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A GLIMPSE OF THE HISTORY AND ACTIVITIES OF OPERATIONAL RESEARCH IN JAPANESE NATIONAL RAILWAYS AND A CASE STUDY BY THE AUTHOR

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Abstract

This paper is composed of two parts. One describes the history and present status of OR activities in JNR. The other includes a case study which the author presented in the magazine "OR as a Management Science" (in Japanese) of JUSE in 1957 with comments by Prof. G. Taguchi of Aoyama Gakuin University and Mr. H. Watanabe of the Tokyo Institute of Technology. These comments were published respectively in the May and October 1959 numbers of the "Hyojunka (Standardization)," (in Japanese) of Japan Standards Association.

1. HISTORY OF "OR" ACTIVITIES IN JNR

The term "OR" was imported from USA by some Japanese scholars who studied there under the Fulbright Program and through books written by university professors in the United States. However, the Japanese Armed Forces during the 2nd World War engaged in what was in fact an "OR" activity.

In JNR also there were similar studies by railwaymen. "The theory of line capacities by the application of probability theories" by the late Dr. Yamagishi before the war, and "Studies on the methods of shunting

wagons in the marshalling yard" by Dr. Yamamoto are representative works. They are, indeed, quite achievements by two able individuals. But we had to wait till after the war for the start of OR activities by groups of specialists, this being the outstanding feature of OR. The author will explain here all such activities in JNR very briefly and chronologically.

1953—Mr. Ryuji Yukawa (Assistant to Director, Long-Term Planning Office) learned of the term "OR" (from "Methods of OR" by Profs. Morse and Kimball) at a Planning Committee meeting of the Japanese Union of Scientists and Engineers (JUSE) and reported it to Mr. Jiro Onogi (Chief of Maintenance of Way Section).

1954—A Railway Communication Committee was set up on the initiative of Mr. T. Oda (Chief of Communication Section). The chairman was Prof. T. Kawata (Tokyo Institute of Technology: TIT). Among the members were Prof. H. Takahashi (Tokyo Univ.), Prof. K. Kunisawa (TIT), and Mr. T. Kayano (Nippon Telegraph and Telephone Public Corporation: NTT). It conducted studies on the communication system in the yard and the operations there. The former activity led to the establishment of a significant committee called "The Application of Cybernetics in Railway Operations," in 1960 with Mr. G. Kajii, former President of NTT, as chairman. Other members are: Profs. H. Yamashita (Prof. Emeritus of Tokyo Univ.), K. Kaneshige (Former President of Japan Science and Technology Conference, and also Prof. Emeritus of Tokyo Univ.), G. Wakimura (Tokyo Univ.) and Messrs. N. Hamada and H. Shima. This committee, which has continued its activities, originated the electronic magnetic system for automatic seat reservation (MARS) in 1962. As a result of the latter study (i.e. operations in the yard) 2 papers by Prof. T. Kawata were submitted to both the 1st and 2nd International Conferences of IFORS (the committe was solely occupied with yard operations from 1957 to 1964).

1955—"LP study group" was set up on the initiative of Mr. T.

Ishida (Assistant to the Vice-President), with Dr. K. Maeda acting as leader for two years. Among its achievements, two fine papers deserve special mention, namely, "Economical timber cutting in Railway Works" by Dr. Maeda, and "Estimation of Inverse Traffic" by Mr. R. Amano.

—Mr. A. Muranaka (The Central Railway Training School: CRTS) attended for the first time the 3rd OR course organized by JUSE. This was the first railwayman from JNR attending an OR course.
1956—The first OR group was set up in the Railway Technical Research Institute (RTRI) as OR laboratory (ORL), including Dr. Maeda as leader (2 pure mathematicians and 4 engineers).

—In the 4th OR course organized by JUSE, 9 railwaymen participated from the Head Office, RTRI and CRTS, thanks to an enthusiastic recommendation by Mr. J. Onogi (Deputy Chief Engineer). After completing the course, an OR group was organized by these 9 men plus Mr. Muranaka. (No leader, Coordinator was the author).

—Part of the group studied the famous book by Prof. W. Feller, "An Introduction to Probability Theory and its Applications," and under the supervision of Prof. T. Kawata (TIT), a Japanese translation was published by Kinokuniya in 2 instalments, in 1960 and 1961, respectively. (co-translators: Urabe, Yabe, Ikemori, Odaira and Abe)

1957—Since the primary concern of RTRI was application studies, a few laboratories in charge of theoretical study were dissolved. In the meantime Mr. M. Kanematsu was named as the chief of OR Laboratory. (4 pure mathematicians, 1 chemist and 3 engineers).

—"LP Study Group for the Transport of Goods" was born by the help of Messrs. Ishida and Onogi. Chairman of the group was Mr. H. Watanabe (TIT), other members being Profs. K. Inada (Toritsu Univ.), T. Miyashita (Tokyo Univ.), S. Kataoka (Hitotsubashi Univ.) and T. Sekine (Keio Univ.).

—"Information Study Group" was organized through the efforts of Mr. J. Onogi. Chairman was Prof. K. Kunisawa (TIT).

—"LP Seminar" for railwaymen of the Head Office was held over a period of 6 days, sponsored by Mr. Ishida and organized by Dr. Maeda. Number of participants was 59.

—Meeting for the economic calculation for investment (*i.e.* MAPI etc.) by specialists outside JNR sponsored by Japanese Railway Engineers Association (JREA). Three papers were given by Dr. Y. Mizuno (Nippon Electric Co.), Mr. T. Murakawa (executive manager of Hitachi Sewing Machine Co.) and Mr. T. Hata (Japan Federation of Machinery Industry).

—Mr. M. Nishida (ORL, RTRI) left Japan to study OR at Case Institue of Technology, USA, for 1 year.

—ORG of Head Office invited 2 Americans in May and August, Mr. Macon Fry (ORO, Johns Hopkins Univ. and OR consultant of the US 5th Air Force) and Dr. G. J. Feeney (Stanford Research Institute) to give lectures on OR to Mr. Hideo Shima, Chief Engineer (equivalent to Technical Vice-President of JNR), and other executive managers of JNR.

1958—Data Processing and Statistics Department (DPSD) in the Head Office and Railway Management Efficiency Research Institute (RMERI) in the Railway Central Training School (RCTS) were set up.

—OR was formally added to the assignments of Long-Term Planning Office. Mr. K. Yokoyama, Assistant to the Vice-President, was appointed to direct the development of OR in JNR.

—In the ORL of RTRI, the 1st giant computer "Bendix G 15D" was introduced and preparation was made to set up a Computational Center.

—"OR Study Committee concerned with Electric Power" was set up and worked for 2 years. Chairman, Prof. T. Fukuda (Tokyo Univ.);

Members, Profs. S. Moriguti and H. Arakawa (both of Tokyo Univ.). One of the representative papers of this committee is "Harmonization of Power Generation of Hydroelectric and Thermal Plants" by Dr. S. Urabe (RTRI, Chief of Operation Laboratory).

—The 1st "Symposium on the Application of OR in Railway Field" (OR Symposium in the Railway Field) was held in December organized by Mr. Yokoyama. It was the 1st report meeting ever held on a system-wide scale in JNR. The symposium is still going on, having already had 9 sittings. The number of papers so far submitted to the symposium is 340. Their contents are shown in Table 1.

1959—When the subway from Tokyo to Shinjuku was opened, the ORG studied facts about the heavy morning commuter traffic on the Chuo-line, Tokyo.

—"Study group for line capacity" was set up, sponsored by Japan Train Operation Association (JTOA) through JREA, Chairman, Prof. H. Noguchi (Prof. Emeritus of Tokyo Univ.); members, Profs. A. Asaka and S. Watanabe (Tokyo Univ.), S. Kometani and T. Sasaki (Kyoto Univ.) and Mr. Nishino (Tokyo Metropolitan Division for Trams and Buses).

—"Study Group for Elementary Analysis of Accidents by OR" sponsored by JTOA through JREA, Chairman Dr. Chikio Hayashi (The Mathematics Statistics Institute: MSI) members, Messrs. Akiyama (The Research Institute of Industrial Safety, Ministry of Labor), Oshima (Aeromedical Laboratory, Japan Defence Agency), Toyohara (Prof. of Rikkyo Univ.), Tsukamoto (Fire Defence Agency), Karatsu (NTT).

—The Operations Research Society of Japan (ORSJ) appointed Mr. Onogi as the Vice-President and Mr. Yokoyama as executive manager for general affairs.

—Mr. H. Odaira left Japan to study on stochastic processes under Prof. G. Kallianpur at State Univ. of Indiana, USA for 4 years (granted Ph. D. at State Univ. of Michigan).

Table 1.

	QUEUE	LP	NLP	INV	INF	REP	DE	SQCC	MSA	PMM	FORC	REL	TSA	MCM	OSIM	GAME	SAMPI	SENSI	IE(WS)	PERT	ETC	TOT
No. 1	3	4	1	3	0	1	2	5	4	1	1	1	0	2	0	2	2	1	0	0	1	34
2	5	5	1	1	0	0	1	2	7	7	0	0	1	0	0	1	1	0	0	0	1	33
3	2	2	2	2	1	0	4	1	13	2	0	0	0	4	2	0	0	2	0	0	4	41
4	5	2	0	4	0	3	11	0	3	3	1	0	0	6	2	1	4	1	0	0	3	49
5	2	2	0	3	0	4	8	2	4	4	3	2	1	5	1	0	0	2	2	0	2	47
6	1	0	1	4	0	3	6	0	10	4	3	2	0	0	1	0	0	0	2	0	0	37
7	2	1	0	2	0	0	6	0	4	2	1	1	0	2	2	0	0	0	4	1	5	33
8	2	1	1	0	0	1	6	0	9	1	0	0	0	1	3	0	0	2	3	2	0	32
9	1	3	1	3	0	0	5	0	4	0	0	2	0	3	4	0	0	0	2	4	2	34
Total	23	20	7	22	1	12	49	10	58	24	9	8	2	23	15	4	7	8	11	7	18	340

Abbreviations (index for table 1)

QUEUE	Queuing Theory
LP	Linear Programming
NLP	Non Linear Programming
INV	Inventory
REP	Replacement Model
DE	Design of Experiments
SQCC	Statistical Quality Control Chart
MSA	Mathematical Statistical Analysis
PMM	Probabilistic Mathematical Model
FORC	Forecasting
REL	Reliability
TSA	Time Series Analysis
MCM	Monte Calro Method
OSIM	Other Simulation
GAME	Game Theory
SAMPI	Sampling Inspection
SENSI	Sensory Inspection
IE (WS)	Industrial Engineering (Work Sampling)
PERT	Program Evaluation and Review Technique
ETC	ETC
TOT	Total

—On the proposal of Mr. Ishida; Messrs. Yokoyama, Kanematsu and Muranaka edited text book for newly opened OR course in the correspondence course of the Central Railway Training School. The text book was composed of 3 parts, Statistical Methods, Statistical Quality Control and OR. The students are limited to railwaymen. Up to the end of March of 1967, *i.e.* the end of the fiscal year of 1966, the number of participating students was 3485 and the number of text books distributed was 13,500 (including special students who receive the text books only).

—Mr. Yokoyama visited USA as Representative of ORSJ in a study mission organized by the Japan Productivity Center. The results of his observations were as follows,

1. It would be necessary to have a group of full-time OR workers in our Head Office, however small in number.

2. It would be necessary to have more electronic computers in use.
3. Research and development of business work would be equally important as technical research and development.

—Univac File Computer was installed in DPSD on a rental basis.

1960—The 32nd congress of the International Statistical Institute (ISI) was held at Sankei Kaikan in Tokyo. Mr. Yokoyama and the author were invited as national guests.

—Marketing Research Division was set up in the Sales Department.

—In the Chief Engineer's Office a committee was set up for standardization of goods used by JNR.

—ORG, a voluntary group, was dissolved and Operational Research Centre was established in the Long-Term Planning Office; Mr. Yokoyama as director, (2 civil engineers and 4 mechanical engineers including Mr. Yokoyama).

1961—Mr. Yokoyama visited European countries to attend the 33rd congress of ISI, held in Paris. He called at the Head Office of the French National Railway (SNCF) to observe the OR activities there.

—"Abstracts on the application of OR in Railway Field" was edited by Mr. Muranaka, supervised by Mr. Yokoyama.

—A 6-day DE Seminar was held at the Head Office of JNR by Dr. Motosaburo Masuyama (Tokyo Univ.).

—Mr. Shigemichi Suzuki (ORL, RTRI) left Japan to study numerical mathematics in the University of North Carolina and Stanford University for 3 years in USA as an exchange student by Fulbright Program.

1962—In ORC, NEAC 1201 was set up (memory; 120 words, made by Nippon Electric Co.).

—Seminar for NEAC Programming held 5 times at ORC.

—Mr. Yokoyama was promoted to Director of the Long-Term Planning Office from Director of ORC, being succeeded by Mr. Yoji Kushida.

—In the ORL of RTRI, Bendix G 20 replacing G 15 was purchased and the group was divided from it as Calculating Center of RTRI.

1963—The author visited France as a student studying abroad under a scholarship from the French Government for about 10 months, mainly with ORG of FNR (SNCF), and with l'Université de Grenoble for 1 month and l'Institut Statistique de l'Universite de Paris (ISUP) for 1 month.

—The author attended 3 symposia in Europe: 1. "On the Possibility of using OR in aiding underdeveloped countries (organized by SoFRO in Paris). 2. "The 3rd IFORS at Oslo" as one of the representatives of ORSJ. 3. "On the Possibility of the Application of Cybernetics in the Railway Fields" (organized by l'Union Internationale des Chemins de fer; UIC) as one of the representatives of JNR.

—The author also visited ORG of the British Railways (with Dr. Odaira) and 4 Northern countries: Norway, Sweden, Finland and Denmark, in order to observe the OR activities in these State Railways.

—A special number of the "Technical News of Foreign Railways" for OR was published by JREA (edited by Messrs. Kushida, Muranaka and Yabe).

—Thanks to Mr. Yokoyama, special studies on management problems (research and development of business work) were organized, expenses being borne by the Long-Term Planning Office.

—Mr. Kawarabata proposed the 1st as management probem by Calculating Center of JUSE, RAND Inc. (CC, JUSE) in order to study the reproduction in computer by simulation of the heavy morning commuter traffic on the Chuo-line in Tokyo. The committee was set up in CC

JUSE. Chairman was Prof. Sigeiti Moriguti. Members are Prof. Masao Iri, Mr. Kozo Okudaira (both of Tokyo Univ.), Prof. Fujikawa (Rikkyo Univ.) and Messrs. Yajima and Tsunekawa (both of CC JUSE), Dr. Urabe (RTRI), Messrs. Kawarabata and Sakaguchi (ORC of JNR). For 2 years they had endeavored to make simulation models for computer.

—On the suggestion of Mr. Matsushima (NTT), study group of Traffic Operational Research (TOR) was set up privately including NTT, Japan Air Lines (JAL), Nippon Highway Public Corporation (NDK), Nippon Express Co. and JNR; Mr. Yokoyama as Chairman.

—The personnel of ORC was increased from 6 to 8 (by the addition of 1 pure mathematician and 1 chemist), following the change of the Railway Management Efficiency Research Institute to the Railway Labor Science Research Institute (RLSRI).

—Tokyo Meeting of TIMS was held. Mr. Kawarabata submitted his papers, "On the study of calculation of necessary brake-vans," and he visited France in order to attend symposium on cybernetics organized by UIC as one of the representatives of JNR.

1964—The author returned to Japan through USA, having been enabled to attend "the 10th National Symposium for Reliability and Quality Control" as the representative of Japan, thanks to Prof. Noboru Takagi (Director of the Spacial and Aeronautical Institute of Tokyo Univ.).

—Mr. Yokoyama was promoted to be one of the officers of JNR as the Representative of JNR in Hokkaido. Mr. Kushida was promoted to Director of Matsuto Railway Workshop, being succeeded by Mr. Muranaka.

—Mr. Yukawa (Director of the Electric Departmet) was elected as a manager of ORSJ.

—The book called "Transportation and Material Handling through OR" (in Japanese) was published by Baifukan. This was edited by Mr.

Kushida and supervised by Mr. Yokoyama.

—On the joint meeting of the Western Chapter of ORSA and ORSJ at Honolulu, Mr. Muranaka gave explanations on the OR activities of JNR and on a model of Commuter Traffic of the Chuo-line in Tokyo by simulation by Prof. Moriguti's committee.

—In Osaka, there are 5 great private railways which are continuing to hold working-committees of OR. This was visited by all members of ORC, JNR and from that time on there has been regular contact.

1965—Mr. Yukio Ichijo was proceeded to the Director of the Long-term Planning Office.

1965—IE Team was absorbed into ORC, so number of ORC was increased to 11 (1 jurist, 2 economists, 1 pure mathematician, 1 chemist, 2 civil engineers, 1 eletrical engineer, 3 mechanical engineers).

—As for the theme of management problem, PERT/Time was accepted and through JUSE a working-committee was set up. Chairman, Prof. Kaoru Tone (Keio Univ., Tokyo), Members: Colonel Sumio Kashiwai (ORG of Japanese Army), Messrs. Yasukazu Tsunoda (Tokyo Expressway Public Corporatin, TEPC), Tomoyasu Nakagawa (Central Research Institute of Electric Power Industry), Tatsuo Ezoye, Shokichi Kato (both of Taisei Construction Co., Ltd.), Goro Sakano, Mikio Shoji (both of Technical Research Institute of Kajima Construction Co., Ltd.). The committee had solved 2 problems: Electrification Work of Mito-line, Replacement of Arakawa Railway Bridge by Prestressed Concrete with great successes.

—Prof. Tone solved by request the problem of "Estimated Date for Opening of New Shimizu Tunnel" by Statistical Method and PERT/Time with great success.

—As for the another theme of management problem, Prof. S. Moriguti's group made an estimation of the load of passenger traffic among the

Sobu-line of JNR, the New-Sobu-line of JNR under construction, and the 5th line of Subway under construction, according to what fares they will introduce, on the basis of Prof. Iri's method for the transportation problems. Members from JNR were Messrs. Yabe, Takase and Arai. The result obtained by these studies was welcomed by JNR officials concerned.

—Anniversary of the 5-year activities of ORC was held at the meeting of the 8th Symposium on the Application of OR in Railway Field and Prof. Moriguti delivered a special message on his study.

1966—Mr. Masayo Kanematsu retired from the post of chief of ORL of RTRI, JNR, and has become a professor of Nihon University, succeeded by Mr. Yoji Kushida.

—Mr. Ichijo was elected as a manager of ORSJ.

—The PERT Group, Profs. Banro Takahashi and Seiemon Ioi (both of Waseda Univ.) joining as additional members, studied the application of PERT/Cost and CPM into JNR operations. On account of the differences of contracting systems and others these methods proved not applicable directly to JNR operations, but the group suggested a hint on the possibility of the use of PERT techniques for long-term planning.

—In order to make a good long-term plan and to perform it successfully, the Investment Control group was set up through JUSE to tackle with them as a management problem. Members are Profs. Moriguti and Iri and Mr. Okudaira (all of Tokyo University), Prof. Tone (Keio Univ.) and Tsunoda (TEPC) and Messers Yajima and Tsunekawa (both of JUSE RAND, Inc.), and Prof. Moriguti as chairman. The committee suggested to adopt the Information Retrieval Technique on a trial basis and the work is now in progress. Members from JNR are Messers Yabe, Yajima, Tsukamoto and Arai.

—As a management problem, "Calculation of the line capacity of the

double track section" was suggested by the author, supported by Mr. Ichijo, and the group was set up through ORSJ. Members are Profs. Kiyonori Kunisawa, Hidenori Morimura and Hajime Makabe (all of TIT) Mr. H. Watanabe (MSI), and Prof. Kunisawa as chairman. Members from JNR are Messrs. Yabe, Yajima, Kako, and Ijuin.

—The Group made it clear that the extension of the so-called "Maximum Flow Minimum Cut Theorem" to this problem suggested by FNR (SNCF) was theoreticaly impossible. Profs. Morimura and Makabe and Mr. Watanabe devised 3 models, respectively (under study).

—Dr. Urabe (RTRI) attended the 4th IFORS Meeting in Boston U.S.A.

1967—Mr. Yukawa (Director of the New Tokaido Line Division, Officer of JNR) is elected as Executive Manager for General Affairs of ORSJ.

—Mr. Muranaka retired from the post of chief of ORC, JNR and has become the chief of Econometric Analysis Laboratory of the Japan Institute of Transportation Economics, Inc., succeeded by Mr. Takeshi Oku.

—The members of ORC has decreased from 10 to 8 (1 mathematician, 1 chemist, 4 engineers, 1 jurist, and 1 economist.).

—Two management problems *i.e.* Investment control and Line capacity of the double track, are under study.
For the ORAW meetings, ORC of JNR assisted in the opening and the operation of the meetings.

2. PRESENT ACTIVITIES OF ORC

2.1 To solve the Management Problems and Requested Problems.

2.2 Publication of 2,000 copies of "OR of JNR" monthly (starting in October, 1960)

2.3 To hold an OR Symposium in the Railway Field every year and to compile the Proceedings.

2.4 ORC should work as the Representative of OR activities of JNR.

2.5 Joint study meeting with groups outside JNR

2.5.1 TOR (Messrs. Kushida, Oku, Yabe, Yajima, Tsukamoto).
2.5.2 Traffic Research Meeting organized by the Ministry of Transportation. (Messrs. Oku and Tsukamoto).

3. SOME EXAMPLES STUDIED BY OR

I. Overall Planning

1. **Analysis of traffic volume;** Ijuin, Kimiaki (OR of JNR No. 5) Traffic volumes for 10 years, both passenger and freight, are analysed by the moving-average method. The result of the freight traffic shows the variations of the business explicitly, so the estimate of the next year's revenue is made by this method more accurately than before.

2. **A note on the demand forecasting for short period;** Ochiai, Akira (OR of JNR No. 3). Using the Analysis of Variances, also imagining as if the values to be forecast were defective values the forecasts for the traffic volume and the revenue are tried.

3. **Determining of the investment priorities;** Ijuin, Kimiaki. (OR of JNR No. 12) Suggested by Mr. K. Yokoyama, the author tries to make a comparison among the different policies, such as increasing the items of rolling-stock, electrification, dieselization, etc., by the Guttman's Paired Comparison Method to unify the importance to be attatched to each policy through all the hierarchy of JNR for making a good long-term planning.

4. **Investment control;** (Management problem for 1966 and 1967); A group is organized through JUSE Rand, Inc. by the chairman, Prof. S. Moriguti and others (under study).

5. **A note on the rate of return;** Yokoyama, Katsuyoshi (OR of JNR No. 2) Ordinary methods of engineering economies adopt the constant rate of return as the first hypothesis, but with the colossal equipment

industries as railways, the return of the first year is unreasonable, *i.e.* deficits are natural for the intial years and then the profit increases year by year. So the author makes the hypothesis that the rate of return increases linearly, and he tries to find some principles for determination.

6. **Relation between traffic volume versus income and outlay.** Nishiwaki, Hitoshi (OR of JNR No. 14) The author analyzes the relation between the traffic volume versus income and outlay and points that the present accountancy are not rational.

7. **Relation between traffic volume versus number of employees in each division.** Yokoyama, Katsuyoshi (OR of JNR No. 7) According to the management decentralization policy and the different labour situations in divisions, the author tries to compare the number of employees in each division with the passenger-kilometres and ton-kilometres.

8. **A study of the line capacity** (Technical Research Problem for 1959-1961). A group studied the so-called Yamagishi's Theory on the line capacitv and tried to modernize it.

9. **A study on the effect of doubling single line.** (Technical Research Problem for 1959~1961). A group studied the effect of doubling single line by computer simulation.

10. **Calculation of the line capacity of the double track section.** (Management Problem for 1966~1967). On account of applying the method developed by the ORG of French National Railway (SNCF), this group, Prof. K. Kunisawa as Chairman, was set up through OR Society of Japan but unfortunately this method was proved not to be theoretically true. 3 new models are devised by Profs Morimura and Makabe and Mr. Watanabe (under study).

11. **Studies on the analysis of the composition of commuter traffic** (Management Problem in 1964~1966) Prof. Moriguti as a chairman, papers subumitted in the autumnal meeting of ORSJ in 1965, Sep. by Dr. N. Urabe and others.

12. **Analysis of the conditions of commuter traffic.** Uchibori, Mitsumasa (Presented at the spring meeting of ORSJ in 1961. Marketing Report quarterly of JNR). The author utilizes all kinds of data on it and analyzes it by the regression and correlation techiques.

13. **Analysis of the preference between different lines by commuter passengers.** Takase, Toru (OR of JNR No. 61, 62). This is analyzed upon the survey of Marketing Center by interviews on the ratio between time and cost. This report explains the activities of the Moriguti group as Management Problem for 1965.

14. **Socio-pshychological study on the commuter traffic.** (Management problem by Moriguti group in 1965.)
The raw data on this survey done by the Marketing Center.

15. **The necessary minimum items of rollingstock calculated from the train diagram.** Yokoyama, Katsuyoshi (OR of JNR No. 19.)
By LP, the author devised a method to calculate the necessary minimum numbers of locomotives.

16. **A note on the number of passenger-cars for long-term plan from the point of view of service factor.** Sugiyama, Takeshi (OR of JNR No. 50)
On the basis of the relation between service factor and load factor, the author makes a plan for the number of the passenger cars in another 10 years.

17. **Scrapping plan of wagons.** Yabe, Makoto (Operations Research as a Management Science, JUSE, Vol. 4, No. 1. Presented at the 1st OR symposium in Railway Field.) 3 types of wagons manufactured in the war times become worne out by corrosion of frames earlier than the ordinary wagons.
These 3 types are a big proportion of the wagon fleet of JNR. In order to replace these wagons it is necessary to know the rate at which these wagons will need replacing of these wagons. Using the hypothesis that the life distribution is normal, the author estimates it by the

maximum likelihood method.

18. **Purchasing and mixing plan of coal** Dr. Urabe, Shunichi (Proceeding of the 1st symposium of OR in Railway Field.)
Application of the solution of the transportation problem, solved manually.

19. **The location of centralised railway workshop.** Yabe, Makoto (Operations Research as a Management Science, JUSE, Vol. 13, No. 1)

20. **Estimation of the occurance of natural disasters.** Kawarabata, Yoshihiro (OR of JNR No. 51).
By the multi-regression analysis the author estimates the occurance of landslides in the Dosan-line in Shikoku.

II. Improvement of transport services.

21. **On the reliabilities of the ATC and CTC equipments of the New Tokaido Line.** Miyazaki, Yoichi (Presented at the spring meeting of ORSJ in 1966.)
ATC and CTC are adopted for safety of NTL trains. The author was one of the designers of it and compared data with the estimated values.

22. **On the dispersed and concentrated systems of motive power in passenger trains.** Tsuyuki, Shinichi (OR of JNR, No. 67, presented at the spring meeting of ORSJ in 1966.)
Economic comparison on both systems.

23. **Analysis of the train congestions of the Chuo-Line in the morning by manual simulation.** Nishiwaki, Hitoshi (OR of JNR No. 6.)
The author makes clear the composition of train congestion of the Chuo-line commuter traffic in the morning, *i.e.* if the number of trains per hour is increased the mean traffic volume is also augumented, but once a train delay by some accident occurs the number of trains per hour decreases rapidly, the more trains the faster.

24. **Distribution of riding passengers in the commuter traffic of the Chuo-line in the morning.** Dr. Urabe, Shunichi (OR of JNR No. 21)

The peak of the number of arrivals in Tokyo (Central) Station is known to be at about 8:30. The author uses counting device by photocell in every wicket in the main stations, found that the peak hour of this station is calculated by deducting the necessary minutes from this station to Tokyo station from 8:30 and the dispersion is symmetrical about the peak as if it were a normal distribution, though it is not correct theoretically.

25. **On the congestion of bus terminal.** Miyata, Hajime (OR of JNR No. 48.)
By steep increase of the population in the large cities in Japan, especially in the suburbs of them, the commuter traffic by bus becomes an important problem. The author surveyed the situation of the open space in front of the station.

26. **The classification of freight train lengths by dynamic programming.** Mitsuhashi, Takeshi (OR of JNR No. 31, presented at the autumnal meeting of ORSJ in 1965.) To know the length of a freight train, it is natural to add the lengths of all cars in the train, but rather cumbersome, so the author devises a simple method by dynamic programming by the stratification on the types of cars.

27. **Calculating method of the conversion indexes of cars.** Yajima Kinichi; Nakata Teizo (OR of JNR, No. 66, presented at the 9th OR on Symposium in the Railway Field.)
The conversion figures are composed of 3 types; normal, heavy and light. But this system doesn't match the real situation of the traffic. So the authors suggest the improvment of the classification of cars.

28. **Selection of freight traffic route.** Yajima, Kinichi (OR of JNR, No. 72)
If there are 2 parallel lines from the origin to the destination we have to

select one from the ecconomical point of view, but it is not so easy that all conditions of 2 lines are different, so the author calculates the merit and the disadvantage of 2 lines based on some hyotheses.

29. **On the calculation of the minimum number of brake-vans.** Kawarabata, Yoshihiro (OR of JNR, No. 36. Presented at the TIMS Meeting in Tokyo, 1963, as "Operation of Caboose in Special Use.")
In the freight train it is usual that the brake van is attached at the end of the train. The number of brake van of JNR is about 5300, the author calculates the best utilization of them in some trunk lines.

30. **Composition method of cars in the train, the inverse of the order of arriving at stations.** Kushida, Yoji (OR of JNR, No. 35)
In order to compose a train in the marshalling yard, the author suggests some ways devised by himself.

31. **On the capacity of the new Koriyama automated marshalling yard.** Ikeda, Hon. (OR of JNR, No. 53. Presented at the 7th OR Symposium in the Railway Field.)

32. **Data Processing Study in the Freight Traffic.** Study by the Group of RTRI.

33. **On the mathematical model of the optimum car distribution.** Konya, Hideaki (Presented at the 7th OR Symposium in the Railway Field and also presented at the spring meeting of ORSJ, 1966.)

34. **Transport by car ferry plan in the Seikan straight.** Yajima, Kinichi (OR of JNR, No. 62.)
Car ferry demands vary month by month. In order to match these variations, the author devises a new plan by the applicaton of the linear programming method.

III. Sales promotion

35. **Competition between rail and bus.** Yokoyama, Katsuyoshi (OR of JNR, No. 1.)
The ratio of passengers between rail and bus is expressed by 2 factors,

i.e. time (time between stations plus waiting time according to the train diagram) and cost.

36. **Traffic distribution model in 2 parallel lines.** Ochiai, Akira (OR of JNR, No. 38.)

37. **Traffic distributions between rail and truck for the timber traffic.** Kato, Susumu (OR of JNR, No. 40. Presented at the 6th OR Symposium in the Railway Field.)
In the Kushiro District of the eastern part of Hokkaido, the timber traffic increases in volume yearly, but the proportion by truck increases sharply compared with the rail traffic. The author makes a model and concludes that the cost prevails against the time.

38. **Calculating method of the measure of passenger service from the data of load factor.** Yokoyama, Katsuyoshi (OR of JNR, No. 8.)
The railwaymen, especially in the commercial department take a serious view of the load factor (ratio of the number of passengers in the train versus the cpacity of the train). But from the point of passenger view, the service is much more important than the load factor. The author defines the service factor as the ratio of the number of passengers who could take their seats versus the total number of passengers in this train. He also defines the utility factor of the seats as the ratio of the number of seats the passengers could take versus the total number of the seats in the train. He also shows the way to calculate these factors from the data calculated by the conductor in order to know the load factor of this train.

39. **Mathematical relations among load factor, service factor and the utility factor of seats.** Kushida, Yōji, (OR of JNR No. 24.)
The author sets up some hypotheses, firstly on the distribution of load factor which follows the normal distribution and secondly there is no correlation between the load factor and the passenger capacity on a train. By these assumptions, he can make a model between service

factor and load factor.

40. **On the survey of the freight traffic service.** Muranaka, Akira; Jimbo, Kazuo; Kawasaki, Kaname; Ijuin, Kimiaki (OR of JNR No. 13) In order to set up the service measure of the freight traffic, authors surveyed some conditions for the freight service.

41. **On the distribution of the car waiting days.** Kushida Yoji (OR of JNR No. 27.)
As the service factor of the freight traffic, the car waiting days, *i.e.* the duration between the day when the demand is received at the station of JNR and the day when the requested car arrives at that station is important. The author tries to fit the observed distribution of this duration to his theoretical distribution.

42. **On the criterion of the stations at which the limited express should stop.** Ochiai, Akira (OR of JNR, No. 15.)
When a limited express is scheduled to run for some distance, the authorities of cities and towns in this line request to stop at their stations. Unfortunately there have been no rational rules to choose these stations, so the author takes the distances between stations, the populations in each city and each town, number of passengers at each station, etc. as conditions, and makes a model using these conditions to decide the stations where the new limited express should stop.

43. **Analysis of the commuting passenger flow in the station.** Ishikawa, Hiroaki (OR of JNR, No. 49.)
The author surveys the patterns of commuting flow in the platforms and staircases in Shinjuku Station of the Chuo-line by the memo-motion method.

44. **Evaluation of riding comfort on under various decelerations.** Dr. Urabe, Shunichi and Nomura, Yoshio, (Railway Technical Research Report No. 341, Mar. 1963. Presented at the 5th and 8th OR Symposia in the Railway Field.)
In order to evaluate the riding comfort, the authors surveyed by hiring

university students and analyzing their opinions by interview by the design of experiment method.

45. **Improvement of the newspaper traffic.** Ishikawa, Hiroaki. (OR of JNR, No. 81)
It is now an important problem for JNR to transport the newspapers which are printed in Tokyo. The group was set up in the Rolling-stock and Mechanical Department, headed by Mr. Tsuneo Sano, including one Industrial Engineer in the Long-term Planning Office with 5 men from 5 railway workshops in the neighbourhood of Tokyo. The group suggests some improving techniques using folding pallets.

46. **Cost analysis of the passenger ticket sale.** Ishikawa, Hiroaki.

IV. Miscellaneous

47. **Shortening the duration of passenger car overhaul by PERT technique.** Hironaka, Hayao (OR of JNR, No. 54. Presented at the 7th OR Symposium in the Railway Field.)
By applying the PERT technique the author was successful in shortening the duration of passenger car overhaul from 7 days to 6 days and in some cases to 5 days.

48. **Application of PERT technique to the New Shimizu Tunnel work.** Hirano, Kaoru (Presented at the 8th OR Symposium in the Railway Field, and also presented at the autumnal meeting of ORSJ, 1966)
By the progress method of cutting rocks, the New Shimizu Tunnel Work was begun from 1964, but the gushing water and cave-ins hinder the work, so the opening date of this tunnel is expected to be postponed. Application of PERT technique makes it clear that the succession of the tunnel work is sequential so the PERT technique is of less use than other construction works. The mathematical statistical method is introduced to estimate the date of break-through. Though some changes occur, the estimated date hit the completion of the break-through very well. This study was guided by Prof. K. Tone.

49. **Adding a new PC girder railway bridge and replacements of 2 old**

bridges with the same PC girder bridges by the PERT techiques. Kitai, Ryokichi. (Presented at the 8th OR Symposium in the Railway Field. Management problem in 1965 by the PERT group.)

Adding a new bridge with PC girder on the Arakawa River was permitted by the Tokyo Division of the Construction Ministry, but it took more days than expected. Among the sub-works of constructing a bridge some of them are forbidden to be done during the rainy season. On the process of the work it was estimated that it would continue during the rainy season so it should have been postponed, so the Division suggested to stop working. As the result of the author depicting the network of PERT the continuation of work was accepted by the Division. There were 2 similar jobs, *i.e.* spans 2—3 and 1—4 the former without PERT took 170 days but the latter with PERT only 78 days and the construction work was completed on the exact date estimated. On the replacement of older one, the author proceeded to use the PERT/ Manpower method and concluded that PERT/ Time was not enough and also he made it clear that there were no sufficient programming yet for the PERT/Manpower method.

50. **Application of PERT to the electrification of the Mito-line.** (Management problem for 1965. Presented at the 9th OR Symposium in the Railway Field by My Minoru Tanaka.)

Electrification work is composed of many different kind of works. Limited by the yearly budget and not by the duration time, this work was successful. Some trials of PERT/Cost were applied.

51. **Application of PERT to the elevation on a viaduct and also the quadrupling the double line of the Chuo-line.** Unno, Takaya (Presented at the 8th OR Symposium in the Railway Field, and also presented at the autumnal meeting of ORSJ in 1966.)

Heavy commuter traffic in the morning leads to the reconstruction of the Chuo-line from the double line to the overhead, quadruple railway. The authors applied PERT/ Time method by circle notation for part of this work with success.

52. **How to decide the number of circulating spare parts to be kept at sheds and the railway workshops.** Fujimoto, Masaaki; Oda, Takumi (OR of JNR, No. 16. Presented at the 4th OR Symposium in the Railway Field and also at the 10th meeting of ORSJ. JORSJ, Vol. 4, No. 3.)
To find the most economical number of circulating spare parts among the workshop and sheds, the authors applied the queuing theory to this problem with success at the Kokura Workshop.

53. **On the numbers of spare wheels and axles for non-bogie freight cars.** Fujimoto, Masaaki; Oda, Takumi (OR of JNR, No. 43. Presented at the 6th OR Symposium in the Railway Field.)
For spare parts like wheels and axles some restrictions, such as the decreasing of the wheel diameter and the combination of two wheels whose diameters must be the same within specified limits should be counted plus than the ordinary spare parts. The authors developed the former method to this problem.

54. **On the material control by ABC classification.** Morioka, Iwao; Murayama, Tsugio (OR of JNR, No. 39.)
With the introduction of inventory control the examples of the ABC analysis in the Head Office are explained.

55. **Inventory control of the parts of diesel engines.** Mukaide, Shigeo; Arai, Takao (OR of JNR, No. 77. Presented at the 9th OR Symposium in the Railway Field.)
For the rationalization of the repair of diesel engines the authors introduced the inventory control technique to the works of the Naebo Workshop successfully.

56. **On deciding the number of spare wheels and axles.** Takano, Yoshio; Tabata, Kenji; Ikukawa, Takashi (OR of JNR, No. 75. Presented at the 9th OR Symposium in the Railway Field.)
For decreasing the number of spare wheels and axles in Omiya Workshop the authors applied the simulation technique successfully.

57. **On the preventive maintenance of armatures of traction motors.** Hirata, Yasuhiro; Hatori, Tsugio; Kawamura, Zenichi. (OR of JNR, No. 74. Presented at the 9th OR Symposium in the Railway Field.)
The authors find the optimum time for the varnish reimpregnation and decide the number of times for the reuse of the used coils by OR.

58. **On the preventive maintenance and simultaneous replacement at a time of the vacuum tubes in SHF microwave stations unmanned.** Sakata, Tatsunori (OR of JNR, No. 42. Presented at the 6th OR Symposium in the Railway Field.)
By the Reliability theory the author suggests the period for simultaneous replacement.

59. **On the maintenance of tele-typewriter by the Statistical Quality Control techniques.** Mitsuhashi, Toshio (OR of JNR No. 27. Presented at the 5th OR Symposium in the Railway Field.)
Instead of former regular check, the new system adopts the check time by the number of strokes using the method of Wald's sequential analysis.

60. **Method for speeding up track clearing after accidents.** Abe, Masao (Presented at the spring meeting of ORSJ in 1959. Keieikagaku, Japanese edition of the Journal of ORSJ Vol. 3, No. 3)
Permitting a little oblique pulling by the crane with a sketch of the locations showing the minimum number of different locations the time for recovery after car derailments is greatly reduced. This method is widely used and also available for exercises.

61. **Forecast of the flood of Shinanogawa River.** Hasegawa, Kikuo; Mizuno, Akira. (Presented at the 3rd OR Symposium in the Railway Field.)
In case a flood occurs some people should come to the hydraulic plant to remove driftwood to protect the machines but if the flood doesn't occur their gathering becomes useless, so the author suggests the exact

forecasting method of it by the volume of rainfall at 3 places in the upper stream of the river and this method is accepted successfully.

62. **A note on the model of the safety and the train operation plan in the high speed railway.** Abe, Shun-ichi. (Presented at the 6th OR symposium in the Railway Field.)
The author suggests a mathematical model between train operation plan and its degree of safety.

63. **Decision of the degree of safety of the safe guard facilities.** Urabe, Shunichi; Ishii, Hiroaki. (Presented at the autumnal meeting of ORSJ in 1965.)
In order to prevent the accidents the railway invests the money for the safe-guard facilities. The authors try to make some measures of their value mathematically.

64. **On the experiment of deciding the factors which determine the amount of rolling work of the roadbed which is necessary.** Muranaka, Akira; Yamada, Goji; Amano, Kozo; Tatebe, Tsunehiko (OR of JNR, No. 22.)
By the design of experiment method they found some important factors.

65. **Choice of the level crossing signs by sensory inspection.** Noguchi, Fumio (OR of JNR, No. 45.)
In order to choose distinct level crossing signs the author suggests the application of sensory inspection.

66. **On the problem of transporting cars by the non-traverser system in the Oi-workshop.** Shoji, Masao; Hamazaki, Junko; Matsuda, Kazuhisa. (OR of JNR, No. 65. Presented at the 8th OR symposium in the Railway Field).
In another 5 years, according to the increase of the number of electric cars in the neighbourhood of Tokyo, the number of cars allocated to the Oi-workshop will increase to 20 per day from 14 now. A plan is being discussed by the members concerned for decreasing the duration

time of the overhaul from 7 days to 4 days, the main problem of this plan depends upon transporting cars without a traverser and the authors confirm the possibility of this system by simulation technique.

67. **On the measurement of the standard car-cleaning working time.** Yajima, Kinichi (OR of JNR, No. 70.)
To get the standard time of this work the author suggests the adoption of several different methods such as the method by the stop-watch, work-sampling method and the survey of the actual data together for getting the results with high efficiency and accuracy.

68. **On the effect of concentrating telephones at exchanges** Aoyagi, Sadao (OR of JNR, No. 64 Presented at the 8th OR Symposium in the Railway Field.)
In order to limit the number of employees according to the increase of calls the author applies queuing theory successfully.

69. **On the clarification of rules by symbolic logic method** Yajima, Kinichi (OR of JNR, No. 46, 47. Presented at the autumual symposium of ORSJ in 1964, published in Keieikagaku, Japanese edition of the Journal of ORSJ Vol. 9, No. 3)
For specifying the rules the author suggests applying symolic logic method.

70. **On the effects of the traffic change caused by a newly born parallel line.** (ORG of JNR, headed by Mr. K. Yokoyama. Yabe, Makoto. Operations Research as a Management Science-JUSE, Vol. 5. No. 6)
On the opening of the new line between Tokyo and Shinjuku of the subway in March, 1959, OR group was asked to estimate the volume of the transfered commuter traffic from the Chuo-line of JNR to this new one. By counting the number of passengers getting off at several doors both at Kanda and Tokyo stations (sampling) and by the Design of Experiments the traffic was analyzed on such conditions as the day of week, the arrival time zone, the locations of the car in a train, etc. This study was highly appreciated by the members concerned.

71. OR Notes (Vol. 1) ORL, RTRI

Railway Technical Research Report No. 478, June 1964 (in Japanese) Summaries are translated into English and published in the "Quarterly Report of the Railway Technical Research Institute" Vol. 7, No. 2, 1966.

The contents are as follows.

1. Two problems arising in train crew scheduling,
   Hideaki Konya
2. On an assignment problem of locomotives to depots,
   Hideaki Konya
3. A distribution schedule of fuel for locomotives,
   Shigemichi Suzuki
4. Derailed car restoration problem,
   Hiroshi Odaira
5. Removing nodes from transportation net-work,
   Yoshio Ibaraki
6. The man-machine one-one combination problem,
   Shunichi Abe
7. Train sequencing problem,
   Hiroshi Odaira
8. A study of train formation for the concentrated transportation in a system of yards,
   Akira Sato
9. A simple graphical solution to the optimal investment problem,
   Shunichi Abe
10. An application of information theory to freight car transportation,
    Akio Enya
11. On reduction error of bulk materials,
    Masayo Kanematsu
12. On the estimate of the long-range cost per unit time for cyclic models,
    Shunichi Abe

4. CONCLUSION

The author has attempted to state the present OR activities of JNR as fairly as possible. But in such a great enterprise as JNR (the number of employees is about 460,000), it is quite out of reach for one person to cover all facts of its OR studies. Some remarks will, therefore, be made.

Following the policy of Mr. K. Yokoyama, the OR techniques in JNR include all modern techniques, such as SQC, DE, MR, SE, IE, although some of them are undertaken separately by various organs with no regard to whether they are applied independently to one organ or not. For instance, in JNR's Rolling-stock and Mechanical Department some members from each workshop were given training for DE (Design of Experiments) for 4 years from 1958 to 1961, under guidance of Dr. Motosaburo Masuyama of Tokyo University, Prof. Genichi Taguchi of Aoyama Gukuin University and others. This Department has decided to prepare papers for its technical study symposium on the basis of this technique. For this reason, the number of papers presented to the OR Symposium in the Railway Field by this Department is the largest, and this technique is now widely used at the workshops.

Though small in the number of papers presented to the Symposium, the Operation Department had also educated its staff through Dr. Urabe, RTRI. He compiled the DE activities in JNR in the form of 4 reports annually (1959-1962) with his colleagues.

On the contrary, SQC technique, especially the Control Chart Method is found not applicable directly to railway operations, as they are different considerably from the practices at ordinary factories, such as those for new production.

As for Reliability Technique, it is studied extensively by members of the 3 departments in JNR, *i.e.* the Electrical, Operation and Rolling stock and Mechanical Departments. As a matter of fact, the design of signalling circuit and train control facilities on the New Tokaido Line was revised for application of this technique by the group concerned,

with Mr. Hiroshi Yoshimura, Chief of Signal and Tele-communication Section of NTL Division (General Secretary, Japan Association of Signal Industries) as leader, and the results are satisfactory.

In the meantime Rolling-stock and Mechanical Department made a study on the maintenance systems of aircraft with the assistance of the Japan Defense Agency and the Japan Air Lines, and concluded that the information gathering system should be improved for the application of this technique.

As for other applicable techniques, the author desires to avail himself of another occasion for introduction.

Some results of the studies by OR are already applied by all departments, divisions and workshops concerned, as their problems come from necessity at hand and they belong to, what they call, a tactic field. On the otherhand, some are not yet materialized, as they are of the "strategic" nature.

Nowadays, the railway is not the sole means of transport, due to hard competitions from air, road and water. During the past more than 90 years, the railwaymen tackled their difficult problems with all techniques known to them, for example, the trial and error method without any knowledge and recognition of OR. Indeed, there are many cases where results gained by optimum solutions by OR are almost the same as those performed now by real operation systems. Therefore, the most of the problems discussed in the various sections of JNR's Head Office and passed to the attention of ORC are those of natures that cannot be easily solved even though by the most modern techniques of OR.

But OR analysts of JNR admire the rationality of OR and its powerful ways for solving the problems and so look forward to the time when these problems can be solved with nothing but OR.

5. ACKNOWLEDGEMENTS

The author wants to express his appreciation to the OR analysts

both of JNR and others for their efforts to improve the operations of JNR. Any comments or questions about the statement contained herein are kindly requested to be made freely to the author at any time.

6. ONE EXAMPLE STUDIED BY THE AUTHOR

6.1 "On the best location of centralized railway works (which is equal to the problem of centralized distribution centres)=Which is more profitable, a few centralized grand railway workshop or many scattered small railway workshop?" by Makoto Yabe, in "Operations Research as Management Science of JUSE" Vol. 3, No. 1 (1957, in Japanese).

6.1.1 Attending the 4th OR Course of JUSE, the author noticed the mistake in what has been a tradition for more than 40 years, to the effect that the best location of railway workshops is equal to the so-called centre of gravity of a mass-point system, if we regard the assigned number of cars (except for freight cars) to the car sheds as the masses there and the railway network with these masses as a mass-point system. (Fig. 1)

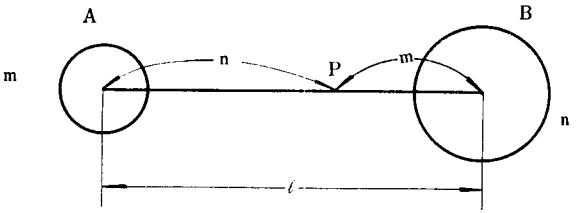

Fig. 1

Thinking of the travelling expenses which are expressed by the product of the number of cars by hauled distances, the best location for several models are gained by the LP.

Supposing that there are m cars at car shed A and n cars at car

shed B (where $m < n$), the distance between A and B is l kilometres and the coefficient of hauling expense is expressed as ¥ c/car-kilometre, then the equation of one-way cost Q for the railway works lying at x from A becomes as follows (Fig. 2):

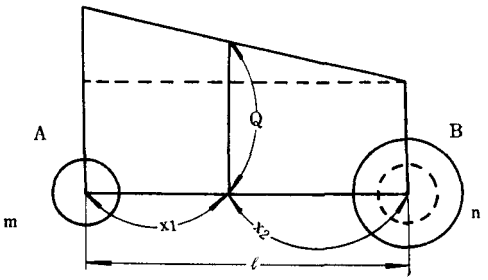

Fig. 2

$$Q=c\{mx+n(l-x)\}$$

If we rewrite this equation using 2 independent variables x_1 and x_2 instead of single variable x, we get the simplest LP equation as follows:

To minimize

$$Q=c(mx_1+nx_2)$$

subject to

$$x_1+x_2=l$$

Thus the result is quite different from the one deduced from the legend; in other words, we find that the best location is at car shed B. In this model the distance between car sheds does not affect the result.

The author then made another simple model of a system like Fig. 3. In this case, we should take into account the distances between each of the three car sheds, and not only of the numbers of cars.

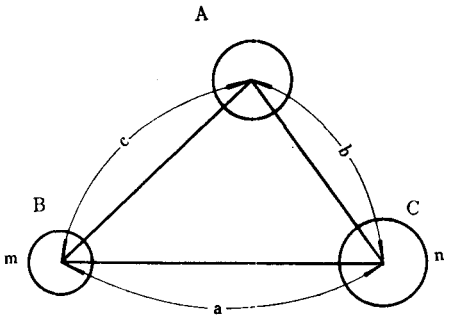

Fig. 3

4.1.2 At the request of the author, Mr. H. Watanabe (who was the teacher of LP in the OR course) schemed 4 models as follows.

(1) N car sheds lying on a line, (Fig 4)

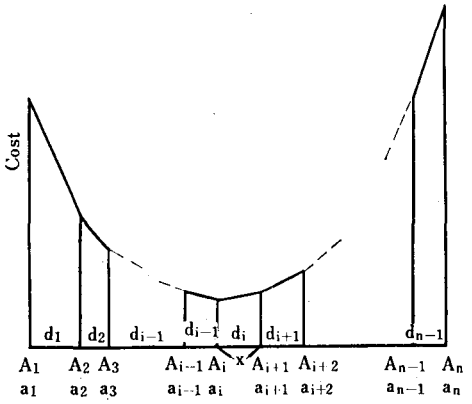

Fig. 4

The best location is gained by adding the numbers of cars from a car shed at either end, one by one, and finding the place where their sum exceeds firstly the half of the total number of cars in this system. Here the distance between the car sheds play no role in the result.

(2) A system having one junction. (Fig. 5)

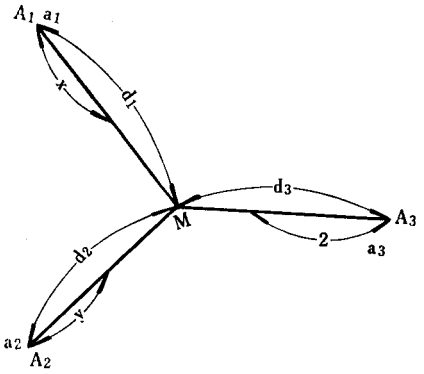

Fig. 5

(3) A system having two junctions. (Fig. 6)

The best locations for these 2 models depend on the situation of assigned numbers of cars, omitting the distances between the car sheds also.

(4) N car sheds lying along a circle. (Fig. 7)

This is an extension of the former model by the author (Fig. 3). Therefore we should take into consideration not only the numbers of cars but also the distances between the car sheds.

After checking that symmetrical points of the car sheds to the centre do not become the best location, the author solved this problem arithmetically.

These results were gained also by Dr. Maeda for (1) and by Dr. Odaira for the others independently of the author.

4.1.3 In the case of diesel railcars, the most advantageous location

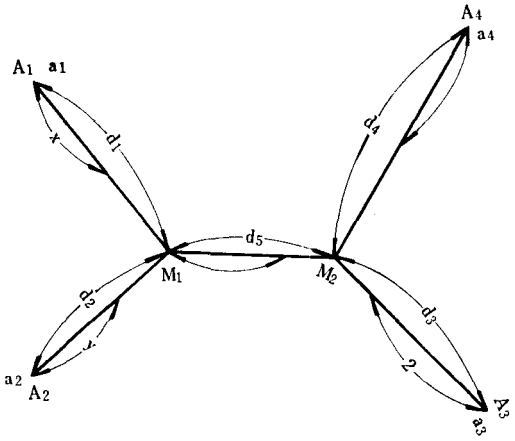

Fig. 6

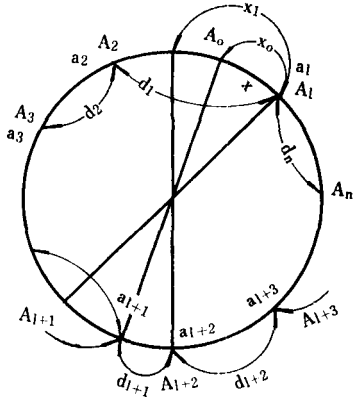

Fig. 7

for engine repair works in 1958, and an estimation for 1965, are shown in Table 3 and Fig. 8.

Table 3. Number of Diesel Railcars Assigned to Each Workshop

	1958	1965 (Plan)
Takasago	29	94
Kyoto	92	229
Nagoya	65	163
Hashimoto	150	288
Niitsu	24	38
Morioka	55	123

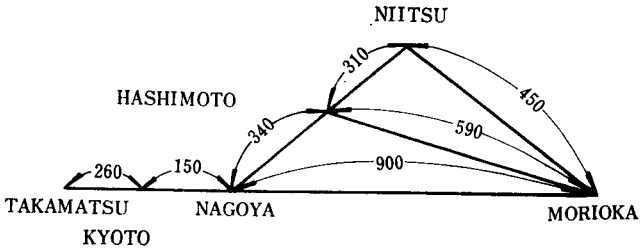

Fig. 8

The author calculated arithmetically one-way products of numbers of cars by distance, both for one centralized railway works and for two centralized railway works, shown in Table 4 and 5, respectively. The

Table 4. Table of Accumulated one way Turn-round Car-kilometers (in case of one centralized work)

	1958		1965 (Plan)	
	km-car	order	km-car	order
Takasago	260, 400	5	382, 800	4
Kyoto	167, 800	3	349, 400	3
Nagoya	141, 800	2	305, 600	1
Hashimoto	128, 750	1	322, 300	2
Niitsu	217, 900	4	533, 800	5
Morioka	292, 300	6	698, 100	6

Table 5. Table of Accumulated one way Turn-round Car-kilometres (in case of two centralized works)

	1958		1965 (Plan)	
	km-car	order	km-car	order
Takasago-Kyoto	160, 250	13	325, 180	13
Takasago-Nagoya	129, 860	12	268, 100	9
Takasago-Hashimoto	85, 830	3	199, 300	5
Takasago-Niitsu	121, 800	10	271, 300	10
Takasago-Morioka	109, 800	8	313, 600	12
Kyoto-Nagoya	123, 650	11	249, 000	7
Kyoto-Hashimoto	57, 150	1	133, 100	1
Kyoto-Niitsu	88, 500	5	193, 700	4
Kyoto-Morioka	165, 350	14	358, 500	14
Nagoya-Hashimoto	65, 630	2	157, 200	2
Nagoya-Niitsu	91, 900	6	217, 700	6
Nagoya-Morioka	87, 500	4	188, 000	3
Hashimoto-Niitsu	113, 700	9	293, 500	11
Hashimoto-Morioka	96, 350	7	249, 800	8
Niitsu-Morioka	192, 900	15	478, 000	15

Table 6. Synthetic Comparative Table of one way Turn-round Car-kilometres

		1958	1965
		km-car	km-car
in case of one work	order 1	128, 750 (A)	305, 600 (C)
	order 2/order 1	1. 10	1. 06
	order 6/order 1	2. 27	2. 28
in case of two work	order 1	57, 150 (B)	133, 100 (D)
	order 2/order 1	1. 15	1. 20
	order 15/order 1	3. 37	3. 58
(A)/(B) and (C)/(D)		2. 25	2. 30

results gained by this simple method are shown in Table 6.

Unfortunately these hauled costs cannot play a definitive role in

the best location problem, as at the same time we should consider other factors like the possibilities of the acquisition of space, and of getting a stable labour force and/or materials. But the author believes that these models are more useful for transport problems by ship or by air where distance is a more important factor than in the case of railways.

6.2 "On the distribution problem by the hypothesis that the distributing cost is equal to the product of distance by number of units," by Prof. Genichi Taguchi, Hyojunka Vol. 12, No. 5 (1959, in Japanese).

The Problem offered by Mr. Yabe of JNR is rewritten as the problem above.

For one centralized centre, saying that the i-th car shed among k as P_i having its abscissa t_i and the number of cars there as W_i ($i=1, 2, \cdots k$), and also the abscissa of the best location as x_1, then by the distribution function $F(t)$ having the density $W_i/\sum_{i=1}^{k} W_i$ at every car shed $P_i(F(t_i+0)-F(t_i-0)=W_i/\sum_{i=1}^{k} W_i)$ we can get x_1 by the next formula $F(x_1)=1/2$ that is, x_1 is the median of the distribution function $F(t)$.

For two centralized centres, saying that the abscissae of the best locations are x_1, x_2 should fulfil the next equations

$$F(x_1)=F((x_1+x_2)/2)/2$$

$$F(\mathrm{n}_2)=\{F((\mathrm{n}_1+\mathrm{n}_2)/2)+1\}/2$$

If there are more than 2 solutions for these equations, it is necessary to examine them for getting the true solution. The author demonstrates a graphical solution for it.

If the car sheds are distributed not on the line but in the network, the best location problem becomes a more complicated one, so the author devises to get narrower existent domain by setting up several criteria.

6.3 "On Mr. Yabe's problem for the best location of railway workshops" by Mr. Hiroshi Watanabe, Hyojunka Vol. 12, No. 10 (1959 in Japanese).

The problem of the best location (or two best locations) for centralized workshops ono ne line have been solved by Mr. Yabe and Prof. Taguchi. The author derived the concrete method of solving the problem of three or more most favourable locations for one line by a similar method to Dynamic Programming.

Suppose that the minimum expense is expressed as $U(l-1, m, n)$ if we construct n railway workshop $(n \leqslant m-l+1)$ between lth and mth car sheds $(1 \leqslant l \leqslant m \leqslant k)$, then generally the next equation holds,

$$U(l', m, n+1) = \min_{l' < p < m} \{U(l', p, n) + U(p, m, 1)\}$$

$$(0 \leqslant l' < p < m \leqslant k)$$

It is easy to decide $U(p, m, 1)$ on arbitrary p and m by Mr. Yabe's method, so we can decide p which minimizes $U(l', m, n+1)$ for arbitrary n through the above equation.

For this case finally it is sufficient to solve the case where $l'=0$, $m=k$ hold. To decide p in the above is equal to deciding the assigned area to each railway works. If it is decided, then the best locations are solved by means of Mr. Yabe's method.

The author explains these results also by numerical examples.