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OPERATIONS RESEARCH - FUTURE PERSPECTIVES

by

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ABSTRACT

Many of the current exciting developments in operations research (OR) will have a major impact on its future. Advances in computer technology and the resulting creation of opportunities for making these technologies available to decision-makers are playing a major role in current OR practice and will continue to do so in the future. Some of these new developments and their potential for operations researchers are discussed in this paper. Emphasis is placed on both mathematical and non-mathematical issues, and future challenges are highlighted.

KEYWORDS: Behavioural, Decision-Making Process, Interdisciplinarity, Artificial Intelligence, Expert Systems, Decision Support Systems.

1. Introduduction

Almost a decade ago, during the late seventies, a sense of gloom and pessimism prevailed within the international operations research (OR) community. Many articles, talks and even entire sessions at conferences were devoted to assessing the state of OR and especially its future. "The future of OR is dead", concluded Ackoff (1979a). He did, however, see some hope in resurrecting this future if there were a change in the OR methodology used at that stage (Ackoff (1979b)). Ackoff believed this could be achieved by imbedding problem solving in planning, involving management in this process and thereby creating an environment in which researchers would have access to all levels in an organization. Furthermore, the interdisciplinary concept of OR and the principle of participation had to be reintroduced into the practice of OR. Many others shared these bleak views about OR and its potential usefulness to organizations, decision-makers and managers.

The feeling of despondency was also due to feelings that OR was stagnating, that it was not making the impact that OR people had hoped for and that many OR projects failed because the solutions that were obtained were solutions to the wrong problems! Decision-makers did not recognize or appreciate the value of OR in the decision-making process and in helping to solve problems. There were even suggestions that the name operations research should be changed to something more descriptive and understandable!

Today, one can state without contradiction that OR is alive and actually doing fairly well. This is partly due to the fact that OR has managed to evolve fast enough to use new computer technologies to its advantage. Although the growth in the OR community has levelled off, people in other disciplines are using OR techniques and methodologies on a regular basis, and a steady flow of new OR and OR-related journals are being published each year. Theoretical developments in the field are proliferating, and no individual can keep up with all these developments. The number and nature of real-world problems that are being tackled and solved by means of the OR approach are substantial although it is true that, in some instances, the successful implementation of these solutions is questionable. The future of OR therefore looks promising.

For this future to be realized there are many and diverse aspects and issues that are of importance to the practice of OR. Because of this diversity it is difficult to give this paper a single theme, which is thus, in a sense, multiple in nature. New developments that can have a great impact on the way in which OR is practised and that can enhance the capabilities of operations researchers are discussed. On the other hand the importance of a number of aspects that have possibly been neglected in the past, such as knowledge and understanding of human behaviour and decision-making styles of managers, are re-emphasized. Operations research is a multi-faceted and expanding discipline. Every one of these facets, namely techniques, algorithms, processes, etc., is important, be it one that has been around for many years or a new one in the process of being established. Ignoring any one of these could result in failure to make OR relevant to the decision-making of the modern managers and decision-makers.

The purpose of this paper is therefore to highlight new developments in operations research and to pin-point future challenges. The paper provides an overview of the nature of OR and discusses development trends in the technology of problem solving, as relevant to OR. The origins of OR, the classical perception of the nature of OR and the way in which OR has developed since World War II are discussed. Issues that may have an impact on future developmental trends are discussed against this background. These factors include behavioural and decision-making issues, interdisciplinarity, decision support systems, artificial intelligence and expert systems, and developments in OR theory and practice.

2. OR - The Beginnings

The term operational research was first used in Britain in 1938 during the development and testing of the new air defence system based on radar (Larnder (1984)). During practical exercises, the technical feasibility of these systems was amply demonstrated, but the operational use thereof was far from adequate. It was felt that *research* was needed into the *operational* use of the radar systems. For example, how could the radar interception system be used to maximum advantage; how should the antennas be distributed, the signals organized, and so on (Levinson and Brown (1951))? Thus, unlike previous applications to and uses of science in warfare, which were mainly focused on the development of weapons, operational research (or operations research) was concerned with the *use* of weapons.

Other applications include the famous campaign against the German U-boats, the devising of search strategies and patterns, determining the operational readiness of aircraft, etc. By then the role of the operations researcher was already established. To quote Lardner (1984):

> "To the scientist - trained in the scientific approach and with the abilities to observe, to reason from observation, to practise with strict scientific integrity, and to relate cause to effect - fell the role of elucidating the facts of a situation and of offering advice. To the serving officer - with his specialized training in leadership and command - fell the role of management and decision making."

The beginnings of OR are described in more detail in, inter alia, Lardner (1984), Levinson and Brown (1951), Morse (1986) and Waddington (1973).

After the war, many OR workers went into industry; this resulted in industrial OR. Before long there were as many operations researchers in academic, government and industrial organizations as in the military.

3. The Nature of OR

There are many definitions of OR, each having many arguments for and against its use. The following definition provides a useful basis for understanding the nature of OR:

Operations research is the application of a scientific approach to solving management decision-making problems in the planning and direction of organizations. It is a formalized process to identify and exploit structures with the purpose of assisting management to determine policies and actions scientifically.

This OR approach is traditionally characterized by:

(i) use of the scientific process;

(ii) aiding decision-making (this does not imply that OR's only role is to assist in solving decision-making problems, but it does include providing insight and creating understanding - "The purpose of Mathematical Programming is insight, not numbers" (Geoffrion (1976));

(iii) interdisciplinarity; and

(iv) the systems approach to decision-making.

The scientific process or methodology of OR is normally considered as a general procedure that should be followed by an operations researcher who has been confronted with an apparent problem. The steps of this process can be summarized as follows (Hildebrandt (1981)):

(i) observing reality and formulating the problem;

(ii) constructing the model;

(iii) testing the model;

(iv) deriving a solution and testing it;

(v) implementing and maintaining the solution.

Modelling therefore forms an integral part of this process. Modelling, however, need not always be of a quantitative or mathematical nature - in many situations various types of cognitive maps or influence diagrams would clearly be more appropriate. The above steps summarize what has generally been considered as being the nature of OR.

4. Some Development Trends since World War II

During the immediate post-war years, OR was considered to be an optimizing science (Kitchener (1986)), with the emphasis on producing optimal solutions to problems. The 60's and 70's were characterized by a shift towards the generation of good solutions that were meaningful, realistic and practical - "satisficing rather than optimizing". Within the last decade there has been an increased effort to tackle and solve more complex and "fuzzy" problems. Developments such as goal programming, multiple criteria decision-making and fuzzy set theory are examples of the theory backing these latest trends. At the same time, the tremendous technological advances and developments in the computer industry have stimulated the use of computers to support and assist decision-making at all levels of management.

Within the OR community one finds two main types of operations researchers. On the one hand, there are those who see operations research as a subset of mathematics and who are fascinated and attracted by the mathematical elegance of model formulations and feel challenged by, for example, the efficiency of algorithms. On the other hand, there are those more practically orientated people who tend to think in terms of decision processes, who love the messes of reality (Ackoff (1973)) and who are challenged by real problem situations requiring decisions. Muller-Merbach (1985) refers to supporters of *Technical Operations Research* and *Social Operations Research*. These two types of operations researchers operate more or less in isolation. The phenomenon has long been recognized, and some efforts are underway to make the work of especially the technical operations researchers in some way more applicable and available to the rest of the OR community.

5. Future Perspectives

Currently, there are many exciting developments in the OR field that will have a major impact on the future of OR. Most of these are aimed at narrowing or bridging the gap between operations research and the human decision-making process. Advances in computer technology and the resulting creation of opportunities for making these technologies available to decision-makers play a major role in current OR practice and will continue to do so in the future. The purpose of this section is to highlight some of these new developments and their potential. Non-technical issues, which are as important as the technicalities of OR and are gaining in importance as the gap between OR and decision-makers is closing, are also emphasized.

5.1 *Behavioural issues*

Today, operations researchers still assist managers in their decision-making. These managers have their own concepts, understanding and images of their organizational environment, etc., which in turn reflect the knowledge of the manager, his psyche and values (Boulding (1956)). To be successful it is crucial for the operations researcher to know and understand the behavioural patterns and styles of managers - "Psychology is the key to successful OR" (title of a report by France (1971)). In assisting decision-makers the operations researchers is in fact intervening or penetrating into the cognitive style of the individual, and therefore it is important to understand the psyche of people. If we don't know how the mind of a decision-maker works, how can we help him make decisions? It is also important to realize that the cognitive styles of managers and analysts differ. Behavioural issues and their influences on decision-making of which the operations researcher should be aware are given by Gibson (1982). The personality of a decision-maker is a factor that cannot be ignored. This is one of the many psychological forces, conscious and unconscious, influencing the decision-maker. Some of the important personality components are:

(i) values - these are guidelines that a decision-maker uses when confronted with a given situation;

(ii) propensity to risk - decision-makers vary greatly in their propensity to take risks;

(iii) potential for dissonance - post-decision anxiety of the decision-maker.

The need for psychological expertise in operations research has been grossly neglected and needs more attention.

Results by two eminent psychologists, Kahneman and Tversky, who have studied the psychology of uncertainty (McKean, 1985 and Kahneman, Slovic and Tversky (1982)) are challenging the fundamental reliability of human reason. This work and the aspects that are highlighted are illustrated by the following two situation examples.

Situation I: "Threatened by a superior enemy force, the general faces a dilemma. His intelligence officers say his soldiers will be caught in an ambush in which 600 of them will die unless he leads them to safety by one of two available routes. If he takes the first route, 200 soldiers will be saved. If he takes the second, there's a one-third chance that 600 soldiers will be saved and a two-thirds chance that none will be saved. Which route should he take?"

Kahneman and Tversky found that most people urge the general to take the first route, arguing that it is better to save those that can be saved than to gamble when the odds favour even higher losses. In Situation II where the general faces the same basic dilemma, the problem is stated as follows:

Situation II: "The general again has to choose between two escape routes. But this time his aides tell him that if he takes the first, 400 soldiers will die. If he takes the second, there's a one-third chance that no soldiers will die, and a two-thirds chance that 600 soldiers will die. Which route should he take?"

Now people urge the general to take the second route. In this situation, route one involves the certain death of 400 men. With the second route there is a one-third chance that nobody will be killed and a two-third's chance that the casualties will be 50 per cent higher than for route one.

If one studies these two situations closely, it turns out they are identical, the only difference being that situation I is stated in terms of lives saved, whereas situation II is stated in terms of lives lost. Even when people realized the contradiction, some still gave conflicting answers.

The surprising and unsettling aspect of this work is not so much that people are often irrational, but that even when people try to be logical, they give *radically* different answers to the same problem when it is posed in a slightly different way. To any operations researcher these findings are very relevant and of utmost importance. In helping decision-makers formulate and/or solve their problems the operations researcher must pose many questions. From the above it is clear that not only should great care be taken in phrasing questions, but also that the answers and judgements given by decision-makers will not necessarily be rational and logical.

There are encouraging indications that the knowledge gained in the work done - mainly by psychologists - on the way in which people actually make decisions is beginning to be assimilated into OR practice and theory [McKean (1985)].

5.2 *The decision-making process*

Traditionally, the basic steps in the decision-making process are:

1. Clearly state the purpose of the decision;
2. establish the different decision criteria;
3. separate or differentiate between these criteria;
4. generate the different alternative solutions;
5. compare these alternatives;
6. identify the risks involved in each of the alternatives;
7. assess the risks; and
8. finally, make the decision.

There is some overlap between these steps and the scientific process described in Section 3. What is, however, important is the involvement of the operations researcher in this decision-making process. There is no doubt that the operations researcher has a role and function to fulfil in all these steps. Each step is important, and therefore there should be a balance between the modelling function - that is the formulation, generation and comparison of alternatives - and the fuzzier aspects of decision-making.

Operations researchers should, however, not have any illusions - real-life decision-making does not always follow these steps or allow for them to be followed. Intuition, experience, "gut feel", time limitations, etc. all have an effect on this process. What is the operations researcher's role in such situations? Do we as operations researchers really know how to function and operate most effectively under such circumstances? Are our logical and rational way of thinking, scientific frame of mind and objectivity more than sufficient for these situations or need we fulfil another role? This is one of the many challenges to the operations researcher to be able to perform effectively and efficiently under all circumstances.

The soft system methodology proposed by Checkland (1981 and 1985) makes great strides towards getting to grips with decision-making and problem solving. The traditional OR methodology, which is referred to as the "hard systems thinking" approach, is based upon and oriented towards optimization or goal seeking. In this case the assumption is made that problems can be formulated, with an objective, in such a way that a choice can be made between alternatives. This is the distinguishing characteristic of the "hard systems thinking" approach. A soft system, on the other hand, is typified as an ill-structured or unstructured *problem situation* in which there are perceived to be problems. The whole soft system methodology is geared towards finding out, learning and understanding the problem situation. Having gone through this process, one can take appropriate actions or steps to improve the situation. In these problem situations there are no such things as "right" or optimized answers. There is not necessarily a final answer or solution, and, in fact, the process of enquiry, learning and action taking may be never ending. What is of importance is that by obtaining increasingly more insight into the problem situation, one is able to do something to assist managers in their decision-making and problem solving.

Supporting decision-making is essentially a problem of coping appropriately with the complexity of a decision problem. In this process there are factors "external" to the actual decision problem that should also receive attention. These are very often ignored or overlooked by the operations researcher and could cause implementation failure or complete failure of a project. The importance of internal organizational politics, and of the personalities that are involved with and might be affected by any decisions taken should never be neglected in a project. It is essential that the people who will be affected by a decision should be kept informed of developments on a regular basis. Furthermore, no result should come as a surprise to people. Therefore, an environment should be created in which it appears to people (the clients) that the operations researcher has helped them discover what they really knew to be the answer. The role of OR is thus that of a helpful catalyst.

In an organization, it is often unclear when and where a crucial decision is prepared and who the decision-makers are (Fortuin and Lootsma (1984)). Before a problem is addressed, this should be clarified. The "things that must go right" for an organization to flourish can be determined by, for example, the critical success factor approach (Rockart (1979)). In this way one can determine who the real decision-makers are and what information they need to allow them to make "good" decisions. It is, however, possibly more important first to determine the *critical failing factors* in an organization - these are "things that always go wrong". Detecting and eliminating them may be just as important as determining the critical success factors.

5.3 *Interdisciplinarity*

Interdisciplinarity was, in the early days, both the cornerstone of the discipline and the means of integrating the contributions and know-how of different disciplines. This important aspect of the OR approach has gradually disappeared, and the challenge to OR is to revitalize this facet. Experts from different disciplines can in this way think and work together and cross-fertilize each other's ideas. The operations researcher should be a generalist (Muller-Merbach (1984)), drawing his knowledge and understanding of the world and problem areas (messes of reality!) from a variety of disciplines. But this does not make him an expert on all of these disciplines! The challenge to the operations researcher is to be the manager of OR projects. By having interdisciplinary teams working on problems, the operations researcher can provide the coordination and integration of the different views and approaches to reach synergy in solving problems.

5.4 *Artificial intelligence and expert systems*

Rapid developments have recently taken place, with limited success, in the application of artificial intelligence (AI) in constructing expert systems. Expert systems, like decision support systems, aim at improving decision-making. An expert system is a knowledge base that can act as an "expert". As such, expert systems are nothing more than another way of modelling the knowledge of an expert, organizing the data in a knowledge base and using this base for reasoned deduction. The software architecture of an expert system thus contains these two parts, namely the knowledge base, which is the procedural part of the system, and the inference machine for controlling the programs within the system, with the main tasks of operating on the knowledge base and applying the laws of logical inference to make further deductions. A third important part is the user interface.

To the operations researcher, the expert system concept is another tool in his tool kit, and therefore it is important for him to be aware of developments in this field.

Nilsson (1982) listed nine elements of AI, four of which are given below:

(i) search, especially heuristic search, typically decision trees;

(ii) modelling and representation of knowledge;

(iii) common-sense reasoning and logic; and

(iv) problem solving and planning.

From these elements it is obvious that OR can provide a major contribution towards technical aspects in the development of expert systems. Other important technical aspects related to expert systems include subjective probability, Bayesian statistics and "fuzzy logic". Furthermore, these systems provide for manipulating the expert "rules of thumb", using these to give explanations in the same terms as humans.

Expert systems are very topical, which may create unreasonably high expectations for these systems. They are, however, still subject to problems and limitations such as:

(i) the area of knowledge that one system can handle is small and specialized; and

(ii) they require a significant software development effort, which has cost, time and manpower implications, although expert shells may ameliorate these problems.

Starfield and Louw (1986) propagate the concept of small expert systems or knowledge-based consultation systems and how these can be useful to scientists. They are, however, only concerned with "unintelligent knowledge-bases" and admit that "what we describe is remote from the general area of artificial intelligence and purists will (with justification) castigate us for ever using the words expert systems".

Real-time operating expert systems are not yet generally available, and it may still take some time before they are. A recent report on expert systems, *Expert Systems 1986*, describes 14 United Kingdom organizations that are engaged in over 100 expert system projects, of which none could report a fully operational system (Meiklejohn (1986)). The same applies to the United States. Hewett and Sasson (1986) present profiles on 14 leading users of expert system technology, engaged in over 100 expert system projects, not one being fully operational when their report was written. This paradox is explained by the fact that developing a prototype is relatively straightforward, whereas moving to a production version is not.

5.5 *Decision support systems*

Decision support systems or interactive computer systems have created opportunities for OR really to *support* decision-making. These opportunities have not been fully realized. Too many decision support systems are of the spreadsheet or financial planning type system. These systems need to include more modelling, based on analytic techniques aimed at enhancing judgement and guiding decision-making. Decision support systems of the future should aim at supporting what Sprague (1986) calls Type II activities. A comparison of Type I and Type II activities is given in Table 1.

Table 1 - Types of information worker activities

Type I activities	Type II activities
- High volume of transactions	- Fewer transactions
- Low cost of transaction	- Each transaction is costly or valuable
- Well-structured procedures	- Unstructured, process-independent
- Output measures defined	- Not easily measured
- Focus on performing process quickly, efficiently and frequently	- Can only specify desired outcome
- Handle data	- Handle concepts

Included in typical Type II functions are problem solving, analysis and design, all tasks that can be supported by models developed by operations researchers. Decision support systems of the future will move away from the traditional "what-if" type of support to more extended support. Developers of these systems will have to find ways of enhancing the systems to increase their capabilities and contributions to problem solving by managers. Guidance, through decision support systems, in the decision-making process and even making suggestions are aims for the future that would make such systems semi-expert systems.

In today's rapidly changing world, particularly regarding knowledge and technology, problem solving has become a complex task. To keep ahead of competitors, managers and decision-makers have to be more creative, more innovative and more attentive to relationships. Decision support systems provide a wonderful opportunity and challenge to operations researchers to stimulate creativity in the problem-solving process. Imaginative support systems, which would create an environment or atmosphere in which decision-makers can ask fundamental and searching questions, are needed to fully utilize, expose, stimulate and facilitate the vast potential towards creativity and innovation residing in decision-makers. The ideal would therefore be to develop systems that would support the process of inquiry and this then would "enable him (the decision-maker) to select courses of action or produce outcomes that he would not otherwise select or produce, and are more efficient or valuable to him than any he would otherwise have chosen" (Ackoff and Vergara (1981)).

Another challenge lies in the area of group decision support systems (DeSanctis and Gallupe (1985)) as in many big organizations decisions are made by groups of people. Group decision support systems aim at supporting these people, in particular, those at strategic or executive level. Group decisions can also apply to committees, review panels, task teams, work groups, board meetings, etc. Four types of group support systems have been identified within the framework of the duration of the decision-making session and the location of the group members. The first is the decision room (Gray (1981)) or the executive board room, which is furnished with special facilities, mostly electronic, to support decision-making. The second is a "local decision network" where the group members are in close proximity and which is operated from a workstation in their individual offices and linked via a network to all the other group participants. In the third system, the group members are not in a single location and teleconferencing technology is used for communicating - that is, communication is between remote "decision stations" in a geographically dispersed organization. Here the group has to make decisions on a regular basis. Many aspects concerning decision-making, specifically in group decision support systems, are of direct interest to operations research. Some of these are management models to be used by executives and boards of directors, voting procedures, consensus forming, conflict handling, weighting procedures for decision alternatives, etc. OR can undoubtedly make major contributions to group decision support systems.

5.6 *Methodological development*

It is beyond any person's capabilities to indicate future trends in all theoretical areas. Many developments have already taken place and will no doubt continue in the future. One can distinguish between developments in two "separate" methodological areas namely the soft theory (represented by, for example, the works of Checkland (1981) and (1985), and Wilson (1984)) and the mathematical (hard) theory.

The soft theory deals mainly with how OR should operate, that is, the OR process. OR's main concern is with the activity of problem solving or "the rational intervention in human affairs" (Checkland (1985)). This process first tries to determine what the problems are and then, through some analysis, establishes what can be done to alleviate these problems. The problems facing organizations in today's rapidly changing world are becoming enormously complex and a major key to solving these problems is a proper diagnosis and analysis of these problems and situations. The soft theory is concerned with how this analysis can be undertaken. Potentially, trends and developments taking place in the soft theory are of great significance and could have a major impact on the future of OR.

The hard theory is becoming very sophisticated and mathematically complex. Work that was hailed as a breakthrough, for example the work by Khachiyan and Karmarkar, still needs to prove its practical value. On the other hand, great strides have been made, for example, in developing efficient computer codes for solving network-type problems.

However, the most striking area of development for the future is the area of conflicting objectives. Before the advent of multi-criteria analysis, most decision problems took the form of optimizing an objective or a utility function. Although this resulted in well-defined mathematical problems, this was not always representative of reality. Many decision problems are hard to solve because there are many decision-makers involved, each with his own criteria. The objective of multi-criteria decision-making is to overcome these problems and to incorporate several points of view.

During the past ten years many methods based on statistics, optimization, game theory, group decision making, etc. have been developed to solve multi-criteria problems. These have offered new perspectives in identifying different points of view and in solving conflicts. Other decision techniques, such as subjective probabilities and fuzzy set theory, which are more adaptable to problem structures and better suited to model human evaluation and decision making processes, have been developed.

What is the challenge for the future? Multi-criteria problems are at the core of decision support. These methods and techniques must be adapted and modified to be used increasingly in interactive computer models and systems. One example of such a system is Expert Choice, which incorporates the analytic hierarchy process of Saaty (1980). This is not the only usable technique and one not applicable to all multi-criteria problems. Keen (1986) suggests that if attention is given to these issues - that is, incorporating multi-criteria methods into decision support systems - they will restore the flavour of operations research/management science to decision support.

5.7 *OR practice*

OR has had an impact on a wide variety of problems in many different fields for example in health, manufacturing, transportation, energy, defence, telecommunications, natural resources, etc. The problems that the operations researcher deals with all occur in special circumstances and thus need "special" solutions, that is, methods, techniques and standard solutions need to be adapted. What are the best ways of achieving solutions that the customer or client can really use? How should results be presented? These are challenges for the future (Checkland (1981) and Wilson (1984)).

Modern technology has created many new challenges and opportunities to OR. In industry, for example, through automation, communication networks and management information systems, it is possible for management to control the flow of raw materials, the work in progress and finished products at any place and at any time. One would thus expect lower inventories, faster throughput and higher flexibility. This can only be achieved by being more efficient and effective, which the operations researcher can provide.

If one looks at the South African situation, there are many areas where OR is very necessary and important, but where it has had little or no impact. What has been achieved in urban and regional planning, transport services, health care, etc.? Many people are developing "models" for a new South Africa, but there are few contributions by the real model builders, that is the operations researchers. We *can* play an important role in these areas, but are we prepared and willing to venture into these unknown areas?

6. Conclusions

The scope of operations research is continually broadening. The mathematical theory of OR is highly developed, with techniques being very sophisticated in many instances, possibly too much so for practical use. Practical OR has advanced from being confined to production and inventory problems to, inter alia, marketing and distribution, long-term, strategic and corporate planning, finance, manpower planning, investment analysis, purchasing, productivity analysis, and many other areas. In essence, OR is aimed at problem solving, and therefore future theoretical developments should be aimed more at practical usefulness. The two broad OR interest groups are dependent on each other, and this must be emphasized in future.

The operations researcher of today must indeed be knowledgeable about statistics, accounting, economics, computer science, systems analysis, behaviour science, politics and applied mathematics (Evans (1985)). This does, however, not imply that he should be an expert in each of these fields. Experts in these disciplines should be called in to establish the interdisciplinary concepts of OR afresh.

Developments in computer technology can cause OR people to become engrossed in these fascinating and exciting new technologies. Our aim still remains to solve problems, particularly real-world problems, and this is the challenge facing all operations researchers.

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