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An Application of System Dynamics Model to Evaluate Information and System Performance.

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Abstract

As more organizational resources are expanded in designing and developing information systems and networks, it becomes increasingly important to assess the benefits actually derived from the systems. Information provided by systems is a resource available to organizations or decision-makers. The introduction of an information system should be justified on a cost-saving ground like other resources. However, it is not easy to measure or quantify the benefit and the value of information system. Although several approaches for evaluating information system have been suggested, they show significant difficulties in applying to complex and dynamic environments. This study applies system dynamics model to evaluate information and system performance. A system dynamics model is used as a laboratory setting to evaluate information system by examining the relative merits of information attributes (availability, accuracy, and timeliness) in terms of their impact on the overall system performance. System performance is discussed with three different aspects; expansion, stability, and efficiency.

Introduction

The evaluation of value or benefit from information and information system is important practical problem in investment and decision-making [Brynjolfsson 1993; Farbey 1993; Kelley 1994; Reardon 1996]. As more organizational resources are expanded in designing and developing information systems and networks, it becomes increasingly important to assess the benefits actually derived from the systems. Information provided by systems is a resource available to organizations or decision-makers. The introduction of an information system should be justified on a cost-saving ground like other resources [Cornford 1994; Hogbin 1994; Powell 1997]. However, it is not easy to measure or quantify the benefit and the value of information system.

This is further complicated because benefits directly attributable to information and information system become more intangible and indirect. Although several approaches for evaluating information system have been suggested, they show significant difficulties in applying to complex and dynamic environments.

This study applies system dynamics model to evaluate information and system performance. A system dynamics model is used as a laboratory setting to evaluate information system by examining the relative merits of information attributes (availability, accuracy, and timeliness) in terms of their impact on the overall system performance. System performance is discussed with three different aspects; expansion, stability, and efficiency.

Approaches to Information Evaluation

Two major approaches can be identified in the literature on evaluating information and information system; the information economics approach and the perceived value approach[1] [Clark and Augustine 1992; Zmud 1987]. The information economics approach employs the statistical decision theory in a rigorous way to account for all possible effects of an information system [Hitt 1996; Mylonopoulos 1995]. The application of this approach consists of first specifying the alternative actions, states, probabilities of states, and conditional outcomes and then selecting the alternative that will result in the maximum expected outcome. For the analysis the information or action environment must be completely specified. That is, the relevant variables, relationships and the parameter values must all be known a priori. Theoretically the information economics approach is appealing; realistically it appears impractical [Clark and Augustine 1992; Jones 1981; Zmud 1987].

The perceived value approach attempts to measure the information user's perception of the overall value of information by uncovering the user's beliefs about the value of information supplied. Techniques employed for the approach include the semantic differential [Gallagher 1974], indexed of appreciation [Swanson 1974], and decision scenarios [Zmud 1987]. The approach makes the user describe his assessment of information system for a specific purpose. It is useful for post-implementation evaluations as it is based on users' perception or experience. A major problem, however, is that items and scales for evaluation are usually subjectively generated and assessed [Clark and Augustine 1992; Jones 1981].

Monetary benefit, user's satisfaction, and user's subjective utility are important criteria in evaluating information and information system. Both the information economics and the perceived value approaches, however, share significant difficulties in dealing with complex system and relating changes in information system to system-wide performance. They fail to attach importance

[1]. Clark and Augustine (1992) and Clark (1987) differentiate the perceived value approach into the economic value approach and the utility value approach.

to the impact which information or an information system may have on decision-making and system performance [Davis 1985; Forrest 1961; McLeod 1990].

Similarly, Forrest [1961] and Langfors [1973] emphasize that the value of information should be measured by the value it has for controlling a system. Since these arguments contend the value of information can only be assessed from the changes in organizational performance which accompany its use, an information feedback model or simulation model of a particular system should provide a mean for evaluation. The systems approach to information evaluation has been demonstrated by many researches in the area of System Dynamics [Clark & Augustine 1992; Gavine 1990; Graham 1976a & 1976b; Henderson 1990; Jones 1981; Morecroft 1979 & 1983; Swanson 1971; Watts 1990; Weil 1981; Wolstenholme 1990]. These studies used system dynamics models to assess the benefits of information by examining the relative merits of a set of information attributes in terms of their impact on the overall system performance.

Information Dimension

Information required for decision-making does not always flow into the decision point. Some information is not available in the decision-making process due to organizational and geographic barriers. Individual cognitive limitation and group miscommunication make it difficult for people to perceive information. Information is also dismissed from the process due to conflicting organizational goals and peer group pressure. Information, even when available, tends to be delayed and distorted by time lag and random errors [Morecroft 1988].

In order to systematically evaluate the impact of information on decision-making process and the behavior of a dynamic system, the overall characteristics of information need to be described by more specific attributes or dimensions. For the purpose of the experiments, the information is controlled with three dimensions; availability, accuracy, and timeliness. Availability means whether decision-makers can access or use certain information in decision-making process. Availability of information is synonymous with relevance or sufficiency, which means whether information available is useful for a certain decision purpose. This study assumes that the information available in the major decision points is relevant to the decision-making for capacity development. Accuracy implies how much information available in decision-making processes is distorted. Timeliness corresponds to 'information delay,' a well-known concept to system dynamicists. It means that decision-making process requires information which represents what is going in the decision environment.

Waste Recycling and Recycling Market

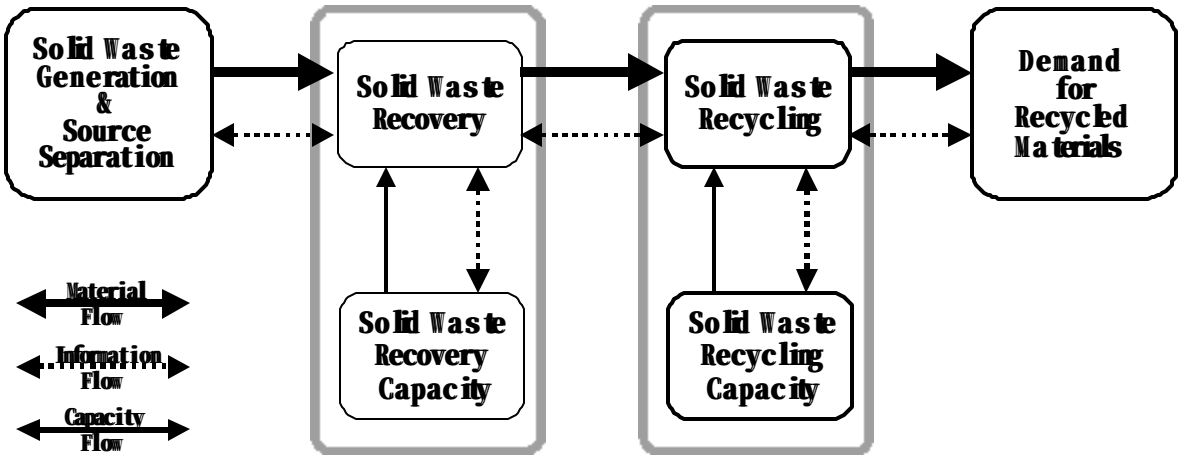
As landfill space and incineration capacity rapidly decrease coupled with a growing volume of waste, waste recycling is recognized as a preferred way of managing "waste crisis." Waste recycling means more than just separation and collection of specific materials. It requires the

introduction of recyclable materials into manufacturing processes, and finally to the end-users. That is, a successful waste recycling program depends on developing or finding strong and durable markets induced by the steady supply of recyclable materials with low contamination at price that varies within reasonable limits, as well as the stable demand for recycled materials. In this regard, state and local governments have proposed or already implemented various market development policies; such as avoided cost subsidies, tax credits, direct financial assistance, government procurement, mandatory source separation, etc. Those policies are intended to expand the recycling market by stimulating either the demand or the supply sides of recycling markets, and inducing more capital investment in the market.

One of the distinctive features of the recycling market is its multi-stage structure. Waste recycling means more than a simple conversion of wastes to re-usable materials. It covers a stream of economic activities involving waste generation, collection and separation, recycling, and re-using. Thus, the market system can be considered as being composed of a set of four connected sectors; 1) waste generation and source separation, 2) waste recovery, 3) waste recycling, and 4) demand for recycled materials.

Each sector in the market interacts through information and material flows. The source separation sector separates recyclable wastes from other waste streams, and sends the separated wastes to the primary recovery sector in response to the demand for source separated wastes. The primary recovery sector gathers and sorts out source separated wastes, and sells the recovered wastes to the waste recycling sector. The economic activities of waste recovery depend on information on the prices of source separated and recovered wastes. The waste recycling sector produces materials using the recovered wastes provided from the primary recovery sector. Waste recycling is influenced by information on the demand and price conditions for the recycled materials in comparison with those of virgin materials.

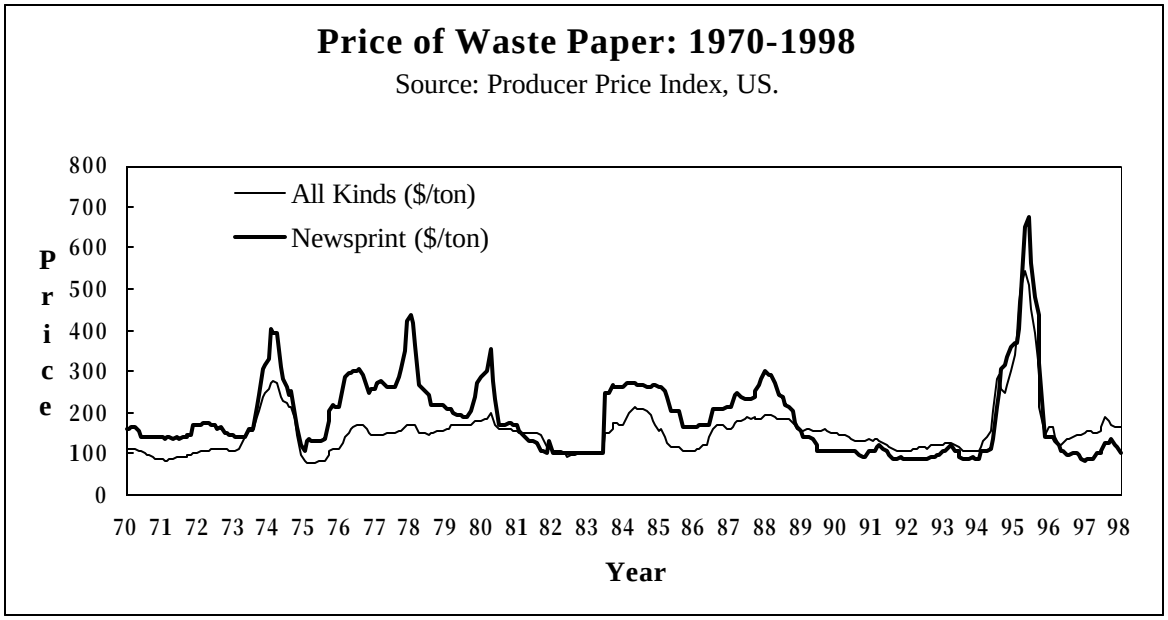
Structure of Recycling Market



Recycling Market Instability

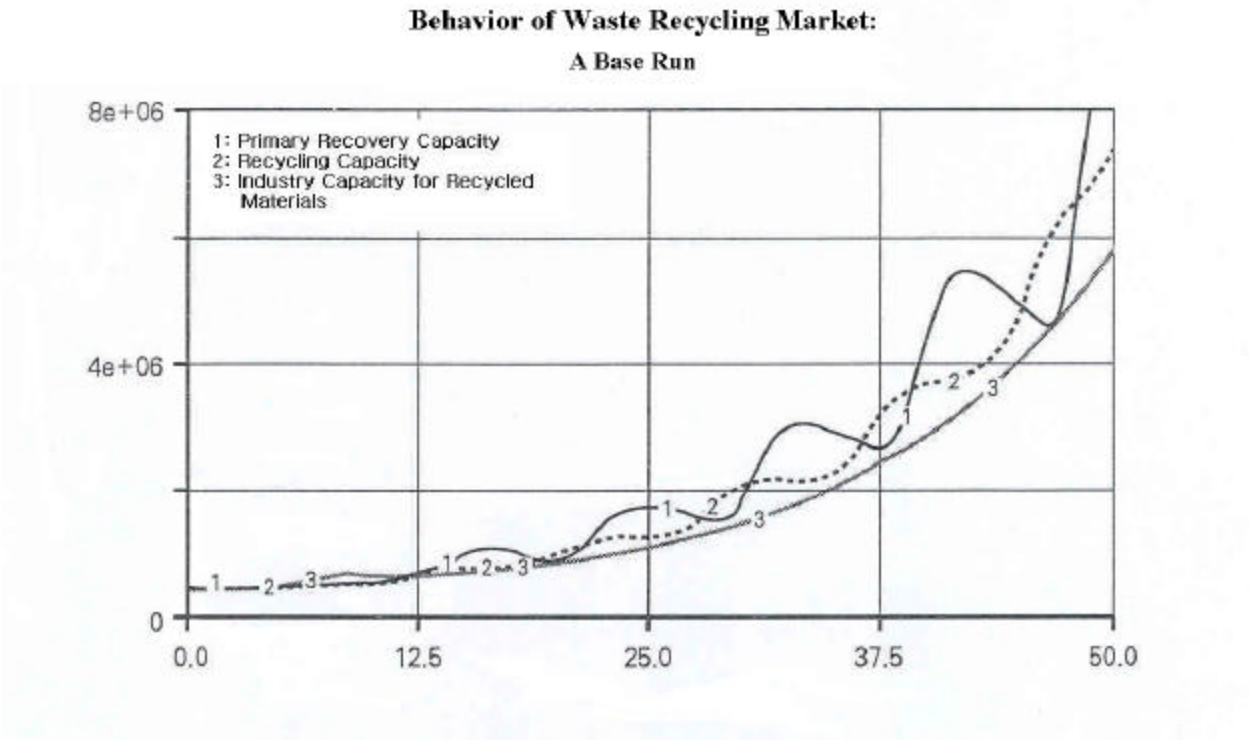
Traditionally, waste recycling markets, the waste paper market in particular, have shown price instability which has presented a significant barrier to market investment. Researches on the market indicate that the supply of wastepaper is relatively insensitive to price changes. This means that small price changes yield little change in the amount of wastepaper supplied, and only large price changes serve as a stimulus to increase the quantities supplied. The demand for wastepaper is also insensitive to the change to the changes in consumer income. The income inelasticity of the wastepaper demand implies some level of demand stability for wastepaper during economic downturns. However, this insensitivity has been a substantial obstacle to market expansion by stimulating the demand side of the market.

In order to develop the markets, state and local governments have proposed or already implemented various policies, such as avoided cost subsidies, tax credits, direct financial assistance, government procurement, and mandatory source separation. Those policies are intended to expand the recycling market by stimulating either the demand or the supply sides of the market, and inducing more capital investment in the market. Policy-makers arguer that those market development policies, even though accompanying market fluctuations in the short term, will stabilize prices of the secondary materials and expand the market in the long term by strengthening market bases. Contrary to the policy expectation, the market shows a behavior of continued instability.



Analysis of Market Behavior: Base Run

Two major policies for developing the market are applied in analyzing the dynamic behavior of the market; 1) an increase in the average waste disposal cost, and 2) an increase in the price of primitive materials. The selection of these policies for the experiment can be justified by the following reasons. The policies are most representative of public efforts to develop the market. Each policy targets a specific sector in the market. The first policy is expected to prime the supply side of the market, or the source separation sector by making the cost of source separation relatively cheaper than cost for landfill and incineration. The second one is designed to stimulate the demand side of the market by making the price of recycled materials competitive to those of primitive materials.



With strong economic incentives in the demand and the supply sides of the recycling market, the material production capacities are increasing. However, the market shows an unstable behavior, or fluctuations in its capacities and prices. The behavior can be explained as follows. In response to the implementation of market development policies, both the demand for recycled materials and the supply of recyclable wastes are increased. However, the information on the demand and the

supply levels does not transfer to each other directly and immediately because of the multi-stage stricture of the recycling market. That is, each sector in the market responds to the economic incentive provided by a specific policy on the basis of locally-available market information. Furthermore, delayed information induces economic agents within each sector to over- or under-investment in material production capacities.

As the price of primitive materials increases, the demand for recycled materials increases. The increasing demand for recycled materials leads to more investment in the recycling capacity. As the recycling capacity expands, the demand for recovered materials increases. The increasing demand for recovered materials induces more investment in the recovery capacity. The way in which information on the increasing demand transfers stage by stage is represented by the time lag in the peak level of the recycling capacity and the recovery capacity. In sum, the market instability can be explained by the information network embedded in the multi-stage structure of the recycling market, and by the capacity adjustment delay in responding to the demand/supply condition.

Experiments of Evaluating Information

In order to evaluate the impacts of information on the overall system behavior, the dynamic behavior of the recycling market under various information environments is analyzed. Information environment is controlled with consideration of three dimensions of information; availability, accuracy, and timeliness. The major variables in the decision-making process of the recycling capacity investment and the recovery capacity investment are changed. The market behavior from each information test is compared with that of the base run.

Availability Test: Experiment 1

The first information test examines the impact which the amount of information available in the decision-making process for capacity investments has on the overall market behavior. To do the test, the amount of information on the level of 'capacity under development' is reduced to 50%. In the base run, however, all the information on 'capacity under development' is assumed to be available.

The overall behavioral patterns of the production capacities and the material prices after the test are similar to those of the base run. However, the levels of production capacities show more fluctuation than the base run. The average amplitude of production capacities after the test is about 227,000 tons per year, while the average amplitude in the base run is about 121,000 tons per year. The amplitude of the recovery capacity is also increased.

Accuracy Test: Experiment 2 & 3

Accuracy tests examine the impact which accuracy of information in forecasting future profit and demand level has on the overall market behavior. In the second test, the forecasting period of profitability of recovered materials and recycled materials increases twice as much as the period in the base run. The base run assume that the forecasting period of material profitability is set by the same period of constructing production capacities, or 3 years for recovery capacity and 4 years for recycling capacity. In the third test, the forecasting period of material demand level for recovered materials and recycled materials is set to 2 years, while the base run assumed that information of the current level of demand immediately available.

The overall behavior of the production capacities and the material prices is similar to those of the base run. At the end of simulation, demand for recycled materials is about 5.8 million tons per year; 5.7 million tons per year in the base run. The recycling rate is 24.1%; 23.3 % in the base run. Although fluctuation is the production capacities increase, it is not significant.

Timeliness Test: Experiment 4 & 5

The fourth and the fifth tests examine impact which information delay has on the overall market behavior. Two decision variables are tested, respectively; 1) information on demand level, which is delayed by smoothing the information by one year, and 2) information on the 'capacity under development' which is delayed by two years. Again, the overall behavioral pattern of the production capacities and the material prices is similar to those of the base run. At the end of the simulation period, the industry-wide demand for recycled materials is about 6.3 million tons per year. The recycling rate is 23.6%. During the entire period of simulation, the total amount of recycled materials is about 93.1 million tons.

A major characteristic of the market behavior in response to the delayed information on the demand level is an increase in the production capacity and the industry-wide final demand for the recycled materials. This can be explained by the behavior of material prices in the recycling market. The overall price level is lower and more stable than the base run. Because of the lower price level, the demand for recycled materials increases. The information on the increased demand is not transferred to other sectors directly because information is smoothed. This means that the smoothed information reduces the sensitiveness of raw information which possibly causes over-investment.

Compared to the base run, the delayed information on 'capacity under development' lowers the overall level of production capacities and the industry-wide demand for the recycled material, and destabilizes material prices. Decision-making for capacity investment is assumed to take into account the level of 'capacity under development.' The final level of capacity investment is calculated by subtracting 'capacity under development' from the desired level of production capacity in order to prevent over-investment or under-investment. However, information regarding 'capacity under development' which is available in the decision-making process is delayed

information. This means that delayed information accelerates over-investment, or precipitates under-investment in production capacity.

The increased amplitude of production capacities leads to higher production cost which in turn increases the material price. The higher production cost is reinforced by lower capacity utilization rate. The capacity utilization rate in this test is 87.8%, while the rate in the base run is 89.3%. Thus, the industry-wide final demand for the recycled material decreases.

Discussions on Information Tests

In the information environment test, the quality of information was controlled on the basis of three dimensions of information; availability, accuracy, and timeliness. That is, the quality of information which was assumed in the base run was lowered by providing less, inaccurate, or delayed information. The following table summarizes the market behavior under various information environments. In terms of market expansion, information does not make any significant difference. Although the industry-wide final demand for recycled materials shows some differences, the average recycling rates during 50year are very similar. It should be noted that the level of the final demand for the recycled materials is measured in one point of time, or in the final year of simulation. Thus it is not a reliable indicator to measure the overall market expansion.

Summary of Market Performance from Information Tests

		Expansion			Stability			Efficiency		
		Dm'd for Rcycled Material (ton/yr)	Rcy'ng Rate (%)	Averg. Rcy'ng Rate (%)	Rcov. Capa'ty Fluct'n (ton/yr)	Rcy'ng Capa'ty Fluct'n (tos/yr)	Averg. Capa'ty Fluct'n (ton/yr)	Rcov. Capa'ty Utiliz'n (%)	Rcy'ng Capa'ty Utiliz'n (%)	Averg. Capa'ty Utiliz'n (%)
Base Run		5.7 M	23.3%	11.7%	241,112	0	120,556	87.8%	90.8%	89.3%
Information Environment Tests	Availability (Test 1)	5.9 M	23.6%	12.1%	390,836	62,161	226,499	83.0%	98.0%	87.0%
	Accuracy (Test 2)	5.8 M	24.1%	11.9%	185,428	100,929	143,179	85.0%	90.8%	87.9%
	Accuracy (Test 3)	5.2 M	21.0%	11.3%	206,623	51,099	128,861	87.2%	89.2%	88.2%
	Timeliness (Test 4)	6.3 M	23.6%	12.0%	263,860	0	131,930	84.4%	92.6%	88.5%
	Timeliness (Test 4)	5.3 M	21.5%	11.2%	202,203	553,466	377,835	84.6%	90.8%	87.7%

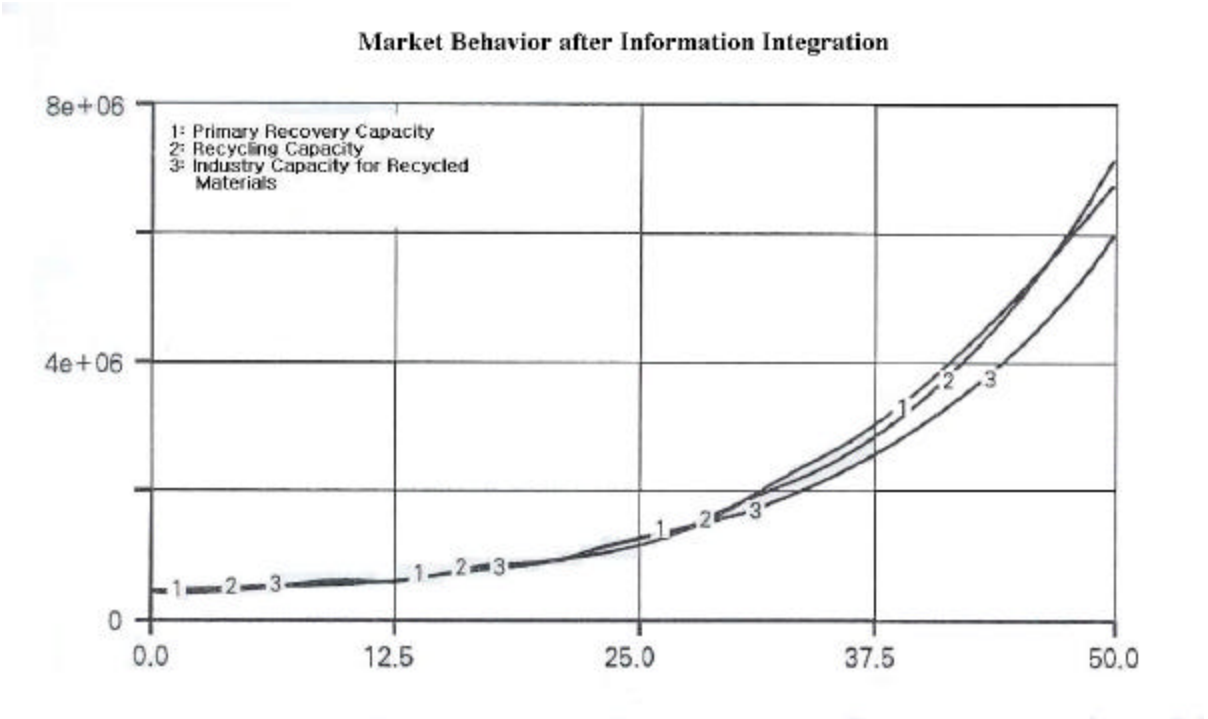
On the other hand, information has a significant influence on market stability. In particular, availability and timeliness of information regarding 'capacity under development' show large impact on the production capacities. In other words, when the information on 'capacity under

development' is not available or is delayed in the decision-making process for the production capacity investment, the final decision leads to over-investment or under-investment in the level of capacity. Furthermore, delayed information on 'capacity under development' results in a higher amplitude that the case without information on 'capacity under development.' This means that less information is better than delayed information for market stability.

Assuming that expansion is represented by the average recycling rate during the entire simulation period, stability is measured by the average capacity fluctuation, and efficiency is measured by the average utilization ratio of production capacities. A general tendency is that a higher recycling rate is accompanied by a higher amplitude. In other words, there is a tradeoff in system behavior between expansion and stability. The performance tradeoff becomes obvious as the information quality lowers. All cases of information tests show more unstable market behavior than the base run.

There is also a tradeoff between expansion and efficiency. As the average recycling rate increases, the production capacities are utilized less efficiently. All cases of information tests show that the production capacities are utilized less efficiently that the base run. The overall trend shows that the production capacities are utilized less efficiently as the amplitudes of the production capacity levels increase.

Vertical integration of market information



Based on the findings from information environment tests, this study analyzes a situation which is expected to improve the system behavior by providing a better information. It is to integrate vertically the information network embedded in the multi-stage structure of the recycling market. Under the present information environment, information on the demand (or supply) side of the market transfers to the supply (or demand) side through sector by sector. As the number of sector in the market increases, information on the market condition tends to be delayed and inaccurate. Thus, information integration tries to reduce those information defects by integrating information network across sectors.

It assumes that a centralized database on the market condition exists, and that timely and accurate market information is available and disseminated to economic agents in the market. Information integration is implemented in this simulation model by connecting information network of each sector. After integrating information, the fluctuations in the level of production capacities disappear. The production capacities are growing smoothly in comparison to the market behavior in the whole model test.

The following table summarizes the market behavior before/after integrating market information in terms of expansion, stability, and efficiency. Although the average recycling rate and the demand for recycled materials do not change significantly, the levels of production capacities are much stabilized and production capacities are more efficiently utilized. That is, information integration removes market instabilities. Before vertically integrating information in the market, there was a general tendency that a higher recycling
activity was accompanied by a higher instability in terms of production capacity. After enhancing market structure by integrating information, market behavior becomes much more stable. This means that the tradeoff in system performance between expansion and stability disappear.

Market Performance Before/After Information Integration

	Expansion			Stability			Efficiency		
	Dm'd for Rcycled Material (ton/yr)	Rcy'ng Rate (%)	Averg. Rcy'ng Rate (%)	Rcov. Capa'ty Fluct'n (ton/yr)	Rcy'ng Capa'ty Fluct'n (tos/yr)	Averg. Capa'ty Fluct'n (ton/yr)	Rcov. Capa'ty Utiliz'n (%)	Rcy'ng Capa'ty Utiliz'n (%)	Averg. Capa'ty Utiliz'n (%)
Base Run	5.7 M	23.3%	11.7%	241,112	0	120,556	87.8%	90.8%	89.3%
Information Integration Test	5.8 M	21.8%	11.6%	0	0	0	95.0%	95.0%	95.0%

Conclusions

Information tests examined the impact of information on market behavior or system performance under various information environments. For the tests, information was controlled according to three dimensions. Less, delayed, or inaccurate information was supplied in the decision-making process of production capacity investment in the primary recovery and recycling sectors. The major findings are summarized below;

First, changes in the quality of information did not make significant differences in terms of market expansion as measured by the average recycling rate. However, as the information qualities were lowered, the overall market behavior showed more instability in the level of material production capacities, and less efficient utilization of production capacities.

Second, the overall behavior of market system under various information environments showed performance tradeoffs between expansion and instability, and between expansion and efficiency. A higher average recycling rate is accompanied by a larger cyclical fluctuation in production capacities and material prices. A higher average recycling rate is also accompanied by a lower utilization rate of production capacities.

Third, information on 'capacity under development,' among others, has a significant impact on market behavior. When the information of 'capacity under development' is partially available or delayed in the decision-making process for the production capacity investment, the final decision leads to over-investment or under-investment. Thus the overall performance of the market system was lowered irrespective of performance criteria; expansion, stability, efficiency.

This study has a methodological implication for measuring the value of information or information system. Two major approaches for information evaluation, the information economics approach and the perceived value approach, have significant limitations in dealing with complex information environments in which the value of information is difficult to quantify. Furthermore, these approaches fail to attach importance to the impact which information or an information system may have on decision-making process and system-wide performance.

This study applies a system approach to information evaluation using a dynamic simulation model to assess the value of information. The research findings from simulation-based experiments demonstrate that the systems approach may be appropriate to measure the value of information with respect to its ability to control a system of interest and to change overall system performance. A vertical integration of multi-stage structure of market information system led to changes in the overall behavior of the market system. The systems approach clearly explained the behavioral changes in terms of the impact which new information structure could have on decision-making process and system control.

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