform design changes on the product, considering the trade-off between the losses associated with not responding to the changes in customer demand, and additional costs caused by changes to product design and penalties due to increased lead-time.

An international survey was conducted in 1988 on design changes among American and European companies that were classified under aerospace, defense, textiles, electronics, consumer products, construction, utility, ship repair, and foundry categories (Boznak 1993). The average, monthly changes in these companies were 330, whereas the range of data was from 2 to 1,000. The administrative processing costs averaged to US$1,400 per change, and an annual additional administrative processing cost ranging from US$3.4million to US$7.7 million was generated in these companies. The survey also revealed that the total product cost was significantly increased due to these costs incurred by design changes. In another study on a manufacturer of computers and their components for end users and OEMs, the number of design changes totaled over 100 per month (Watts 1984). These design changes originated from new

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products releases in that company that were made to respond to changing market. On average, each design change corresponded with 40 days for developing a modified design, 40 days for processing of paperwork, and additional 40 days for implementation in the production processes. The company had to respond to the design changes to stay in business.

In general, components of a product cannot be manufactured independent of each other. Thus, design changes in upstream components and corresponding manufacturing processes affect downstream product designs and processes. The propagation of the impact of design change from upstream components towards downstream components in the product realization process is called change propagation. A change initiated upstream can penetrate multiple components both in downstream and on the same level as the component in which it is initiated. Here, the changes induced on the shapes, dimensions, functionalities and material types of the downstream components are called change propagation effects.

The goal of this work is to assess the change propagation effect in aircrafts considering their logistics and manufacturing processes information. To accomplish the goal, extensions are made to conventional approach using design structure matrix (DSM) to model change propagation effect. First, logistics factor representing the product of transportation distance and transport cost per unit per distance related to supply of components to aircraft is considered in the current paper. The probability of propagation of design change to a particular component will be influenced by its logistics constraints (Ouertani 2008). This aspect of the logistics of supply of product components is not addressed in the literature dealing with the assessment of design change propagation effect. Second, flexibility of the aircraft manufacturing system is considered in the proposed analysis. This is important for the case where a factory is not well equipped to respond to a design change leading to increased lead-time. Without considering the manufacturing system flexibility factor, following a trial and error method to experiment with alternative implementations of design changes and observe the change propagation effect may not be efficient even when the change propagation effects are deemed small. Third, uncertainty is included in impact and likelihood parameters to obtain the bounds in the assessment of change propagation effect. This is due to uncertainties in the probabilities of occurrence of design change and amounts of design changes, which may not be fully considered or understood during planning stage.

A real aircraft is considered as case study. The design change information based on DSM along with the proposed extensions are mathematically modeled for the aircraft. Then, logistics and manufacturing process of the considered aircraft is simulated in Arena. Discrete-event simulation is useful to model the logistics and manufacturing process with multiple random variables and obtain outputs with precision under different scenarios. A design change propagation scenario is proposed and what-if analyses are performed to assess the extent of change propagated to different components under varying levels of logistics and manufacturing system flexibility factors considering uncertainty in design change parameters. Also a simulation-based optimization problem is solved using OptQuest with impact and likelihood as decision variables with logistics and manufacturing system flexibility factors included in constraints to determine the change propagation path with the minimal risk of design change.

The rest of the paper is structured as follows. A brief review of literature on the important topics related to the current work is provided in Section 2. The bill of material (BOM) of the real aircraft used for case study, mathematical model of design change propagation, and the simulation model of the logistics and manufacturing process of the aircraft are described in Section 3. Section 4 describes the experiments conducted to illustrate the proposed approach for a design change represented through a design change propagation tree. Finally, Section 5 discusses the conclusions drawn from the experiments, and future work for illustrating the proposed approach to assess change propagation effect for different design changes.

2 BACKGROUND AND LITERATURE SURVEY

Browning (2001) provides an exhaustive survey of different DSM decomposition methods such as component-based DSM, people-based DSM, activity-based DSM and parameter-based DSM. Design and development of aircraft is a highly interactive social process involving many people designing interrelated components. In general, the complexity to model such a system spans across the following three domains in a company: 1) product domain; 2) process domain; 3) organization domain (Tang et al. 2010). In the event of a design change, while the product domain comprises the detailed information on the design change of product component, the process domain comprises the required tasks to be performed by the production system to achieve the product design changes. All these activities are performed by the working teams and personnel who belong to the organization domain. Cross-domain influences on design change should be identified in order to assess change propagation effects completely.

Significant research efforts have been made to assess the design change propagation effect. A formal method called Change Favorable Representation (C-FAR) is proposed in Cohen, Navathe, and Fulton (2000), where the available product data information is utilized to facilitate design change representation and capture possible design change propagation effects to conduct qualitative evaluations. The design change prediction method proposed in Clarkson, Simons, and Eckert (2004) focused on the development of method to predict design change propagation risk in terms of change propagation likelihood and impact. DSM was used throughout the analysis, and the design change propagation tree was adopted to capture the relationship of change dependency. A comprehensive analysis of problems and processes related with product design changes was presented in Eckert, Clarkson, and Zanker (2004), parts of which deal with change propagation issues such as design change reasons, linking parameters, propagation types, as well as system responses to changes. In the current work, the concepts of design change propagation likelihood and impact are adopted from Clarkson, Simon, and Eckert (2004) with the updated approaches to calculate and apply them. A simulation-based optimization method is employed to estimate and determine the optimal design change propagation path with the objective to minimize total change propagation risk. The simulation-based method proposed in the current work broadens the scope of the assessment of design change propagation effects, by involving the optimization problem in design change propagation risk analysis.

Table 1: Selected types of flexibility in Sethi and Sethi (1990), Vokurka and O'Leary-Kelly (2000).

Types of flexibility	**Definition**
Operation flexibility	The ability to produce a product in different ways
Process flexibility	The set of product types that the system can produce
Product flexibility	The ability to add new products to the system
Volume flexibility	The ease to profitably increase or decrease the output of an existing system
New design flexibility	the speed at which products can be designed and introduced into the system
Expansion flexibility	The ability to exceed the capacity of a system
Production flexibility	The number of products a system can currently produce

In the current work, the influence of transportation cost and distance under logistics capability risk on product design changes is considered along with design and manufacturing flexibility. Flexibility has been defined as the property of a system that is capable of undergoing specified classes of changes with relative ease (Moses et al. 2002). In this work, the flexibility refers to the new design and operation flexibility of the totally 15 different flexibility dimensions described in Sethi and Sethi (1990), Vokurka and O'Leary-Kelly (2000) (see Table 1). The relationship between design change effects and supply chain risk issues are not well studied in the literature (Khan, Christopher, and Burnes 2008). Table 2 summarizes multiple supply chain risks during design changes identified in Lin and Zhou (2011). External and internal risks are two supply chain risk categories that exist due to product design changes. External risk focuses more on the supplier logistics issues, while internal risk is related to the aspects of the operations within the company such as production planning and information sharing. Some specific risk items corresponding to each type of risk are enclosed in brackets.

Table 2: Supply chain risks due to product design changes.

External Risk	Internal Risk
Supplier selection risk (supplier capability; selection cycle)	Production risk (production flexibility; inability to control cost)
Inventory availability risk (volume, price; production capability)	Organizational management risk (objective conflict; labor)
Logistics capability risk (transportation distance, cost; urgent order)	Information risk (low information accuracy; security and sharing)
	Planning risk (incorrect forecasting)

3 SIMULATION-BASEDASSESSMENT FRAMEWORK FOR CHANGE PROPAGATION EFFECT ANALYSIS

Figure 1 shows the BOM of a typical aircraft including its sub-assemblies. The direction of the progress of the assembly operations on the aircraft shop floor is from the bottom to top of the BOM. In total, there are 17 sub-assemblies that are at the bottom of the BOM that merge to form bigger sub-assemblies. The three major sub-assemblies are 1) Fuselage FWD, 2) Fuselage AFT, and 3) Wing body and wings. After the Final body assembly is completed, minor assemblies are performed on the outer area of the aircraft to produce the Aircraft final assembly. Subsequent to the Aircraft Final Assembly, inspection tests on the functioning of the aircraft and fitting of interiors of the aircraft with kitchen and seats are simultaneously performed. The left and right engines are also fitted at this stage of the assembly of the aircraft. The end-product of this BOM is termed as Roll-out ready aircraft and it is ready to be delivered to customers.

To evaluate the effect of design change propagation in the current work, only five sub-assemblies from the BOM are chosen. They are Fuselage FWD, Fuselage AFT, Left wing, Wing box, and Right wing. Each of these sub-assemblies is referred to as a sub-system. Each sub-system is considered to be an aggregation of multiple components and each component can further be divided into smaller sub-assemblies. The change propagation network includes the components supply processes to aircraft shop floor. The supply processes represent the moving of components from one location to another until it is delivered to the aircraft shop floor. The supply of components to each sub-system is associated with a supplier and each supplier in Figure 2 can be decomposed into a number of discrete transportation processes each associated with an inventory and testing process. There are n transportation processes assumed for each supplier. At the end of the supply process, the delivered components are stored in the sub-system inventory. Supply to Left Wing in Figure 2 (enclosed in a box) is decomposed in Figure 3. Three components are illustrated for each sub-system but the number of components may vary depending on the specific case at hand.

The arrows in Figure 2 indicate the correlations within components, sub-systems, and also between components and sub-systems. The thicker and darker arrows containing symbols of the general form '$S_n s_m O$' and '$s_m O s_p Q$' denote encoded correlations between components. The symbols 'S_n', 's_n', '$S_n s_m O$', '$s_m O s_p Q$' represent n^{th} supplier, n^{th} sub-system, correlation in design change originated at n^{th} supplier with component 'O' in m^{th} sub-system, and correlation in design change originated in component 'O' in m^{th} sub-system with component 'Q' in p^{th} sub-system, respectively. The arrows in Figure 3 represent the direction in which a design change effect propagates within the supply process. The symbols IS_{mnp}, TS_{mnp}, TrS_{mnp}, represent inventory, testing and actual transfer of m^{th} supplier components at n^{th} transportation process for p^{th} sub-system, and Is_p represents inventory of components arriving at p^{th} sub-system. The effect of design change that originates at a particular component follows the direction of the arrow leading out of the component, into the next component and propagates along the way till the end.

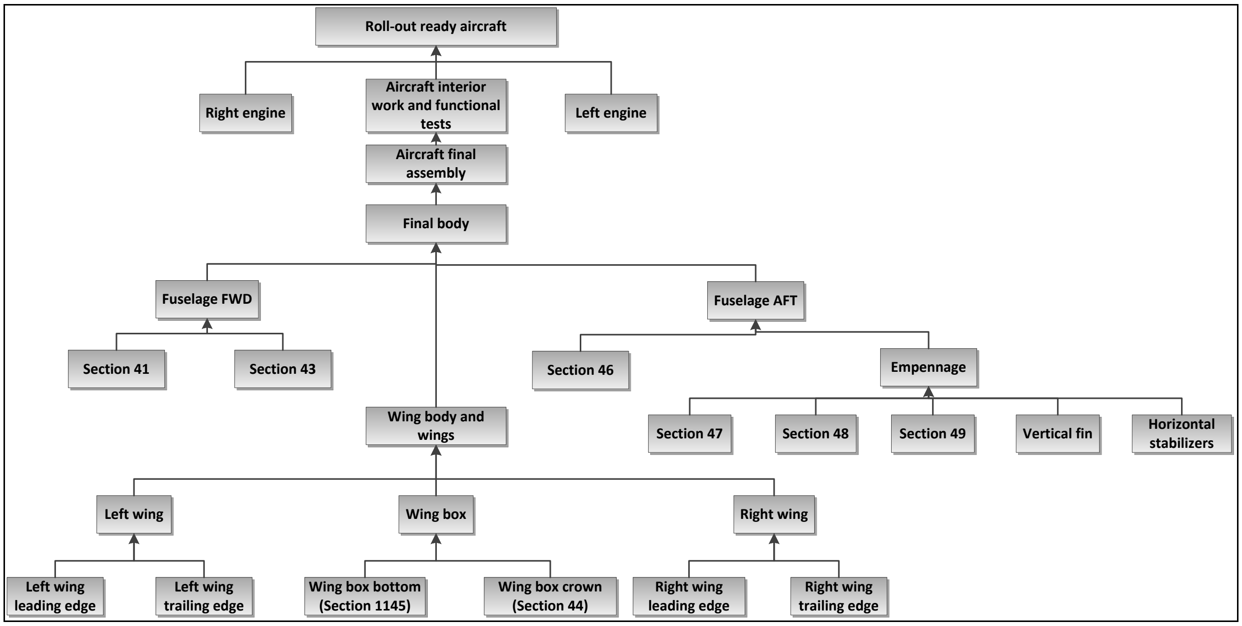


Figure 1: Bill of materials of a typical aircraft considered in the current work (Xu et al. 2011)

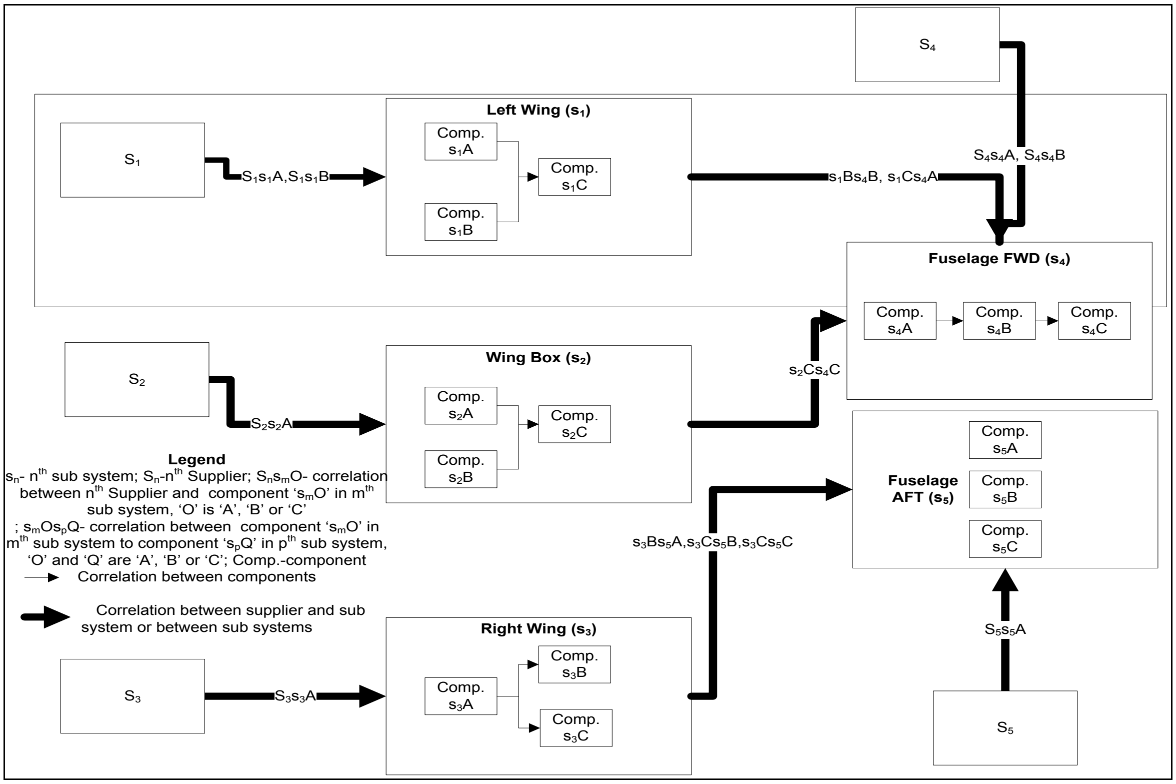


Figure 2: Considered change propagation network

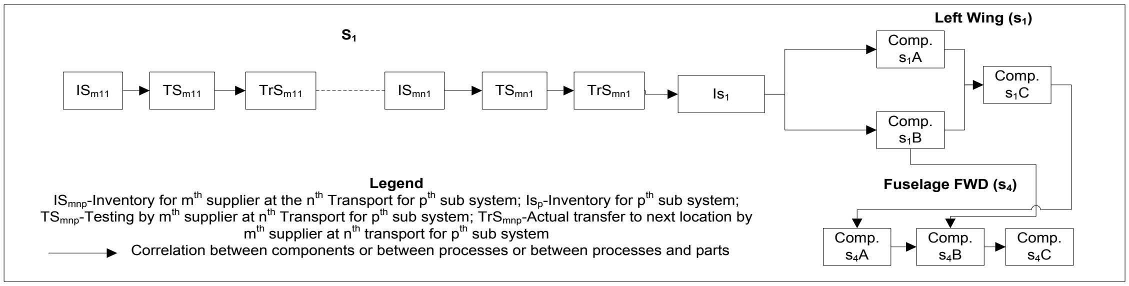


Figure 3: Decomposition of change propagation network

3.1 Design Change Propagation Analysis in an Aircraft Supply Chain System

The design change propagation effect is hard to be captured in aircraft design. Several change prediction methods (CPM) have been proposed in order to gain insights into propagation of design change into different components of an aircraft. The CPM in Clarkson, Simons, and Eckert (2004) enables the managers and designers to assess the risk of changes early in the design process using likelihood and impact parameters. Simulation methods can be used to replace the likelihood and impact parameter based analyses, and the risk can be calculated as a function of the specific change mechanism (Jarratt, Eckert, and Clarkson 2003).

Table 3: Nomenclature

T_i	design processing time of component i without considering design changes	R_{ij}	combined risk of design change in component j due to changes in component i
l_{ij}	direct likelihood of design change in component j due to changes in component i	imp_{ij}	direct impact of design change in component j due to changes in component i
L_{ij}	combined likelihood of design change in component j due to changes in component i	$I_{ij}(x_j)$	combined impact of design change in component j due to changes in component i
α_{ij}	component logistics factor between i and j	d_{ij}	component transportation distance factor between i and j
c_{ij}	Factor of component transportation cost per unit/distance between i and j	x_i	System flexibility factor of component i

It is suggested that the design change propagation analysis should involve the logistics factor (Ouertani 2008). Assuming that the logistics factor is only impacted by the transportation distance and unit transportation cost, the factor equals to the product of transportation distance factor and transportation unit cost factor as shown in (1). All the factors of transportation distance and unit transportation cost are normalized between 0 and 1. In the current work, the equations used to calculate the design change propagation likelihood and impact from Clarkson, Simons, and Eckert (2004) are enhanced by adding the following two features. Firstly, to include the logistics conditions into the design propagation likelihood calculations, the empirical equations (2) and (3) are proposed in order to associate the unfavorable (large transportation and cost) logistics condition with higher risk of design change. This is done by including the logistics factor into the likelihood calculation. Secondly, direct impact value is included into the design processing time denoted by f, and the combined design change propagation impact is calculated by summing over processing time values as shown in (4). Assuming known process time of the original component (denoted by T_j), the updated impact depends upon two values: 1) direct impact (denoted by imp_{ij}) 2) system flexibility factor (denoted by x_j). The impact is assumed to increase the original processing time and the flexibility factor is empirically modeled as inversely proportional to the new design handling time as shown in (5). The combined design change propagation risk equals the product of combined change propagation likelihood and impact as shown in (6). Experiment scenario involving different values of logistics factor, flexibility factor, design change propagation likelihood, and impact are discussed in Section 4.1.

$$\alpha_{ij} = d_{ij} * c_{ij} \tag{1}$$

$$\alpha l_{ij} \cup_s \alpha l_{ik} = \left(\alpha_{ij} * l_{ij}\right) * (\alpha_{ik} * l_{ik}) \tag{2}$$

$$\alpha l_{ij} \cap_s \alpha l_{ik} = \left(\alpha_{ij} * l_{ij}\right) + (\alpha_{ik} * l_{ik}) - \left(\alpha_{ij} * l_{ij}\right) * (\alpha_{ik} * l_{ik}) \tag{3}$$

$$I_{ij}(x_j) = \sum_i f(imp_{ij}, x_j) \tag{4}$$

$$f\left(imp_{ij}, x_j\right) = T_j * (1 + imp_{ij})/x_j \tag{5}$$

$$R_{ij} = I_{ij}(x_j) * L_{ij} \tag{6}$$

3.2 Design Change Risk Optimization Problem in an Aircraft Supply Chain System

In reality, there exist a large different number of alternative design changes to an aircraft. In addition, if constraints such as the logistics and system flexibility factor, mechanical parameter design limits and component/system margins are considered, the design change propagation path that has minimal total risk is not easy to identify. In the current work, this problem is resolved by employing simulation-based optimization technique. Under the simulation umbrella, possible constraints involving the logistics and system flexibility factors can be added and the outputs can be analyzed.

The objective function in the optimization problem is given in (7), which is the summation of risks of design changes over all possible combinations (‘i’, ‘j’) components. In practice, the design change propagation constraints would provide the estimated minimum and maximum amount of design work due to change propagation effects. By adjusting the constraints, different types of change requirements can be maintained. In this work, these constraints are represented by (8) and (9), which are formed using the linear combinations of combined impact and likelihood values. It means the total work need to be done in (8) and the summation of design change propagation likelihoods in each component of the system in (9) should be within specified upper and lower bounds. Parameters of *a, b, c, d* are varied under two different problem scenarios as shown in Table 4.

$$Min \sum_{i=1}^{8} \sum_{j=1}^{8} R_{ij} \tag{7}$$

$$a < \sum_{j=1}^{8} I_{ij} < b,\ i = 1, 2, \dots, 8 \tag{8}$$

$$c < \sum_{j=1}^{8} L_{ij} < d,\ i = 1, 2, \dots, 8 \tag{9}$$

Table 4: Optimization problem scenarios

No.	Problem Scenario	Constraints	Decision Variables
1	Find the best design change propagation path with minimal total risk over different system flexibility levels	Given fixed logistics conditions	Direct likelihood and impact matrix value, system flexibility factor
2	Find the best design change propagation path with minimal total risk over different logistics conditions	Given fixed flexibility levels	Direct likelihood and impact matrix value, transportation distance and cost factors

3.3 System Implementation

Figure 4 displays the overview of the simulation model in Arena simulation software. The logistics and manufacturing process of the following five sub-assemblies are simulated: left wing, right wing, wing box, fuselage AFT & FWD and final body assembly processes. These sub-assemblies are further divided and classified into eight components which are-left wing, right wing, wing box, fuselage AFT1, fuselage AFT2, fuselage FWD, vertical fin and horizontal stabilizers. Each of these components is simulated using the sub-models represented by their respective names. The parts for each of these components arrive via N=2 transportation processes (fixed in the current work; see Figure 3). The vertical fin and horizontal stabilizer components are batched together with other sub-assemblies to form fuselage AFT2 (same as Empennage in Figure 1) in “Fuselage FWD, AFT1, AFT2”. Fuselage AFT1 is represented by Section 46 in Figure 1. Fuselage AFT1, AFT2 and FWD components pass through mill, lathe, inspection and manual fab stations, and then sent to “Departure Station” from where they are dispatched to “Exit Station”. For both left and right wing, the leading and trailing edges are assembled to form the respective wing components. Wing box crown and bottom are assembled to form wing box component. Then wing box, left and right wings are assembled to form wing body and wings in “Batch Wing Box, Right Wing, Left Wing” which is later assembled with fuselage FWD, AFT1 and AFT2 in “Exit Station”. The variables, attributes, tallies, resources and outputs in the simulation model are declared in “Elements”. At the start of every replication in a simulation run the first event takes place in the “Assign Impact and Likelihood Values” sub model where each of the impact and likelihood values are assigned a value from a uniform probability distribution.

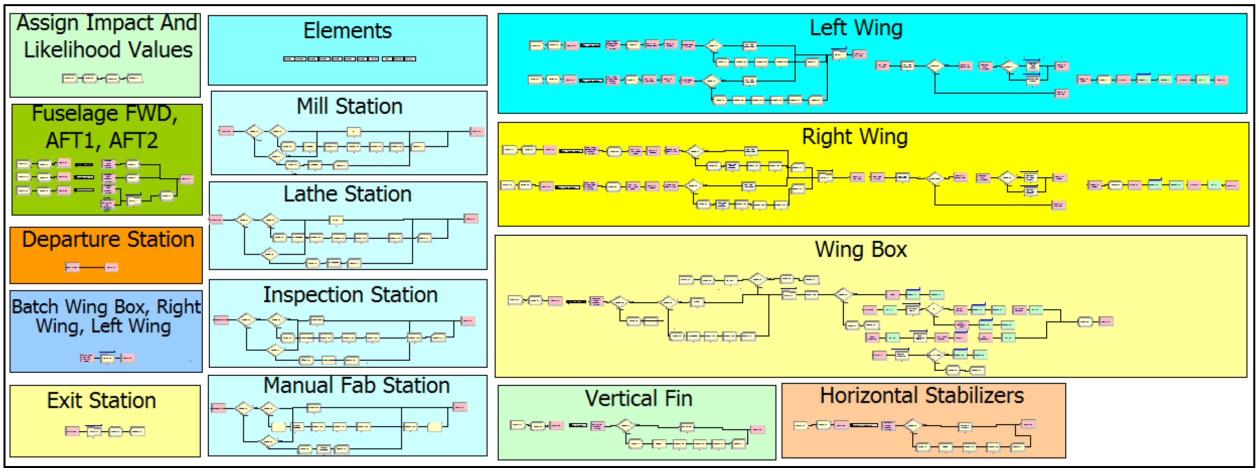


Figure 4: System implementation in Arena

4 EXPERIMENT RESULTS AND ANALYSIS

In this section, 8 different components are used to set up the experiments. Figure 5 shows a design change propagation tree including 8 different components that is used in the experiment and the name of each component. For the current experiment, the design change is initiated at wing box bottom and then it propagates to all other components. There are nodes and lines connecting nodes in the figure. Each node is named by a letter that denotes the name of an aircraft component. A line connecting two nodes is associated with a likelihood value that denotes the probability of design change initiated at the node in the top of the line to propagate to the node at the bottom of the line. The figure illustrates the direction of design change propagation initiated at a component (component 1 in Figure 5) that lies at the lower level of the BOM of an aircraft, to nodes in various positions of the tree that represent components that lie elsewhere in the same BOM. Then, the combined design change likelihood and impact value are calculated by applying (1)-(6) based on the design change propagation tree and the values are inputted into the simulation model manually. Two types of experiment are conducted in the current work: 1) What-if analysis of design change propagation effects; 2) Simulation-based optimization results of design change propagation risk.

4.1 What-if Analysis of Design Change Propagation Effect

The simulation replication run length for the what-if analyses experiments is fixed at 1000 hours assuming that the logistics and design process of the aircraft will be continued for this amount of time before there is another design change. The number of replications is fixed at 30 to obtain reasonable confidence intervals. Two simulation outputs are chosen and their values are plotted in Figures 6(a) and 6(b). These outputs are mentioned in y axis in each of these figures. Number of aircrafts processed is the number of aircrafts that were completely processed and assembled to form the Final body (Figure 1). Number of vertical fin design changes is the number of design changes as recorded in "Vertical Fin" sub model in Figure 4. A number of what-if analyses are done by varying the values of x_i, l_{ij} and imp_{ij} and different simulation outputs are observed.

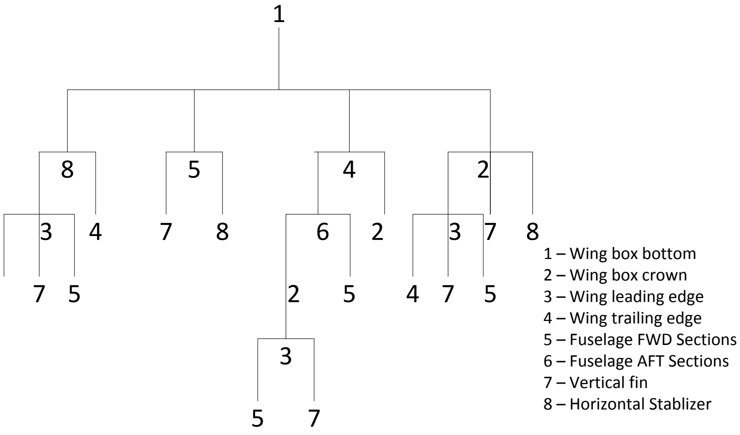
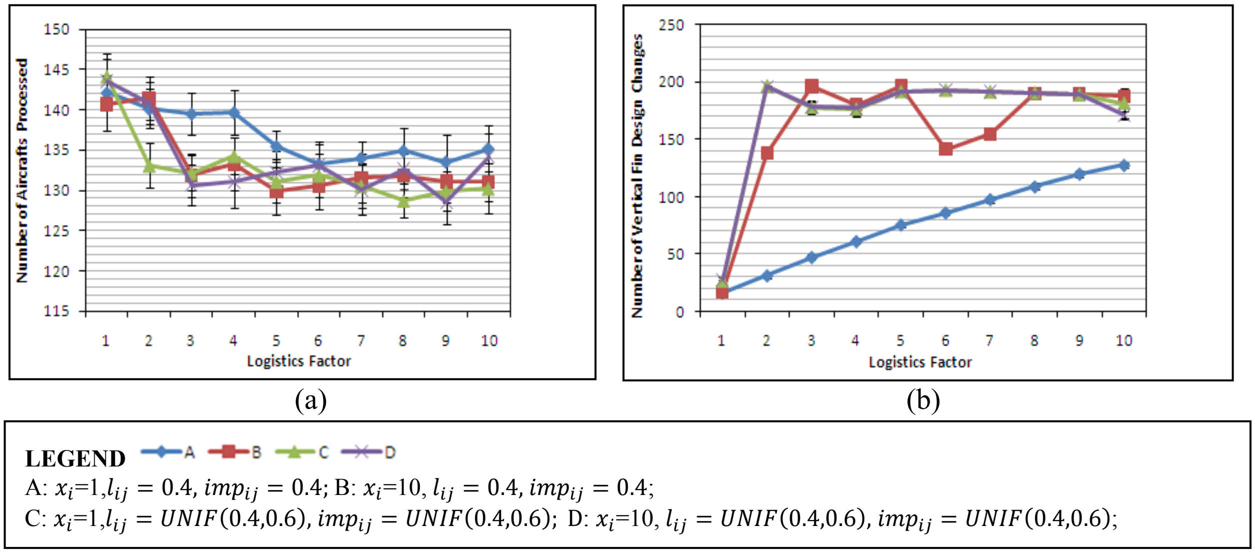


Figure 5: Change propagation tree



(a)

(b)

LEGEND ◆A ■B ▲C ✕D

A: x_i=1,$l_{ij} = 0.4$, $imp_{ij} = 0.4$; B: x_i=10, $l_{ij} = 0.4$, $imp_{ij} = 0.4$;

C: x_i=1,$l_{ij} = UNIF(0.4,0.6)$, $imp_{ij} = UNIF(0.4,0.6)$; D: x_i=10, $l_{ij} = UNIF(0.4,0.6)$, $imp_{ij} = UNIF(0.4,0.6)$;

Figure 6: (a) Effect of variation of logistics factor on number of aircrafts processed; (b) effect of variation of logistics factor on number of vertical fin design changes.

From Figure 6(a) it can be observed that the there is a decrease in the number of aircrafts processed as the logistics factor increased for all the four settings A, B, C and D. By increasing the logistics factor, the total processing time for an aircraft is also increased which results in decrease in the number of aircraft processed for total of 1000 hours.

From Figure 6(b) it is clear that there is in general an increase in the number of vertical fin design changes corresponding to increase in logistics factor since the likelihood of design change is increased. Also the number of design changes increases due to uncertainty in the change propagation parameters since the means of design change likelihood and impact are greater in C and D compared to A. High flexibility factor decreases the processing time in the event of design change thereby increasing the number of design changes as can be observed in B relative to A. Further experiments may explore in the combined influence of different arrival rates and logistics/flexibility factors into the number of design changes that can be handled in a certain amount of time for particular component.

4.2 Simulation-based Optimization Results of Design Change Propagation Risk

Further experiments are conducted based on different logistics, flexibility factors and constraints involving design change propagation parameters on the impact and likelihood values. The overall range of flexibility and logistics factors are broken down into four levels with equal size, and random numbers are generated in each level for every one of total 30 replications in the experiment. Five different constraint lower bounds are all set as 0, and upper bounds are chosen as 0.75, 1, 1.25, 1.5 and 2, respectively. OptQuest is used together with Arena to obtain the optimization results for each experiment. Table 5 summarizes the results and confidence intervals of these experiments. The higher level of flexibility factor (e.g. F level 4) indicates greater flexibility. The higher level of logistics factor (e.g. S level 4) indicates longer transportation distance and higher transportation cost. First four columns of Table 5 are included to test the combined effects of different flexibility levels and constraints levels under the fixed logistics factor, while the last four columns of Table 5 are included to test the combined effects of different logistics factor levels and constraint levels under the fixed flexibility condition. The rows indicate the mean or confidence interval values of total risk corresponding to each constraint level.

Table 5: Simulation optimization results of minimizing total design change propagation risk

	F level 1	**F level 2**	**F level 3**	**F level 4**	**L level 1**	**L level 2**	**L level 3**	**L level 4**
Average (Cons 1)	4.7869	1.5956	0.9574	0.6838	0.3329	0.9769	1.5916	2.1777
H.W. of 95% C.I.	± 0.0248	± 0.0246	± 0.0245	± 0.0242	± 0.0072	± 0.0226	± 0.0233	± 0.0248
Average (Cons 2)	7.3805	2.4602	1.4761	1.0544	0.5533	1.5983	2.5635	3.4520
H.W. of 95% C.I.	± 0.0278	± 0.0299	± 0.0284	± 0.0298	± 0.0090	± 0.0259	± 0.0292	± 0.0359
Average (Cons 3)	9.2282	3.8683	2.3210	1.6579	0.8474	2.4137	3.8173	5.0678
H.W. of 95% C.I.	± 0.0325	± 0.0353	± 0.0343	± 0.0355	± 0.0119	± 0.0183	± 0.0301	± 0.0426
Average (Cons 4)	9.7792	4.9850	3.1299	2.4166	1.1390	3.1822	4.9326	6.4134
H.W. of 95% C.I.	± 0.0391	± 0.0407	± 0.0395	± 0.0411	± 0.0147	± 0.0203	± 0.0342	± 0.0523
Average (Cons 5)	11.4582	5.7291	3.8194	2.8646	1.5504	4.2685	6.5102	8.1811
H.W. of 95% C.I.	± 0.0468	± 0.0460	± 0.0454	± 0.0467	± 0.0185	± 0.0303	± 0.0396	± 0.0564

*Cons X: Constraint level X, H.W.: Half Width, F level X: flexibility level X, L level X: logistics condition level X

As shown in the table, high values of flexibility factor in the simulation result in low total design change propagation risk. And low logistics factor levels result in low total design change propagation risks in the system. Going from top to bottom in Table 5, it can be observed that the change propagation risk increases along the increasing direction of the design change probability and amount under the same levels of logistics and flexibility factors. As the design change constraint level increases, the total risk amount increases more under low logistics and flexibility factor levels than those under high logistics and flexibility factor levels.

5 CONCLUSION AND FUTURE WORK

In the current work, a simulation-based approach for assessment of design change propagation effect is proposed. Three extensions are made to the traditional DSM to model change propagation effect. They are 1) logistics factor; 2) manufacturing system flexibility factor; 3) uncertainty in design parameters. What-if analysis was conducted by varying these factors and parameters for assessing the change propagation effect. The results revealed that with an increase in the logistics factor which is the product of transportation distance and cost per unit distance per unit product, the number of aircrafts processed decreased; with an increase in the flexibility levels, the number of design changes in one of the components that can be completed over a fixed period of time also increased. A simulation-based optimization method is then used to determine the best change propagation path with the minimal total propagation risk. From results it is concluded that under the same amounts and probabilities of design change, the total change propagation risk can vary due to different flexibility levels and logistics conditions. For the case of high amount of design change, it is suggested to maintain a high flexibility and low logistics factor values since the total change propagation risk will increase tremendously along the direction of decreasing flexibility levels and increasing logistics factor values.

Future work will involve the following tasks: 1) distributed and hierarchical simulations can be used to simulate design processes of each component in a detailed manner, so as to overcome the drawback of computational intensity issues in the monolithic simulation method; 2) the influences of product design changes into the manufacturing and material handling system will be included; 3) given a specific design change propagation tree, the simulation model for design change can be automatically generated.

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