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## **Configuration and coordination of activities within a supply chain: exploring the synergy between modularity and information technology**

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**Abstract:** This research studies the impact of information technology-enabled coordination on product modularisation in the automotive industry. A structural equation model is tested based on 177 responses to questionnaires from 177 Korean first-tier automotive suppliers. The results provide support for the hypothesis that high quality of exchanged information enables better supply chain coordination, which in turn supports product modularisation.

**Keywords:** product development, modularity, information technology, decomposition and integration, supply chain LISREL.

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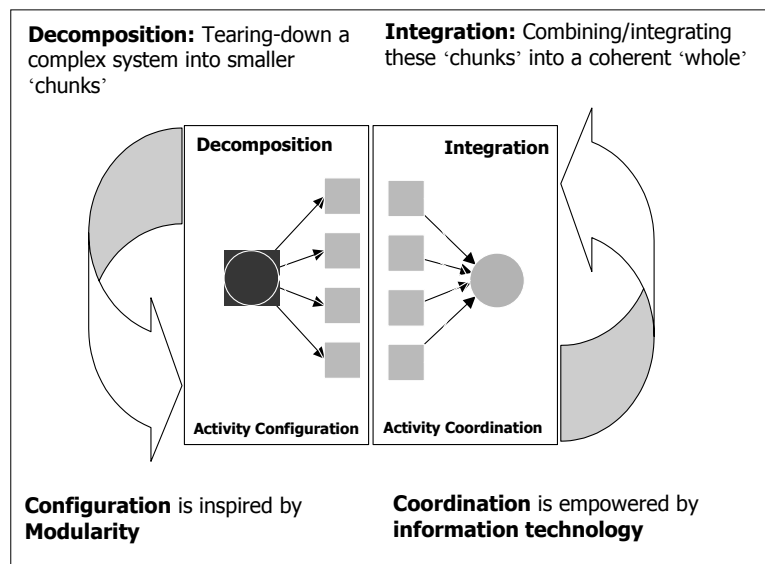
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## 1 Introduction

Complex systems are often decomposed into a number of simpler subsystems that can be understood and developed independently. Decomposition is intended to exploit opportunities for parallel development and is an attempt for companies to focus on their core competence. Indeed, decomposition is often considered the essence of complex problem solving (Simon, 1996).

In complex product development, products are generally divided into modules, or simply, ‘chunks’. These chunks can be developed independently by different teams within an organisation or by different organisations across a development supply chain. The choice of elements that define a module is generally based on a simple, but powerful rule: assign elements that require high problem-solving interaction into the same chunk and those requiring low problem-solving interaction to different chunks. As a result, the need for problem solving across modules and, with it, the communication and coordination requirements between teams are oftentimes drastically reduced (Figure 1).

**Figure 1** Decomposition and integration of a complex product



Proper decomposition of the product into meaningful chunks is based on the underlying product architecture. Modularity allows for ‘clean’ decomposition of the product and well-defined interfaces among the different modules that are scattered across a development supply chain. However, the risks of integration, *i.e.*, the complex web of dependencies, interactions, and interfaces among the modules must also be considered. These risks require careful management through continuous information exchanges. Bad decomposition procedures result in integration problems, which are manifested by excessive design iterations across the supply chain. Furthermore, decompositions that do not consider organisational boundaries can also be dangerous. Successful decompositions should take into account the information channels required to facilitate integration.

The decomposition of a product into independent modules should allow the delegation of model-specific design tasks to independent entities that are loosely interrelated. As such, the choice of product architecture directly impacts the distribution of work associated with individual models and, ultimately the supply chain architecture. In this context, modularisation can be regarded as a tool for activity configuration along supply chain partners. Managing this dynamic interaction and interplay between configuration and coordination of activities becomes, thus, a cornerstone for successful management of supply chains.

Activity coordination requires effective communication and information sharing between supply chain partners and relies heavily on effective Information Technology (IT). In this paper, we therefore hypothesise that IT enables better activity coordination, which in turn improves activity configuration and thus, modularisation.

In the next section we consider recent trends of configuration and coordination trends in the automotive industry. Section 3 introduces a formal model for the relationship between coordination and configuration, and is followed by a discussion in Section 4.

## **2 Activity configuration and coordination: the automobile industry**

### *2.1 Activity configuration*

The typical automobile today requires about 5000 different parts. Its creation requires a large variety of design, manufacturing and assembly procedures. Rapidly advancing technologies, ever increasing feature content, and the drive towards more customisation of vehicles contribute to the difficulties in managing this process. Average overhead costs of 45% of total part costs necessitate carry- and cross-over parts, further adding complexity.

To cope with these challenges, automobile assembly companies (OEMs) increasingly adopt modular architectures. For example, 60% of Kia's Sorento SUV is preassembled by suppliers. Daimler-Chrysler's Smart assembly plant is surrounded by seven module suppliers that cover 70% of the vehicle's content. Even Toyota, which has been known to largely resist the modularity trend, insists that the purpose of its CCC21<sup>1</sup> is to facilitate modular design (Satoshi, 2003).

Modularity, in its ideal form, aims beyond simply facilitating final assembly to systematically include the generation of superior ideas and designs. The role of the supplier extends therefore to that of an independent innovator. For such an approach, activity coordination through information and knowledge sharing is essential. Thus, as we hypothesise in this paper, the necessary conditions for advanced modularity must include the support of IT networks as a tool for activity coordination.

### *2.2 Activity coordination*

Increased modularisation thus shifts the locus of complexity from module development to the integration and coordination of activities throughout the supply chain. The supply chain structures of the automobile industry with their propensity to amplify instability (Fine, 1998), bear witness to this development. Consequently, the importance of information technology, which has long played an important role in intrabusiness activity coordination (Porter, 1986), has increasingly been employed for coordinating

interbusiness activities such as development and manufacturing processes or part sharing (Akoi and Anto, 2002). IT networks enable companies in supply chains to streamline activities by communicating effectively with each other.

Ideally, IT networks enable companies to overcome regional and ownership territories, and to accelerate design and manufacturing processes. For example, Collaborative Product Commerce (CPC) aims to facilitate collaboration in creating, developing, and managing products throughout the entire product design and development process. CPC subsumes many smaller, previously isolated markets that address various phases of product development, such as CAD/CAM/CAE, Product Data Management (PDM), and project management (Yassine *et al.*, 2004).

CPC enterprise solutions typically employ one of the three modes: Firstly, *traditional EDI* systems, sometimes referred to as Value Added Networks (VANs), link two companies with each other. Many automobile companies have used private networks for information exchange for specialised parts and very close data-intensive and security-sensitive direct collaboration with tier 1 suppliers. Examples are Toyota's TDCnet, and Nissan's NET23 network (see Table 1).

**Table 1** Major Automotive Information Network

	<i>Toyota</i>	<i>Nissan</i>	<i>Hyundai</i>	<i>GM</i>	<i>Ford</i>
VAN	TDCnet	NET23	HD-VAN	Covisint	Covisint
	Primarily for co-development of parts and highly confidential exchanges				
VPN	JNX	JNX	KNX	ANX	ANX
	Market transactions with medium high security demand				
Internet	Commodity market				

Secondly, *internet-based EDI* systems or Virtual Private Networks (VPNs) were developed to overcome the problems of private networks such as lack of approachability, stability and general popularity among suppliers. For example, a consortium of US companies developed the Automotive Network eXchange (ANX) as a networking infrastructure for B2B communication. ANX emphasises security, stability, and reliability based on TCP/IP protocol. Problems of security and stability were solved by setting up EDI and CAD/CAM standards. ANX plans to integrate steel industries and chemical industries that are related to automobile industries and is also developing a global form of ANX (GNX) to establish standardised networks for multinational automobile industries. Similar networks exist in Europe (ENX), Japan (JNX), and Korea (KNX) (see Table 1).

Thirdly, pure *internet-based* data exchanges are typically employed only for the purchase of commodity items on spot markets. Table 1 provides an overview of some of the existing networks and their typical usage.

### 3 Empirical research

#### 3.1 Conceptual framework and hypotheses

In this paper we investigate the impact of IT networks on modularisation through activity coordination and configuration. More specifically, the ability to securely exchange large quantities of high-quality data allows closer committed relationships with suppliers and therefore a higher level of information integration and activity coordination (Kim and Im, 2002). We therefore investigate first if the quantity and the quality (*i.e.*, reliability, validity, and integrity) of exchanged information improve the ability to effectively coordinate activities. In particular, we want to test the following two hypotheses:

*Hypothesis 1*     *Better information quality, exchanged through IT networks, improves value activity coordination.*

*Hypothesis 2*     *Higher information quantity, exchanged through IT networks, improves value activity coordination.*

As Kim and Im (2002) demonstrates, IT-enabled coordination yields significant effects on co-engineering in developing parts. In this light, we hypothesise that IT networks, and more specifically, the activity coordination it enables, will further a company's ability to cope with the complexity of large interconnected and interdependent supply networks and thus provide the foundation for increased modularity by interconnecting supply chain partners.

*Hypothesis 3*     *IT-enabled activity coordination supports modularisation strategies through activity configuration among supply chain partners.*

Based on the above hypothesis, we constructed the causal relationship model to be tested empirically. Structural equation methodology was employed to test the model presented in Figure 2.

The equations of structural equation methodology are as follows:

$$\eta_1 = \lambda_{1,1} \cdot \varepsilon_1 + \lambda_{1,2} \cdot \varepsilon_2 + \zeta_1$$

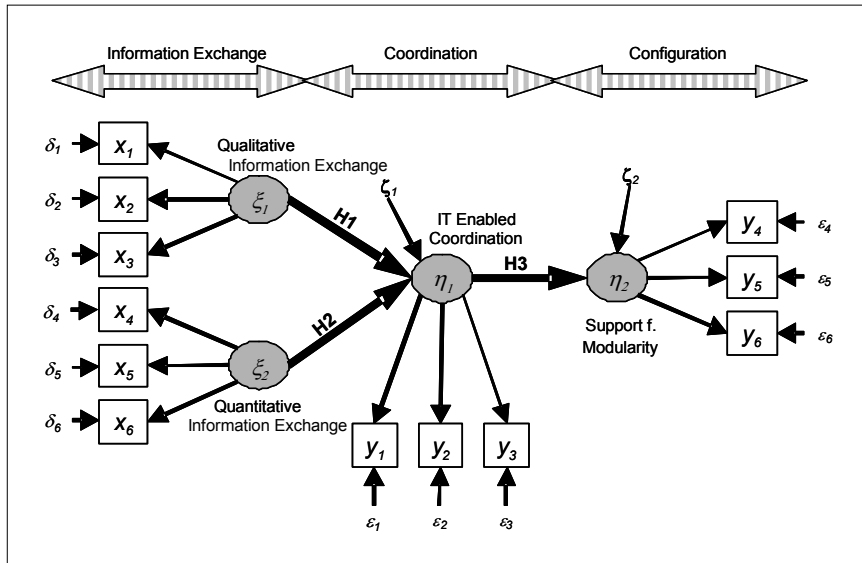
$$\eta_2 = \beta_{2,1} \cdot \eta_1 + \zeta_2$$

where:

- $\varepsilon_1$  = qualitative information exchange
- $\varepsilon_2$  = quantitative information exchange
- $\eta_1$  = IT-enabled coordination
- $\eta_2$  = support for modularity strategy
- $\lambda, \beta$  = parameters
- $\zeta$  = error terms.

Boxes in Figure 2 outline measurement variables that relate to the respective operational definitions for each theoretical construct. For example,  $\xi_1$  is defined by three measurement variables,  $X_1$ ,  $X_2$ , and  $X_3$ . The statistical package used for the analysis was AMOS 4.0 from SPSS Inc.

**Figure 2** Empirical test model



### 3.2 Operational variables

In our analysis, we used two independent variables (‘qualitative information exchange’ and ‘quantitative information exchange’) and two dependent variables (‘IT-enabled coordination’ and ‘support for modularity strategy’). To actually measure these variables, we defined one or more measurement variables as shown below. All variables were measured with seven-point Likert scales.

#### 3.2.1 Qualitative information exchange

The operational definition of ‘qualitative information exchange’ was developed based on previous studies (Kim and Im, 2002). The construct is defined through three measurement variables that relate to the indices for reliability, validity and integrity of information.

#### 3.2.2 Quantitative information exchange

The operational definition of ‘quantitative information exchange’ was developed through in-depth interviews with automobile industry experts. We focus on information exchanged between automakers and suppliers for *future* transactions. The construct is defined by three measurement variables: information for new project development, future transaction-related information, and new product development information.

### 3.2.3 IT-enabled activity coordination

IT on the supply chain is used as a tool for activity coordination among automakers and suppliers on the value chain. The construct represents the degree that interaction with IT enhances the coordination between automakers and suppliers on the network. It is defined by three measurement variables: coordination of inventory levels, coordination of activities, and cost and time savings by sharing the information.

### 3.2.4 Supporting for modularity strategy

The construct is defined by three measurement variables: supporting indices for design improvement of the product, new product development, and interface-ability enhancing the function for the interconnection among parts.

## 3.3 Research setting

The data to test the hypotheses were collected from Korean first-tier automotive suppliers. Due to the single industry setting, generalisation of findings is expected to be limited; however, realism and internal validity are expected to be significantly enhanced (Judd *et al.*, 1991).

To collect data, we developed a structured, undisguised survey questionnaire eliciting supplier attitudes towards the connection between IT tools and modularity trends. To quantify the relevant constructs and relationship that are built upon the conceptual model (*i.e.*, Figure 2), the survey technique requires a standardised instrument. The survey design is thus specifically laid out to allow for the application of a Linear Structural Relationships (LISREL) analysis of the responses (Joreskog and Sorbom, 1993).

Questionnaires were mailed between 1 June 2002 and 31 August 2002. To obtain the greatest number of responses as quickly as possible, a follow-up letter and a follow-up call were delivered to the designated respondents one month after the initial questionnaire administration. A total of 450 survey questionnaires were sent out to Korean automotive first-tier suppliers, (*i.e.*, those who supply Hyundai-Kia, GM-Daewoo, Ssang-Yong, and Renault-Samsung). Among 182 responses, five were inadequate because of incomplete answers or invalid responses. The descriptive statistics for the remaining 177 samples are shown in Tables 2, 3, and 4. Overall, the spread by OEM customer mirrors the production volumes by these manufacturers, and thus eliminates any concerns regarding a bias towards a certain vehicle manufacturer, or even a single production site.

**Table 2** Sample size by OEM customer

<i>Major OEM</i>	<i>Number of companies</i>	<i>Percentage (%)</i>
Hyundai/Kia	86	48.6
GM-Daewoo	55	31.1
Ssang-Yong	15	8.5
Renault-Samsung	21	11.9
<i>Total</i>	177	100

Table 3 outlines the number of major customers by supplier. In our view, this is a critical prerequisite for developing an in-depth and collaborative relationship with customers, because multicustomer suppliers are prone to face concerns with loyalty and confidentiality.

**Table 3** Percentage of suppliers' sales to major OEM

<i>Sales ratio of major OEM (%)</i>	<i>Number of companies</i>	<i>Percentage (%)</i>
0–20	28	15.8
21–40	13	7.3
41–60	19	10.7
61–80	17	9.6
81–100	100	56.4
<i>Total</i>	177	100

Table 4 outlines the products supplied by the companies surveyed. Again, the spread of components is important to avoid any bias towards a certain component cluster, or production technology or process (*i.e.*, metal pressing or plastic moulding).

**Table 4** Categories of suppliers by product type

<i>Component</i>	<i>Number of companies</i>	<i>Percentage (%)</i>
Power train	41	24
Steering, brake, suspension	11	6
Body and sash	33	19
Battery and parts	1	1
Electric parts and wiring	27	16
Interior	26	15
Wheel, tire	8	5
Other	24	14
<i>Total</i>	171	100
Not applicable	6	

### 3.4 Results

#### 3.4.1 Reliability test for measurement variables

The reliability of the measurement variables was tested by Cronbach's  $\alpha$  coefficients. The minimum criteria for acceptance of reliability of 0.7 (Nunnally, 1978) were used. The results are shown in Table 5, indicating that reliability of all constructs was satisfactory.

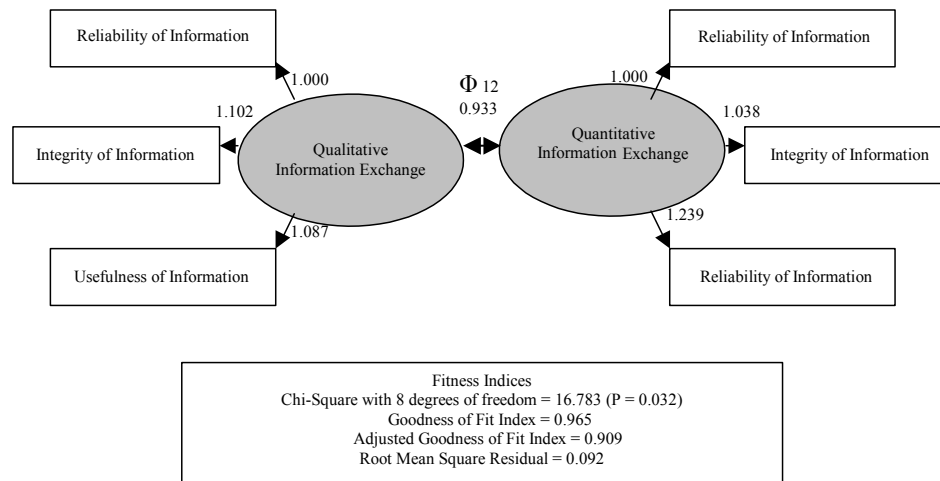
**Table 5** The reliability test for the measurement variables

Constructs	Measurement variables	Cronbach's $\alpha$
Qualitative information exchanges on the network	Reliability of information	0.9282
	Validity of information	
	Integrity of information	
Quantitative information exchanges on the network	Information for new project development	0.8145
	Future transaction related information	
	New product development information	
Role of IT on the value activity coordination	Coordination of inventory level	0.9324
	Tool for the coordination of each activities	
	Cost and time savings by sharing the information	
Supporting effect for modularity strategy with value activity configuration among supply chain	Supporting for design improvement of product	0.7944
	Supporting for new product development	
	Supporting for interface-ability	

3.4.2 Convergent validity and discriminant validity

In order to confirm construct validity, convergent validity and discriminant validity were analysed. Convergent validity means that each measurement items of the same construct must have high correlation among of them. Discriminant validity means that measures among different constructs must have dissimilar relationship. The confirmatory factor analysis was conducted to statistically check for convergent validity and discriminant validity.

**Figure 3** The result of convergent validity and discriminate validity



As shown in Figure 3, reliability of information and integrity of information as measurements of ‘qualitative information exchanges on the network’ show acceptable fitness with bidding information, new product information, and future transaction information as measures of ‘quantitative information exchange’, implying that relationship among variables and constructs fitted very well. As the  $\lambda$  values are statistically significant, the measures have convergent validity. The  $\Phi$  values showing the relationship among constructs do not include 1.0 within the confidence interval ( $\Phi \pm 2SE$ ), indicating that the constructs have discriminate validity.

### 3.4.3 Analysis results and hypothesis testing

Structural equation modelling using conventional maximum-likelihood estimation techniques (Joreskog and Sorbom, 1993) was used to determine the general fit of the model and the data, as well as to test individual hypotheses. The test statistics in Table 6 show that chi-square was 65.093 with 50 degrees of freedom, and that the p-value was significant at the 5% level. In general, a structural equation model is considered adequate if the  $p$  value for  $\chi^2$  is greater than 0.05. The other indices further confirmed that the data fit into the conceptualised model: Both Goodness of Fit (GFI) and Adjusted GFI (AGFI) are greater than 0.9. Therefore, the overall fit of the model, except for RMR, which was slightly above 0.05, was found to be acceptable.

**Table 6** Summary of fit indices

$\chi^2$	65.093 ( $p = 0.074$ , $df = 50$ )
GFI	0.936
AGFI	0.900
RMR	0.056

As Table 7 shows, two of the three paths of the hypotheses were found to be significant and most LISREL coefficients are significant at the  $\alpha = 0.01$  level, except for the causal relationship between ‘quantitative information exchange’ and ‘IT-enabled coordination’, with a nonsignificant t-value of 1.573.

**Table 7** Parameter estimates of theoretical model

<i>Hypothesis: causal relationship between variable</i>	<i>Positive/negative</i>	<i>Standardised coefficient</i>	<i>t-value</i>	<i>P-value</i>	<i>Acceptance</i>
H1. ‘qualitative information exchange’ $\Rightarrow$ ‘IT-enabled activity coordination’	+	0.445	4.648	0.000	Yes
H2. ‘quantitative information exchange’ $\Rightarrow$ ‘IT-enabled activity coordination’	+	0.157	1.573	0.116	No
H3. ‘IT-enabled activity coordination’ $\Rightarrow$ ‘support for modularity strategy’	+	0.227	3.263	0.001	Yes

**Table 8** Parameter estimates of measurement model

<i>Theoretical constructs</i>	<i>Measurement variable</i>	<i>Factor loadings</i>	<i>Standardised factor loadings</i>	<i>Error variance (<math>\delta</math> or <math>\varepsilon</math>)</i>
Qualitative information exchange ( $\xi_1$ )	Reliability of information	$\Lambda_{x11} = 1.000$	0.950	0.244
	Validity of information	$\Lambda_{x21} = 1.014$	0.976	0.114
	Integrity of information	$\Lambda_{x31} = 0.996$	0.965	0.164
Quantitative information exchange ( $\xi_2$ )	Information for new project development	$\Lambda_{x42} = 1.000$	0.926	0.409
	Future transaction related information	$\Lambda_{x52} = 1.052$	0.962	0.221
	New product development information	$\Lambda_{x62} = 0.825$	0.805	0.910
IT-enabled activity coordination ( $\eta_1$ )	Coordination of inventory levels	$\Lambda_{y11} = 1.000$	0.915	1.112
	Tool for the coordination of each activities	$\Lambda_{y21} = 1.016$	0.977	0.281
	Cost and time savings by sharing information	$\Lambda_{y31} = 1.042$	0.855	0.070
Support for modularity strategy ( $\eta_2$ )	Support for design improvement of product	$\Lambda_{y42} = 1.000$	0.815	0.431
	Support for new product development	$\Lambda_{y52} = 1.076$	0.812	0.517
	Support for interface-ability	$\Lambda_{y62} = 0.703$	0.567	0.895

#### 4 Discussion and conclusion

This study analysed the dynamics of IT-enabled information exchange and product modularity in the automobile industry. As shown in Table 7, results indicate that two of our three hypotheses (H1 and H3) are significant. Value activity coordination through IT network supports modularity through value activity configuration. Also, qualitative information exchange over the network accounts significantly for value activity through IT network, while quantitative information exchange over the network does not explain value activity coordination significantly. These results have two implications.

Firstly, information sharing is indeed important for facilitating modularity. Information sharing among companies is accelerated by the use of IT. When automakers adopt internet-based EDI, they can work with a network of suppliers. In traditional EDI,

automakers must lease individual lines for each supplier. This is inefficient in terms of costs. By switching to internet-based EDI, automakers reduce costs and face no limitation on the number of suppliers.

Although internet-based EDI uses VPN for private and secure transactions, it is less secure than traditional EDI. Despite the current efforts, such as Point-to-Point Tunneling Protocol, to improve security levels, many companies still use traditional EDI such as VAN as shown in Table 9.

**Table 9** Reasons to select information network

	<i>Internet-based EDI</i>	<i>KNX</i>	<i>VAN</i>	<i>Total</i>
Easy access	15	9	6	30
Information security and reliability	1	31	43	75
Existing systems	2	10	7	19
<i>Total</i>	18	50	56	124

Secondly, in contrast to qualitative information exchange, quantitative information exchange does not significantly explain value IT-enabled activity coordination. This implies that the quality, rather than the quantity of information, is important. High quality of information must meet three criteria: accuracy, timeliness and consistency. In addition, it must satisfy users' need for information. Thus, information communicated between suppliers and automakers (or among suppliers) must satisfy receivers' needs, and must be accurate, timely and consistent.

Information Technology and modularity provide new challenges for customisation in the automotive industry. Above all, modularity leads configuration for part development in automobile industries. IT networks can be used to coordinate related activities in the value chains. To the best of our knowledge, our study is the first to exhibit the direct impact of IT networks on modular design. It is our hope that this study will contribute to a better understanding of the challenges of modular design throughout supply chains. Ideally, this understanding will lead to a simultaneous decrease in development lead times and costs, and an increase in product quality.

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### **Note**

- 1 CCC21 (Construction of Cost Competitiveness 21) is a campaign to reduce costs through reduction of manufacturing costs by 30% annually for three years from July 2000. In order to achieve the goal, Toyota has used the 'concept-in' system to link suppliers from the starting point.