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The Analyst's Bookshelf

Joseph F. McCloskey, Editor

BOOKS

Reviews

A ADAM, *Messen und Regeln in der Betriebswirtschaft*, Physica-Verlag, Wurzburg, Germany, 1959, 174 pages, DM 27

THE TITLE of this book may be rendered *Measurement and Servo Control in Micro-Economics* (Economics of the Firm), the subtitle is "An Introduction to the Information-Theoretic Principles of Industrial Operations Research"

In the introductory Chapters 1-3 'measurement' is defined as a process of mapping a set of objects ('real' or conceivable) into a set of symbols. These symbols constitute a 'language' which may be used to express 'information' about 'a real world'. The set of symbols used in measurement may be metric (a distance between symbols is defined), ordered (a rank relation is defined), or diverse (two symbols are either equivalent or not equivalent).

In Chapter 4, the 'channel' of the classical information theory is introduced. For transmitting information through the channel, a language, V , is employed which is defined by the finite scheme

$$V = \begin{bmatrix} V_1 \neq V_2 \neq & \neq V_k \\ p_1, & p_2, & p_k \end{bmatrix}, \quad p_i \geq 0, \quad \sum_1^k p_i = 1,$$

where the V_i are diverse symbols that are transmitted with known probabilities p_i . The 'information entropy' of the finite scheme, V , is defined by

$$H(V) = - \sum_{i=1}^{i=k} p_i \log_2 p_i$$

Information channels are used for two main purposes

1. Transmission of information from a transmitter to a receiver
2. Transformation of information by the channel, with the purpose of exploring the structure of the channel on the basis of the information input and output

The first is the domain of classical information theory, while the second is the domain of modern statistics inclusive of 'imperfect model construction'. Most of the remainder of the book is devoted to the second subject. Suppose that the information input is given in a language (finite scheme), V , and the transformed information in a language, W . Then the entropy $H(W)$ and the conditional entropy $H(W|V)$ are well-defined. The quantity

$$B(W|V) = [H(W) - H(W|V)]/H(W) = 1 - H(W|V)/H(W), \quad 0 \leq B(W|V) \leq 1$$

is introduced as a 'measure of determinateness' that measures the degree of correspondence between the topological (ordered or diverse) characteristics V , and W . Perfect correspondence is indicated by $B(W|V) = 1$. The closer this degree of per-

fection is approximated, the better the potential of servo control. It helps to view V as a control variable and W as a payoff.

Chapter 5 points out strong analogies between the entropy of topological schemes and the variance of metric schemes so that one may speak of a digital (topological) and an analog (metric) entropy. Chapter 6 further exploits such analogies for the construction of other scalar measures of topological schemes. Chapter 7 has conclusions for the control of real operations. Economic and sociological facts usually are measurable only in an imperfect way. The degree of imperfection is exhibited by entropies. Mathematical modeling and/or servo control of a process will have no success unless its measure of determinateness as defined before is close to unity. If this is not the case, it may be achievable by stabilizing the process through appropriate measures.

Chapters 8–12 are devoted to the technical treatment of special information transforming channels (e.g., channels with linear transformation treated by linear programming).

The last chapter (13) is devoted to operations research. The purpose of operations research is “to make a purposeful selection from internal and external information which is usable for servo control by top management.” A few short examples of operations-research studies and problems are given. It is remarked that “the structure of a complex operation rarely is such that usable results may be deduced by the usual tools of analysis (and the conventional methods of operations research).”

The author advocates a “general science of information” in order to counter “the striking tendency toward splitting a field with natural boundaries” into a multitude of disciplines such as semiotics, information theory, cybernetics, but also statistics, decision theory, operations research, econometrics, and the other metrics. Apart from this all-embracing proposal, the reviewer feels that the author’s concept of operations research is too narrow. This may be due to the fact that American publications about operations research do not give the best picture of what operations research is. The examples in the book are greatly oversimplified, isolated problems that may explain the author’s opinion about conventional operations-research methods. While it has long been common practice of operations researchers to test their mathematical models by the fraction of total variance explained, the extension of this principle to topological characteristics by use of a measure of determinateness is certainly of interest to operations researchers, especially since it may open up new possibilities for including nonmetric psychological and sociological variables in formal models.

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Books Received

MARITIME CARGO TRANSPORTATION CONFERENCE, *Maritime Transportation of Utilized Cargo*, NRC Publication 745, National Academy of Sciences, National Research Council, 2101 Constitution Avenue, Washington, D. C., 1959, 102 pages, \$2.00

F. H. GEORGE, *Automation, Cybernetics and Society*, Philosophical Library, New York, 1959, 283 pages, \$12.00

EDWARD G. BENNING, *Elementary Mathematics of Linear Programming and Game*

- Theory*, Bureau of Business and Economic Research, College of Business and Public Service, Michigan State University, East Lansing, Michigan, 1960, 140 pages, \$5.00
- GEORGE W. MORGENTHAUER, *Operations Research: Decision Aid for Management*, Education-Industry Service, 1225 E. 60th Street, Chicago 37, Illinois, #AA-204, 1960, 32 pages, \$0.50
- OFFICE OF ORDNANCE RESEARCH, *Proceedings of the Fourth Ordnance Conference on Operations Research*, Report No. 59-3, Office of Ordnance Research, U. S. Army, Box CM, Duke Station, Durham, North Carolina, 1959, 216 pages, no price
- CHARLES E. CLARK AND BETTY WEBER HOLZ, *Exponentially Distributed Random Numbers*, The Johns Hopkins Press, Baltimore, Maryland, 1960, 249 pages, \$6.50
- ROBERT S. TITCHEN, ARNOLD J. ROSENTHAL, BRUCE BOLLERMAN, FRANK NISTICO, Eds., *Quality Control and Applied Statistics including Operations Research Yearbook 1959*, Interscience Publishers, New York, 1959, 1348 pages, \$60.00
- MARGARET W. RABEN, *A Survey of Operations and Systems Research Literature*, Institute for Applied Experimental Psychology, Tufts University, Medford, Mass., 1960, 122 pages
- PAUL G. HOEL, *Elementary Statistics*, John Wiley & Sons, New York, 1960, 261 pages, \$5.50
- EMANUEL PARZEN, *Modern Probability Theory and Its Applications*, John Wiley & Sons, New York, 1960, 464 pages, \$10.75
- MORRIS JAMES SLONIM, *Sampling in a Nutshell*, Simon and Shuster, New York, 1960, 144 pages, \$3.50
- ANTHONY RALSTON AND HERBERT S. WILF, Eds., *Mathematical Methods for Digital Computers*, John Wiley & Sons, New York, 1960, 293 pages, \$9.00
- ROBERT H. GREGORY AND RICHARD L. VAN HORN, *Automatic Data-Processing Systems, Principles and Procedures*, Wadsworth Publishing Company, San Francisco, 1960, 705 pages, \$11.65
- LARS V. AHLFORS AND LEO SARIO, *Riemann Surfaces*, Princeton University Press, Princeton, New Jersey, 1960, 382 pages, \$10.00
- AMERICAN SOCIETY FOR ENGINEERING EDUCATION AND AMERICAN INSTITUTE OF INDUSTRIAL ENGINEERS, *1959 Summer Symposium Papers: Planning and Justifying Capital Expenditures*, The Engineering Economist, Stevens Institute of Technology, Hoboken, New Jersey, 1960, \$10.00 (\$4.00 to members of ASEE and AIIE)
- ARTHUR M. ROSS AND PAUL T. HARTMAN, *Changing Patterns of Industrial Conflict*, John Wiley & Sons, New York, 1960, 220 pages, \$6.50

Comments

GEORGE MORGENTHAUER has done one of the best jobs to date of identifying and defining the essentials of operations research within small scope. There are a few unfortunate errors and distortions of emphasis, but these are likely to bother only the professional. Most interested executives will find the brochure balanced, factual, and understandable.

THE FOURTH ORDNANCE CONFERENCE ON Operations Research produced its usual mixture of interesting papers, but, as in preceding years, some of the papers are listed only by title, either because no written version was prepared or because the papers are available only in the classified appendix, issued separately. In all, 13 papers (out of 20 presented) are published. They run the gamut from organiza-

tional papers, through experimental design and use of specific techniques, to simulation and gaming.

THE CLARK-HOLZ volume provides 1,000 blocks of 100 pseudo-random five-digit numbers from the exponential distribution whose probability density is e^{-x} , $0 \leq x \leq \infty$. For each block of numbers the empirical mean, second moment, expected fraction of samples of 100 with mean less than that of the sample, expected fraction of samples with second moment less than that of the sample, and other sample statistics are given. The authors note that the terminal digits in the tables may be used as a source of uniformly distributed random digits, and that with proper manipulation these tables may be used as a source of random numbers from the chi-square distribution with $2n$ degrees of freedom.

Quality Control and Applied Statistics, including Operations Research, Yearbook 1959, is a single-volume publication of the abstract service that appeared in twelve issues under the title *Quality Control and Applied Statistics* during 1959. It is seriously limited by the failure of the editors and publisher to include the classification scheme. Thus, eight articles are listed as operations research in the subject index. They came from *Operations Research* (3) and five other journals; most have "operations research" in the title, but several do not. On the other hand, one article is listed under R. L. ACKOFF in the author index; it turns out to be D. F. CLARK AND R. L. ACKOFF, "A Report on Some Operational Experiments," *Operations Research*, 7, 279-93 (1959), and is indexed by subject as "Organizational Experiments." Thus, the user is forced to roam through the author and subject indexes without guidance. This situation would have been alleviated to some extent if the individual abstracts had been reordered according to classification. They are, however, simply grouped in the page order of the periodical publication. All this is unfortunate, indeed, because the quality and completeness of the abstracts deserve much better treatment.

THE RABEN *Survey* is based in part upon a questionnaire sent to 200 experts in the field of operations and systems research in June, 1958, and in part upon availability of the references. There are approximately 1,000 references gathered in the second section of the book. Books are given much greater relative emphasis than articles. About half of the references are cited in the text that comprises the first part of the book. This portion is divided into three parts (Introduction, Methods, Problems) consisting of a total of fifteen chapters. Each chapter or section thereof is a bibliographical essay that uses the references cited to trace the development of the subfield treated. The scheme is thus interesting and ambitious. It succeeds in integrating most of the book-length treatments reasonably well but leaves much to be desired in terms of treatment of the periodical literature. The old truism about being too superficial for the expert and too compressed for the novice appears to apply.

HOEL's *Elementary Statistics* "is designed for a one-semester course . . . for students with only a limited background in mathematics (high school algebra is sufficient)" (Jacket). At an appropriately higher level, PARZEN's *Modern Probability Theory and Its Applications* is also an introductory text.

Sampling in a Nutshell is not quite in a class with *Parkinson's Law* or *How to Lie With Statistics* as a witty treatment of a serious subject, but it is an excellent introduction to statistical sampling for the executive who wants to know what he is likely to get when he 'buys' some sampling.

THE RALSTON-WILF volume brings together the fundamental techniques of digital computation and the mathematics of analysis. The chapters, after an initial one on "Generation of Elementary Functions," cover Matrices and Linear Equations (6 chapters), Ordinary Differential Equations (4 chapters), Partial Differential Equations (5 chapters), Statistics (Multiple Regression, Factor Analysis, Autocorrelation and Spectral Analysis, and Analysis of Variance) (4 chapters), and Miscellaneous Methods (6 chapters). Each chapter except the first "consists of a mathematical discussion of the method under consideration followed by . . . calculation procedure, flow chart, sample problem, etc." (Preface).

Automatic Data-Processing Systems is a well-organized introductory text covering equipment, programming, processing, system design, equipment acquisition and utilization, and prospects in the field. There is also a chapter on "Scientific Decision Processes" in which some of the better established models of operations research are reviewed.

THE AHLFORS AND SARIO volume is described on the jacket as serving partly as an introduction to the theory of Riemann surfaces and partly to acquaint the reader with some recent problems and results. "The emphasis is on properties of open surfaces rather than on the more algebraic properties of closed surfaces."

THE 1959 *Summer Symposium Papers* cover capital budgeting and project justification, post auditing, estimation of working capital requirements for long-range planning, effects of taxes on investment decisions, and evaluating uncertainty.

PERIODICALS

Selected Contents

Naval Research Logistics Quarterly, December 1959

M. R. MICKEL, *A Method for Determining Supply Quantity for the Case of Poisson Distribution of Demand*

N. M. BLACHMAN, *Prolegomena to Optimum Discrete Search Procedures*

J. PFANZAGL, *A General Theory of Measurement Applications to Utility*

R. E. QUANDT, *On the Solution of Probabilistic Leontief Systems*

F. HARARY AND M. RICHARDSON, *A Matrix Algorithm for Solutions and r -Bases of a Finite Irreflexive Relation*

Author Index for Volumes 1-6

Subject Index for Volumes 1-6

Journal of Industrial Engineering, January-February 1960

CHARLES E. CLARK AND ALAN J. ROWE, *Inventory Policies and Related Numerical Approximations*

L. G. MITTEN, *On Obtaining Consistency in Application of Predetermined Time Systems*

Journal of Industrial Engineering, March–April 1960

D. G. MALCOLM, *Real-Time Management Control in a Large Scale Man-Machine System*

MELVIN R. WITMER, *Industrial Engineering and Mathematics at the Department Head Level*

HAROLD O. DAVIDSON, *The Management, Engineering, and Scientific Functions*

ALAN J. ROWE, *Toward a Theory of Scheduling*

AIEE Membership Roster

Recherche Opérationnelle, Volume 4, Number 1

F. D'ÉPENOUX, *Sur un problème de production et de stockage dans l'aléatoire*

R. FORTET, *Applications de l'algèbre de Boole en recherche opérationnelle*

G. PILÉ, *Étude fonctionnelle de certains processus de Markov homogènes*

Correspondance à propos de processus de Poisson en grappes

Cahiers du Centre d'Etudes de Recherche Opérationnelle, Volume 2, No. 1, 1960

PAUL CAMION, *Quelques propriétés des chemins et circuits hamiltoniens dans la théorie des graphes*

ANDRÉ DHONDT, *Sur une généralisation d'un théorème de R. Frisch en analyse de la confluence*

FRANÇOIS LAMBERT, *Programmes linéaires mixtes*

And Some Notes

RAOUL J. FREEMAN writes on "A Stochastic Model for Determining the Size and Allocation of the Research Budget" in *IRE Transactions on Engineering Management* for March 1960; the article is a discussion of the use of operations-research techniques in research and development management. He also has an article on "Basic Resources of Research" in the Spring 1960 issue of *Research Management*; it considers the basic inputs to the national research and development effort.

THE APRIL 1960 issue of the *N.A.A. Bulletin* has two articles of interest to operations-research workers. In "Reporting to Management—New Frontier for the 1960's," ARTHUR H. SMITH outlines what he considers the necessary requisites of management reports and how new tools such as computers, integrated data processing, operations research and analysis, and new accounting methodologies must be blended and employed to provide an effective and efficient system of communicating financial data to management. RICHARD L. YOUNG, in "Mathematics Confronts the Accountant with Opportunity," points out that the task of information accumulation, tabulating, and reporting is becoming increasingly mechanized. This mechanization is giving the accountant more opportunity for forecasting, controlling, analyzing, and similar judgment and decision-making processes. In order to be qualified to perform the above functions, the accountant must know what mathematical tools are available to him and must be capable of working with the mathematician in performing analytical work.

THE *Referativnyi Zhurnal-Matematika* is a Russian journal devoted to abstracts of mathematical articles published throughout the world. For some time it has included a section entitled "Theory of Games and Mathematical Economics." It is

interesting to note that beginning with the March 1959 issue the title of this section has been expanded to "Theory of Games, Operations Research, and Mathematical Economics." Some idea of the Soviet interests in operations research may be obtained by observing the articles by Russian and Russia-oriented authors reviewed in this section of the *Zhurnal*. The 1959 volume (less the December issue), and the first issue of 1960, contain abstracts of the following articles by authors in Russia and satellite countries, or translations from other sources. (Submitted by R. F. RINEHART.)

- "On the Stability of Solutions in the Transportation Problem of Linear Programming," ABRAHAM JAROMÍR, *Czech. Math. Zhurnal* (1958), in German with Russian summary
- "Approximation Methods for Nonlinear Programming," ABRAHAM JAROMÍR, *Časopis pro pěstování matematiky a fyziky* (1958), in Czech with Russian and English summaries
- Linear Programming (Method of Choice of Best Solution), S. A. DUMLER, *Tek.-Ékon. Byul. Cob. Nar. x-va Chelyab. Ékon.* (1958), in Russian with English summary
- "Linear Programming and its Application to Production," S. A. DUMLER, *Vestnik Mashinostroeniâ* (1958), in Russian
- "Solution of an Extremal Problem," G. SH. RUBINSHTEIN, AND K. UBRANIK, *Teoriia Veroiatnostei i eë Primeneniâ* (1957), in Russian; English summary
- "First Convention on the Application of Mathematics and Statistics to Economic Studies (Belgrade)," D. NIKOLICH, *Stat. Review* (1957)
- "On a Problem in Regulation of Prices," ANDRÁS BRÓDY, AND ALFRED RÀNÝI, *Magyar Tud. Akad. Mat. int. közl* (1956), in Hungarian; Russian and English summaries
- "General Problems Concerning the Extreme Point of the Intersection of an Axis with a Convex Polyhedron," G. SH. RUBINSHTEIN, *Doklady Akad. Nauk SSSR.* (1957), in Russian
- "On a Functional Space and Some Extremal Problems," L. V. KANTOROVICH AND G. SH. RUBINSHTEIN, *Doklady Akad. Nauk SSSR.* (1957), in Russian
- "Application of the Simplex Method to the Solution of Questions in Linear Programming," IRENEUSZ NYKOVSKI, *Przegl. Statyst.* (1958), in Polish; Russian and English summaries
- "Theory of Games and Statistical Decisions," D. BLACKWELL AND M. A. GERSCHICK (translator not mentioned), *Publication of Inst. Lit.*, in Russian
- "Equilibrium Situations in Bimatrix Games," N. N. VOROB'EV, *Teoriia Veroiatnostei i eë Primeneniâ* (1958), in Russian; English summary
- "Application of the Theory of Graphs to the Solution of the Transportation Problem," JOSEF BÍLÝ, MIROSLAV FIEDLER, AND FRANTIŠEK NOŽIČKA, *Czech. Mat. Zhurnal* (1958), in German; Russian summary
- "Linear Programming," Z. RUMIANTSEVA, *Grazhd. Aviatsiâ* (1958), in Russian

A WEEKLY review of scientific and technical articles appearing in the Soviet press and of significant new Russian books is now being published by the Office of Technical Services, Business and Defense Services Administration, U. S. Department of Commerce. Called *Current Review of the Soviet Technical Press* (Order No. 60-21441), the publication is sold on subscription by OTS at \$7 for six months (\$2 additional for foreign mailing).

Metrika 3, No. 1 (1960) includes the following articles of possible interest to operations-research workers. (Submitted by FRED HANSSMANN.)

J. PFANZAGL, *Tests and Confidence Intervals for Exponential Distributions and Their Application to Some Discrete Distributions* (in German)

K. ABT, *Analysis of Covariance and Analysis of Differences, Part One* (in French)

S. K. NASR, *A Note on a Noise Process* (in English)

S. S. ZARKOVIC, *On the Efficiency of Sampling with Varying Probabilities and the Selection of Units with Replacement* (in English)

R. HENN, *Markov Chains in Economic Processes* (in German)

R. IHM, *On the Numerical Integration of n -Dimensional Normal Distributions*

AND, *Unternehmensforschung*, Vol. 3 (1959), No. 3, has (all in German):

E. RUSCH, *Solution of a Special Linear Programming Problem, e.g., for Problems of Cost Comparison*

H. WINKEL, *The Dual Problem in Linear Programming*

W. HEYN, *Problems of Statistical Significance in Marketing Research*

NOEL M. MIRASOL, Case Institute of Technology, summarizes P. ZOROA's "Saddle Matrix in Rectangular Games," in *Trabajos de Estadística* X, No. 1, 1959, as follows: The saddle-matrix is defined as a generalization of the saddle-point for rectangular games. Let T_1 be the rectangular game whose matrix is the saddle-matrix and T the first considered rectangular game. Then one optimal strategy of the game, T_1 , may be obtained from every optimal strategy of the game T in the following way: We may write a zero for every row or column omitted in writing the saddle-matrix. So the saddle-matrix appears as a generalization of the relations of dominance between rows or columns of the initial matrix. Some other properties of the optimal strategies of the saddle-point are considered.

THE FOLLOWING notes were prepared by DEV P. BASU of Case Institute of Technology after reviewing the *Pakistan Council of Scientific and Industrial Research Report, 1953-1958*:

(a) Objectives of the Pakistan Council of Scientific and Industrial Research were "to initiate, promote and guide scientific and industrial research, primarily directed towards utilization of indigenous raw materials and development of industries based on such research." It is therefore to be assumed that this Council aims at fulfilling an important aspect of the government's planning function.

(b) One of the decisions taken by the authorities was in regard to the choice of the type of laboratories to be set up, whether they should be (i) regional and multi-purpose, or (ii) central laboratories dealing with specialized research in each field of activity. This could very well be an O.R. problem (notwithstanding the fact that government has decided to make the laboratories operate according to the first type) because of the large amount of capital, deployment and utilization of scientific talent, involved in such a national enterprise.

(c) Means of scientific communication resulting from research carried out in the laboratories could also form an O.R. problem with documentation and information retrieval, costs and effectiveness thereof, being important objectives.

(d) Research already carried out with significant results points toward existence of adequate potentials in utilization of indigenous resources, in a *converted* or in an

improved form. It would be interesting to evaluate such results by O.R. methods, using tools like linear and dynamic programming, how best such developmental costs could be minimized or how the use of such converted or improved resources could be maximized, relative to the country's present and future economic plans.

- (e) Items of significant potential use could be listed here:
- (i) Rauwolfia Serpentina and Caffra.
 - (ii) Beneficiation of iron and sulphur ores.
 - (iii) Shark liver oil extraction.
 - (iv) Manufacture of Fuller's Earth.
 - (v) Hardboard from bagasse and other agricultural wastes.
 - (vi) Utilization of jute, coconut, and some other herbal products for pharmaceuticals.
 - (vii) Fish and seafood development.

THESIS

***Dynamics of Single-Lane Vehicular Traffic Flow*, WALTER HELLY, Ph.D. in Physics, Massachusetts Institute of Technology, February 1960, 145 pages, Operations Research Center, M.I.T. (available on loan)**

IN THE LAST few years there have been several attempts to synthesize dynamical models of automobile traffic flow. There have been two lines of endeavor. In the first, the flow of vehicles is viewed macroscopically by analogy to the behavior of compressible fluids. The present thesis is largely devoted to the second, in which individual vehicles are represented by experimentally justified equations of motion. Prior work by L. PIPES, R. HERMAN, *et al.*, has been largely confined to equations of motion simple enough to be at least partially susceptible to analytic solution. By recourse to computer simulation in the present thesis, it has been possible to include additional factors such as driver errors in observation, limitations to vehicle performance, and nonuniform environments. As a result, new insight is gained on the formation and alleviation of bottlenecks.

Traffic is studied for environments where passing cannot occur and where vehicles neither enter nor leave the traffic stream. Using a 'follow-the-leader' philosophy for the individual driver, a computer simulation model is constructed and its parameters are fitted to experimental data. The model consists of a reaction-time-lagged system of differential equations in which the acceleration of each driver is a function of his headway, his velocity difference from the car ahead of him, and other pertinent factors. In particular, provision is made for driver error in estimating headways and velocities. Model behavior and stability are studied for various parameter values. When suitable values are used, the model presents a realistic traffic picture with most features paralleling closely its real life counterpart.

Since vehicles cluster into compact platoons when they cannot pass each other, the platooning mechanism is studied both theoretically and via computer simulation.

The model is applied to the study of vehicular tunnel bottlenecks. It is found that there are two basic types of bottleneck, differentiated by the behavior in each of an isolated compact platoon of vehicles. In a bottleneck of the first kind, the average time headway of the n th vehicle in such a platoon is independent of n

(n is counted backwards from the platoon leader). In a bottleneck of the second kind, the average time headway increases with n . Under certain specified conditions, a bottleneck of the second kind can handle an increased traffic flow, as compared to the steady-state value, if the vehicles are deliberately platooned by the introduction of substantial car-free gaps at the tunnel entrance. A theoretical model of a bottleneck of the second kind is developed in the form of a Markov process.

The effect on flow of atypical drivers may be simulated, and is illustrated with the simulation of drunken drivers to show how rear-end collision rates rise with the fraction of such drivers in the stream.

Because they are wide, trucks tend to inhibit flow in traffic lanes adjacent to themselves. A theoretical study is performed to determine how trucks should be distributed in two adjacent lanes to minimize this friction effect and thus to maximize flow. It is found that the optimum solution depends sharply on the actual quantitative interaction between lanes.