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ABSTRACT

Scientific advances in cognitive science and instructional technology suggest significant changes in methods of curricular and instructional design that will strongly affect educational practice. This paper discusses one of the major areas in which cognitive science and instructional technology are affecting instructional design theory: the analysis of the information to be learned. A methodology for information analysis is presented that uses an integrated instructional design theory. The analysis is based on a modular or contextual knowledge representation. Contextual modular analysis provides an initial instructional schema that accounts for the dynamic and complex nature of mental models. An example is presented using a computer-based instructional program. Basic steps for a contextual module analysis are: (1) define the content for using the information-to-be-learned; (2) define the complex problems associated with the context; (3) analyze the problems to identify concepts, principles, rules, or facts used; (4) analyze the concepts within the module; and (5) sequence the clusters into instructional components. The example is taken from a research program using business management principles as the content domain. Eight figures illustrate the discussion, and there is a 35-item list of references. (SLD)

Mental Models and the Analysis of Content

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Abstract

Developments in cognitive learning theory over the past two decades has contributed to the general understanding of knowledge representation in memory. Knowledge is now viewed more than a mere association or connection of concepts but, rather, a dynamic mental model of content and perceptions. Perceptions include values, feelings, attitudes, appropriateness, among other non-content aspects, all of which are relative to situational context. Conventional instructional theory has yet to account for advancements in cognitive psychology dealing with knowledge representations that go beyond declarative and procedural. On the other hand, cognitive psychology only presents descriptive theories which do not directly provide the prescriptive variables for analyzing complex and dynamic information for learning. In this presentation, I will present a methodology for information analysis that employs an integrated instructional design theory. Extending theoretical work in cognitive learning theory, I propose an analysis based on a modular or contextual knowledge representation. Contextual modular analysis provides an initial instructional schema that accounts for the dynamic and complex nature of mental models. Presented along with the discussion will be a worked-out example employing a computer-based instructional program.

Mental Models and the Analysis of Content

Scientific advancements in cognitive science and instructional technology suggest significant changes in methods of curricular and instructional design which will strongly affect educational practice (Tennyson, 1990b). These advancements extend the predominantly applied behaviorally oriented learning paradigm of instructional design and management (Case & Bereiter, 1984). In this paper I will discuss one of the major areas in which cognitive science and instructional technology are affecting instructional design (ID) theory: the analysis of the information-to-be-learned.

Analysis of Information-to-be-Learned

An important component of ID models is the analysis of the information-to-be-learned. Two basic types of analyses include: (a) a content analysis that focuses on defining the critical features of the information and the relationship of those features according to superordinate and subordinate organizations; and (b) a task analysis that focuses on a hierarchical organization of the information based on prerequisites. Both of these analyses identify the external structure of the information but do so independent of how it might actually be stored in human memory. However, research in cognitive psychology on human memory suggests that the internal organization of information in a knowledge base is based more on employment needs than by attribute or hierarchical associations

(Fodor, 1983). That is, the utility of the knowledge base is attributed to its situational organization not the amount of information. The implication of knowledge base organization is the need for a further analysis of the information to better understand the possible internal organization of the information (Garner, 1990). Better organization in memory may also imply better accessibility within the knowledge base for such higher order cognitive activities as problem solving and creativity (Harré,1984).

To understand the nature of knowledge base organization, cognitive psychologists analyze problem complexity and the way individuals try to solve given problems (Klahr, Langley, & Neches, 1987). By analyzing problems, it is possible to identify the concepts employed; and, by analyzing the solutions, it is possible to identify the associations of those concepts within given problem situations. The implication for ID theory is that the sequence of information for instruction should be based in part on internal situational associations (and connections) as well as external structures (Bereiter, 1990). The assumption is that because external structures are independent of employment needs, an analysis of possible internal associations would improve the initial organization of the new information, resulting in better employment.

In addition to the analyzing of specific problems and solutions, is the issue of understanding problems within given situations or contexts (Mishler, 1979). For example, expert systems reside within the constraints of a specific context: That is, they can solve problems only associated with that given context (Newman, Griffin, & Cole, 1989). Likewise, research in cognitive psychology shows that individuals can solve complex problems only if they possess the necessary contextual knowledge (i.e., knowledge of why, when and where) (Tennyson, 1990d). For example, the objective in learning to play chess is the learning of problem solving skills within the context of both the given game and the current move: not just how the various chess pieces move (i.e., procedural knowledge). Thus, the key to both effective acquisition and employment of knowledge is the organization of the information according to contextual applications. That is, contextual knowledge includes not only information (i.e., content/task) but also the cultural aspects directly associated with that information (Brown, Collins, & Duguid, 1989). Cultural implies the selection criteria, values, feelings and appropriateness associated with the information of given contextual situations.

The extension for a content/task analysis suggested by cognitive science is the method employed for an information analysis. In addition to the conventional content and task analyses, a context analysis is proposed if the goal of the instruction includes employment and improvement of cognitive skills and strategies, such as problem solving, decision making, and trouble shooting. Basic steps for a contextual module analysis are as follows:

1. Define the context for the employment of the information-to-be-learned. A context is meaningful application of the information (i.e., the complexity of the situation including the content/task, skills, goals, and culture) (Lawler, 1985).

2. Define the complex problems associated with the context. This step follows a knowledge engineering approach where problems associated with the context are identified (Laird, Newell, & Rosenbloom, 1987).

3. Analyze problems to identify concepts, principles, rules, or facts employed (Merrill, Tennyson, & Posey, 1992).

4. Analyze the concepts within the module, identifying possible clusters of concepts employed in the solution of the various problems (Tennyson 1990e). This provides for the overall organization of the module. The analysis should include as much as possible the why, when and where aspects of the information employment. This is the initial information to help form the culture of the knowledge base (Fodor & Pylshyn, 1988).

5. Sequence the clusters into instructional components, by grouping problems according to shared concepts (Tennyson & Cocchiarella, 1986). Analyzing problems within a context and then identifying the concepts and their employment

organization provides a means for sequencing the instruction to improve higher order cognition. In other words, the sequence of the instruction is based on the objective of improving employment of knowledge in addition to improvements in acquisition.

Example of A Contextual Module Analysis

The following example is presented to illustrate the above defined procedures for a contextual module analysis. The example is taken from our research program using business management principles as the content domain. The project uses a contextual module analysis to design an instructional program to improve problem-solving in an operations management environment. The example will follow the steps defined above.

Step 1: Define the Context.

Using a simulation for the management of a kitchen cabinet factory, the student makes operational decisions which affect the profit or loss of the company. Based on the contextual module analysis, three instructional modules were developed to prepare the student to solve problems commonly encountered during the simulation.

Step 2: Define the Complex Problems.

Using a knowledge engineering approach, problems were identified as representative of the situations encountered in the management of the factory. The problems were then rank-ordered by complexity; complexity being determined by the number of relevant principles required to solve the problem.

Step 3: Analyze the Problems.

Initially there were a large number of problems identified. After assigning principles to each problem, many of the problems were dropped from the list because the particular grouping of principles involved was already related to another problem. The remaining smaller group (ten problems) was then determined to represent the knowledge necessary to manage the factory. Relevant principles were identified for each problem. More complex problems required more principles to be employed in the solution of the problem and most of the principles were used in the solution of several problems.

Step 4: Organize Information into Clusters.

Figure 1 illustrates the grouping of problems by their associated principles. The instructional design focuses on related principles for specific problems and on shared principles which provide context for problems. That is, for each specific problem the focus is on the related principles used to solve the problem and their relationships. Principles which are used for several problems (shared principles) provide more context for the problems. As shown in Figure 1, the principles required to solve a problem are grouped according to their association.

Insert Figure 1 about here

Step 5: Sequence Clusters into Instructional Components.

Figure 2 shows the ten problems divided into three instructional components or modules. As you can see from Figure 2, the problems in the first two modules are less complex, yet most of the principles are being introduced for the first time in these problems. The problems in module three are more complex, but all the principles except one have been used in previous problems.

Insert Figure 2 about here

Example of A Contextual Module Analysis Integrated in an Instructional Program

Extending the example described above from the business management project, I will illustrate how an integrated instructional system can be designed employing the three modules identified in Figure 2. (The three modules are converted into three respective instructional units.) Following the guidelines for the instructional prescriptions presented in Tennyson, Elmore, and Synder (in press), the instruction is sequenced per unit by (a) presenting the sub-context for the content in each module, (b) presenting the concepts in an expository manner with practice problems employing the principles in a limited context, and (c) providing a problem-oriented simulation limited to the problems and principles presented in that unit.

The instructional program was developed for computer-assisted instruction using the Control Data Corporation's PCD3 authoring system, which uses icons to illustrate the overall instructional design. Figure 3 shows the structure of unit 1 (i.e., module 1 from Figure 2), in which the material is presented first in an expository manner, with worked examples, followed by practice problems.

Insert Figure 3 about here

Figure 4 shows the application of an expository screen, including a worked example demonstrating the application of a principle. The worked example is presented by having the learner work through each step of the problem (by pressing the RETURN key).

Insert Figure 4 about here

Figure 5 shows a practice problem in which the student is able to employ a set of principles in a given situation. In this practice example, the student is asked to determine how much money to spend in maintenance of two different machines. Principles are like rules-of-thumb, and consequently there is generally not one correct application of a principle, but effective applications fall into ranges. The practice problems allow the student to identify these ranges, based on the feedback given, and select values within them to make good decisions. As principles are combined into more complex problem solutions, correct response ranges vary according to the inter-relationships of the principles involved.

Insert Figure 5 about here

For instance, the effects of advertising in an isolated context are relatively easy to observe; more advertising leads to more demand. However, the selling price of the product also affects demand and the available production capacity may not be able to accommodate an increased demand. An understanding of the effects of advertising in relation to other principles (i.e., contextual knowledge) is more important than a knowledge of the simple effects of advertising (i.e., procedural). As more of these principles are introduced into the context, problem solutions require an understanding of the principles and their effects, rather than learned values only.

At the end of each instructional unit the student is branched to the management simulation (i.e., problem-oriented strategy), but is only allowed to make decisions which require principles covered in that specific unit. All other variables and conditions of the simulation are held at constant levels. This allows the student to see the inter-relationships of the selected principles in the context of the total simulation, but isolated from decisions related to other principles.

Figure 6 shows the choices given to the student in the simulation for unit 1. These choices correspond to the problems and related principles covered in this unit. The student is branched through three planning periods (months) and then returned to the instruction to begin unit 2. At the end of each planning period, the student is given detailed information (see Figure 6) about the performance of the company during that period.

Insert Figure 6 about here

At the conclusion of the three instructional units student is branched to the simulation again. At this point, the student is required to make all the decisions related to the management of the factory for 12 planning periods. Figure 7 shows the decisions the student makes in the complete simulation. Because of the increased complexity of the complete simulation, 12 cycles are necessary to allow students to encounter problems and follow through on solution strategies. Again, the student is given detailed information at the conclusion of each planning period (see Figure 7).

Insert Figure 7 about here

Conclusion

The purpose of this article was to discuss an important area in which recent advancements in cognitive science and instructional technology may affect instructional design theory. In this area, information analysis, an extension to standard methods of content/task analysis was made so as to include the situation or context for which the new information may be employed. Contextual module analysis proposes an additional analysis of the information based upon complex problems associated with a given situation. Whereas conventional content and task analyses identify the attributes of the information, the contextual module analysis identifies the organization and accessibility of the information in reference to a given situation or culture (Wertsch, 1985). The modular organization improves the service of the knowledge base for higher level employment situations (i.e., problem solving and creativity, Rasch, 1988).

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Figure Captions

Figure 1. Problems grouped by associated principles.

Figure 2. Example of component organization.

Figure 3. Structure of instructional unit 1.

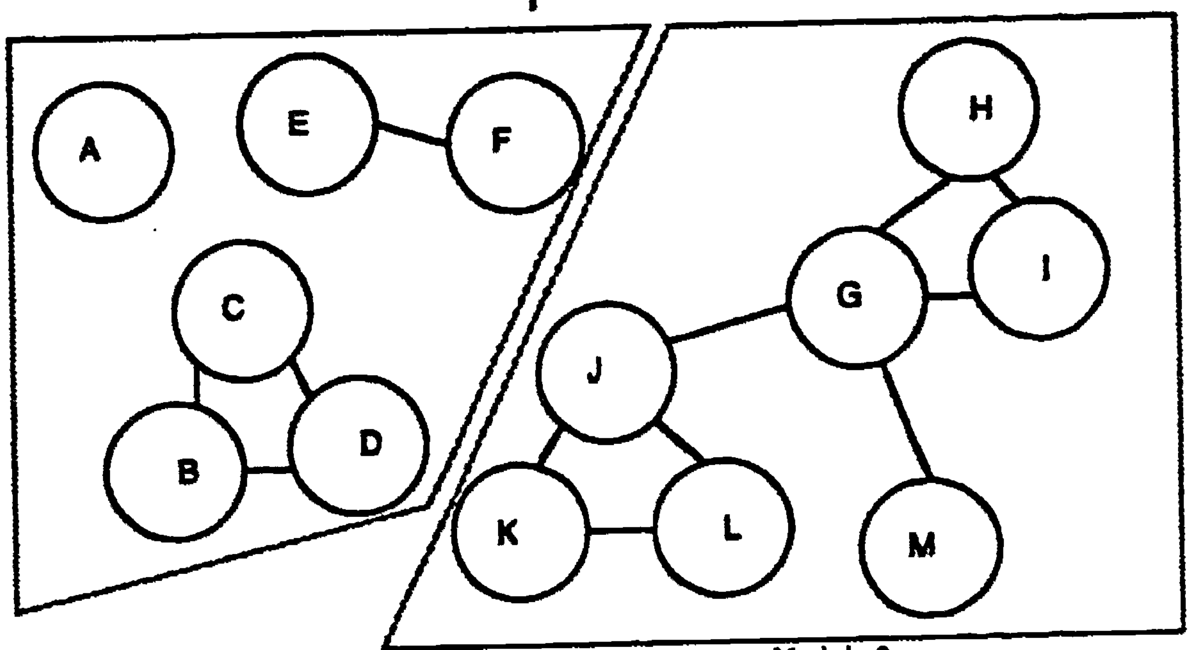
Figure 4. Example of an expository screen, with worked example.

Figure 5. Practice problem for instructional unit 1.

Figure 6. Simulation of problem-oriented strategy for instructional unit 1.

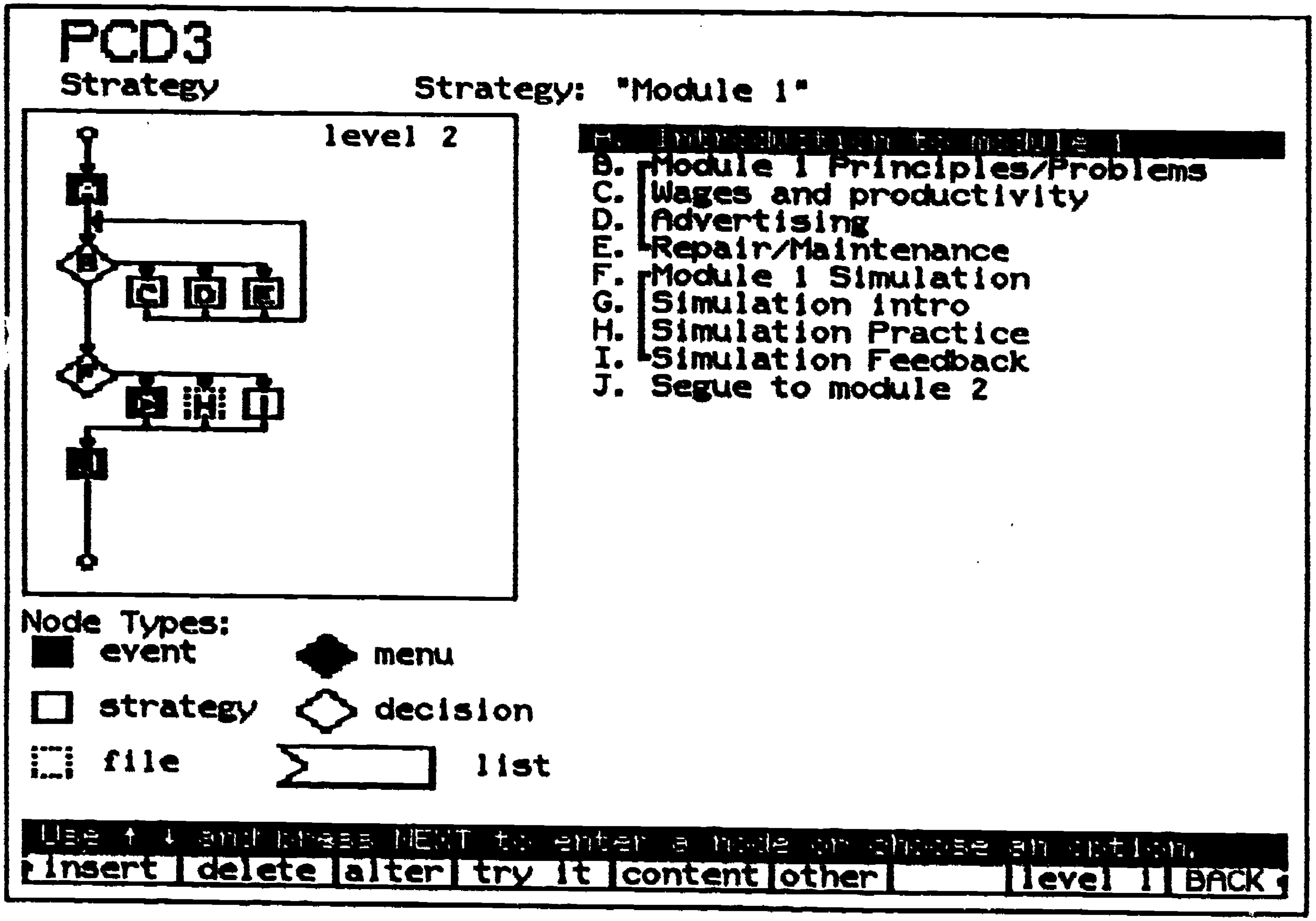
Figure 7. Complete set of variables and conditions for dynamic simulation.

	Problem	Principles
Module 1	Wages too low or too high	A - Wage effects on productivity
Module 1	Inappropriate rate of advert'sing	B - Role of advertising C - Demand D - Market Saturation
Module 1	Machine maintenance	E - Replacement of older machines F - Optimum level of repair
Module 2	Inappropriate number of machines	G - Production goals H - Number of workers I - Machine types
Module 2	Raw materials not available or price too high	G - Production goals J - Inventory K - Raw material orders L - Price differences of raw material orders
Module 2	Inappropriate number of workers	G - Production goals M - Number of machines



Module 1 Module 2

Module	Problem	Principles
Module 1	Wages too low or too high	A - Wage effects on productivity
Module 1	Inappropriate rate of advertising	B - Role of advertising C - Demand D - Market Saturation
Module 1	Machine maintenance	E - Replacement of older machines F - Optimum level of repair
Module 2	Inappropriate number of machines	G - Production goals H - Number of workers I - Machine types
Module 2	Raw materials not available or price too high	G - Production goals J - Inventory K - Raw material orders L - Price differences of raw material orders
Module 2	Inappropriate number of workers	G - Production goals M - Number of machines
Module 3	Production capacity not consistent with demand	F - Optimum level of repair G - Production goals H - Number of workers I - Machine types M - Number of machines
Module 3	Production and inventory not consistent with demand	B - Role of advertising G - Production goals H - Number of workers J - Inventory M - Number of machines N - Selling price
Module 3	Raw materials on hand not consistent with production goals	G - Production goals H - Number of workers K - Raw material orders L - Price differences of raw material orders M - Number of machines N - Selling price
Module 3	Demand is too low	B- Role of advertising D - Market saturation N - Price


PCD3
Strategy
Strategy: "Module 1"
level 2
A. Introduction to module 1
B. Module 1 Principles/Problems
C. Wages and productivity
D. Advertising
E. Repair/Maintenance
F. Module 1 Simulation
G. Simulation intro
H. Simulation Practice
I. Simulation Feedback
J. Segue to module 2
Node Types:
event
menu
strategy
decision
file
list
Use ↑ ↓ and press NEXT to enter a node or choose an option.
insert
delete
alter
try it
content
other
level 1
BACK

In order for machines to run at optimum efficiency you must spend a certain amount of money on repair and maintenance.

The following example illustrates how the repair and maintenance budget influences machine efficiency and capacity.

Example

The current repair budget is $18,000 per month for 14 T50 machines and no T100 machines. The machines are currently running at 80% efficiency, giving a maximum capacity of 560 (14 × 50 × 80%).

Press RETURN to continue.

Example

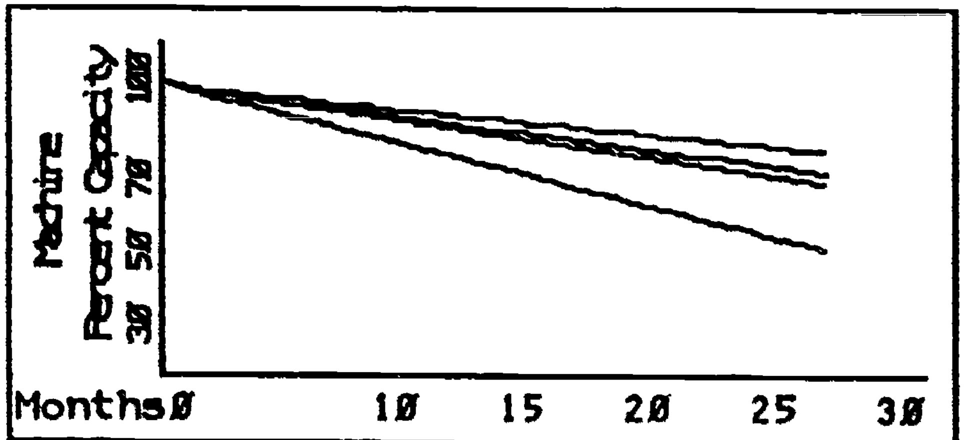
We want to increase our capacity from 560 to 600 units per month. If we increase our budget from $18,000 to $22,000 our efficiency will increase to 84%, giving a capacity of 600 units (14 × 50 × 84%).

Press RETURN to continue.

Practice Problem

The following practice problem will help you determine the appropriate amount to budget for machine repairs and maintenance.

With a repair budget of $15000, after 30 months the machine capacity is
T50 machines: 75.8333%.
T100 machines: 69.7917%.



Monthly budget

- 7000
- 12000
- 18000
- Your value

Press RETURN for more

Press F9 to leave

Team: ROBERT — Income statement for last month — Month: 6

Income	: 576 units sold @ $250 per unit	$	144000
	Interest		4980
	Total income:	$	148980
Expenditures:	Wages for 12 workers (wage per worker $2250/mo)	$	27000
	Fringe benefits (per worker $1200/mo)		14400
	Raw material expense 572 units @ $86		49192
	Repair budget		19000
	Advertising budget		12000
	Other expenses		20000
	Storage cost for 296 units raw material		296
	Total expenditures:	$	141888
	Gain:	$	7092

Monthly statement   Accept decisions

Team: ROBERT DECISION ENTRY Month: 10

Team: ROBERT Monthly statement for last month Month: 6

Assets

Fixed assets:
14 Type 50 mach @ $43044 $ 602627

Inventory:
Raw material 296 units 14800

Total assets : $ 617427

Cash flow

Cash last month $ 199216
Gain for month 7092

Cash on hand $ 206308

Production data

12 workers for 14 Type 50 machines
average capacity T50 mach: 89.68 %

Production goal : 600 units
Production : 576 units
Demand in constant market : 622 units

Material schedule

Arriving in		Qty	Price
month	6	503 units	$ 123
month	7	0 units	$ 0

Spot mkt supply: 437 units
Spot mkt price : $ 135

Income statement Accept decisions

Team: ROBERT	Income statement for last month		Month: 10
Income	: 478 units sold @ $280 per unit	$	133840
	Total income:	$	133840
Expenditures:	Wages for 10 workers (wage per worker $2100/mo)	$	21000
	Fringe benefits (per worker $1200/mo)		12000
	Raw material expense 600 units @ $60		36000
	Repair budget		10500
	Advertising budget		2000
	Other expenses		20000
	Storage cost for 122 units raw material		122
	Total expenditures:	$	111643
	Gain:	$	22196

Monthly statement   Accept decisions