

# The Role of Operations Research towards Advanced Logistics

EIZO TAKAI  
*Affiliated Fellow*

## 1 Introduction

Product supply chains of recent Japanese industries are now at a major turning point in two major aspects, namely, structural changes in the nature of supply chains and more advanced functional requirements. Structural changes have been brought about by various circumstances, including the more complex and geographically wider international logistics associated with the globalization of corporate activities, a change in the relationships between companies from the simple serial procurement/supply chains of the past to open network-type supply chains, and changes in modes of logistics due to expansion of e-business accompanying the development of information and communications technology (ICT), among others. On the other hand, more advanced functional requirement levels are the result of shortening of product model change cycles and the need for adaptability to rapidly-changing markets, rationalization and energy conservation in response to high energy costs, and the like. The importance of the more advanced supply chains resulting from the progress of globalization is emphasized in this year's "White Paper on Monozukuri (Promotion Policy for Basic Technologies in Monozukuri in FY2007)."<sup>[1]</sup>

These requirements mean, in other words, that innovation and more advanced techniques are demanded in logistics in supply chains.

In realizing innovation and more advanced techniques in logistics, use of more advanced and sophisticated information technology is necessary. In this meaning promotion of the practical application of Operations Research (OR) is strongly required, as well as the development of more sophisticated OR theories and methodologies. Although improvement of hardware, such as transportation facilities and the

infrastructure, is also important, problems will not be solved without more advanced planning and operation management systems using advanced software technologies and optimization methodologies. In rational planning of the highly complex distribution network as a whole, optimization of factory and warehouse location, and optimization of transportation routes by using OR is indispensable. In order to respond to recent business environment with rapidly-changing markets, and continual entry of new products an efficient operating system with flexibility and speed achieved by OR is demanded. The evolution of logistics is not limited simply to progress in hardware in the form of automation of warehouses and transportation facilities; progress and adaptation of OR techniques are also extremely important.

Furthermore, as recent challenges, high expectations are placed on innovation by service science as a means of increasing productivity and improving quality in the service industry, which now accounts for a major part of the industrial structure. As an important object of research in this field, logistics is considered to be an extremely promising area.

This report focuses on research and development of logistics design for realizing more advanced supply chains, the importance of which has been pointed out in the above-mentioned "White Paper on Monozukuri." The concepts and current problems of supply chains and logistics are introduced, and secondly the proper roles of OR in solving the current and future logistics problems are discussed. Finally, the primary issues for the promotion of research on logistics and OR in Japan in the future are proposed.

## 2 Challenges and problems for logistics in Japan

### 2-1 Development of logistics in supply chains and related issues

The concept of “physical distribution,” meaning the activities of distribution and inventory of the raw materials and products which support the real economy, has a long history. The movement of improving and rationalizing such activities through economic and technical research has been accelerated particularly in the United States since the end of World War II. The concept of “physical distribution management” appeared following World War II, and evolved into the concept of “logistics” as a new business model representing a fusion of physical distribution and information systems. In Japan, these two terms are used virtually synonymously, but properly speaking the former is a concept that focuses on the individual work of movement (transportation) and storage of goods, while the focus of the logistics is the rational design, management, and operation of distribution as a whole utilizing information. “Logistics” is originally a military term meaning the activities of supplying required troops, weapons and ammunition, provisions, etc. in accordance with tactical plans. Thus, the analogous activities in the field of economics were sometimes termed “business logistics.” Quoting the definition of the Council of Logistics Management (CLM; now the Council of Supply Chain Management Professionals, CSCMP),<sup>[2]</sup> “Logistics management is the part of supply chain management that plans, implements, and controls the efficient, effective forward and reverses flow and storage of goods, services and related information between the point of origin and the point of consumption in order to meet customers’ requirements.”<sup>[2]</sup>

The activities in logistics, include inventory management, transportation management, warehouse management, material handling, packaging, returns/recovery in general, In some cases, such activities as demand forecasting, order management are also included. In addition to these, Lambert<sup>[3]</sup> mentions some other activities as plants and/or warehouse location design, customer service, procurement, parts/service support, and others. While top management function of logistics, CLO (Chief Logistics Officer),

is just started to be recognized in Japan, this management function is already established in the United States. From this, one may say that the function of logistics is considered to be much larger and important in the United States than in Japan.

The concept of “supply chain” appears in the above-mentioned definition of logistics, and indicates the series of activities for supplying goods and services from procurement of raw materials to the final customer, through the chain of activities of production, sales, and distribution. The basic concept of traditional transportation business development is “correct delivery of products” for a single company or product. Differs from the concept of former simple transportation of single goods, the concept of “supply chain” is to create and provide final value to consumers considering wider range of integrated corporate activities starting from raw materials to final products, R&D and CRM. The concept of a “supply chain” was further expanded by the concept of Supply Chain Management (SCM) starting from 1990s that intend to realize new, rational business process through the integration of business activities clearing the boundaries of different business divisions and/or companies.

Figure 1 shows the general concept of a supply chain.<sup>[4]</sup> The totality in which the activities of central companies and the various related companies in the process from raw materials to the final consumption are combined by flows of business, information, and products/services (raw materials, parts, products, goods) forms entire supply chain. The solid line arrows in the figure show the flows of products from upstream to downstream, while the broken line arrows show the major flows of information such as order issuance, demand, etc., which run from downstream to upstream. It also shows that the supply chain is constrained by the capabilities of the member organizations in various factors such as the production or processing capacity, specialties, information, capital, human resources, etc. The aim of SCM is to realize more advanced supply chain by increasing the productivity, efficiency, and effectiveness of this system as a whole through establishing appropriate memberships, well balanced capabilities, and information connection.

SCM is a management methodology developed in the 1990s. Its aim is to create an efficient operation system by eliminating overproduction and shortages

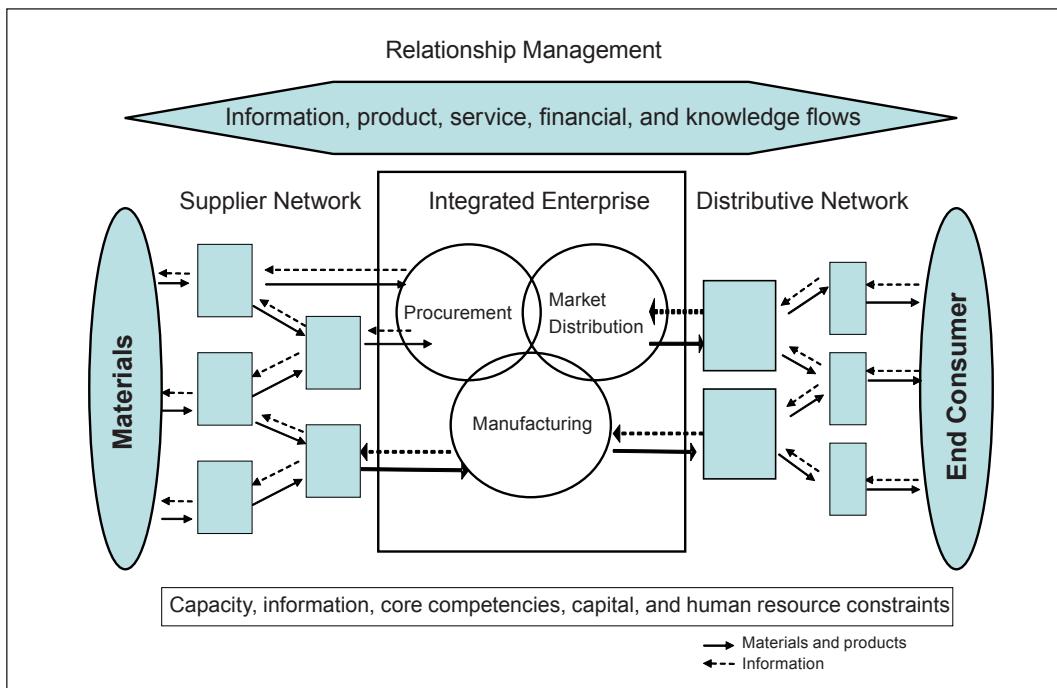


Figure1 : Generalized supply chain model

Prepared by the STFC based on reference [4]

to cope with rapidly changing volatile market situation, where conventional production planning based on traditional demand forecasting is not appropriate. This is to be achieved by rational combination of production and logistics management at the same level. Its basis is reconsidering the whole business process across the barriers between organizations and integrate it as a single stream. In a sense, SCM has accelerated such changes as the shortening of product life cycles and the evolution of the internationalization of product manufacturing. In other words, in the era of physical distribution, supply chains were consisted of simple transportation connecting the inventories distributed all of the stages from source suppliers, production plants, warehouses, and retail stores. SCM is a methodology of transforming supply chains by connecting final consumer to the suppliers directly eliminating intermediate inventories as far as possible and provide efficiency with shortening of lead time.

The success achieved by the integrated model of the business process called QR (Quick Response), which enabled the rebirth of the apparel industry in the United States, is considered to be the beginning of the concept of SCM.<sup>[5]</sup> That success made it popular and many models of various names using various techniques were then conceived by the pioneers as Dell Corporation, Wal-Mart, and others. Although a variety of methodologies were proposed, their aims can be summarized as shortening of supply lead

time, avoidance of defects, reduction of wasteful overproduction and excess inventories by sharing downstream information (demand side) with the upstream process, and controlling the upstream process on this basis. With the above-mentioned QR, the American domestic apparel industry succeeded in shortening the total process, which originally had required 56 weeks from thread for weaving to the finished product, to 12 weeks by realizing flexible production scheduling coupled to market information, shortened production lead time and shortened inventory turn around time of materials and semi products, etc. This represented the establishment of a business model which made it possible to supply products quickly in line with market trends, while greatly reducing total stocks, and introducing new products within a short time. This made it possible to compete successfully with imported cloths, which only had the advantage of low production cost. The implementation of this model was the occasion for the birth of the new type of apparel companies with worldwide retail networks. The concept that “downstream controls upstream” is also the basis for the world-renowned model called the “Toyota kanban system.” and JIT (Just-In-Time) procurement.

Today, SCM has developed into a concept covering wide range of operation design and management including product design to customer relationship management. However, its basis is still on the

establishment of closer coordination of the information flow and operational workflow in production and logistics. Accordingly, the heart of the system lies in logistics.

As mentioned previously, the focus of this report is research and development related to designing logistics. Figure 2 shows the major issues in logistics existing among the major stakeholders in a supply chain. In this figure, although the problems in actual logistics are more congested, one may recognize that the importance of establishing plans in all operational flows and management levels, from strategic decision-making to routine operational control. As classified very broadly in Figure 2, the main issues in the planning can be divided into (1) issues related to international logistics, (2) issues in the location problems and network design for production plants and warehouses, (3) issues in the inventory management and inventory allocation in the network, (4) issues on the decision of transportation route, modal selection, vehicle assignment., (5) other related issues such as demand forecasting, cargo loading, labor management, etc. In addition, recently, as a combination of the above mentioned problems, issues of green logistics, including greenhouse gas reduction,

conservation and recycling of materials, have also become important

In establishing the various types of plans shown in Figure 2, it is necessary to pursue optimality by using diverse data in many cases under various external conditions. In order to obtain rational optimum plans for these diverse and complex problems, application of mathematical techniques using OR is demanded. Moreover, research and development of more advanced techniques corresponding to the complexity and larger scale of problems is also necessary. These problems are discussed in Chapter 3.

**2-2 Recent problems in logistics in Japan**

As discussed at the outset, supply chain of Japanese industry is now facing major turning points, and rationalization and advancement of logistics is a crucial issue for strengthening the foundations of monozukuri (art of manufacturing) in Japan to cope with the various problems such as the ever widening international logistics, requirements for higher market adaptability, economic pressure for rationalization, and satisfying energy conservation and environment-friendliness needs. All of these requirements are the keys to the procurement of raw materials and parts

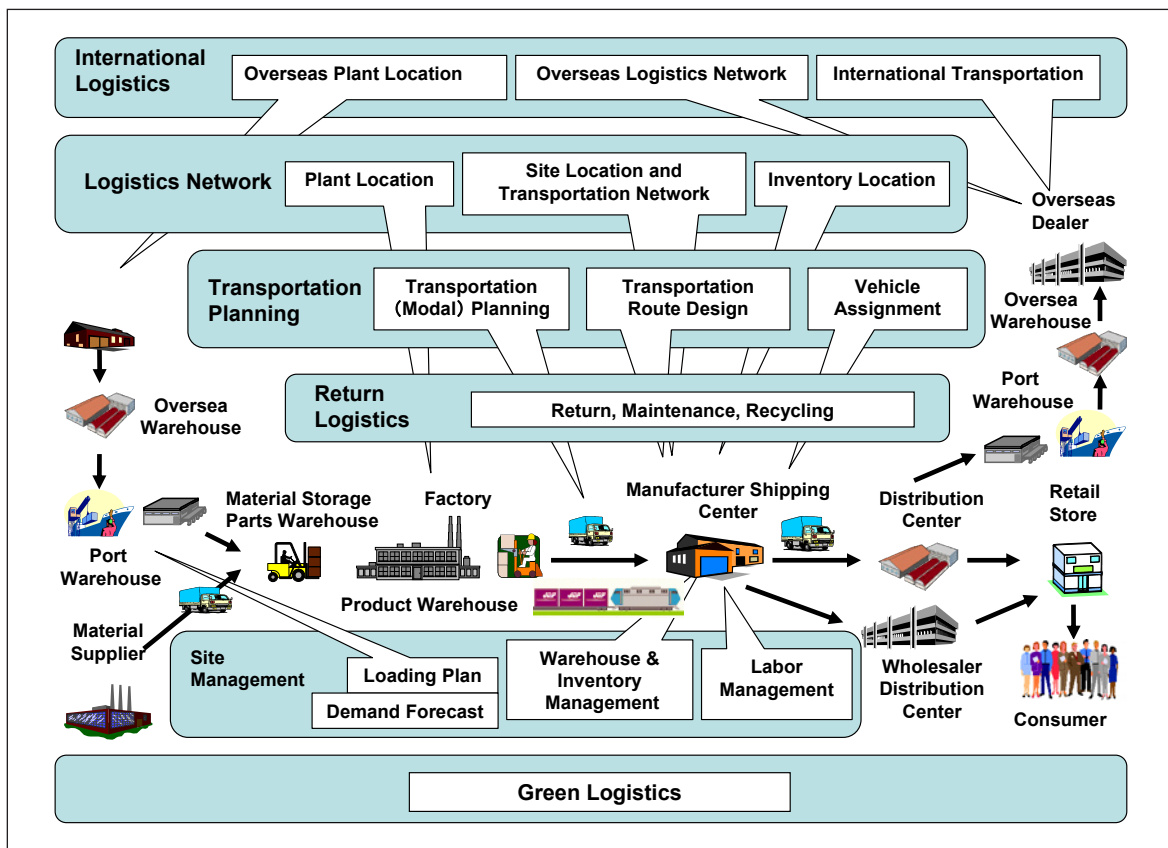


Figure2 : Major issues in logistics planning and management

Prepared by the STFC

and product supply to the market. Internationally, the development of a large-scale land transportation network extending from northeastern Asia to India, the Middle East, and Europe (“Eurasian Land Bridge”) is considered likely in the future. Therefore, research on policies for strengthening Japan’s international competitiveness, such as cooperation and contribution toward the realization of international transportation systems including these regions, is also an important issue.

The total amount of logistics costs in Japan’s domestic industries is approximately ¥42 trillion/year (2005), amounting to about 8% of this country’s gross domestic product (GDP).<sup>[6]</sup> Technical progress can be seen in this field, as exemplified by the use of advanced material handling tools, transportation facilities and RFID, and improvements have been realized in the software aspect, such as popularization of inventory optimization software and transportation management systems. However, the labor productivity in this sector is still low. According to the “International Comparison of Labor Productivity (2006)” published by the Japan Productivity Center for Socio-Economic Development.<sup>[7]</sup> Japan’s labor productivity in the logistics sector is approximately 50% of that of the United States. Thus, further rationalization is strongly demanded in this sector.

It has been pointed out that the possible causes of this low productivity may include various factors, the as-delivered pricing system, which is a unique business custom in the logistics and sales industries in Japan (system in which the cost of transportation to the customer is included in the price of the product; because this makes the cost of distribution a latent factor, it is considered to be a cause of low consciousness of rationalization in distribution), delivery with small lot and high frequency due to the small storage space of stores, strong preference of consumers on freshness, requirements for large variety of goods, and other cultural factors. However, there is also an opinion that one big factor is strict quality requirements on delivery in Japan (on-time delivery rate, order fulfillment rate, less damage rate, etc.), which are without parallel in other countries. For example, according to the recent research, the on-time delivery rate in the United States is approximately 90%, but in contrast, the rate in Japan is 99.99%.<sup>[8]</sup> This undoubtedly supports highly efficient production in Japanese manufacturing factories, but on the other

hand, the possibility that this increases delivery costs by requiring the same accuracy in areas where strict on-time delivery is not necessarily essential has also been pointed out.

In the distribution costs of ¥42 trillion mentioned previously, nearly 70% is costs associated with transportation. Due to heightened interest in so-called green logistics, the main purpose of which is reduction of CO<sub>2</sub> emission demanded by global warming countermeasures in recent years, and the necessity of energy and fuel saving on transportation due to the spike in the oil price, interest in rational transportation technology and delivery systems is extremely high. Research on the solutions involving a combination of transportation methods, such as land transport by truck and rail, sea transport, air transport, etc., which is termed multi-modal transportation, is a promising area on this problem. In order to realize this rationally, R&D activities should not be limited on hardware, but also should include optimization planning using advanced mathematical techniques by OR to realize complex and large scale logistics.

Needless to say, the effects of changes in the supply chain will extend to industry as a whole. Rationalization in logistics is not a problem only for the logistics industry (transportation and shipping industry, forwarders, warehousing industry, 3PL (third-party logistics)) in the service industry sector; its necessity in manufacturing industries and the energy industry is also increasing.

In the logistics planning’s shown in the Figure 2, there are areas where advanced techniques have already been accepted. However, considering the effect of changes in the supply chain as a whole, solutions to problems which are difficult for the private sector alone, such as optimum design of large-scale international transportation networks, including their operation, development of advanced technologies for realizing green logistics, and the like, are expected in specialized research institutions such as universities. Chapter 3 describes problem-solving techniques using OR and the necessary research and development to solve the important focused problems for which effects are expected.

### 3 Advancement of logistics by OR and expected research fields

In a complex activity like logistics, problem solving by assumptions of a simple cause-and-effect relationship alone is not sufficient. Optimum plan should be derived through the analysis and comparison of many alternative case studies simulating the behavior of logistics organization or processing system under the premises based on present situations or future planning. This means that application of the OR methodology based on mathematical process is strongly required.

#### 3-1 Development of OR and logistics

OR (operations research) was born as operational research, which is a technique corresponding to technical research, in order to make effective use of new military technologies such as radar, night fighters, underwater mines, etc. in the United Kingdom in the final stage of World War II. Subsequently, the concept migrated to the United States, where it developed under the name of operations research (in this case, tactical operation research), and provide a wide range of achievement, from frontline military operations as such to logistical support in behind. After the war, this

technology was made available to private business sectors and was widely applied in various industries, evolving into the OR of today.

Many definitions have been given for OR. In general, however, as shown in Figure 3, the term indicates a methodology in which corporate and social activities producing goods and services are understood as a system which outputs results when inputs are given, the system of those basic activities is constructed as a mathematical model, and problems regarding the operational methods of the system are analyzed using mathematical tools conforming to the purpose in order to produce the optimum solution. In practice, the problem finding and derivation of solutions are carried out by using a variety of techniques, such as mathematical and statistical analyses, system simulations, optimization algorithms, etc.

From the very start of its development, OR had a strong relationship with problems related to logistics. Many of the basic technologies in the initial stage have also become basic technologies of logistics planning, even today. That is, the basic technologies of demand forecasting, inventory theory, determination of optimum order quantity (economic order quantity), shortest path planning, mathematical programming methods (resource allocation problems, optimal location problems), queuing theory, discrete

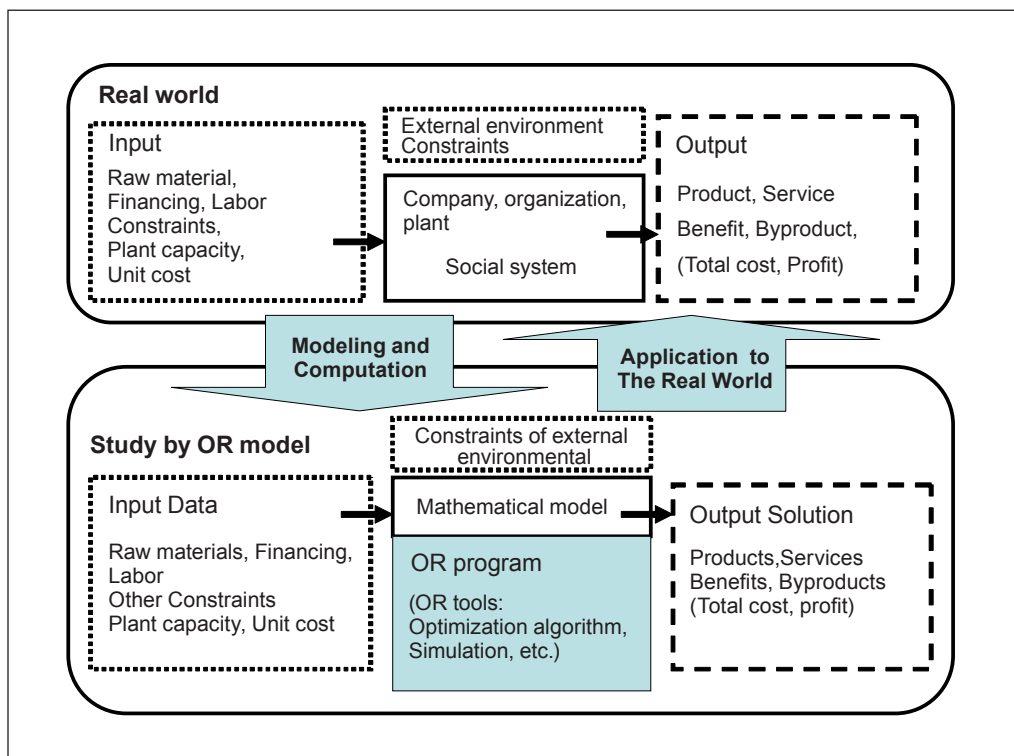


Figure3 : Concept of study by OR model

Prepared by the STFC

simulation, etc. were researched as problem-solving techniques.

OR is an academic discipline which has already produced successful results in the real world, but like other fields of research, it is also one where evolution is constantly demanded. Since its birth, OR has continued to develop and evolve by developing new solution methods as a science for problem-solving in management and planning, which is always unified with practical business in dealing with new problems. As a result, the cycle of opening new situations for application by the development of new theories has continued to bring about further progress.

In an example related to logistics, the remarkable drop of airline fares in recent years is a result of adopting rational fleet operation scheduling using state of art planning techniques. It had long been understood that large-scale mathematical models for this type of problems could be solved by integer programming method, there was no method of solving large-scale integer programming problems with a model size exceeding one million variables at a practical speed and the application of the technique was limited to small partial planning models. The breakthrough was made by the algorithm develops by Narendra Karmarkar of AT&T's Bell Laboratories (at the time). (AT&T was granted a patent for the Karmarkar algorithm. As this was the world's first patent for a mathematical equation, it caused a controversy argument on the patentability of equations over the world ).<sup>[9]</sup> Today, many practical methods to solve this type of problems have been proposed and commercially available in the form of optimization software, and are widely used in the planning for semiconductor production, optimization of the logistics network, and similar problems.

Penetration of OR in the logistics field in Japan is still in behind with Europe and the United States. One reason for this is the fact that virtually not much practical research has been conducted in universities. In Europe and the United States, research on and the establishment of logistics strategies using OR is carried out widely as joint research by universities and private companies and/or public organizations, and the results of the research are often made public in journals and presentations at academic conferences, etc., including the results of research and implementation by private companies. However, in the Japan, there is little awareness of the importance

of this. Not only collaboration between companies and universities are rare, but companies also tend to avoid publication of data and results to a greater extent than is actually necessary. As a result, there have been delays in a variety of aspects, including practice, R&D, and the training of skillful people with advanced knowledge and application capabilities in companies. Although Japan has many outstanding researchers, it is unfortunate that their work has been limited to theoretical study in the laboratory. The development of policies that overcome this condition is demanded. The author hopes to see the establishment of policies which activate research and development in connection with practical problems and research issues desirable to promote from a policy standpoint, as will be discussed in the following and sharing of the results by industry and universities. Logistics in Japan has achieved a unique development suited to the culture of consumers and corporate management in this country. This is also an area where more advanced techniques and contributions can be expected from research and development using Japanese approaches. In addition to practical benefits, promotion of public research and publication of the results can be expected to improve the current situation in which research results are not made public, and thus will also be useful in promoting theoretical research.

### *3-2 Challenges toward advanced logistics and the role of OR*

#### **(1) Response to wider area, more complex supply chain networks**

##### **(a) Optimization of facility location and transportation route in large-scale logistics networks**

One issue with particular attention in recent logistics is the problem of optimization of the network structure as a whole, as these networks are spreading and also more complex.<sup>[10,11]</sup>

A transportation network in logistics comprises connecting nodes such as resource suppliers, production plants, warehouses, and the final consumer, and the transportation links joining those nodes. The mathematical model of entire network could be an extremely large-scale network model, often having equations and variables more than 10,000. A number of reports have presented examples in which it was possible to realize nearly 30% reduction of operation

and transportation cost by optimal rationalization of the site location arrangement and selection, and transportation network. In particular, reduction of transportation costs, which accounts for the main part of cost reduction, makes a direct contribution to reducing transportation distance, and therefore also contributes to reducing emission of greenhouse gases.

Because problems of optimum routes and site locations in large-scale, multi-stage networks treat variables which must be expressed by numerical values, i.e., the number of site, number of cars or transportation facilities, and combinations of delivery routes and sites, these are fundamentally optimization computation by using extremely large-scale integer programming models (several 10,000 to 1 million variables or more). Until recently, this type of problem could only be handled by research institutions with very limited computational capabilities. In recent years, with progress in computational algorithms and higher speed and larger capacity of computer hardware, it has now become possible to solve these problems at a practical speed using a general personal computer. As a result, it has become relatively easy to perform optimal design and planning for large-scale, wide area supply chains.

Figure 4 shows an example of the scale of that type of computational model. An optimization model for route selection which includes combinations of all the alternatives, such as the number of nodes, product models, transportation method, and the like, will be enormous. In Japan, application of mathematical models for rationalization of this type of supply chain network had attracted a little attention in the past due to the lack of knowledge of and interest in mathematical optimization. However, due to the increased transportation costs caused by the recent jump in fuel prices, ongoing closure/consolidation of bases in response to corporate mergers and other factors, etc., application is continuing to advance in a wide range of areas in Japan. Figure 5 shows an example of optimization planning for distribution network in North America for a consumer electronics maker.<sup>[12]</sup> In Europe and the United States, where transportation network is spread in broad geographical fields, many variations of research including multi-modal transportation are being carried out in both the theoretical and practical aspects by private corporations, universities and other research institutions.

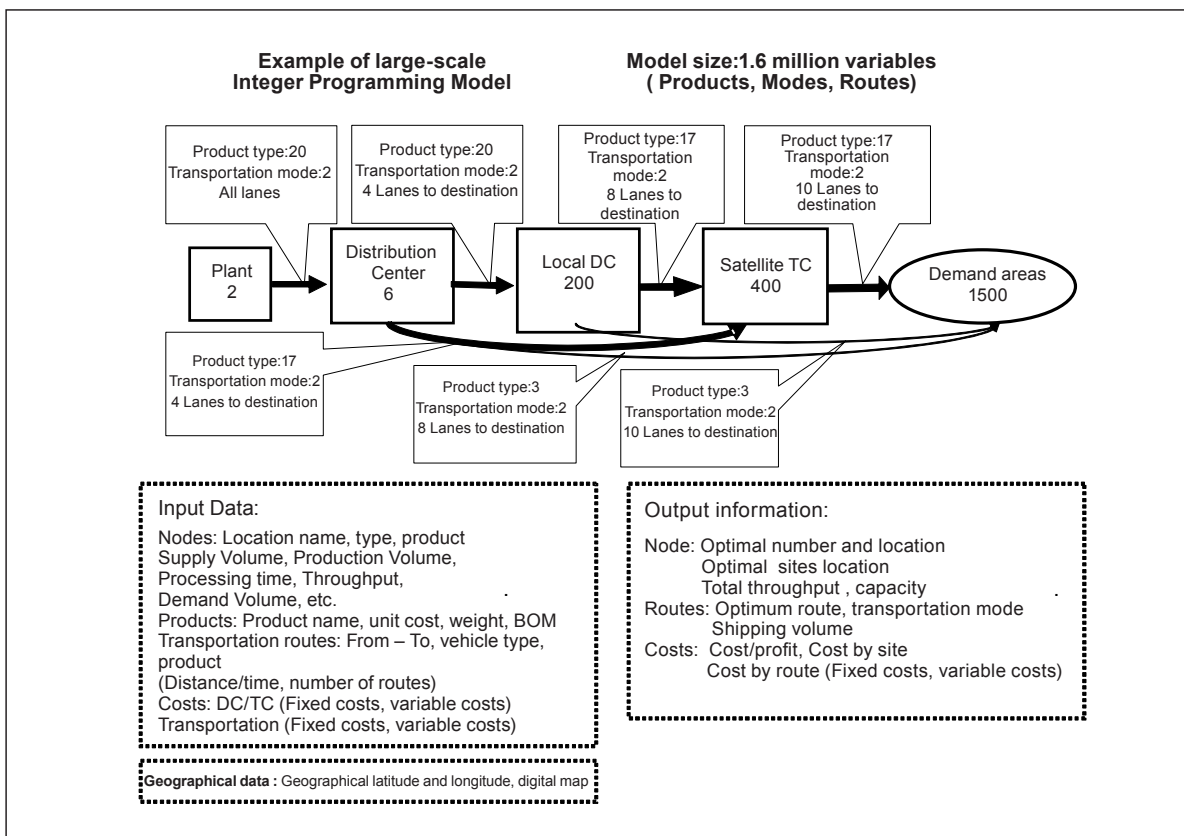
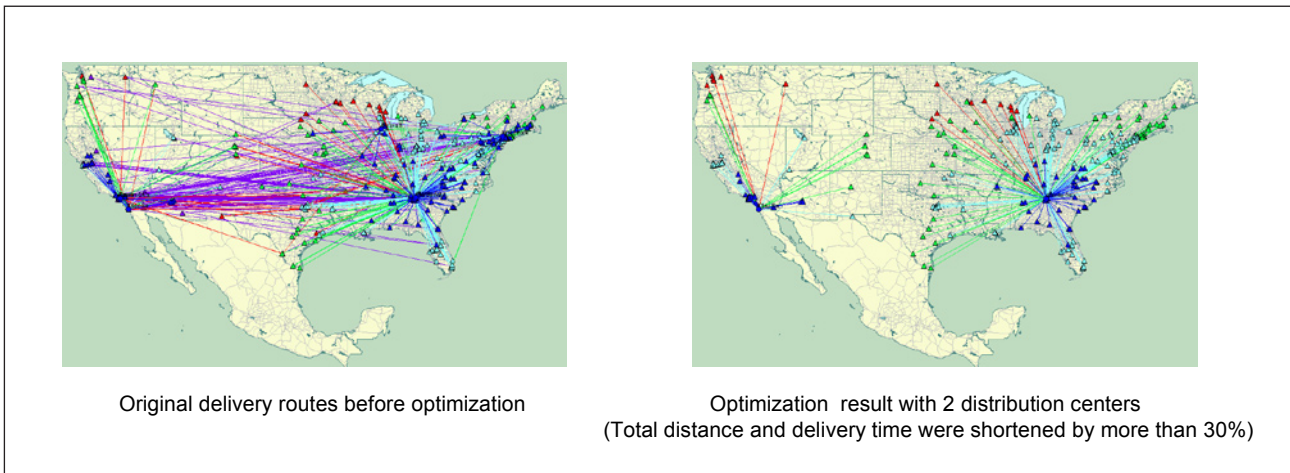


Figure4 : Example of large-scale logistics network model

Prepared by the STFC based on materials of Frameworx Inc.





**Figure5 :** Optimization results of North American distribution network of a consumer electronics maker.

Prepared by the STFC based on reference<sup>[12]</sup>

In particular, in the European nations, for example, the Netherlands and Belgium, government policy promotion measures has been studied by using mathematical models and proposed,<sup>[13-15]</sup> and logistics centers have been developed targeting to service American and Japanese companies, with the country's port or airport as the point of origin, and a multi-modal integrated transportation network combining sea transportation (short sea shipping by Ro-Ro ship), truck, railway, and river transportation for the entire EU region.

In Japan, the opening of the FY2008 "White Paper on Monozukuri" mentioned the importance of supply chains and the necessity of promotion of strategic logistics networks. In this aspect, cooperation in logistics with the Asian countries and Russia will be particularly important for Japan in the future. For example, that report states that several companies are already started using the Trans-Siberian Railway to cut transportation time from Japan to Europe by half, from more than 40 days to around 20 days, and the government has also announced that it will support modernization under the "Eurasian Industrial Investment Bridge" concept.<sup>[16]</sup> While hardware such as measures for vibration of railways and transportation facilities will be necessary in the construction and operation of an Asia-wide transportation network, what will be particularly important in the future will be rational operation of the entire network of transportation routes, combining land and sea routes. Therefore, it is desirable to carry out a strategic research, including cooperation with the other East Asian nations, and to implement construction and improvement of port and harbor

facilities and inland terminal warehouses in a policy-oriented manner, based on horizontal cooperation among the ministries and agencies concerned. In the future modernization of logistics in Asia, Japan must take the lead in optimization research on the international logistics network cooperating other neighboring nations.<sup>[17]</sup>

**(b) Inventory reduction by optimization of safety stocks**

In wide area networks, placement of large quantities of inventories close to the final demand is not the optimal solution, economically speaking, for responding to fluctuations in final demand and shortening lead time in supplying customers. Where in the network to hold the optimum safety stock, and what amount to hold, considering supply and transportation lead time, are major problems from the viewpoints of effective utilization of resources and economic optimality. Obtaining practical solutions had been considered a difficult problem, but this is now approaching a solution by recently-developed techniques using dynamic programming and complex system simulation technology, and others.<sup>[10,18]</sup> There are examples in which the cost reduction achieved by this type of optimization reaches 30%. Likewise, in order to respond to globalization, which was mentioned previously, a large economic effect by further development of optimization technology is also expected in the future. In particular, in manufacturing industries which are engaged in international market development, the profit from optimization of the inventory location and quantity of service parts, based on the relationship between the service level and

inventory costs, is large. A leading northern European furniture maker<sup>[19]</sup> and a European tire maker, PC printer makers, automobile makers, and others who are expanding internationally are actively engaged in research. Theoretically, optimization of site locations from the viewpoint of transportation costs and inventory handling in network should essentially be performed simultaneously; however, no solution method which enables simultaneous optimization of these two problems has been discovered as of the present. This is a field where further research is expected.

### **(c) Modal shifting and multi-modal transportation**

Accompanying the recent globalization of production and market, optimization programming of multi-modal, internationally integrated transportation combining land (truck, container, rail), sea (container ships and trailer ships), and air has become necessary. Because this is accompanied by greater complexity in transportation routes and the difficulty of time planning, here, new mathematical method is expected for rational selection of transportation routes and operational planning. Furthermore, as mentioned previously, in the establishment of plans for large geographical areas, and particularly the Asian region and transportation between Asia and Europe, research on multi-modal transportation will be indispensable.

Similar problems have arisen in CO<sub>2</sub> reduction plans by modal shift in Japan. Here, planning which combines trunk-line transportation and local transportation (“last one mile”) has become necessary.<sup>[20-23]</sup> Recently, examples have been published in which a CO<sub>2</sub> reduction of 20% was realized by large-scale milk run-type collection/delivery to an electronic part assembly plant, and trunk-line transportation to complete-product demand areas and combined delivery to final customers implementing a large-scale vehicle allocation and control system.<sup>[24-26]</sup>

It has become difficult for research institutions such as universities to do research in the field represented by the above case due to the difficulty of obtaining practical data in Japan. In Europe and the United States, it is possible to obtain transportation cost tariffs openly. Moreover, as mentioned previously, several alternative means of transportation exist for the geographically extensive networks (truck, trailer,

rail, river transportation, air routes). Therefore, research on this area is being carried from a variety of directions. In Japan, joint research with private companies is of course being carried out for effective utilization of local ports and harbors and activation of regional industrial clusters, but more active research on optimization of transportation extending beyond administrative divisions is also desired.

## **(2) Issues in which development of new methodologies for model construction and optimization are expected**

The following are the topics important in the logistics of any company. However, further research on solution methods, conducted through industry-university collaboration, is expected. If the development of new techniques can be realized by cooperation between practical businesspeople and Japan’s outstanding researchers in the mathematical sciences, this will have the potential to contribute to logistics and OR at the world level, although there are still problems which are left to individual companies in practical responses.

### **(a) Dynamic delivery planning optimization for agile response to demand**

In the future, high expectations will be placed on the development of new mathematical solution techniques for realizing advanced production and transportation systems which are capable of responding quickly to changing demand. Technologies for real-time rescheduling and vehicle assignment and route planning by using real-time data collection through GPS and RFID are expected by breakthroughs such as practical application of the aforementioned large-scale optimization algorithms, etc.

Rationalization of truck dispatching using tools involving mathematical algorithms is continuing to gain acceptance in Japan. However, because energy saving and cost reduction by alleviation of urban traffic and improvement of the current 50% truck load rate will contribute directly to reduction of greenhouse gases, more sophisticated vehicle allocation planning systems and their dissemination are desired. Wide implementation of detailed operation plans by these technologies, including higher efficiency by joint loading and joint delivery of cargos, reduction of operating costs by proper time windows for deliveries, combined collection and delivery, etc. will also

contribute to promoting green logistics, which will be discussed later in this paper.

**(b) Procurement planning for risk management and economic optimality**

Accompanying globalization and open sourcing in the procurement of raw materials and parts, solutions using combinatorial theory can be expected in responding to risks such as natural disasters and terrorism, procurement planning with stable supply and economy, and optimum selection of sources involving complex factors.

In order to secure alternate means of transportation in response to traffic disruptions due to natural disasters such as earthquakes, etc., the necessary public financing must be decided rationally. Simulation of social costs by mathematical study is considered useful in this kind of decision making.

**(c) Concurrent design of products and supply chain**

Recently, one area where research is also continuing to advance in other countries is a methodology of performing design of the supply chain simultaneously and in parallel with product design, in which the product design itself is changed considering optimum procurement and product delivery. In one example from Japan, a copying machine maker succeeded in reducing costs by broadly shortening delivery time and reducing stocks, by restudying where the location of final product assembly should be located in the supply chain and performing design for modularization of parts to enable production of final products easily at intermediate locations in response to market requirement, however this practice was not led from theoretical optimization. In generalizing this kind of design technique, including part procurement routes, research and development of new mathematical techniques is required, including simulation techniques for complex systems, etc.

Supply chain optimization, including the product design, will have a positive influence in the implementation of carbon footprint, which will be applied in the near future. The carbon footprint of products will be shown on the product package, etc. Under this concept, the greenhouse gases emitted over the entire life cycle of the product, from raw materials to production, sale, distribution and consumption, are expressed in terms of the amount

of CO<sub>2</sub> emissions. This is being promoted actively in the United Kingdom, and study in Japan has also begun. By encouraging consumers to select products with low environmental impacts, manufacturers can be encouraged to produce products with lower impacts.<sup>[27]</sup> In addition to generation of greenhouse gases by energy sources in the production plant, environmental loads can also increase as a result of transportation, depending on the site location of the plant.

**(d) Research on mathematical solution measures for new transportation methods and their effective utilization**

In the future, it is thought that the development of new means of transportation will be promoted with the aim of reducing energy costs and environmental impacts. Innovations in the hardware aspect are continuing to be realized. These include international trailer transportation using Ro-Ro ships, responding to the needs of medium- and short-distance marine transportation. Ro-Ro is an abbreviation for Roll-on/Roll-off ship, and is a type of cargo vessel with a structure that enables loading and unloading of vehicles such as trailers under their own power. This method is more suitable than the container method for medium- and short-distance transportation. Other examples include practical application of multi-modal transportation using new rail containers and dedicated trailers, which have already been implemented by an automobile maker, transportation of 40 foot marine containers by rail and consolidation of cargos and arrangement of transshipment centers for its effective utilization, etc. New optimization systems for operation planning suited to these innovations are demanded. In addition to this, in order to realize circulatory-type logistics for resource saving, further research must be carried out on international container management, pallet management, route planning techniques for circulatory transportation, and similar topics.

**(e) Design of business work flow structure in supply chains and research for optimization**

Research on application of a standardized process operation reference model (SCOR model)<sup>[29]</sup> and business process modeling (IDEF, etc.) for optimization of the structure and work flow of supply chains combining multiple companies and different business entities is

increasingly necessary. In supply chain rationalization in Japan, which tends to begin and end with only a response to individual issues, there is little familiarity with top-down type model structures and design concepts that intend this kind of total optimality from the outset. Recently, these have at last begun to attract attention. Further research for future supply chain rationalization from a total viewpoint is demanded. On the other hand, methodologies such as SCOR are fundamentally premised on top-down organizational management. Accordingly, in order to demonstrate effectiveness in Japan's bottom-up type decision function, unique theories for modeling and implementation which are not simply copies of those in Europe and the United States must be researched.

**(f) Research on supply chain structures in cooperation with social science approach**

Supply chain networks comprise numerous companies in the same or different industries (and in cases, companies with different nationalities). The decision-making in each company must be conscious of the existence of other decision-making units (other companies). However, conventional theory and management solutions are materialized on the precondition of a single decision-making unit. For scientific treatment of strategic decision-making premised on this type of interaction, it is necessary to borrow the assistance of game theory and microeconomics, or agent model approach, etc.<sup>[29]</sup> In order to analyze the behavior of a supply chain network, which has a complex structure, including environmental problems, and measure and improve their efficiency, interdisciplinary cooperative work between research by scientific and mathematical approaches and research by social science approaches is indispensable. In other countries, research on supply chain and logistics problems by this kind of cooperative work are made widely, and a number of papers have been published in management science journals. It is thought that researching the ideal form of management from an interdisciplinary standpoint will not be only useful in corporate decision-making, but will also provide valuable knowledge for making industrial policy in Japan.

**3-3 Role of OR in promotion of green logistics**

With the start of the 1st commitment period under the Kyoto Protocol, which is from 2008 to 2012, Japan is targeting a 6% reduction in emissions of greenhouse gases during this period from the baseline years (fiscal 1990 for CO<sub>2</sub>, CH<sub>3</sub>, and N<sub>2</sub>O and fiscal 1995 for the 3 gases classified as chlorofluorocarbon-replacing material, etc.). However, in actuality, Japan's emissions of greenhouse gases in fiscal 2006 were 1.34 billion tons (CO<sub>2</sub> conversion), which was an increase of 6.2% against the baseline year.

The main cause of this increase was a large increase of 12% in fiscal 2006 against the baseline year in CO<sub>2</sub> emissions originating from fossil fuels, which account for approximately 90% of Japan's emissions of greenhouse gases. Emissions from the transportation sector, which is responsible for approximately 20% of CO<sub>2</sub> emissions originating from fossil fuels, increased by about 20% from fiscal 1990.

In addition to these circumstances, transportation costs have also increased due to the recent sharp rise in the price of fuel oil. Against this background, energy conservation in the logistics sector has become extremely important for protecting the foundations of Japanese industry.

As touched on in the connection with the application of OR to various problems discussed in Chapter 3, rationalization of logistics can make many direct contributions to the realization of green logistics. However, distinctive problems or challenges also exist in green logistics.

In application of OR to green logistics, one topic which particularly requires research is a technique and model structure for simultaneous optimization of multiple objective functions, i.e., energy efficiency, greenhouse gas emissions, cost, and the like. In optimization of mathematical models, research on the establishment of solutions which simultaneously satisfy multiple objective functions and so-called multi-objective programming is necessary. Several proposals have been advanced as solution methods for multi-objective function models for green logistics. These proposals can be broadly classified into (1) methods in which multiple objective functions are solved individually, assigned certain weights, and summarized in a single function, which is then either minimized (total environmental impacts + cost, etc.) or maximized (effect of countermeasures), (2)

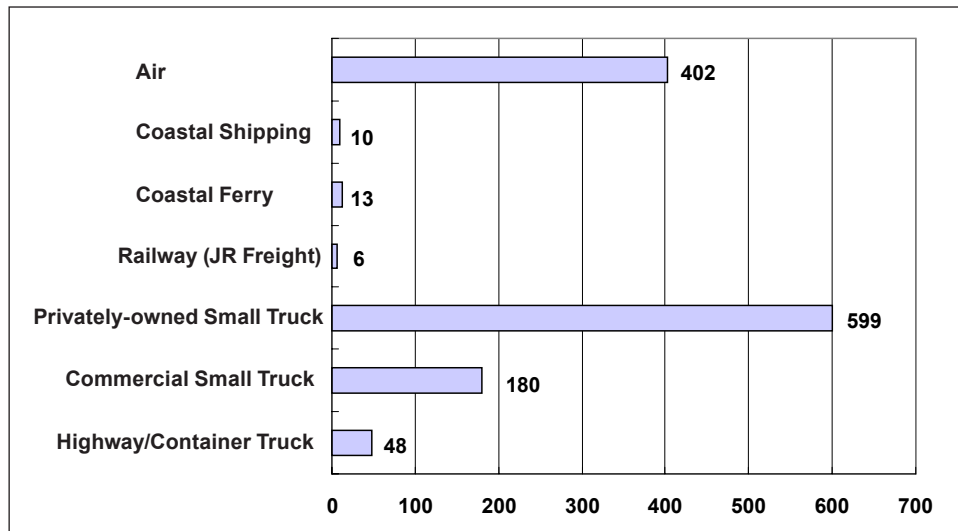


Figure6 : CO<sub>2</sub> emissions by means of transportation (g/ton-km)

Prepared by the STFC based on reference<sup>[30]</sup>

methods in which minimization or maximization of a certain objective function is solved using the target values of other objective functions as constraints, and (3) methods in which the point of convergence of the values of multiple objective functions is obtained using, for example, Pareto optimization, etc. However, none of these proposals has become a definitive method. Therefore, research on both methods of modeling actual problems and mathematical solution methods is expected.<sup>[20]</sup>

Although already touched on in Chapter 3, one other major challenge is research in connection with modal shift and multi-modal transportation. Emissions of CO<sub>2</sub> differ greatly depending on the means of transportation, as shown in Figure 6. Accordingly, research on means of transportation will demonstrate effectiveness in the prevention of global warming. Among concrete countermeasures, an example in which a CO<sub>2</sub> reduction of 20% was achieved by appropriate vehicle assignment and deliver planning was mentioned previously as one method that has already begun to be implemented. Modal shift is expected to have an even larger effect. Already, an example in which a CO<sub>2</sub> reduction of nearly 80% was realized by switching to rail transport for trunk-line transportation and future reduction plans by joint use of short sea shipping have been reported.<sup>[25]</sup> As also noted previously, it is considered that implementation of the concept of carbon footprint and its importance will become increasingly great.

In Japan, however, until now study has been limited to the range of individual companies, and almost no research has been done by OR on inter-company

problems or toward national policy. In Europe, much research is being done on the EU as a whole, particularly in universities, and proposals are being made. In promoting rationalization of logistics as a national policy, a cooperative system which extends beyond the boundaries not only of companies, but also those of government ministries and agencies and local governments is indispensable.

Universities and public research institutes should play a large role in drafting composite and comprehensive plans, not limited to structuring individual infrastructure such as port and harbor or road construction and improvement, but also in the effective distribution of cargo collection and delivery bases and improvement of their functions, combination of trunk-line transportation, including railways, and deliveries to individual customers, which is called “last one mile,” etc., as well as in the development of models for these problems, research on optimization algorithms, and the like. Prioritized financial support policies for this type of research may also be effective.

As mentioned earlier, it is also necessary to study modal selection, including land, sea, and air, in research in connection with construction of a transportation network which includes the entire Asian region and Russia, and policies for reducing international environmental impacts accompanying the realization of such a network.

### 3-4 Expectations on service science research towards advanced logistics

In the final report of the United States’ Council of

Competitiveness, which is entitled “Innovate America: Thriving in a World of Challenge and Change” (April 12, 2004; generally abbreviated as the “Palmisano Report”),<sup>[31]</sup> “service science” was introduced as a new academic field with the potential to induce innovation. Service science is important as one direction for the development of science and technology responding to new industrial structures. Needless to say, it is considered possible to obtain substantial benefits by advances in service science in the logistics industry, which occupies a large position in the service industry.

The Palmisano Report also pointed out the following with regard to the relationship between service science and OR: “There is no field in which a new interdisciplinary approach is so clearly necessary as in the new field of ‘service science’. Service science is a fusion of existing fields, including computer science, operations research (OR), production engineering, mathematics, management science, decision science, the social sciences, forensic sciences, and others. This causes reform in corporate activities as a whole, and encourages innovation in the region where the specialized knowledge of technology intersects with business.”

As good examples of improvement of service productivity by OR, bank ATM windows and JR railway ticket counters can be mentioned. By changing the form of queuing from the previous queuing at each window to a forked form of queuing, waiting time as a whole was shortened and the service rate per unit of time was increased. This change also had a positive effect on customer psychology. This is an example of application of queuing theory, which is one typical OR technique. Although popularization in Japan was comparatively recent, it is generally said that a demonstration experiment video by (then) Prof. Morimura of Tokyo Institute of Technology on the 1991 NHK television program “Try and Try” had an very large influence on its rapid acceptance.<sup>[32]</sup> Queuing theory is used in the design of the number of service windows and their operation, and in addition to ticket counters, has also been applied to the design of toll booths on expressways, the number of passport inspection gates in airports, etc.

One of the purposes of service science is improvement of productivity, reduction of costs, and improvement of quality by application of engineering techniques to services. In other words, it is a science which researches a total design by quantifying

services, modularizing and standardizing service solutions, and combining modules, and through these practices, applying engineering techniques to the service industry and thereby improving service productivity.

Logistics is considered to be an area where important effects can be expected by promoting interdisciplinary research by the service science approach. In particular, in the aspect of service quality, quantitative concepts such as KPI (Key Performance Indicator), metrics, benchmarking, and similar techniques applied to service quality have already achieved penetration. This field also has conditions which facilitate study of objects of research, in that data collection is easy, the relationship between the service provider and beneficiary (customer) can be defined relatively clearly, etc.

For example, one quality-related concept in logistics is “Perfect Order Fulfillment Rate.” Although several different definitions of this concept exist, for instance, in the definition in the above-mentioned SCOR, this is defined as the numerical value obtained by multiplying the four percentages of the quantitative completion rate, on-time delivery rate, documentation completeness, and non-damage rate.<sup>[28]</sup> This has become one index of quality assurance for logistics contractors in Europe and the United States. However, in Japan, contracts which attach importance to numerical values other than cost are still rare. In the future, it is thought that this may be suitable material for research on the relationship between quality and cost or productivity.

On the other hand, in research on service science, it is considered necessary to avoid over-reliance on a reductionism methodology that reduces the object to its basic elements and understands it in numerical values that can be quantified physically. In performing analyses of service quality and customer satisfaction and preparing the optimum design, techniques in the field called decision science within the larger discipline of OR could be very effective. Examples include AHP<sup>[34]</sup> (Analytical Hierarchy Process; recently used in narrowing the field of candidates for relocation of the capital) for assessing the value of non-quantitative factors, conjoint analysis (technique used in analysis in marketing for product design, etc.), DEA<sup>[35]</sup> (Data Envelopment Analysis; in actual examples, has been used in analysis of public service institutions such as libraries and hospitals, etc.) for evaluating the

efficiency of organizations while simultaneously handling multiple inputs and outputs, and others.

In service science, areas of research where Japan can particularly contribute are research in connection with evaluations of qualitative/sensible quality, which tends to be slighted in the Western European approach, and research based on holistic ideas, which consider the whole and its parts simultaneously and are a distinctive quality of the Japanese people's way of understanding the world

Japan's unique, and it can be said, excessive insistence on quality can also be seen in the field of logistics. While this also has an aspect of increasing social costs, at the same time, its effect in bringing about a more pleasant life for the country's citizens must not be overlooked. If the Japanese approach can compensate for the weaknesses of other evaluation standards that insist on quantifiable numerical values by promoting interdisciplinary and boundary-region research, this will be important as part of this country's contribution to the development of service science. In the past, in quality control of industrial products, Japan demonstrated that it is possible to satisfy both quality improvement and cost reduction simultaneously, which had been considered mutually contradictory until that time. Similar examples can be seen in logistics. For instance, in deliveries of goods to convenience stores, vehicle allocation planning by OR and transfer-type delivery centers have been used, and delivery schedules by detailed temperature range have been combined in dedicated vehicles. When the first convenience stores were opened in 1974 in Tokyo, the number of deliveries was 70 vehicles per store per day and 42 two years later. As a result of these efforts, the number of deliveries was reduced to 15 in 1987 and to only 9 in 2005, while the freshness of boxed lunches and bread has actually improved. This is an example in which both service and efficiency issues were successfully solved.<sup>[36]</sup> From this viewpoint, it is thought that Japan can contribute to service science as a whole if it can analyze this country's strengths and weaknesses in logistics and, with this as a reference point, conduct research on quality in logistics using an interdisciplinary approach.

#### 4 Conclusions and recommendations

Supply chains play a critical role as the foundation for industry, but are now facing major turning

points. This report has described the effectiveness of support for rational planning and operation of supply chains by optimization methods and simulations using OR techniques, and in particular, the challenges which will require research and development efforts in the future.

In particular, Figure 7 summarizes five key themes among problems requiring solutions, as described in Chapter 3, and the corresponding R&D themes for OR techniques. As mentioned previously, in order to respond to the challenges of greater complexity, large geographic extent, and internationalization which today's logistics confronts, and to solve future problems when they arise, research must be promoted on issues having a strategic viewpoint, as shown on the left in Figure 7. It is also necessary to simultaneously promote research and development of more advanced OR techniques which are capable of modeling complex realities, as shown on the right, and providing practical solutions.

In addition to promoting research on these key challenges, when promoting developmental research on advanced logistics and OR techniques for this purpose in the future, the policy responses outlined below will also be necessary.

#### **(1) Logistics as an engineering subject and development of human resources**

In comparison with Europe and the United States, rationalization and optimization of logistics by OR techniques has not been well promoted in Japan in the past. One reason for this is that logistics has been understood as basically an engineering subject in Europe and the U.S. As a result, research has been actively promoted in science and technology-related educational and research institutions, and independent departments or faculties were established in higher education from an early date. In contrast, in Japan, there is a strong tendency to understand logistics as a business in commercial science and as an ancillary to sales and marketing. For this reason, its position has not been well established; either in companies or in the science and engineering community.<sup>[37]</sup> In recent years, science and engineering universities have become central to the promotion of advanced logistics in Europe, the U.S., and some Asian countries. Likewise, it is desirable to create a logistics research promotion system which prioritizes science and engineering in Japan. In Europe and the U.S., training

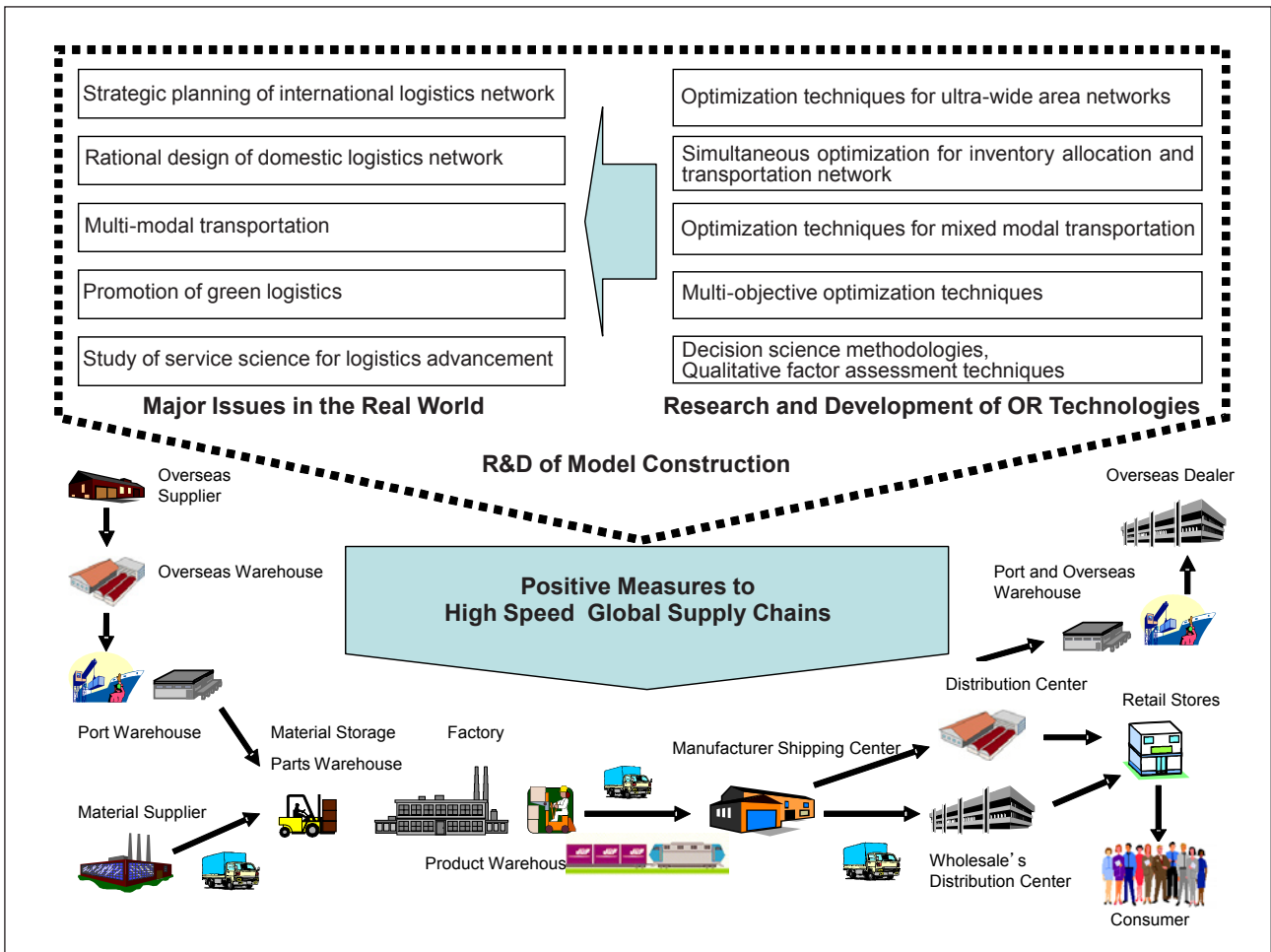


Figure7 : Real problems requiring solution R&D on model construction methods

Prepared by the STFC

of specialists with advanced capabilities, for example, who can make full use of OR techniques, has been mentioned in policy recommendations in connection with supply chains, and joint research to establish practical academic system and curriculum to educate SCM specialist has begun in industry, universities, and government agencies.<sup>[38,39]</sup> Universities in the Asian countries have also embarked on training of specialists in SCM and logistics specialists with advanced capabilities by promoting cooperation with European and American universities.<sup>[40-42]</sup> In order to realize more advanced logistics in Japan, training of human resources on the same level as those in other countries is an urgent matter for promoting research and development, and does not permit further delay. By promoting logistics education and research in institutions of higher education, Japan can contribute to improvement of the international level in Asia in this area, and can become a promoter of international cooperation. This is considered one important policy issue for the future.

**(2) Recognition of logistics, SCM, and OR as research fields**

At present, the items of supply chain management and logistics are not included in the systems, fields, sub-divisions, or detailed items of the Grant-in-Aid for Scientific Research (Kakenhi) program of the Japan Society for the Promotion of Science (JSPS). In order to promote research and development in these fields, it is considered necessary to recognize these as research fields by adding them to the JSPS program. These items are also not included in the classification of technical fields by the Japan Science and Technology Agency (JST), and it is desirable that they be added to this classification. Furthermore, the items of management science, OR, and management engineering, which are considered important areas for promoting research in Europe and the United States, are not independently included in the technical fields of both programs. It is desirable that addition of these items also be realized quickly. A number of academic societies which already have histories and scales exist. Hence, if this type of action can be taken, it will



make a large contribution to activating research and development in the related academic societies.

### (3) Interdisciplinary and interagency research system

If the development of OR to green logistics and services science is considered, promotion of interdisciplinary research combining science and engineering related fields, fields of social science such as economics, and the human sciences is demanded. In this kind of boundary-area research and development, there are latent possibilities for Japan to contribute to the development of OR at the world level by researching the strengths and weaknesses of the Japanese social system and realizing problem-solving from a more total viewpoint, without being bound by the reductionism approaches favored in Europe

and the United States. A research support system for realizing these possibilities is required.

### Acknowledgements

In writing this paper, the author interviewed more than 30 persons including university researchers and businesspeople. I wish to express my profound gratitude to all those concerned for the information and materials provided, which brought invaluable reference for this work. In particular, I wish to acknowledge the valuable suggestions received through discussions with the members of the supply chain-related research chapter of Operations Research Society of Japan, Japan Industrial Management Association, Japan Logistics Society, CSCMP Japan Roundtable, and Japan Chapter of Supply Chain Council.

### References

- [1] Ministry of Economy, Trade and Industry, Ministry of Health, Welfare and Labor, Ministry of Education, Culture, Sports, Science and Technology, "White Paper on Monodzukuri 2008 (Promotion Policy for Basic Technologies in Monodzukuri in FY2007)." (2008). (Japanese)
- [2] Council of Supply Chain Management Professionals : <http://cscmp.org/default.asp>
- [3] D. M. Lambert, J.R. Stock, "Strategic Logistics Management," McGraw Hill/Irwin (2000).
- [4] Donald J. Bowersox, et al. (trans. by Eji Abo), "Supply Chain Logistics," Asakura Publishing Co., Ltd. (2004). (Japanese)
- [5] Mitsuru Kuroda, ed., "Supply Chain Management : Theory and Reality of Intercompany Cooperation," Asakura Publishing Co., Ltd. (2004). (Japanese)
- [6] Japan Institute of Logistics Systems, "Report on Survey of Logistics Costs FY2007," (2008). (Japanese)
- [7] Japan Productivity Center for Socio-Economic Development, "International Comparison of Labor Productivity (2006)." (Japanese)
- [8] Takao Enkawa, "Strengths of Japan's Site Capabilities and Weaknesses of Management Seen from an International Comparison by SCM Performance Score Card," National Institute of Science and Technology Policy, Materials of an internal lecture (2008). (Japanese)
- [9] Hiroshi Konno, "Useful Linear Equation – 50 Years of the Integer Programming 'Capricious Princess,'" Nippon-Hyoron-sha Co., Ltd. (2006). (Japanese)
- [10] David Simchi-Levi, et al. (trans. supervised by Mikio Kubo), "Designing and Managing the Supply Chain – Concepts, Strategies, and Examples," Asakura Publishing Co., Ltd. (2006). (Japanese)
- [11] Mikio Kubo, "Introduction to Supply Chain Optimization," Asakura Publishing Co., Ltd. (2004). (Japanese)
- [12] Kazuyuki Izutsu, "Basic Concepts and Functional Requirements of International Logistics," Report of the Supply Chain Workshop, Operations Research Society of Japan, (2005). (Japanese)
- [13] "Supply Chain 2020 Project Working Paper, A Review of the Leading Opinions on the Future of Supply Chains," Dec. 2004.
- [14] Allan Woodburn, "An Investigation of Container Train Service Provision and Load Factors In Great Britain," University of Westminster (2006).

- [15] Toshihisa Fujiwara, "Survey of Total Land, Sea, and Air Logistics in Belgium – As an Advanced Example for East Asia/Northern Kyushu –," Preprints of the 25th National Conference of the Japan Logistics Society (2008). (Japanese)
- [16] Japan Association for Trade with Russia and NIS, Materials of the 16th RBC International Business Conference, Noriaki Kojima, Director, Russia Office, Europe-Middle East-Africa Division, Economic and Industrial Policy Bureau, Ministry of Economy, Trade and Industry (METI), "The Japanese-Russian Economic Relationship and the Railway Field" : [http://www.rotobo.or.jp/activities/rbc/rbc9\\_2.pdf](http://www.rotobo.or.jp/activities/rbc/rbc9_2.pdf) (Japanese)
- [17] Masaharu Iwama, "Globalization of Asia Considered from the Viewpoint of Logistics," Shizuoka Academic Press (2008). (Japanese)
- [18] David Simchi-Levi, "A New Approach for Inventory Planning," Presentation, CLM2004 (2004).
- [19] J. Shapiro, T. Dudas, "Building the Optimal Logistics & Distribution Network Strategy," Presentation, CLM2004 (2004).
- [20] Irina Harris, Mohamed Naim and Dr. Christine Mumford, "A Review of Infrastructure Modeling for Green Logistics," Cardiff University (2007).
- [21] J. Quariguasi Frota Neto, J.M. Bloemhof-Ruwaard, J.A.E.E. van Nunen and H.W.G.M. van Heck, "Designing and Evaluating Sustainable Logistics Networks," Erasmus Research Institute of Management (ERIM) (2006).
- [22] A. Sbihi, R.W. Eglese, "The Relationship between Vehicle Routing & Scheduling and Green Logistics- , A Literature Survey," Lancaster University Management School (2007).
- [23] Julie Paquett, "The Supply Chain Response to Environmental Pressures," MIT (2005).
- [24] Green Logistics Partnership Conference, "Guide to Green Logistics," Commerce and Information Policy Bureau, METI (2008). (Japanese)
- [25] Japan Institute of Logistics Systems, "2nd Period Conference on Green Logistics in Japan, Report on Activities of the Green Logistics Study Group FY2007," Japan Institute of Logistics Systems (2008). (Japanese)
- [26] Yuji Yano, Katsuhiko Hayashi, "Typology of Efforts by Japanese Companies to Address Logistics-related Environmental Issues," Ryutsu Keizai University (2007)
- [27] Hiroki Kudo (Institute of Energy Economics, Japan), "Recent Trends and Future Outlook for Standardization of Greenhouse Gas Management," Japan Environmental Management Association for Industry (2008). (Japanese)
- [28] Supply Chain Council, "Supply Chain Operation Reference Model V.9.0" (2008).
- [29] M. Nagarajan, G. Sosis, "Game-theoretic Analysis of Cooperation Among Supply Chain Agents: Review and Extensions," European Journal of Operations Research (2006).
- [30] Japan Federation of Freight Industries "Logistics Data Book" (2007). (Japanese)
- [31] National Innovation Initiative and Summit and Report, "Innovate America-Thriving in a World of Challenge and Change," Council of Competitiveness (2005).
- [32] Hidenori Morimura et al., "Try & Try: Smart Waiting and Making Wait," NHK Archives (January 29, 1991). (Japanese)
- [33] Seiichi Fujita et al., "Actuality of the Japanese Logistics Site and the Quest for Best Practice," Material Flow (August 2008). (Japanese)
- [34] Eizo Kinoshita and Eiji Ono eds., "AHP and Conjoint Analysis," Gendai-Sugakusha (2004). (Japanese)
- [35] Kaoru Tone, "Measurement and Improvement of Management Efficiency," Union of Japanese Scientists and Engineers (1993). (Japanese)
- [36] Yoh Tanaka, "Seven-Eleven – Secrets of the Winner," Nikkei Publishing, Inc. (2006). (Japanese)
- [37] Takao Enkawa, Ryuichi Ichikawa, "Managers Born from Logisticians," Management and Logistics Vol. 1 (2008). (Japanese)
- [38] Jake Barr John Dischinger, "The Emerging Need for Supply Chain Talent: Working to fill the gap . . . , " Supply-Chain World 2008, Supply Chain Council (2008).
- [39] D. Aquino and L. Draper, "Supply Chain Talent : State of the Discipline," AMR Research
- [40] National University of Singapore : <http://www.tliap.nus.edu.sg/>
- [41] The Hong Kong University of Science and Technology : <http://www.ielm.ust.hk/>

- [42] Supply Chain & Logistics Institute : <http://www.tli.gatech.edu/research/china/>  
“TLI-Asia Pacific Program Sets Goals for Next Five Years” :  
<http://www.tli.gatech.edu/news-events/release.php?id=188>

---

## Profile

---



**Eizo TAKAI**  
Affiliated Fellow, NISTEP

Chief Technical Advisor, Frameworkx Inc.  
<http://www.frame-wx.com>

Mr. Takai's research field is OR/MS. He is also attracted by the interesting possibilities of application of these techniques to SCM and logistics in various industries. Regardless of age, he enjoys thinking about and realizing new ideas with young people. He feels that collaboration beyond the boundaries of generation and specialization is a source of new vitality and innovation.

---

(Original Japanese version: published in October 2008)

---