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## SYSTEM ENGINEERING WORKSHARE RISK ANALYSIS

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### ABSTRACT

In today's global economy, companies develop products not only to target a single market, but to sell them to the entire world. Companies that realize the importance of collaborative design develop regional engineering centers worldwide to balance design variations while ensuring local market success. This paradigm enables diverse customer values to be integrated into products, but also introduces challenges in the management of work distribution. Typically, workshare decisions consider the capability and capacity of the regional centers. This strategy, however, overlooks the interdependence of the design systems, leading to delays and quality problems. This paper describes a method to formulate the workshare risk based on the couplings of the design system components and to evaluate overall workshare scenario. The method involves two relationships, Component-to-Component Coupling and Workshare Coupling, and a technique to combine these two relationships to measure the workshare risk. A simple case of hair dryer illustrates the concepts, while the method is serving actual global automotive development projects.

**Keywords:** *Global Engineering, Worksharing, Systems Engineering, Risk Factor, Risk Index, Percentage Workshare, Workshare Scenario, Penalty Factors*

## 1. INTRODUCTION

### 1.1. Motivation

In the age of globalization, most companies no longer develop unique products for particular regions or marketplaces. Rather, they develop a platform of designs that optimizes part commonality to leverage the economies of scale for the global

markets and enables efficient localization efforts to meet the diverse needs of different customers. To ensure local success and delivery of profitable platform products, companies realize the importance of incorporating diverse customers' values during the product development stage. As a result, they establish regional centers globally to accommodate this emerging need.

The role of regional centers has drastically evolved since their original establishment. Begun as supportive agents to collect voices of customers (VOCs) and to customize design for local market requirements, these centers gradually gain expertise and become capable engineering centers for more critical development tasks. Current global collaborations include not only distribution of service or manufacturing jobs, but also engineering design, integration and validation work.

However, companies face many delays and quality issues with a distributed, collaborative product development process that are caused by cross-system interactions. Indeed, the design teams spend much of the time and effort in coordinating and collaborating instead of engineering the product. The root cause of the problems originates in the historic development of the regional centers.

In the beginning when these centers were gaining maturity and expertise, workload and skill level were the leading criteria for distributed task decisions. As the centers became more capable, they were assigned to more critical responsibilities. However, workshare decisions solely based on capability and capacity oftentimes ignored the interdependence of the components. Thus, in many occasions, components with close interactions during development are engineered in different sites. Besides, distributed teams usually do not report to the

common first- or second-line of management and this leads to major communication and collaboration issues. When carefully reviewing system interdependence, cross-system interactions can not be completely eliminated, yet its effect can be minimized by skillfully bundling system components together for workshare planning.

## 1.2. Global Engineering and Worksharing

### 1.2.1. Definitions

In this paper, globally distributed projects are defined as projects in which designs are completed in multiple locations. Globally distributed projects generally result in two types of works: multiple final designs or one final design with subsystem designs distributed. The distributed locations of the projects may be in different companies or different countries and the project participants can be internal company subsidiaries, supply chain partners or joint ventures and alliances. This distributed paradigm of engineering design is called **Global Engineering**. Global Engineering is not a novel collaboration model, but is often confused with another work distribution model as *outsourcing*. Hence, reviewing the two definitions in more detail will provide more insights in understanding the management of globally distributed projects.

Webster's Dictionary defines outsourcing as "the practice of subcontracting manufacturing work to outside and especially foreign or nonunion companies." It typically involves non-core design work where outside vendors offer more competitive solutions than internal operations. Since outsourcing usually takes place in the form of subcontracting or service purchases, there is little or no collaboration between the involved parties. This contrasts sharply with Global Engineering's emphasis on collaboration among design teams to achieve an integrated, global product development environment. In this paper, Global Engineering is also referred to as **Worksharing** where system designs are decomposed and shared among the distributed teams. The terms **Global Engineering** and **Worksharing** will be used interchangeably in this paper.

### 1.2.2. Benefits

There are many benefits to run a product program in a distributed mode, and the most notable advantage is to incorporate diverse customer values into product development. When globally distributed teams collaborate in the design, assorted cultural expectations in esthetics, workmanship, design, and function can be included in the product, thus ensuring local market success while providing a global platform to cover different market segments. In addition, the project can access skills and expertise that may be rare and geographically localized. Additionally, economic incentives due to the effective use of labor and other resources globally make Global Engineering attractive to multinational companies.

### 1.2.3. Workshare Models

In general, workshare applications can be categorized into four models, each of which falls into the different stages of establishing worksharing in a company. The four models, in the order of development, are as follows:

1. **A core product that is localized for each region.**  
When companies introduce worksharing to their operations, it typically starts with the establishment of regional centers that serve as supportive agents to localize its core product for the domestic market.
2. **Distinctive product for unique market which is presumably developed and manufactured locally.**  
As domestic market sales begin to grow, it is more economical to develop and manufacture the products locally rather than import from the home state. As a result, corporate headquarters start to distribute simple component designs to the regional centers based on its capability and capacity. This division of labor is supplemented with a strategy to transfer knowledge to the regional centers.
3. **A common architecture that is engineered with global requirements and also with specific product derivatives from the architecture for each region.**  
To leverage the economies of scale for global markets, common architectures emerge that allow companies to offer a wider range of products with minimal design variations. Meanwhile, as regional centers overcome the learning curve, they are capable of handling more major responsibilities. As a result, these centers can be in charge of the product derivatives development while architecture design remains in the headquarters.
4. **A true global product that is marketed relatively unchanged throughout the world.**  
This is the ultimate goal for any product development where its product specifications fulfill the complete set of customer requirements globally. Nevertheless, not all products are candidates for being a true global product, as its feature sets may be unique and difficult to globalize. In this case, workshare enables integration of diverse voices of customers into product development, which yields an outstanding architecture design.

## 1.3. Risk Analysis in Product Development

### 1.3.1. Risk Management & Probabilistic Risk Assessment

Risk Analysis is a general term to describe risk assessment and risk management. The early phase of risk analysis is referred to as risk management where priorities are placed in risk reduction alternatives on the basis of intuitions, beliefs, and common senses. Risk management has been introduced to the engineering fields since World War II. In the 1950's, electrical and aerospace engineers applied risk management to estimate the design reliability; civil engineers adapted risk management in the 60's to analyze structural reliability. Risk management was first brought up to the system level in the 70's when engineers evaluated design systems risk of nuclear and chemical plants and extended to complex space systems in the 90's (Pate-Cornell 2003).

Judgments between technical facts and social values are often mixed, not only in workshare planning, but also in many

engineering disciplines (Whittemore 1983). Thus, more than providing a quantifiable metric for risk measurements, this System Engineering Workshare Risk analysis method aims to serve as a guidance tool that offers a methodological approach of analyzing risk based on system components interdependence, and more important, of generating plans for risk mitigations.

### 1.3.2. Risk Definition

*Risk* has different meanings in different applications, but can be generalized as “the possibility of undesirable outcomes, or a description of potential losses from a given hazard based on probability and consequences (Pate-Cornell 2003)”. In the context of Global Engineering, workshare risk was defined as the probability of *not achieving success* of a given distribution project (Leung 2005). More specifically, *not achieving success* represents the likelihood of rework of the project deliverables. This paper focuses in analyzing the system level risk due to the distribution of the coupled system components that increases the likelihood of rework during the project.

### 1.4. Interdependence of Design

As engineering systems become complex, it is impossible to handle design and validation as a whole. Therefore, different tools and techniques emerge for system decomposition and integration. There are many logical methods to decompose a system into small segments for analysis, and the structural-based approach is a very common practice in industry. Structural decomposition uses product structure as the division criteria, and the partitions are typically described in a Bill of Material (BOM). A BOM is a part listing that describes the details of each assembly, intermediate part and raw materials, and the requirements to build a product.

A structural decomposition breaks down a system into multiple levels of subsystems, and finally components. At each level of decomposition, any individual unit, or element, can be correlated to others based on a variety of engineering attributes. This relationship, based on the couplings of the components, will be the key considering factor in analyzing workshare risk.

#### 1.4.1. Unit of Work Distributions

In this paper, the risk analysis method follows a structural approach to decompose a system into structural elements, or *components*, as the unit of analysis. However, the level of decomposition varies according to the design system to be analyzed. For instance, simple designs decompose directly to individual components whereas complex systems may have several decomposition levels. Distribution of work may take place at any level in the hierarchy.

Many literature reviews on **Systems Engineering** discuss the relationship between systems and components during product development in some detail. Maier and Rechtin defined “a system as the collections of different things which together produce results unachievable by the elements alone (Maier 2002)”; Hertz stated a system is “an assemblage of related elements comprising a whole, such that each element may be seen to be a part of that whole in some sense (Hertz 1956)”. Each component is crucial for the system to function

as an integrated whole and relationships exist between the components. Some components, in fact, are more related than others due to the engineering characteristics of the system. In this paper to simplify the analysis, all components are assumed to be equally important. However in the next round of analysis, ranking the components based on impact to the overall design is necessary for a comprehensive study. Moreover, this risk analysis offers a scalable solution, from component to system or even to program level, as long as a consistent level of structural elements is applied to define the relationships.

### 1.4.2. Related Work

Mori and Ishii listed the design task dependencies with a matrix-based and a graph-based process model to plan for the order of design activities at the early product development stage (Mori 1999). This algorithm is only applicable to large-scale development projects having many work tasks and complicated task relationships. Eppinger et al. described the design tasks during product development with the Design Structure Matrix (DSM) and applied simulations to generate optimal project management schemes (Eppinger 2001). The DSM concept was originated from Steward’s model of information flow between design tasks and identification of the iterative loops (Steward 1981). Eppinger elaborated on Steward’s work to the design tasks for efficient product development process. DSM outputs a square matrix that represents dependencies among the design tasks (Eppinger 1990).

There are many algorithms and strategies to manipulate DSM for design process analysis. Examples of different types of DSM include static-based and time-based DSM. Other DSM applications consist of team-based, component-based, activity-based, and parameter-based DSM (Browning 2001). These DSM applications employ different engineering qualities to establish relationships between the subsystems to depict the system’s behavior. The risk analysis method of this paper implements similar techniques, using a common metric to define component-to-component relationships.

## 2. METHODOLOGY

System Engineering Workshare Risk Analysis (SEWRA) has two primary objectives: to determine the interdependencies of the elements, or *components*, of the system, and to estimate workshare risk based on the work distribution arrangements being used or proposed to design these components. The risk results not only assist companies in making strategic decisions of alternate work distributions, but also attempt to generate risk mitigation plans for any given work distributions. This method involves two key relationships, Component-to-Component Coupling and the Workshare Coupling, and the technique to combine these two relationships to formulate risk estimates due to component couplings and work distribution arrangements.

### 2.1. Component-to-Component Coupling Relationship

The first step of the SEWRA formulation is to establish the Component-to-Component Coupling Relationship (CCCR). CCCR describes the couplings of system components based on a common metric which can be the attributes of the system level performance such as functional requirements or customer

expectations. CCCR can be either an ordinal assessment to represent the strength of the couplings or a binary scale indicating the presence or the absence of a relationship. For concept demonstration, the CCCR formulation is expressed in matrix notation and can be summarized in the following steps:

1. First, populate the relationships between components (C) and common metric (CM) in a matrix (Figure 1).

		Common Metric (CM)					
		A	B	C	D	E	...
Component (C)	1						
	2						
	3						
	4						
	5						
	6						
	...						
	N						

Figure 1: Matrix of Component vs. Common Metric

2. Then, calculate the transpose of the component vs. common metric matrix (Figure 2).

		Component (C)							
		1	2	3	4	5	6	...	N
Common Metrics (CM)	A								
	B								
	C								
	D								
	E								
	...								
	N								

Figure 2: Transpose of Component vs. CM Matrix

3. Finally, multiply the component vs. common metric matrix to its transpose to obtain the Component-to-Component Coupling Matrix (CCCM) as in Figure 3.

$$C \times CM \times (C \times CM)^T = CCCM$$

Figure 3: Component-to-Component Coupling Matrix (CCCM) Formulation

		Component (C)							
		1	2	3	4	5	6	...	N
Component (C)	1	█							
	2		█						
	3			█					
	4				█				
	5					█			
	6						█		
	...							█	
	N								█

Figure 4: CCCM

CCCM (Figure 4) is a square matrix with identical row and column labels. Off-diagonal entries indicate dependencies of the components. Reading across a row indicates what other components the component in that row relates to, whereas down a column lists what other components the component in that column depends on.

## 2.2. Workshare Coupling Relationship

The next step of the analysis addresses the geographical distributions of the work tasks among the engineering sites. The Workshare Coupling Relationship (WCR) describes the work distribution of the system components and determines which site is responsible for which work tasks in the system development. Responsibilities, such as design or validation, can be used to define the relationships. Besides, partial or complete responsibilities can be assigned to a site. This work arrangement is referred to as Work Distribution Relationship (WDR) as shown in Figure 5. With the WDR assignment, similar steps as shown in the CCCM formulation can be applied to obtain the Workshare Coupling Matrix (WCM):

1. First, plot the work distribution information to the Work Distribution Matrix (WDM) as in Figure 5.

		Site			
		A	B	C	...
Component (C)	1				
	2				
	3				
	4				
	5				
	6				
	...				
	N				

Figure 5: Work Distribution Matrix (WDM)

2. Then, multiply the WDM by its own transpose to formulate the WCM (Figure 6).

$$WDM \times WDM^T = WCM$$

Figure 6: Workshare Coupling Matrix (WCM) Formulation

WCM (Figure 7) is a square, diagonal matrix which shares similar properties with the CCCM. Each entry represents the location of the component to be engineered in the same or different location with respect to other system components. The diagonal values are not considered as it is interpreted as the self-coupling of the components.

		Component (C)							
		1	2	3	4	5	6	7	8
Component (C)	1	█							
	2		█						
	3			█					
	4				█				
	5					█			
	6						█		
	7							█	
	8								█

Figure 7: WCM

In order to represent the absence of workshare by zero in the risk formulation, elements greater than or equal 1 in the WCM are converted to 0, whereas entries of 0's are converted to 1's. The new matrix is referred to as the WCM' and this procedure is summarized in Equation 1.

$$WCM'_{i,j} = \begin{cases} 0, & WCM_{i,j} \geq 1 \\ 1, & WCM_{i,j} = 0 \end{cases} \dots\dots\dots (1)$$

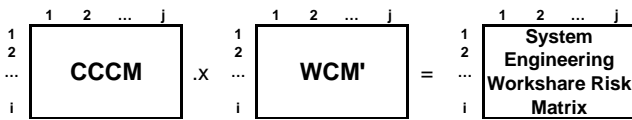
**2.3. System Engineering Workshare Risk Analysis (SEWRA)**

System Engineering Workshare Risk Relationship (SEWRR) is a risk estimate based on the couplings between the components of a design system (CCCR), and how the design of those components is geographically distributed (WCR). Risk increases when highly coupled components are designed in different locations. Equation 2 shows the SEWRR formulation in a mathematical set notation.

$$SEWRR_{i,j} = CCCR_{i,j} \times WCR_{i,j} \dots\dots\dots (2)$$

SEWRA formulation can also be expressed in a matrix, and is called the System Engineering Workshare Risk Matrix (SEWRM). SEWRM is a square matrix with the same size as CCCM and WCM' and is the '.x' of CCCM and WCM'. '.x' is the element-by-element array multiplication of the two matrices (Equation 3).

$$SEWRM_{i,j} = CCCM_{i,j} \cdot WCM'_{i,j} \dots\dots\dots (3)$$



**Figure 8: System Engineering Workshare Risk Matrix (SEWRM) Formulation**

Entries of the SEWRM are known as the **Risk Factor** that signifies the risk level based on the component couplings with others of a given workshare arrangement. High Risk Factors indicate highly-coupled components are distributed to different locations whereas '0' values mean either the components are independent from others and / or its design is collocated.

**Risk Index** is another evaluation metric that sums all the Risk Factors across a row. Similar to Risk Factor, higher Risk Index represents riskier workshare operations. Even though Risk Factors and Indices are relative values, they can be compared directly for workshare planning. For absolute analysis, an evaluation scheme with risk level thresholds based on specific applications and design requirements is still lacking.

Although this analysis focuses on the system risk based on component dependencies, percentage of work distribution is also of a concern in estimating the workload for the overall workshare planning. **Percentage of Workshare** divides the Risk Index of each component based on the workshare arrangement by the total possible Risk Index from the CCCR (Equation 4). In summary, Risk Factor and Risk Index, and Percentage of Workshare are the three key evaluation metrics of the SEWRA.

$$\% \text{ of Workshare} = \frac{\text{Workshare Risk Index}}{\text{Total Risk Index (CCCR)}} \dots\dots (4)$$

**3. CASE STUDY**

This case study deals with a hair dryer and the System Engineering Workshare Risk Analysis (SEWRA) of its global product development. It is a hypothetical study that demonstrates the steps of SEWRA and its robustness in solving simple to complex designs very effectively. The hair dryer has a basic design and Figure 9 exhibits a picture of the actual product.



**Figure 9: Hair Dryer and its Major Component**

The first step of the SEWRA is to decompose the design and this case study adopts a structural approach to break down the product into six major components: motor, fan, heater elements, wiring harness, housing and switch.

**3.1. Product Background**

The case study begins with a Quality Function Deployment (QFD) exercise to identify the product features that contribute most to a particular quality attribute and to translate non-measurable, vague customer requirement into specific product development activities (Cohen 1988). In conventional QFD, House I, or the House of Quality, relates customer requirements with engineering metrics and House II, or Part Development, associates Engineering Metrics with Part Characteristics. The center of QFD is the correlation matrix which ranks the importance of the Engineering Metrics. Figure 10 shows the QFD House I of the hair dryer.

Customer Requirements	Engineering Metrics								
	Customer Weights	Airflow	Air Temperature	Balance (Torque)	Weight	Size	dB Level	Power Consumption	# of Switch Settings
Dries Quickly	9	9	9						
Operates Safely	3	1	9	3			1		
Comfortable to Hold	9		3	9	9	3			
Quiet	3	3					9		
Reliable	3	1	1				1		
Attractive	3							9	
Cheap to Operate	3								
Portable	1				9	9			3
Operates Easily	1			3	3				
<b>Raw Score</b>	<b>96</b>	<b>138</b>	<b>93</b>	<b>93</b>	<b>36</b>	<b>33</b>	<b>27</b>	<b>3</b>	
<b>Relative Weight</b>	<b>18%</b>	<b>27%</b>	<b>18%</b>	<b>18%</b>	<b>7%</b>	<b>6%</b>	<b>5%</b>	<b>1%</b>	

**Figure 10: QFD I – House of Quality of Hair Dryer**

A useful QFD analysis relies on accurate input information and the selection of parameters to depict the product attributes. The data used in this study came from a class exercise which about 70 students role-played as customers and development team members to compile the engineering metrics and the customer requirements as well as the ratings of the customers' weights and the correlation matrix. From QFD I, the top engineering metrics are air temperature, airflow, balance (torque), and weight.

**3.2. CCCR Formulation**

QFD House I relates customer requirements to engineering metrics, and then House II flows down the engineering metrics to components. Rankings of QFD II are based on the relative weights calculated in QFD House I. Traditional QFD II places parts at the top row to simulate information flow, but this study labels parts in the column to be consistent with the formulation in section 2.1 (Figure 11). QFD House II, indeed, can serve as the component vs. common metric matrix to define the CCCR:

1. First, express the relationship between components (parts) and common metric (engineering metric) in a matrix format, which is the QFD House II (Figure 11).

Parts	Engineering Metric							
	Airflow	Air Temperature	Balance	Weight	Size	dB Level	Power Consumption	# of Switch Setting
Motor	9	3	9	9	3	9	3	3
Fan	9	3	3	3	3	9	3	0
Heater Element	3	9	1	3	3	0	9	3
Switch	0	0	0	1	1	0	1	9
Wiring Harness	0	1	0	1	1	0	1	0
Housing	3	0	9	9	9	3	0	0

Figure 11: QFD II – Part Development of a Hair Dryer

The QFD method in this study adopts an ordinal scale of 0, 1, 3, and 9 to indicate the coupling level of the correlation metric. To simplify the analysis, the ranking is translated to a binary notation of 0's and 1's to represent the presence or the absence of the coupling between the components and the engineering metrics (Figure 12).

Parts	Engineering Metric							
	Airflow	Air Temperature	Balance	Weight	Size	dB Level	Power Consumption	# of Switch Setting
Motor	1	1	1	1	1	1	1	1
Fan	1	1	1	1	1	1	1	0
Heater Element	1	1	1	1	1	0	1	1
Switch	0	0	0	1	1	0	1	1
Wiring Harness	0	1	0	1	1	0	1	0
Housing	1	0	1	1	1	1	0	0

Figure 12: QFD II – Part Development (Binary Scale)

2. Then, calculate the transpose of the QFD II matrix as shown in Figure 13.

Engineering Metric	Parts					
	Motor	Fan	Heater Element	Switch	Wiring Harness	Housing
Airflow	1	1	1	0	0	1
Air Temperature	1	1	1	0	1	0
Balance	1	1	1	0	0	1
Weight	1	1	1	1	1	1
Size	1	1	1	1	1	1
dB Level	1	1	0	0	0	1
Power Con.	1	1	1	1	1	0
# of Switch Set	1	0	1	1	0	0

Figure 13: Transpose of QFD II Matrix

3. Last, multiply QFD II matrix by its transpose to formulate CCCR (Figure 14).

Parts	Parts						Sum
	Motor	Fan	Heater Element	Switch	Wiring Harness	Housing	
Motor	7	7	7	4	4	5	27
Fan	7	6	6	3	4	5	25
Heater Element	7	6	4	4	4	4	25
Switch	4	3	4	4	3	2	16
Wiring Harness	4	4	4	3	4	2	17
Housing	5	5	4	2	2	2	18

Figure 14: CCCR Matrix of a Hair Dryer

**3.3. WCR Formulation**

In this case study, the hair dryer is a global project with its product development distributed in three locations: China, Australia, and Romania. All of these sites are capable regional centers to engineer any hair dryer component. For the workshare arrangements, motor and switch are distributed to China, fan and wiring harness to Australia, and heater element and housing to Romania. This work distribution arrangement is also known as **workshare scenario** and can be expressed in a Work Distribution Matrix (WDM) as in Figure 15. 0's and 1's are used to indicate work to be completed at the sites and only one site is responsible for each component.

Parts	Sites		
	China	Australia	Romania
Motor	1	0	0
Fan	0	1	0
Heater Element	0	0	1
Switch	1	0	0
Wiring Harness	0	1	0
Housing	0	0	1

Figure 15: Work Distribution Matrix (WDM)

With the WDM in place, the next step is to establish the Workshare Coupling Relationship (WCR), which shows if a component is engineered in the same or different locations to other components. The WCR matrix calculation follows the same steps as shown in the CCCR formulation: First, map the distribution of work to the site as shown in the WDM (Figure 15), then calculate the transpose of the WDM and multiple it to the original WDM to obtain the WCM (Figure 16).

		Parts					
		Motor	Fan	Heater Element	Switch	Wiring Harness	Housing
Motor		1	0	0	1	0	0
Fan		0	1	0	0	1	0
Heater Element		0	0	1	0	0	1
Switch		1	0	0	1	0	0
Wiring Harness		0	1	0	0	1	0
Housing		0	0	1	0	0	1

Figure 16: WCM of a Hair Dryer

In order to have '0' to represent the absence of workshare, thus when multiplying the WCM to the CCCM yields a zero system engineering risk, the '0' entries of the WCM are converted to '1' and greater than or equal to '1' entries to '0's. Figure 17 displays the WCM'.

		Parts					
		Motor	Fan	Heater Element	Switch	Wiring Harness	Housing
Motor		0	1	1	0	1	1
Fan		1	0	1	1	0	1
Heater Element		1	1	0	1	1	0
Switch		0	1	1	0	1	1
Wiring Harness		1	0	1	1	0	1
Housing		1	1	0	1	1	0

Figure 17: WCM' of a Hair Dryer

### 3.4. SEWRA Formulation

SEWRA is based on the couplings between components (CCCR), and the work distribution according to the workshare scenario (WCR). In the matrix notation, System Engineering Workshare Risk Matrix (SEWRM) equals to the array multiplication of CCCM and WCM' as in Figure 18.

		Parts						Sum	% Wk-sh
		Motor	Fan	Heater Element	Switch	Wiring Harness	Housing		
Motor		0	7	7	0	4	5	23	85%
Fan		7	0	6	3	0	5	21	84%
Heater Element		7	6	0	4	4	0	21	84%
Switch		0	3	4	0	3	2	12	75%
Wiring Harness		4	0	4	3	0	2	13	76%
Housing		5	5	0	2	2	0	14	78%
Sum								104	

Figure 18: Workshare System Risk Matrix

With the given workshare scenario, the top three Risk Indices are motor, fan, and heater element with the value of 23, 21, and 21 respectively. Compared to the top Risk Indices, other components yield significantly lower index values. Motor, fan and heater element also constitute the highest Percentage of Workshare of 85%, 84%, and 84% accordingly, whereas other components generate high Workshare Percentage of 75% or above.

Besides these two risk measurements, this case study also introduces a new metric to summarize the overall risk of the workshare scenario. This is called the **Workshare Scenario Risk Index** and is calculated by summing up the Risk Indices of all components in a design. This overall index corresponds to the feedbacks of having a single index to characterize entire workshare scenario for strategic planning. However, this

metric is not recommended as the only output of the study because this risk analysis provides more information than a single value for comparison. Nevertheless, this is another reference metric for analysis.

### 3.5. Comparative Study

With only one workshare scenario, it is difficult to gauge if this distribution of work is at high risk or not. There is no scheme for absolute analysis. In this regard, another workshare scenario is introduced as a comparative study that aims to gain more insights in understanding the risk values. Besides, this comparative study also attempts to establish the ranking of the Risk Indices across possible workshare scenarios.

For the new scenario, design work of motor, fan, heater element, and housing are engineered in China, while the switch is distributed to Australia and the wiring harness to Romania. Compared to the first case, design activities are more centralized and the work distributions are expressed in the WDM in Figure 19.

		Sites		
		China	Australia	Romania
Motor		1	0	0
Fan		1	0	0
Heater Element		1	0	0
Switch		0	1	0
Wiring Harness		0	0	1
Housing		1	0	0

Figure 19: WDM of New Workshare Scenario

Following the same steps from the first workshare scenario formulation, Figures 20 displays the risk values of the new scenario.

		Parts						Sum	% Wk-sh
		Motor	Fan	Heater Element	Switch	Wiring Harness	Housing		
Motor		0	0	0	4	4	0	8	30%
Fan		0	0	0	3	4	0	7	28%
Heater Element		0	0	0	4	4	0	8	32%
Switch		4	3	4	0	3	2	16	100%
Wiring Harness		4	4	4	3	0	2	17	100%
Housing		0	0	0	2	2	0	4	22%
Sum								60	

Figure 20: New Workshare System Risk Matrix

### 3.6. Case Study Discussion

The first workshare scenario presents a uniform work distribution; each regional center is in charge of designing for two components. The results indicate the motor has the highest Risk Index and Percentage of Workshare. Referring to the CCCM, the motor is a critical component that is highly-coupled to other system components and QFD II results also support this claim as the motor has the highest correlations to other engineering metrics. Therefore, when motor is not engineered in the same location with other components, the results reveal high Risk Index and high Percentage of Workshare.

In the second scenario, design tasks are centrally located; the motor, the fan, the heater element, and the housing design are all engineered in China. As a rule of thumb, workshare risk

is lower when component designs are collocated. Thus, motor and fan yield significantly lower Risk Factor and Index values, whereas the switch and the wiring hardness generate high Percentage of Workshare when their design works are completed in different locations than others.

Considering the two workshare scenarios as a whole, the first work distribution arrangement is a riskier operation than the second as indicated by the higher Overall Workshare Scenario Risk Index (104 vs. 60). However, this conclusion is only based on the interdependence of the system components with the engineering metrics. Different recommendations are possible when other common metrics or factors are considered for the risk analysis.

## 4. DISCUSSION

### 4.1. Usage of Tool: Planning vs. Optimization

The System Engineering Workshare Risk Analysis can be applied in two levels of usage: planning and optimization. The case study illustrates the planning approach of the risk analysis that applies as a guidance tool to first define the relationships of the system components, and then to estimate the risk due to the workshare scenario. Although Risk Factors and Indices can only be interpreted as relative values, it enables direct comparison for making workshare planning decisions.

Besides adopting as a planning tool, this risk method can also couple with linear programming techniques to formulate the optimal workshare scenario. Typical optimization problem involves a relation that can be expressed as a transfer function with input and output variables and the objective is to determine the optimal balance of the relations. SEWRR can serve as the transfer function with the CCCR and the WCR as the input variables and the Risk Factors as the output values to determine the minimal workshare risk.

For extension to a complete optimization framework, this risk method will need to include an explicit cost function, constraint variables and a risk evaluation scheme which are still under development. Besides, the primary objective of this risk analysis is to identify risky workshare operations. Hence, the planning approach is more appropriate. However, optimization approach has high potential in future workshare applications and research will continue to interpret and to analyze the risk values and other factors that affects the optimization results.

### 4.2. Common Metrics

The case study uses the engineering design attributes, i.e. Engineering Metric of the QFD, as the common metrics to define the Component-to-Component Relationship (CCCR) Matrix. In fact, a single or a collection of common metrics can be used to define the couplings of the system components. Examples of the common metric include assembly sequences, part requirements, technical specifications, functionalities, and bill of process.

For each common metric, some parameters are more dominant than others based on its severity and impact to the overall system. The current analysis assumes equal importance of the common metric and design components. However, in the next round of analysis, weights will be applied to the

system components and the common metrics to establish a more accurate relationship.

### 4.3. Other Opportunities

This paper illustrates the basic framework of the risk analysis in a workshare context where design works are geographically distributed among companies' regional centers for product development. The distribution of work is often accompanied by greater *organizational distance* that is not necessarily to be the physical distance that separates the design teams. Rather, work distribution across engineering disciplines such as a mechatronics design involves both mechanical and electrical elements, or workshare across capabilities when expert and novice engineers participate in the same product development, can be the other work distribution dimensions. Instead of populating regional center locations, WCM columns can substitute with engineering disciplines or capabilities for workshare risk analysis.

Besides internal company subsidiaries, this risk analysis also offers a robust solution to cross-corporation collaborations or supply chain partners to evaluate the cooperative product development risk. For example, in a supply chain application, the CCCR can be used to express the relationships of the system components along the supply chain based on a common metric, while the WCR describes the components to be developed by which suppliers. The risk results determine which *supplier scenario* best fits the company's objective in its supply chain applications.

### 4.4. Component Engineering Workshare Risk Analysis

Within the current trend of global product development, component design tasks such as specification definition, production preparation, product validation and testing, are also distributed and collaborated. The analysis in this paper only presents the section of the risk framework based on the interdependence of system components. The other portions concentrate in the interdependence of the lifecycle development tasks of a component. Similar to the system risk assessment, the distribution of work at the component level generates significant risk that affects the effectiveness of global product development. Thus, it is critical to consider both component and system workshare risk simultaneously for a complete workshare risk analysis. The component risk, as well as the mechanism to combine the component and system risks, is still in process and will be presented in the next round of analysis.

### 4.5. Other Consideration Factors

The overall risk framework, which comprises system and component workshare risks, only addresses two of the seven dimensions identified by the workshare survey of the Global Failure Modes and Effects Analysis (Leung 2005). The two dimensions are Workshare Scope and Geographic Distribution of Work, together with Level of Design Changes, are the three objective factors, where the remaining four factors are subjective measures. They are the Involvement of the Centers, Management Complexity, Timing of Workshare Planning and Capability of the Centers. Although these four subjective dimensions are difficult to quantify, they are the areas that

receive most attention in Global Engineering research. This research will remain focusing on analyzing the objective factors of global worksharing and will incorporate the Level of Design Changes into the System Workshare Risk Analysis in the next iteration.

#### 4.6. Future Research

Preliminary results of the sensitivity analysis indicate the Component-to-Component Relationship formulation involves subjective measures to relate the system components with the common metric. Thus, when multiplying the CCCR to the WCR to formulate the system risk, the Risk Factors are biased. However, many companies have data that documents the design process during product development and this information will be helpful to define the relationships. Research will continue to examine the sensitivity of the relationships with respect to the overall risk framework as well as the usage of existing data to assist the definition of these relationships.

The case study adopts a structural decomposition approach to break down the design system into components for risk assessments. In general, there exist many partition methods including task-based, organization-based, or manufacturing-based approaches where each has strengths and weaknesses in different applications. For example, manufacturing-based decomposition ensures components of the same assembly develop within the same location, however the correlations of the components based on the engineering metric are not considered. Ongoing literature reviews will explore these alternate system decomposition approaches and determine which method is most suitable for which types of application to yield an effective risk analysis.

Initial feedback of the risk analysis repeatedly request a risk evaluation scheme that sets the threshold level of acceptable risk for a workshare scenario analysis. The current approach only allows relative risk comparisons and the preliminary findings reveal that risk levels are case specific as the definitions of risk may vary in different applications and industries. However, similar design systems may share a common risk scheme. An evaluation scheme in the form of a band analysis is under development which enables absolute risk comparisons for the next iteration.

The current risk framework assumes all component designs are of equal weights in workload and difficulty. However, this assumption becomes invalid when some components require higher skills (capability) or more manpower (capacity) to complete. Besides, some components are more critical to the overall system where its failure could be catastrophic. Thus, an impact study will be incorporated in the next round that analyzes the system component severity to the overall design for a more complete analysis.

This paper frames the risk analysis as a decision aid to assist planning team for workshare planning. Thus, when a risky operation is identified by high risk values, mitigation plans can then be generated accordingly to remedy the failure. However, to recognize risky practice, reverse engineering the risk factors is necessary in order to classify the root causes of the risky operations. The current approach relies on experts to identify the leading causes that drive high risk values. To make risk

interpretations more robust and independent, the analysis will adopt the *penalty factor* principles from the Design for Assembly (DFA) for error analysis (Sturges 1992).

For each Risk Index, the risk analysis generates a list of *Penalty Factor(s)* that indicate the cause of the risky operations. This penalty factor scheme is easy to implement, but an inclusive study is necessary to identify the penalty factors as well as to determine the risk value levels to flag the penalty. As a whole, this penalty scheme offers operator independence in the risk interpretations and will be implemented.

In summary, all these future research proposals aim to enhance the robustness and repeatability of the risk analysis. Although this method attempts to be comprehensive, current analysis still relies on manual operations to define relationships and to interpret risk values. In the next round, the risk analysis targets to minimize operator dependence in data analysis and to improve overall confidence of the analysis.

#### 4.7. Next Steps

Validation on complex products is the next key step in this research. This risk analysis has only been applied to simple designs, like a hair dryer in the case study, and it will continue to be tested on more global product development projects as proof-of-concept. In the meantime, the authors are actively involved in a collaborative product development of a global automobile company to validate the risk analysis with a complex application. This global product is a program level application that deals with the development of a vehicle model in multiple locations worldwide. The entire risk framework, both the system and the component workshare risk analysis, is currently used in the vehicle development for validation. One of the emerging implementation challenges comes from the system complexity. As the system become complex, couplings of components increase exponentially. Thus, data manipulations become troublesome and problematic. The search for software or mathematical solutions is in process to ease the matrix formulations.

Finally, this framework will apply to not only system, but also program level risk analysis to confirm its capability of offering a scalable solution. Besides, improving overall confidence of the risk analysis will be a focal point in the next iteration. The authors have presented the workshare risk results to the engineers who are in charge of the component designs to confirm the risky practices. The initial findings match with the engineers' expectations and the risk analysis is well received by the engineers. As a whole, this risk analysis is still under development and will go through continuous refinement as it is exercised by more examples.

## 5. CONCLUSIONS

This paper described a method to evaluate technical workshare risks in globally distributed product development. In today's global economy, companies develop products not only target to a single market, country, or region, but rather offer products to the entire world. To balance design variations, while ensuring local market success, companies realize the importance of collaborative product development. This paradigm enables diverse customer values to be integrated

into products, but also introduces challenges in project planning and management.

Delays and quality problems are common because engineers spend most of their time and efforts in coordination rather than design. To address this issue, the authors proposed a method to formulate the workshare risk based on the interdependencies of the system components and to evaluate the overall workshare scenario. The method involves two relationships, Component-to-Component Coupling and Workshare Coupling, and the technique to combine the two relationships to formulate the System Engineering Workshare Risk Analysis (SEWRA). A simple hair dryer case study demonstrated the concept.

The case study showed rational results in which highly-coupled, distributed system components generated high risk values, whereas centrally developed products yielded significantly low risk from the risk analysis. As a comparative study, another workshare scenario was introduced and the findings confirmed the rule of thumb which workshare risk is lower when component designs are collocated.

This paper addressed only a portion of the overall risk framework to analyze risk due to the interdependence of system components. Other important issues such as the risk due to worksharing individual component lifecycle design tasks, the planning and optimization usage, and the different opportunities of the analysis were also thoroughly discussed.

For the next steps, this risk analysis will continue to test on complex product development examples in industries such as automotive, aerospace, and electronics for validations and refinements. In summary, this analysis provides a systematic solution to identify and to compare risk of different workshare scenarios. Moreover, it can reverse engineer risky workshare practices in order to generate mitigation plans to prevent project failure.

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