MAN-MACHINE COOPERATION ON PLANNING AND CONTROL PROBLEMS*

by

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Introduction

My proposition is a simple one, namely, that new information technology has created unparalleled opportunities for more effective planning, both long and short range. By more effective plans, I mean plans which achieve greater utility in theory, plans based on more detailed and hence valid models, and plans carried more faithfully into execution and which, as a consequence, achieve higher utility in practice. Information technology as used here includes most prominently: high-speed digital computers; the so-called "time-sharing" systems such as that realized at M.I.T.'s Project MAC; "on-line, real-time" computer systems in general; operations research; and our body of understanding of decision processes including heuristic programming, and what little we know about closely coupled man-machine decision making.

As a point of departure, I will assume that the role of the formal, explicit model in planning is granted as useful. The employment in planning of thoroughly explicit modeling techniques such as linear programming and simulation is clearly on the increase as attested to by the papers given here. I shall assume, furthermore, that the planning process is such that it is indistinguishable in the abstract from the variety of other problem solving activities such as theorem proving and chess playing which Simon denotes as "nonprogrammed."[1] That is, one would expect to find planning characterized by criteria problems, combinatorial solution spaces, iteration and reiteration of search procedures and a look of perplexity on the faces of the practitioners.

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[1]Herbert A. Simon, The New Science of Management Decision, (New York: Harper and Bros., 1960), 5.

This identification of planning with unstructured problems will permit the use of the Newell-Shaw-Simon model of problem solving as captured in their computer program, the "General Problem Solver."[2]

In order to argue this proposition, I will consider the incremental application of information technology to planning. First will be considered briefly the value of applying computers in the conventional "batch processing" mode to planning; next, the potential additional efficacy of close man-machine cooperation will be examined; and, finally the integration within a single on-line, real-time system of both planning and control will be evaluated. Excepting the first increment, for which current experience has provided generous empirical evidence, the values to be cited have been rigorously demonstrated neither in the laboratory nor in the field. The following are hypotheses, hopefully defended at the speculative level, but yet to be tested empirically.

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[2] Allen Newell, J. C. Shaw, and Herbert Simon, "A General Problem Solving Program for a Computer," Computers and Automation, (VIII, July, 1959), 10-17.

Planning and Conventional Computers

The questions is: Given formal planning models, what is to be gained from using a computer in the process? Some answers are practically self-evident while others may be considered more subtle or controversial.

One of the more obvious answers is this. If planning consists of a search through a set of alternative plans for one which is superior, then the sheer computational power of the computer permits many more alternatives to be considered. In the highly artificial case in which alternatives may be considered points in a well-behaved space and utility measured as a scalar, a well-known theorem of statistics assures us that the expectation of the maximum value of a sample increases monotonically with sample size. In any event, the burden of eliminating all but a few alternatives thought to be most promising can be reduced.

This argument assumes, however, that one would employ the same model within the computer as without, and this is naive. It is precisely the ability to cope with detail that is the great advantage of computer over mere man. What this suggests is that, for the most part, the computer's power should be used in employing more detailed and, it follows, potentially more valid models of the firm or organization and its environment.

But what value is there in such detail: is validity *per se* the coin of the realm? To answer this consider a few of the deficiencies of conventional planning methods.[3] It is the planner's inability to process detailed data that

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[3] I draw heavily in this section on my colleague J. C. Emery, "The Planning Process and Its Formalization in Computer Models," paper presented at the Second Congress on the Information System Sciences, 22-25 November, 1964, to be published in the Proceedings thereof this year by Spartan Books, Inc.

leads him to aggregate goals and data which, in turn, forces him to ignore detailed organizational interdependencies or constraints.[4] The penalties for this often arise in the form of buffers such as inventories which permit the "decoupling" of subunits. If detailed constraints are overlooked moreover, the plan may not be carried out simply because it is infeasible. In many cases, in order to alleviate the aggregate-detail conflict, the plan is gradually refined to consistency with detailed reality through an "iterative dialogue" between subunits and planners, which process is at best time-consuming, costly, and imperfect.

One of the more dramatic examples of the value of detail in planning is that of the Polaris submarine-launched missile system. It was in this project that PERT was first used for detailed planning and control of a vast set of interrelated activities, and PERT is "widely credited with helping to shorten by two years the time originally estimated for ... the engineering and development program ..."[5]

Another device often invoked by planners who are overwhelmed by complexity is to constrain the inputs or outcomes in order to limit the search for a satisfactory plan. Thus, the outage frequency of major inventory items may be constrained instead of being allowed to vary over its full range. But experience with linear programming suggests that constraints which truly limit the solution space carry an economic penalty, a "shadow price."

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[4]This is not to preclude purposeful aggregation, e.g., noise filtering or application of the Law of Large Numbers.

[5]F. K. Levy, G. L. Thompson, and J. D. Wiest, "The ABCs of the Critical Path Method," Harvard Business Review, (XLI, October, 1963), 100-101. The success of the Polaris program has been argued as justification of nearly everything which went into it, it should be noted.

Further, it should not be necessary to elaborate on the general problems of local suboptimization, as noted by Hitch among others, in carrying an aggregate plan down the organizational hierarchy to execution in detail.[6]

There are some additional advantages in bringing the computer's large memory and computational power to the planning process. Planners, even those who use formal models, are apt to employ a grand and universally invalid assumption: they assume that the real world is static. Yet Forrester has argued that the dynamic interaction of decisions, information distortion and delays can lead to unstable, uneconomic behavior in organizations.[7] Indeed, Roberts, in assessing the problems of research and development management states:

> "... the total results of research and development projects are created by a complex dynamic system of activities which interrelates the characteristics of the product, the customer, and the R and D firm; [planning and] control systems which ignore vital aspects [of this system] cannot succeed ..."[8]

The modeling of dynamic non-linear systems requires a computer, needless to say.

The foregoing has dealt mostly with questions of model validity; there is an unrelated but no less valuable characteristic of computer models vis a vis those in a planner's head, this being immortality. Computer programs, once created, are permanent entities. They do not die or seek other employment.

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[6] Charles Hitch, "Sub-Optimization in Operations Problems," Journal of Operations Research Society (I, May 1953), 87-99.

[7] Jay W. Forrester, Industrial Dynamics, (Cambridge, Mass.: M.I.T. Press, 1961).

[8] E. B. Roberts, "Industrial Dynamics and the Design of Management Control Systems," Management Technology, (III, December, 1963), 108.

In extolling these virtues deriving from computer usage, no attempt has been made to exhaust the list.[9] The mere fact that computers are finding wide-spread use in planning may be evidence enough of value.

[9] For a more comprehensive coverage, the reader is directed to J. C. Emery, "Organizational Planning and Control," unpublished Ph.D. Dissertation, Sloan School of Management, M.I.T., 1965.

Closely Coupled Man-Machine Planning

In conventional man-computer relationships the coupling has not been close for perfectly sound economic reasons. As described by Licklider,

> "... the only way to ensure using the computer's time efficiently was to adopt the strategy of the employment interviewer--to keep the reception room full of work waiting to be done and to be cavalier about how long it had to wait"[10]

In other words, the expense of computer time has necessitated queuing the human problem solvers (or their problems) in order to guarantee high utilization of the computer.[11] Licklider notes that this has resulted in the hueristic aspects of problem solving, that is,

> "... the setting of goals, the generation of hypotheses, the selection of criteria--the problem solving phases in which one has to lay down the guidelines, choose approaches, follow intuition, exercise judgment or make an evaluation..."

being almost wholly separated from the algorithmic aspects, that is, the computer's computational treatment of the problem presented to it.[12]

Recent advances in computer technology have made the "reception room" approach no longer necessary. In particular, "time-sharing," a hardware-software system in which the services of the computer are rapidly commutated among many independent, active users at remote input-output consoles for

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[10] J. C. R. Licklider, "Man-Computer Partnership," International Science and Technology, (May, 1965), 20.

[11] Also the economics of specialization (or long set-up times on media converters, e.g., card-to-tape) argue for "batching" similar requests.

[12] Licklider, op. cit., 19.

short bursts ("quanta") of time, provides both for close contact between user and computer and for high utilization.[13] Since the probability is high that some subset of the users will require computational service during a given circuit of the commutator, the fact that the complementary subset of users may be lost in thought or otherwise engaged in "heuristic" activities will not result in idle capacity. In fact, the idea of maintaining a backlog of low priority "background" programs to be run only in otherwise idle time guarantees high utilization. Of course, time-sharing is not accomplished without cost. There is loss of effective memory capacity to the supervisory programs, there is necessity for "swapping" programs in and out of high speed memory, and other "overhead" costs. Also, no one user is obtaining the full power of the computer, rather, he obtains some fraction based on the number of active users and the fraction of time that each user requires computing service.[14]

Time-sharing systems are no longer wild academic dreams: in addition to two operating systems at M.I.T., there are about a dozen others either operating or in advanced stages of development in the United States.

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[13]For a more complete discussion, see, E. L. Glaser and F. J. Corbato, "An Introduction to Time-Sharing," Datamation, (X, November, 1964), 24-27. The original thinking and design is credited to Corbato and J. McCarthy, "Time-Sharing Computer Systems," in M. Greenberger, ed., Management and the Computer of the Future, (Cambridge, Mass.: M.I.T. Press, 1962), 221-236.

[14]The current MAC System and its twin in operation at the M.I.T. Computation Center provide for up to thirty simultaneous users. For details see, R. M. Fano (Director of Project MAC), "The MAC System: A Progress Report," in M. A. Sass and W. D. Wilkinson, eds., Computer Augmentation of Human Reasoning, (Washington: Spartan Books, London: Macmillan, 1965), 131-150.

To return to the main discussion, time-sharing permits the close coupling of the human problem solver with the computer. The question is: What is the value? Referring again to Licklider, we find:

> "Because of the forced separation of heuristic from algorithmic aspects, conventional digital computing is limited in application to those problem areas in which such separation can be made ... essentially the domains in which the problems have already been solved ... The vast majority of the problems of the frontier--of the unsolved problems that scientists, engineers, managers, administrators and commanders are going to solve in the comming years--are characterized by an intertwining of heuristic and algorithmic threads."[15]

My assumption is that the large majority of planning problems are of the intertwined type, or at least are not in the "already solved" domain.

To elaborate one manifestation of this intertwining, let us consider the Simon-Newell model of human problem solving:

> "Problem solving proceeds by erecting goals, detecting differences between present situation and goals, finding in memory or by search, tools or processes ["operators"] that are relevant to reducing differences of these particular kinds, and applying these tools or processes. Each problem generates subproblems until we find a subproblem we can solve--for which we already have a program [i.e., algorithm] stored in memory. We proceed until, by successive solution of such subproblems, we eventually achieve our over-all goal--or give up."[16]

In other words, their "means-ends" approach is a recursive application of operators to reduce differences. As noted by Minsky, the efficiency of the process depends upon the appropriate association of operators with difference

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[15]Licklider, <u>op. cit.</u>, 20.

[16]Simon, <u>op. cit.</u>, 27.

types and the ability to recognize the difference types in order to employ the appropriate set of operators.[17]

But it is precisely in pattern recognition that humans enjoy a decided, if possibly temporary, advantage over computers. A familiar example of comparative advantage of man over machine is in the recognition (decoding) of human handwriting. Another example may be more closely related to the type of recognition employed in typical planning activities. For several years I have asked my students in production analysis to lay out a Gantt chart schedule for five jobs each having five tasks in specified sequence to be performed on each of five machines. The object is to minimize the completion time of the last task. As it happens, the secret of success in this particular problem is to hold one machine idle, even though a lengthy task is ready to start, until several short tasks arrive and can be disposed of.

Once the requirements of the problem have been comprehended, students have quickly and unerringly discovered the secret. That is, they recognize the "bottleneck" caused by the long task and apply a "hold off" operator. Yet they, and I, found it very difficult to specify a general procedure or a computer program which can duplicate this ability.[18]

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[17] Marvin Minsky, "Steps Towards Artificial Intelligence," Proceedings of the IRE, (IL, January, 1961), 8-30. Also in E. A. Feigenbaum and J. Feldman, eds., Computers and Thought, (New York: McGraw-Hill, 1963), 406-450.

[18] For an experimental investigation of a partially successful procedure see D. C. Carroll, "Heuristic Sequencing of Single and Multiple Component Jobs," unpublished Ph.D. Dissertation, Sloan School of Management, M.I.T., 1965, 81 et seq.

Let me summarize the argument so far. If planning is just unstructured problem solving, and problem solving is recursive recognition of goal-situation differences and application of operators to reduce the differences, and if humans are better recognizers than computers, then effective planning calls for the presence of humans within the process. The close coupling is demanded by the recursive nature of problem solving, the "intertwining" of the heuristic process (recognition) with the algorithmic process (application of the operator and computation of the new difference).

The cited value of human pattern recognition applies when all of the necessary information is available to the computer. There are practical reasons, however, which call for using the man as a repository for additional information, information so rarely used, so difficult to quantify, or so inherently subjective that it would be uneconomic or awkward to supply to the computer. Thus, knowledge about individual customer characteristics and the subjective idiosyncrasies of particular work sections might more conveniently reside with and be applied by the man who is working out a production plan with a computer, for example; and, in general, the usual mode of operation would be for the man to propose alternatives and to evaluate the consequences as produced by the computer at least to the extent that the evaluation is subjective.

There are now many research projects underway on closely-coupled problem solving. In Shuford's CORTEX system for example, the man formulates the problem and specifies the alternatives he wishes to consider in a dialogue with the computer.[19] The computer will evaluate the alternatives using

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[19] Emir H. Shuford, "CORTEX: A Computer-Based System for Aiding Decision Making," paper presented at the Second Congress on the Information System Sciences, proceedings to be published by Spartan Books this year.

a specified utility function or continue to assist modification of the formulation as results become available. Edwards' PIP system, similarly constructed, makes use of man for subjective probability estimates in a Bayesian decision structure.[20] Probably the clearest example of the totally intertwined man-machine process is Ivan Sutherland's SKETCHPAD program wherein visual display consoles are used for machine-aided engineering design.[21]

There has been speculation on the existence of man-computer "symbiosis" in closely coupled systems.[22] The thought is that in an interactive dialogue the rapid disposal of each proposal by the man will lead him more rapidly to perceive answers or promising plans. To my knowledge the symbiotic phenomenon has not been explicitly demonstrated although I should hasten to state that my own experience with interactive computation leads me to agree with the speculation. It is my opinion, for example, that I can produce a correctly running computer program from initial conception in roughly one-fourth the elapsed time using the time-shared system (my own time and actual computer running time assumed remaining the same--which they do not).

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[20] Ward Edwards, "Probabalistic Information Processing System for Diagnosis and Action Selection," paper presented at the Second Congress see Shuford, fn., _supra_ , also Edwards and L. D. Phillips, "Man as Transducer for Probabilities in Bayesian Command and Control Systems," in M. W. Shelby and G. L. Bryan, eds., _Human Judgments and Optimality_, (New York and London: Wiley, 1964) 360-404.

[21] "Sketchpad: A Man-Machine Graphical Communication System," _AFIPS Conference Proceedings_, (1963, Spring Joint Computer Conference), (Washington: Spartan Books, 1963), 329-346.

[22] J. C. R. Licklider, "Man-Computer Symbiosis," _I.R.E. Transactions on Human Factors in Electronics_ (March, 1960), 4-11.

There is an additional application of time-shared computers that would appear particularly fruitful for planning, namely, multiple user cooperation on problem solving through access to a single model. For example, consider how such an approach might be used in capital goods manufacture. Current practice would likely call for rather sharp boundries drawn between the functions of engineering, production management and marketing. Yet clearly these functions are interdependent. For instance, the engineers often specify the routing of particular orders through the factory, that is, the machine assignments and sequence of operations. The production manager, taking this routing as input, must decide on allocation of work station capacity to competing jobs, based on the situation as it arises and, not infrequently, considerable advice on priorities from marketing.

It would be perfectly feasible to establish plans for all three functions via their interaction with a common predictive model. Routing assignments could then reflect not only engineering considerations, but production congestion problems and marketing priorities as well. Additionally, marketing's efforts to acquire new business could be reconciled with engineering and production capabilities. Such team planning, if performed rationally, holds, as a consequence, great potential for elimination of additional suboptimal activity beyond that which can be attacked with conventional computer models.

I suggested earlier that man's peculiar abilities may be only temporarily superior to those of machines. Indeed, considerable progress is being made in programming pattern recognition. This suggests that a man-machine attack

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on any particular problem is likely to be in a constant state of evolution (assuming a wholesome attitude towards self-automation on the part of the man). As the heuristic aspects of his problem solving become well defined, to the point where his "protocol" can be explicitly stated, in most cases these aspects can be programmed and economically assigned to the computer.

The feasibility and success of time-sharing notwithstanding, much development work remains before close cooperation on planning problems becomes convenient. One major problem to overcome is the language barrier. In conventional computer applications, languages such as COBOL, SIMSCRIPT, and a variety of specialized analytical program packages represent attempts to permit reasonably easy expression of business problems to the computer. Interactive problem solving raises additional problems in that communication is continual, the essence of the process. My colleague, Martin Greenberger, and his associates have mounted a major effort to create the software necessary to make close coupling on management problems convenient, flexible, and natural.[23]

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[23] M. Greenberger, "The Two Sides of Time Sharing," to be published in Datamation this Fall.

Integrated Operations Planning and Control[24]

The new on-line, real-time computer systems for management offer even further promise of improved planning. The important new element is bringing the planner into intimate contact not only with the algorithmic power of the computer, but also with the current, global "data base" of the entire organization and the various processes, decision rules and control mechansims which govern its detailed operation. Before analyzing the nature and economic impact of these systems, let me venture a definition. An on-line, real-time control system is one in which the activities, though possibly distant and numerous, are connected by information channels (typically, electrical) directly ("on-line") to the controlling agency (the computer in cases of interest here), and in which the controller's response (direction) to a stimulus (status report) from an activity is forthcoming within a time small enough such that the status of the entire system will not have changed materially (in "real-time"). The system responds "while you wait", so to speak. A component ordinarily on-line in such a system is some sort of mass storage device which permits accessing any particular datum in the file in order to provide an appropriate response. The general idea is that the detailed status accounts are updated continuously as transactions and changes occur. Generally, in these systems there are provided routines for making the numerous detailed decisions required as status changes occur "on the firing line."

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[24] Lest the following material seem too speculative, it should be pointed out that the general system structure advocated here was proposed and defended over six years ago by D. Malcolm in "Real-Time Management Control in a Large Scale Man-Machine System," Industrial Engineering, (XI, March-April, 1960), 103-110.

The first major on-line, real-time system was SAGE, providing for control of various widespread air defense activities some years ago. The current major commercial system in the U.S. is American Airlines reservation, passenger, and flight seat control system denoted as SABRE. There are several dozens of systems now operating or under development in application areas as diverse as police work, libraries, savings banks, distribution of industrial goods, and manufacturing.[25]

To clarify a point, time-sharing systems as described earlier are on-line, real-time systems for computation. I draw a distinction only in the area of application of essentially the same technology. Because it is the same technology, it follows that a closely coupled man-machine planning system is perfectly compatible with this type of configuration. That is, interactive planning, interrupted when required by on-going activities, can take place with the on-line, real-time control of previously laid plans.

The salient point to be raised is this. If the detailed current status of the organization has no relevance to the plans being determined, this coexistence has no value except perhaps as to clever use of computer capacity, i.e., avoidance of idle time in the time-sharing sense. On the other hand, current status (detailed or aggregate) is almost certainly relevant to operations planning: it is the point of departure. Furthermore, there is no theoretical bar to maintaining a data base on the environment beyond the limits of the organization's own control. As reported by Burck, Westinghouse Electric

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[25]For a survey of the recent applications see Richard Sprague, Electronic Business Systems, (New York: Ronald Press, 1962).

is experimenting with an extra-corporate management information system, which if successful, will greatly expand the usefulness of the approach that I am advocating.[26]

In order to delve more deeply into the implications of integrated planning and control, let us return for inspiration once more to Herbert Simon. He states,

> "Organizations [of the future] will ... be constructed in three layers; an underlying system of physical production and distribution processes, a layer of programmed (and probably largely automated) decision processes for governing the routine day-to-day operation of the physical system and a layer of nonprogrammed [i.e., heuristic] decision processes (carried out in a man-machine system) for monitoring the first level processes, redesigning them, and changing parameter values."[27]

What I wish to propose goes a shade further: the automated decision processes I see as on-line and in real-time, the non-programmed decisions I see performed in closely coupled man-machine systems which themselves are closely coupled to the control layer through sharing the same data base and detailed decision routines.

As to the defense of these views, let me offer this quick summary. On-line, real-time control systems offer not only the obvious advantage of quick and continuous response to changing situations but, more importantly, provide for bringing global information to bear on local situations. Once again, the value is derived from avoidance of local suboptimal decisions.

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[26] G. Burck, The Computer Age, (New York: Harper and Row, 1965), 113.

[27] Simon, op. cit., 49.

The utility of this for an airline accepting reservations for a single flight from many remote offices is clear; it can avoid "overbooking" or its expensive alternative "underbooking." In recent research on manufacturing control systems, Russo and I have found significant efficiencies resulting from application of global information, i.e., information concerning all jobs and all work stations, to detailed real-time sequencing and routing decisions.[28] Sprague, it may be noted, predicts, that "nearly all business systems will be of the on-line, real-time variety by 1970."[29]

Parenthetically, a characteristic of such automated, sequential control systems of distinct interest to the planner is their predictability and ease of modeling. One need only supply appropriate inputs (perhaps directly from the data base, see below) and executive routines and the control system will, faithfully and without error, simulate itself. Reducing uncertainty in the planning process almost certainly is useful in addition to the obvious convenience and inexpensiveness (as to model creation) implied.

Continuing the defense: what reasons are there for superimposing the higher level decisions which we call operations planning on the detailed automatic control system? The first is this. With planning tied directly to current status, the planner has a valid starting point for his model. It is granted that this is less important the longer the planning horizon and the lower the "resolution" of the model, but it is nonetheless a frequent and

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[28] Francis J. Russo, "Heuristic Approach to Alternate Routing in a Job Shop," unpublished master's thesis, Sloan School of Management, M.I.T., 1965, and Carroll, op. cit.

[29] Op. cit., 3.

pressing problem in the intermediate range planning for which detailed data is required, my industrial confreres assure me. The frequently voiced lament on data unavailability in simulations is symptomatic.

A second advantage is that with continuous monitoring of the low-level activity, the point in time at which the latest plan is no longer feasible, economic or otherwise appropriate can be recognized more quickly and replanning instituted immediately. As a generalization, major reductions of the well-known "planning lag" can be effected.[30]

Finally, implementation of plans, once established, becomes a trivial task. Communication of the plan consists simply of setting parameter values or selecting particular procedures to operate; miscomprehension and the other noise problems inherent in the "iterative discourse" simply disappear.

There is one other aspect to on-line real-time control systems deserving of note here. With the capability of responding in real-time based on full global status information and with massive algorithmic power available at the moment of detailed decision, much of the activity which we now call planning will simply disappear. My contention is that much planning is performed for the purpose of seeking solutions to global problems at a time when global information can be conveniently brought to bear, i.e., well ahead of execution. The previously cited example of machine scheduling will illustrate this. A detailed work schedule is established and promulgated considerably prior to execution in order to consider conflicts among jobs and interdependencies

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[30]Of course, the inappropriateness of the plan may result from factors not measured within the system. In these cases, only the replanning advantages can be secured.

among work stations--global problems.[31] This planning is done because there is no way adequately to monitor current status and to communicate decisions reflecting interdependencies at execution time. With on-line, real-time systems, however, solution search can be deferred until the problems actually arise, the full computational power of the computer and comprehensive information being available at that time, while the interim uncertainties and model invalidities will have been resolved.[32]

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[31]Emery examines the process in some detail in, "An Approach to Job Shop Scheduling Using a Large-Scale Computer," Industrial Management Review, (III, Fall, 1961), 78-96.

[32]Of course, even the automatic system must "plan ahead" in order to institute preventive measures; but given total flexibility as to timing it may do so when required by the nature of the problem and "lead times" rather than by delays inherent in the information system.

Summary and Conclusions

In a nutshell, the argument has been this. Conventional computer employment in planning problems has value derived from two aspects, more alternative plans can be evaluated and more valid models can be used. The incremental value of closely coupled man-machine planning is attributable to enabling the man's superior heuristic, pattern recognition, and subjective judgmental abilities to be brought to bear directly in the recursive problem-solving process. Finally, when man-machine planning is integrated with on-line, real-time control there are distinct additional values to be found in validity, ease of replanning, and implementation.

As noted in the introduction, the paper has been largely speculative. I shan't apologize for this, consideration of future possibilities being substantially the raison d'etre for planning. But the conjectures and hypotheses proposed here do beg for more objective testing. I have attempted to cite examples of practice or research tending to validate the bits and pieces from which the total structure has been fabricated, but even so, these do not permit quantitative evaluation of the systems I have proposed.

It is partially to fill this void that my group at the Sloan School of Management and Project MAC is bending its efforts. We have constructed a large simulation model of a "job shop" and are experimenting with various structures for planning and control of the flow of goods. We have started at the bottom of the decision hierarchy, with routing and sequencing control decisions, and are working upwards through capacity, flow allowance, and

bidding decisions, the latter three being dealt with in a closely coupled man-machine system. We hope to be able experimentally to accept or reject these hypotheses of value, and, if accepting, to establish the magnitude of the value.[33]

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[32]An overview of the whole project is given in D. Carroll, "Simulation Research in On-Line, Real-Time Systems," presented at the Institute for Management Sciences Eastern Meeting, Rochester, N. Y., October 15, 1965, to be published.