Fifth-Generation Railways —Innovating through Knowledge Creation

Yoshihiko Sato

Introduction

I gave this article a rather roundabout title, but when I look at today's railways, I wonder whether the present course of railway development is actually on track. I thought that one approach to this question would be to consider it on the basis of 'knowledge creation.'

It is often said that since Japanese National Railways (JNR) was privatized and divided into six passenger companies and one freight company, Japanese railways have greatly improved or have completely recovered their strength. However, JNR's 38.2% share of passenger transportation at privatization soon dropped to 31.1% and has continued falling to 26.8% today. In freight, the railways' share of volume peaked in 1971 and then declined continuously until the JNR privatization. After JR Freight took over, the share rose briefly to about 5% and then fell again. At present, it has slightly improved to 3.9% but JR Freight has still to reclaim its peak.

I would also like to mention environmental protection. Railways are often described as 'environment friendly' and although this may be true, I wonder whether every effort has been made to enhance environment friendliness. To be sure, various noise and vibration measures have been taken, especially on the shinkansen system, but in view of the remarkable improvements made to motor vehicles, such as the introduction of Intelligent Transportation Systems (ITS) and fuel cells, I wonder whether similar efforts have been made in railways.

On the other hand, in the last days of JNR, railways had an 86% share of passenger transportation between Tokyo and Osaka relative to planes. At the time, it was expected that the share would eventually drop to 68% unless drastic measures were taken. However, that has not happened thanks to various efforts, such as speeding-up trains by implementing 270 km/h shinkansen operations, and making the timetable more convenient, although the share dropped temporarily to about 71% under the worst circumstances. When Shinagawa Station was opened last year, the number of *Nozomi* services increased considerably, causing share to rebound recently to 81%. Looking at only the Tokyo metropolitan area, railways' share is 55% and Japan accounts for 40% of all daily railway journeys, making Japan undoubtedly a 'railway superpower.'

There is one other point to consider—the fact that Japan's own natural resources are calculated as being able to sustain only about 40 million people, leaving more than 80 million Japanese dependent on imported natural resources.

Looking at the present conditions of world railways, in most industrialized countries railways are dwindling, while they are expanding rapidly in China and India. In these circumstances, I feel Japan should have the grit to develop its railways into a strategic export.

Railway System and Business Creation

Railway systems consist mainly of several main components, which I classify into 'tracks,' 'rolling stock,' 'operations,' 'network' and 'management' (Fig. 1). Formerly, tracks, rolling stock and power supply, which are all mainly hardware, were described as the basic elements of a railway system, but today network and management need to be added to these elements. Namely, running a railway

Figure 1 Railway System Configuration

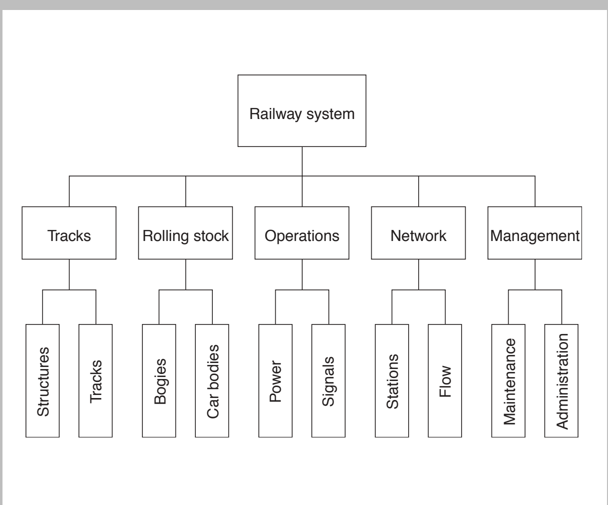
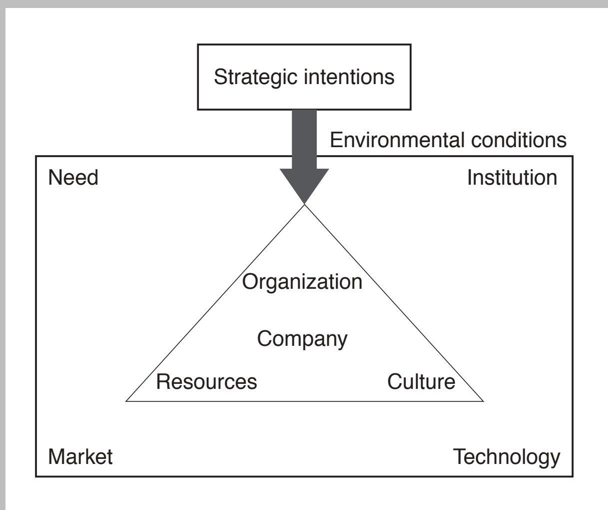


Figure 2 Composition of Corporate Activity



system requires knowledge in order to ensure the system at least maintains its present status or keeps growing at the same pace as productivity or GNP.

Based on this viewpoint, I think it is worthwhile considering the problems of organization, knowledge and learning.

So, how should we consider 'organization'? Here, organization can be replaced by 'company.' There are four major external conditions for an organization: need, market, institution, and technology. In a company, all that needs to be considered is organization, resources, and culture (Fig. 2). The organization is a group of people gathered together for specific purposes, and the resources are the money and things required to accomplish the purposes. There is also the knowledge that backs up the company and another important element is corporate culture, determining the methods for handling the organization and resources. By using its organization, resources and culture, the company conducts it business in accordance with its strategic intentions. In more concrete terms, corporate activities are based on the defined strategic intention of producing a product or service through use of labour, objects and capital, and selling the product or service at a profit (Fig. 3). However, there is actually another aspect of corporate activity—the accumulation of new knowledge while doing business. This accumulated new knowledge becomes an intellectual resource that helps the company improve its product, in turn helping promote growth of the company. Thus, as long as a company continues increasing production, the volume of accumulated new knowledge or know-how continues expanding and the company increases in competitiveness. For example, cutting the cost of production is made possible largely by accumulation of new knowledge.

Currently, we know of four modes of knowledge creation (Fig. 4). First, people talk with each other thereby sharing existing knowledge about subjects (socialization). Next, the shared knowledge is recorded (externalization), making it accessible and comprehensible by others. Then, the pieces of relevant knowledge are put together and organized properly (combination) before they are memorized, understood and put to practical use (internalization). New knowledge is created in the same way.

Figure 3 Corporate Activity and Knowledge Creation

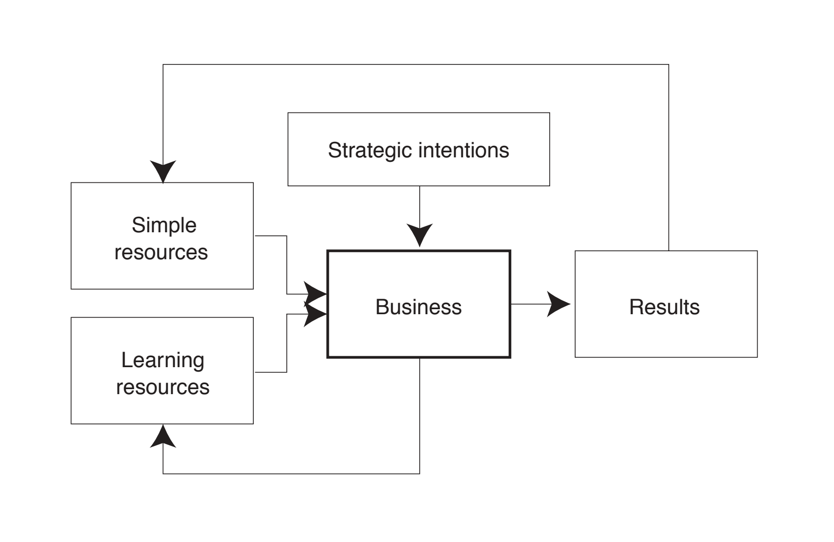


Figure 4 Four Modes of Knowledge Creation[*1]

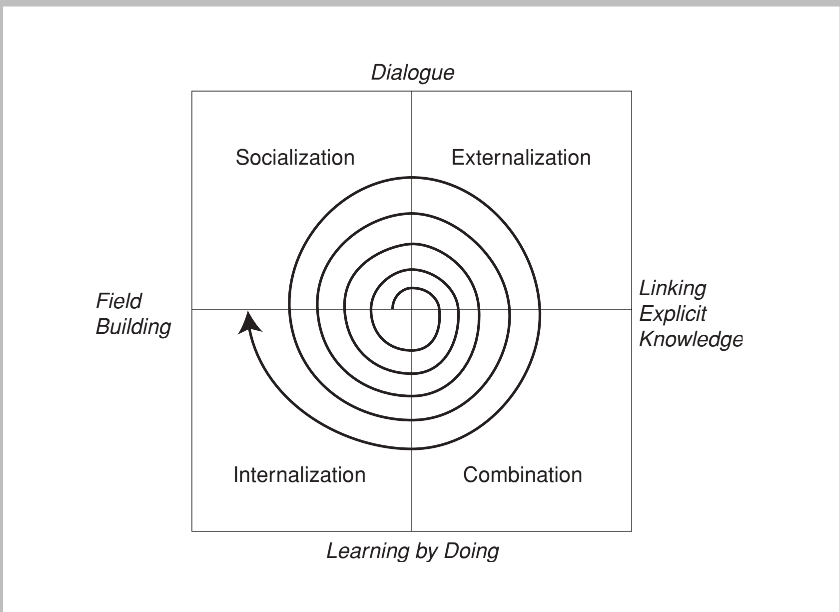


Figure 5 Process for Producing Learning Resources

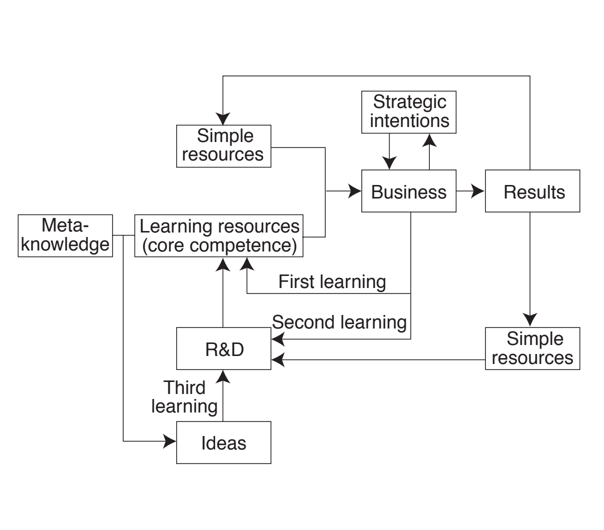
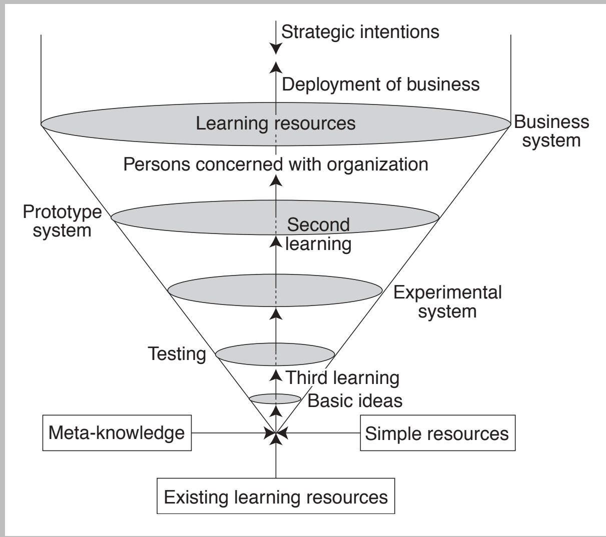


Figure 6 Creation of Innovative New Knowledge



What results can we obtain by combining this process with a process for creating a new business (Fig. 5)?

Knowledge creation involves three types of learning that are closely related to business: learning essential to the business (first learning), R&D for improvement of processes called process innovation (second learning), and radical innovation called product innovation (third learning).

For example, assume that an automaker needs to improve its business or expand its product line. If this automaker has decided to build a new model as a solution, it will put some of its simple resources or available funds into R&D to learn and create new knowledge (second learning). Since the new knowledge obtained by R&D is an intellectual resource, it is called a learning resource. When learning resources are accumulated, they give the company a new ability called core competence that enables creation of the new business.

However, the second learning only concerns improvement and development activities. If the company wants to start a new business or create something entirely novel, it won't be able to do that within the framework of the existing corporate culture. The company can come up with innovative new ideas only by combining its own knowledge with outside knowledge called meta-knowledge (third learning). When the company presses ahead with third learning while carrying out R&D, it can accumulate new learning resources, allowing creation of an entirely new business.

From this perspective, all activities of every organization are based on human implicit knowledge. In other words, they are always done by people, and implicit knowledge, including the knowledge of how to control people, underlies all organizational activities.

Figure 7 Possibility of Various New Super-high-speed Railways

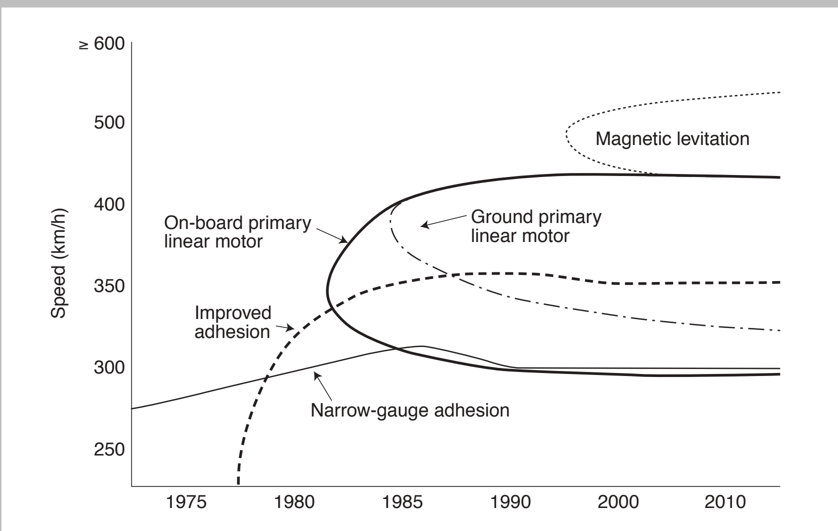


Figure 8 Progress of Testing of Levitation Railway and Accumulation of Learning Resources

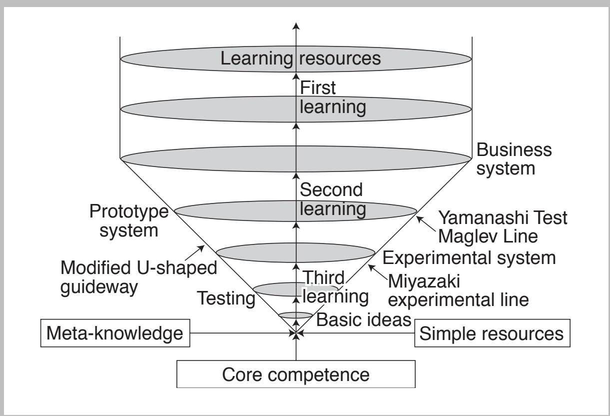
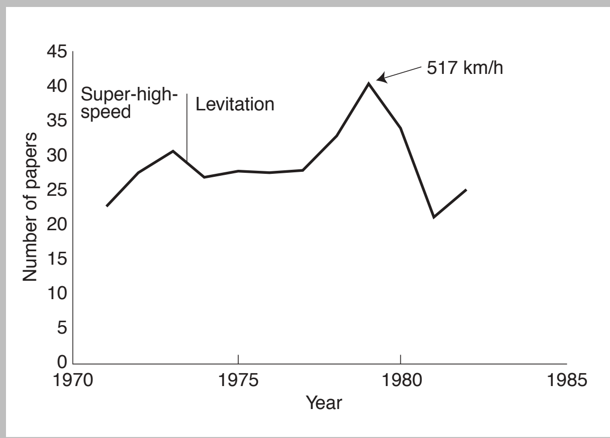


Figure 9 Change in Number of Research Papers

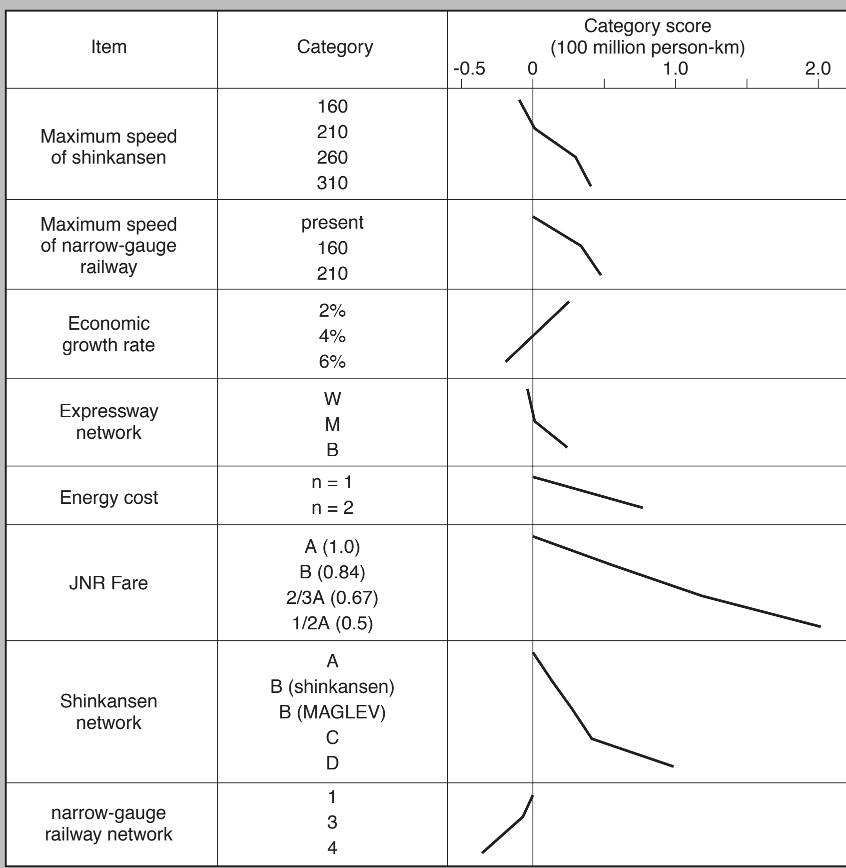


First, look at the scale of each type of learning. Naturally, all 68 million people in the Japanese workforce are involved in first learning, costing ¥500 trillion and nearly equivalent to Japan's GDP. One million researchers or 1.5% of the workforce are engaged in R&D. At present, R&D expenditure totals ¥16 trillion, or 3.2% of Japan's GNP. Although the number of researchers is very small compared to the total workforce, R&D is vitally important because it contributes enormously to creation of new businesses. So how does new knowledge grow? New knowledge created by combining existing knowledge with meta-knowledge grows with workable ideas—what I call effective ideas (Fig. 6).

The new knowledge is tested and incorporated first in an experimental system, then in a prototype system, and finally in a business system. However, this is actually not the end of the growth of new knowledge. Even after the business system is built, the new knowledge must be supplemented and refined continuously before it can become viable. If left unmaintained, new knowledge disappears as people's memory fades with time or as people with that knowledge are gradually lost through natural wastage.

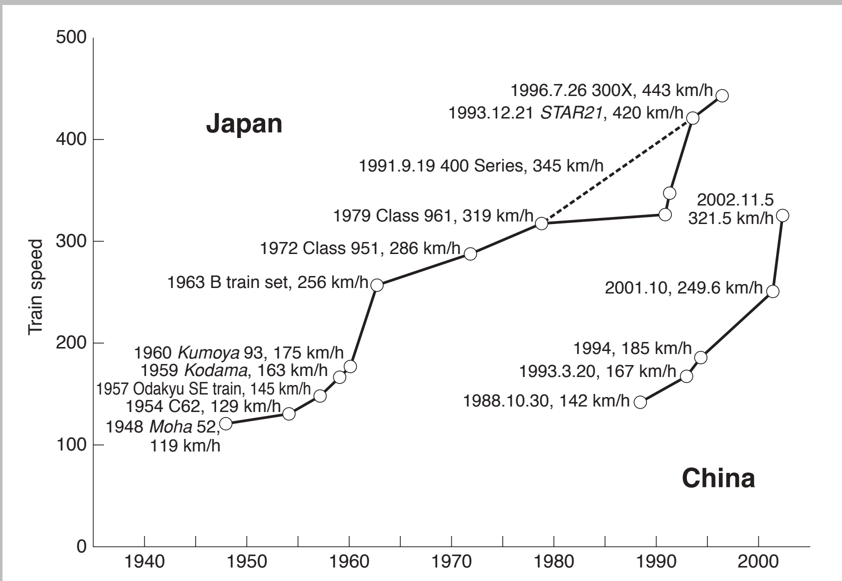
If the knowledge diminishes, various

Figure 10 Category Score of Total Volume of Rail Transportation in Urban Areas



A: Proportion of personnel expenses 58.8% (present)
B: Proportion of personnel expenses 34.1% (shinkansen)

Figure 11 Speed Improvement in Chinese Trains



inconveniences and accidents can occur. Therefore, the organization must continue supplementing existing knowledge and creating new knowledge in order to keep up with demands of the times.

Birth of New Railway Systems

This part looks briefly into the fourth-generation railways that should follow the third-generation Tokaido Shinkansen. One revolutionary new system is levitation MAGLEV railways, involving many of the elements of a railway system I mentioned earlier (Fig. 1). In view of the complexity and effect of each of these elements, the most important element involved in MAGLEVs is the combination of the lift and driving systems. When JNR's Institute of Railway Technology (RTRI's predecessor) started planning development of a MAGLEV around 1970, we studied the feasibility of several candidate systems (Fig. 7), predicting that an improved steel wheel on rails system would reach the 300-km/h range by around 1985. We also predicted that speeds of 500 km/h would be achieved by magnetic levitation some time after 2000. Now that the Shanghai *Transrapid* MAGLEV is operating at speeds exceeding 500 km/h, I think our predictions were not too wide of the mark.

Looking at the accumulation of knowledge for building a MAGLEV (Fig. 8), there were already basic ideas on levitation systems, U-shaped guideways as well as the Yamanashi Maglev Test Line for testing prototypes. The RTRI was inviting papers on studies of super-high speed (levitation) railways (Fig. 9) and the number of papers was especially large when speeds of 517 km/h were targeted, indicating that knowledge was being positively accumulated.

What about railway volumes for 2000 predicted around 1985? Analysis of relevant items (Fig. 10) shows that the maximum speed of shinkansen and narrow-gauge railways has a positive impact on expanding railway transport

Figure 12 Passenger Volume (passenger-km)

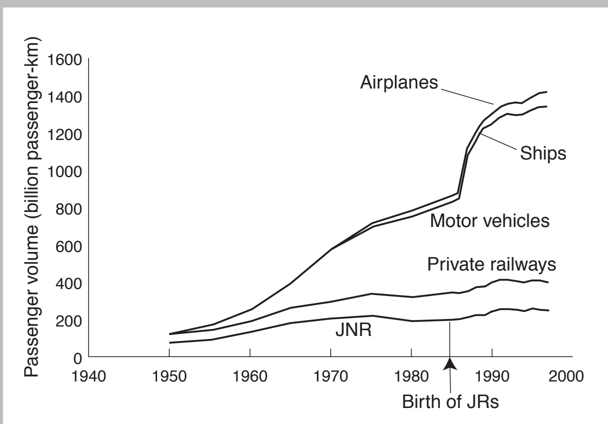


Figure 13 Shares of Various Passenger Modes

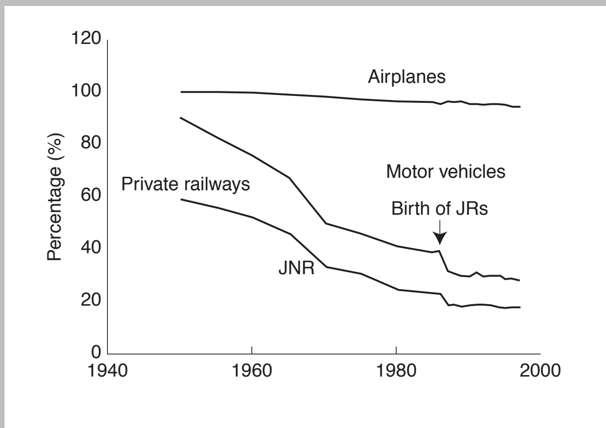


Figure 14 Railway Revenue and GNP

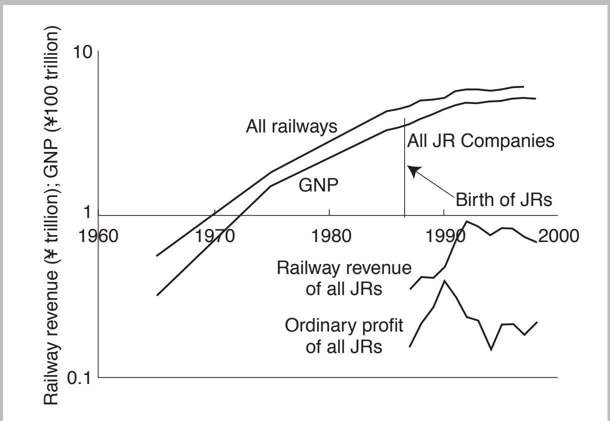


Figure 15 Change in USA Railway Route Length

Figure 16 Shares of Passenger Various Transport Modes in USA

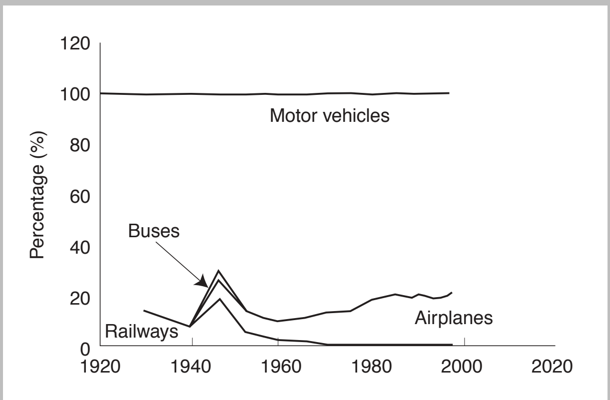


Figure 17 Shares of Various Freight Transport Modes

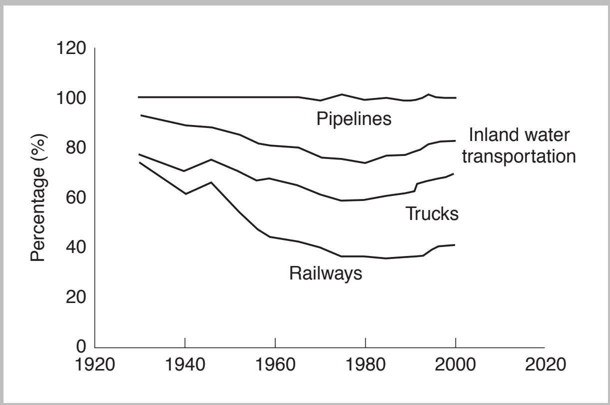


Figure 18 Volumes of Passenger Transport in Various Countries (passenger-km)

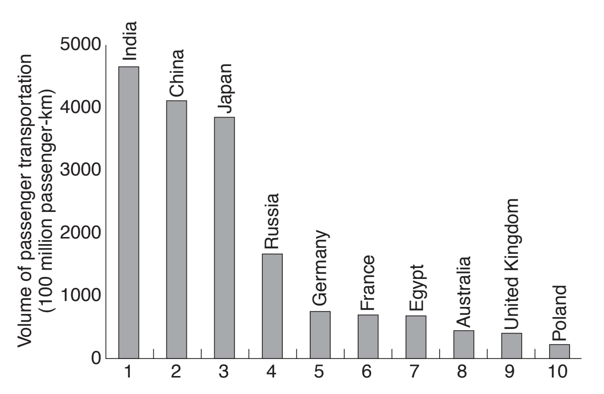
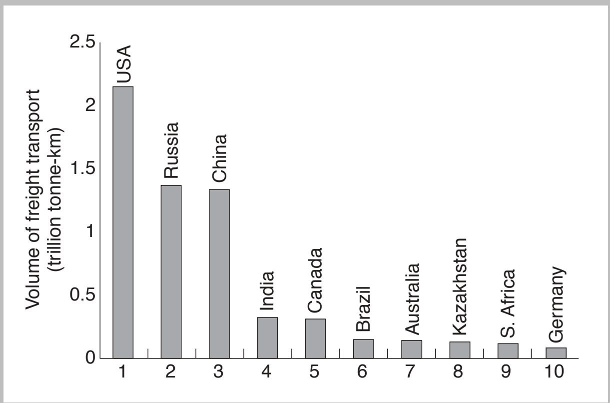


Figure 19 Volumes of Freight Transport in Various Countries



volumes. Other factors helping to expand the volume of railway transportation include: decline in economic growth rate; limits on new road building; rising energy costs; cuts in rail fares; expansion of shinkansen network. However, reducing fares involves some risk while changes in economic growth rate, building new roads, and rising energy costs are all external factors, and expansion of the shinkansen network requires huge investment. Consequently, the only remaining practical option is to increase train speed. Increasing train speed, requires new and difficult-to-develop hardware, but 'software' is comparatively easy to develop and no less important than hardware. As a result, software development has seen remarkable progress.

As a World Bank consultant, I worked in China helping get the Beijing–Shanghai Railway Project off the ground and I would like to compare increases in train speed in Japan and China (Fig. 11). About 10 years ago, China was 30 years behind Japan in terms of train speed. However, today, the maximum train speed in China is 321 km/h, a point that Japan reached 13 years ago and indicating that China's railway technology is progressing at a higher pace. However, if the 1979 point is connected by a straight line to the 1993 point, Japan's lead increases from 13 to about 20 years.

When all is said and done, it seems very likely the activity of any organization is based on implicit knowledge and that there are three types of learning that are closely connected with business activities.

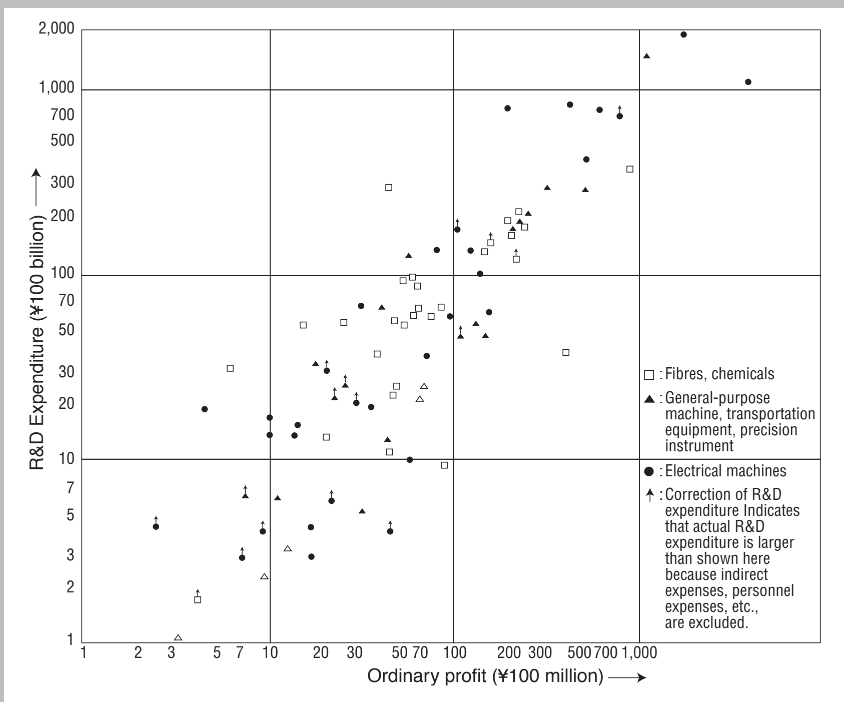
Road to Fifth-Generation Railways

Last, what route leads to fifth-generation railways? When JNR was privatized, it was necessary to consider what to do with its huge debts and to clarify responsibility for them. As already mentioned, rail's share of passenger transport decreased from 38.2% to 31.1% after the formation of the six passenger JRs. Due to Japan's 'bubble' economy, the total volume of all passenger transport increased rapidly (Figs. 12 and 13) and the volume of passenger transportation by motor vehicles nearly doubled during 3 years. However, railways failed to keep abreast with motor vehicles, explaining the marked decline in their share. Looking at rail earnings, the maximum operating revenue was ¥900 billion (¥600 billion today) (Fig. 14) and the maximum ordinary profit of all six JR passenger companies was ¥400 billion (¥200 billion today). At the height of rail prosperity in the USA, the total route length was 400,000 km. Today, it is 200,000 km (Fig. 15) and rail's share of passenger transport has been declining (Fig. 16). In freight transport, rail's share declined until 1980, when it began to pick up, and today it is around 40% (Fig. 17). However, railways in the USA are still an important mode of transport and ordinary profits are around $2.5 billion (¥270 billion). Thus, in terms of revenues, the USA and Japan are two railway superpowers without rival. The revival of us railways is attributable largely to major deregulation of rail freight. Technologically, the development of double-stack containers has doubled freight transportation capacity.

Looking at the volumes (in 2000) of railway transport in various countries. In terms of passenger volumes today, India, China and Japan are the top three. The volume of rail passenger transport in Japan is comparable to the total for all Europe (Fig. 18).

In 1995, Japan held the top spot, followed by Russia, India and China. The disappearance of Russia from the top rank is due to political change. On the other hand, India and China have expanded rapidly. In terms of rail freight, the USA still holds an unquestioned lead, followed by Russia and China (Fig. 19).

Figure 20 Relationship between R&D Expenditure and Ordinary Profit



New Railway Business

About how much money should we put in to start an innovative new business? Figure 20 shows the relationship between R&D expenditure and ordinary profit determined by the Technology and Economics Committee at the request of the JNR Institute of Railway Technology not long before the JNR privatization and division. Clearly, R&D expenditure is nearly proportional to ordinary profit, so it was expected that the ordinary profit of the JRs would be ¥30 billion, and there were some opinions that about one-third to one-half of that amount might well be invested in the RTRI! Eventually, it was decided that 0.35% of railway income should be spent on R&D. At present, the JRs' ordinary profit is ¥200 billion. When added to the ordinary profits of all private railway companies, the total comes to ¥300 billion.

So what should future railways be like? If left alone, they will surely dwindle in the future. Why do I say this? As shown in Figure 21, the government's R&D expenditure has been increasing and is now approximately 3% of GNP. Although the total R&D expenditure of all railways is unknown, the expenditure of thee predecessor JNR Institute of Railway Technology and its successor RTRI is known and is somewhere near this bottom line. Probably, about three times that amount was spent on R&D during the Tokaido Shinkansen development (1960). If so, JNR's R&D expenditure was nearly equal to the government's R&D expenditure. However, it is hard to believe that present R&D expenditure of railway companies is three times that amount. Both JR Central and JR East have their own smallish research institutes with 120 to 150 staff members. The RTRI has a staff of 550 and spends considerable amounts on R&D. Even when all are put together, R&D expenditure on railways has probably levelled off or decreased. I think this situation should be reviewed in earnest.

Figure 21 Ratio of R&D Expenditure to GNP

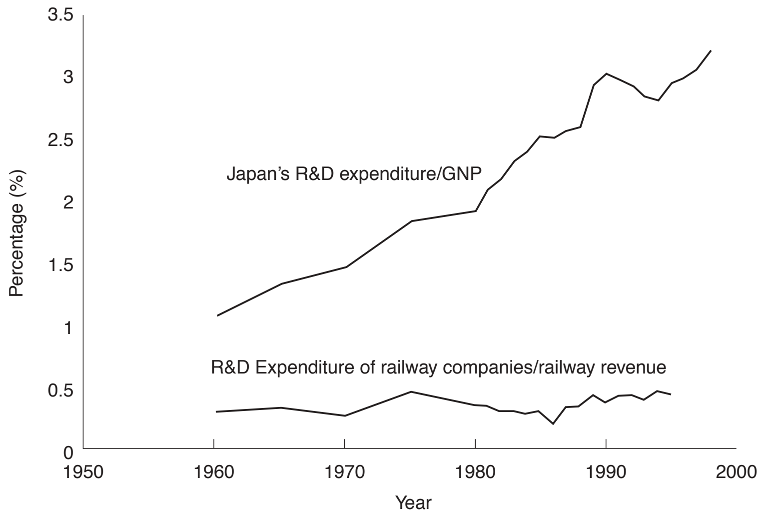


Table 1 Examples of Railway R&D Targets

Costs of construction and maintenance:	Reduce costs as much as possible.		
Target shares:	Passenger transportation	50%	(27% now)
	Freight transportation	25%	(4% now)
	Transportation in large cities	70%	(50% now)
When the above targets are attained, it is possible to reduce energy consumption for transportation by 22% and CO_2 emissions by 24%.			
Target travel time:	Passenger transport	-25%	
	Commuting time	-30%	
	Freight arrival time	-30%	
Embarking/disembarking time:	Halve present times		
Ride quality:	Attain Class 1		
Levitation railway/new urban traffic:	In addition to improvements to existing systems, carry out extensive research on existing and new systems.		
Local traffic lines:	Develop innovative, low-cost, high-speed frequent-demand systems, including compact, exclusive vehicle and automatic operation (wireless) system.		

Another problem is that there is no main R&D organization in railway companies or elsewhere. In 1980, 13 of 1170 university researchers in civil engineering were experts in railways. Today, there are no railway experts among 2844 researchers. All the railway people should pay due attention to this fact.

With this in mind, what should we consider for the future of railways? First, concerning numerical targets (Table 1), we should consider what should be done about plans to increase rail's share of

Figure 22 Vehicle Running through Vacuum Tunnel

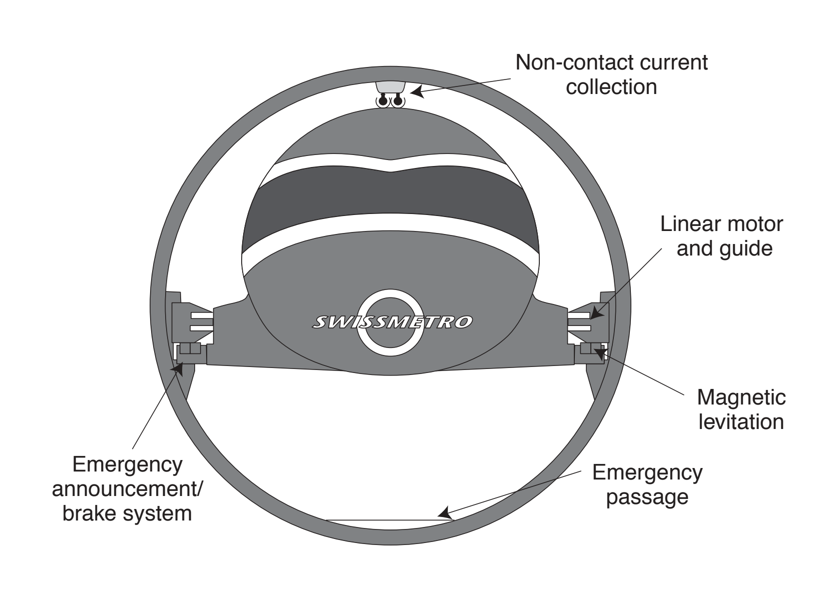
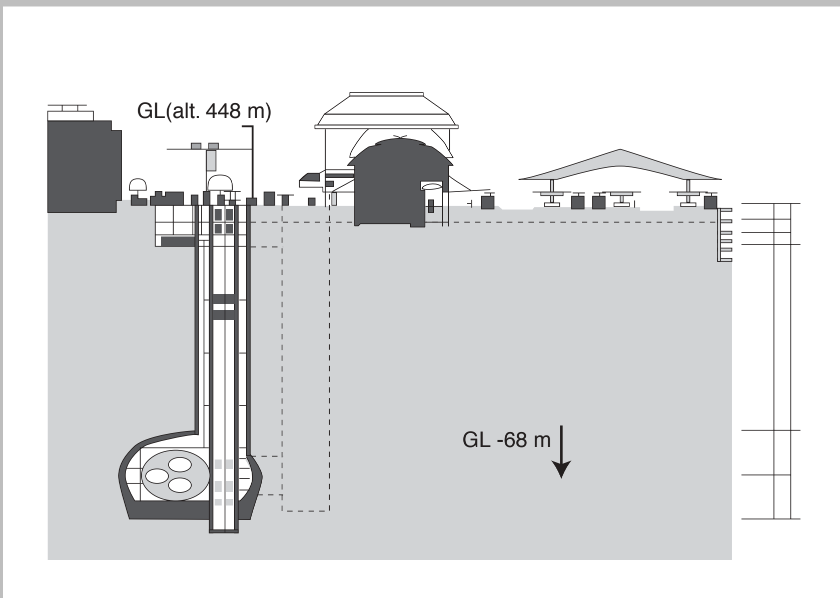


Figure 23 Vacuum Tunnel Railway Station Configuration



passenger transportation to 50%, and freight transport to 25%.

Another possible approach is to consider a long-range scenario up to 2025. One thing to bear in mind is whether today's technology has the seeds of technology for 2025. Personally, I think we have about 50% of the seeds and the other 50% will have to be found within 20 years—a big challenge.

Railcars using fuel cells and variable gauge technologies do look promising. The so-called satellite train is a unique idea in which carriages to stop at a specific station are uncoupled from the train along the way so that only those carriages enter the station. If such a thing were possible, the length of station platforms could be shortened and intermediate stations could be simplified significantly. It is also conceivable to develop a system, allowing for hotel reservations and follow-up of travel by using a mobile phone at any time.

In freight transport, not only freight railways but also the passenger companies should consider ways to increase shares. As examples, setting reasonable freight rates will increase freight shares; railway stations could function as nodes in communities; track maintenance should be roboticized and civil engineering structures should be safe and attractive.

One recent interesting development is Switzerland's energetic pressing ahead with development of a reduced-pressure, high-speed railway where a magnetically-levitated linear motor car runs through a tunnel with inside reduced pressure (Figs. 22 and 23). So far, ¥1.5 billion has been put into the project and there are plans for additional investment of ¥360 million in the future. If completed, the new railway system will enable the passengers to travel from one end of the country to the other in less than 1 hour.

Another development is the building of high-speed experimental lines in various countries (Table 2)—Russia, China, Czechoslovakia, USA, Romania, Poland, Germany and France. The implication is that it has become difficult to carry out various tests on revenue lines and that makers are taking the initiative to test and demonstrate new cars on experimental line before delivery to the customer. Therefore, for Japan to export railway systems as a strategic product, it may be necessary to build such facilities.

Table 2 High-speed Experimental World Lines

Country	Russia	China	Czechoslovakia	USA	Romania	Poland	Germany	France
Location	Shcherbinka	Beijing	Velim	Pueblo	Faurei	Wroclow outskirts	Wildenrath	Valenciennes outskirts
Line length (km)	6.0	9.0	13.277	75.4	13.709	7.725	6.082	2.8
Radius of curvature (m)	1000,800,600	1432,1000,800 600,350	800,600,450 300,250			Includes R150 turnaround curve	Min. 15	325,305,190,185
Maximum gradient (%)							70	6
Maximum speed (km/h)	140	167 (actual)		250	200	120	160	120
Axle weight (te)	30		25		25			22.5
Electrical equipment			25 kV-50 Hz 17 to 29 kVAC -12 MVA			3 kV-DC 25 kV-50 Hz	All international systems Max. 15 MVA	750.1500 VDC 3000.25000 V-50/60 Hz 15000 V-16 2/3 Hz 5 MVA-
Year built	1932	1958	1963	1971	1978	1996	1997	2000
Remarks				Total area 80 km^2			Siemens	

Keeping this mind, can we compare railway generations with computer generations (Table 3)? I think that next-generation railways will probably be intelligent railways.

Table 3 Computers/Railways Generations

Generation	Computer	Railway
I	Vacuum tube	Steam
II	Transistor	Electric/diesel
III	IC	Centralized information/control
IV	Super LSICw	Innovation on propulsion and suspension
V	Non-Neumann	Intelligent railway?

Summary

Since the JNR privatization and division, the three JR passenger companies on Honshu have registered better operating profits than first expected. Due to these impressive achievements, some people are saying that Japanese railways have regained their strength. However, they are actually still on a downward slope. Despite being environment-friendly, Japanese railways are not really making further positive efforts to enhance the environment-friendliness.

Although Japan's natural resources can readily support only 40 million people, it does have good nearby markets; I think we should press ahead with development in the spirit of providing railways to contribute to world welfare and, by doing so, we will find new reserves of power and energy for the future evolution of railway systems. ■

Acknowledgments

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The author passed away on 24 February 2006 before the article was published.

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Late Dr Sato was Director of the Track Systems Institute. He joined JNR in 1960 where he served as head of the Track Laboratory of the Institute of Railway Technology for several years. He holds doctorates in engineering from The University of Tokyo and in commercial science from Waseda University. He is the author of *The Fifth-Generation Railways—Innovating on Railways through Creation of Knowledge* (2005, in Japanese) and *Updated Track Dynamics* (1997, in Japanese).