*Journal of Medical Systems, Vol. 22, No. 5, 1998*

# Patient Dependency Knowledge-Based Systems

**F. Soliman**[1]

*The ability of Patient Dependency Systems to provide information for staffing decisions and budgetary development has been demonstrated. In addition, they have become powerful tools in modern hospital management. This growing interest in Patient Dependency Systems has renewed calls for their automation. As advances in Information Technology and in particular Knowledge-Based Engineering reach new heights, hospitals can no longer afford to ignore the potential benefits obtainable from developing and implementing Patient Dependency Knowledge-Based Systems. Experience has shown that the vast majority of decisions and rules used in the Patient Dependency method are too complex to capture in the form of a traditional programming language. Furthermore, the conventional Patient Dependency Information System automates the simple and rigid bookkeeping functions. On the other hand Knowledge-Based Systems automate complex decision making and judgmental processes and therefore are the appropriate technology for automating the Patient Dependency method. In this paper a new technique to automate Patient Dependency Systems using knowledge processing is presented. In this approach all Patient Dependency factors have been translated into a set of Decision Rules suitable for use in a Knowledge-Based System. The system is capable of providing the decision-maker with a number of scenarios and their possible outcomes. This paper also presents the development of Patient Dependency Knowledge-Based Systems, which can be used in allocating and evaluating resources and nursing staff in hospitals on the basis of patients' needs.*

**KEY WORDS:** patient dependency information; knowledge-based resources; systems hospitals nursing human management.

## INTRODUCTION

Allocation of nursing staff time to meet patients' needs has been widely accepted as an efficient method in hospital resource allocation.(1–3) Accordingly the interest in Patient Dependency Systems has been growing. There are a number of reasons for adopting the Patient Dependency approach, including:

1. Pressure on hospitals to control costs and to be more efficient in using their nursing resources.

[1]School of Management, University of Technology, Sydney, Australia.



0148-5598/98/1000-0357$15.00/0 

2. Hospital administrators are required, more than ever, to justify the number of staff they need to provide quality care to patients.

3. Staff planning and the preparation of hospital budgets require a reliable and valid method, which must logically be based on patients' needs, rather than their numbers.

4. For accreditation purposes, many hospitals are required to demonstrate that the staffing duties are in accordance with patient needs.

5. Increasing accountability of hospital administrators has resulted in the need to maintain fast and accurate databases for patients' needs and care levels over a period of time.

Patient Dependency Systems are the most effective way of addressing the above mentioned hospital needs.[1,3–5] Furthermore, Patient Dependency Systems can provide information for: (a) forecasting nursing time and equipment required, (b) determining the quality of care provided to patients, (c) monitoring nursing productivity within each unit and between units, (d) identifying current and future staff education needs.

However, the problem is *where to start and how to acquire a Patient Dependency System?* Up to now there are no commercial Patient Dependency Software Systems that could be used off-the-shelf in a general application.

In order to develop and implement a Patient Dependency System, hospitals must follow an exhausting program to ensure that the system is reliable and valid before it is used.[1,3] This requires:

1. Construction of "Indicators of Care."
2. Conducting a Nursing Activities Audit.
3. Performing Content Analysis.
4. Construction of Subjective Dependency Levels.
5. Construction of Data Collection Instruments for Timing Study.
6. Evaluation of Data Collection Instruction by a Panel of Experts.
7. Conducting the Timing Study.
8. Development of the Dependency Instrument.
9. Development of Objective Dependency Levels.
10. Evaluation of Dependency Instrument.
11. Trial of the System.
12. Constant monitoring after implementation to ensure reliability and validity.
13. Safeguarding against inflating patient dependency levels.
14. Using the system to predict staffing requirements.
15. Testing the system in a crisis situation.
16. Modifying, fine tuning and re-using the Instruments as needed.

Following the above steps without the use of a sophisticated computerized system can be very costly and slow. In addition, the manual systems use patient classification, which is limited to that moment in time and can only reflect the state of dependency for that period.[1,3] What is needed is an efficient and fast way of automating the Patient Dependency functions.

There are many functions in the manual Patient Dependency Systems that are potential candidates for computerization. However, the most important functions in the automation of Patient Dependency Systems are the calculation of:

1. "Critical Indicators of Care" used on a continuous basis to identify the needs of patients. These Indicators are reviewed and updated continuously as the situation requires.

2. "Patient Dependency Levels" used to convert the identified patient's needs into nursing hours required. This process is continuously calculated and updated according to the changes in patients' and units' needs.

3. Allocation of current and projected staff time and duties based on patients' needs.

## AUTOMATION OF PATIENT DEPENDENCY FUNCTIONS

At the heart of the Automated Patient Dependency System is the *Evaluator* Module. This Module uses a Computational Model to evaluate the various Patient Dependency Parameters required to perform the analysis. The following Flow Chart describes this Computational Model (Fig. 1).

The main five functions performed by the *Evaluator* Module are as follows:

1. **Standard Time of Care:** Each time the system is used the calculation of Frequency of Occurrence, Average Time, and Standard Deviation takes place. This calculation is performed for every patient for all activities during every shift. The *Evaluator* Module then calculates the Weighted Average Time (WAT) and stores the results in the Patient Dependency DataBase.[2]

2. **Scores of Care:** A Score of Care for each patient is calculated by the normalization of the Standard Time of Care using a suitable Interval of Time.[2]

3. **Patient Dependency Levels:** A Dependency Level exists for every patient. The Automated Patient Dependency System employs Patient Dependency Levels, which are used to group patients into categories that reflect the magnitude of nursing care required. The selection of the Dependency Level defines the Dependency Level Time for the patient.[2]

4. **Nursing Staff Time:** The Nursing Time required to provide care to a patient is based on the degree of need (Dependency Level) for that patient.[2]

5. **Number of Nursing Staff required:** The Automated Patient Dependency System calculates the number of nurses required to provide care for all patients in every shift and then approximates that number to the nearest whole number of nurses.

In a recent article[2] Soliman presents a set of algorithms and mathematical models, which could be used to computerize the Patient Dependency method.

One important function of the Patient Dependency System is the forecasting of the number of nurses that are required for each shift. However, nurses' rosters are usually prepared many days ahead, i.e., it is necessary to predict the patients' needs a few days in advance. In most cases this requires some input from the experienced nurses. The expert advice is usually based on historical decisions previously made in similar situations. Knowledge-Based Systems, utilizing Knowledge-Based rules, provide a proven automated technology for tasks which require judgement. These rules are usually complex and are based on the ongoing decision of the System. Accordingly, once staffing decisions are made, they are

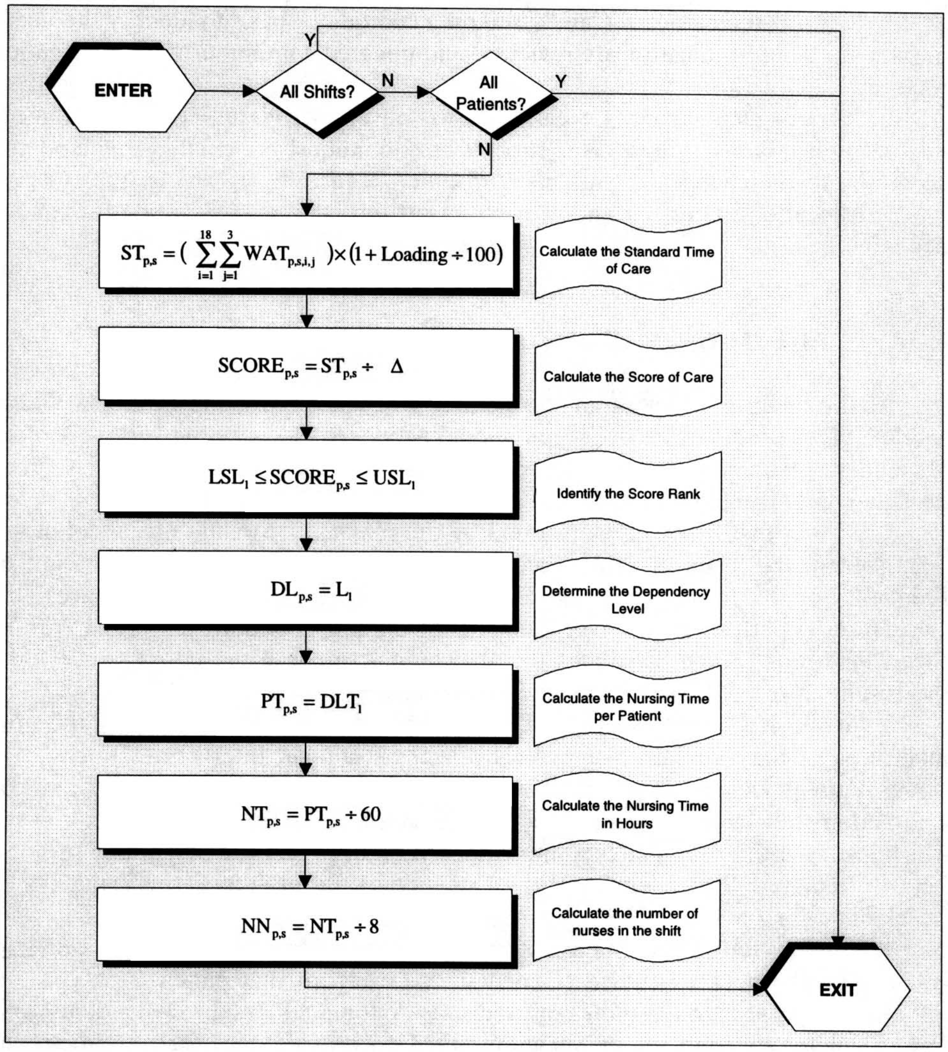


**Fig. 1.** Flow chart of the Patient Dependency Computational Model.

stored in the Patient Dependency Knowledge Base where they can be retrieved and re-used as many times as required.

## PATIENT DEPENDENCY KNOWLEDGE-BASED SYSTEMS

There are many Information Technologies (IT) applications which could support the automation of Patient Dependency Systems, such as Workflow Automation, Document Imaging, Client/Server Data Repositories and e-mail. However, over the past decade Knowledge-Based Systems (KBS) have emerged as an alternative set of techniques and methods for building systems that support and/or automate decision making. A review of the literature indicates that little attention has been given to the application of Knowledge-Based Systems in the field of resource planning using a Patient Dependency System. Furthermore, the importance of Knowledge-Based Systems for hospital management has not received enough attention and its effects on reducing the cost of health care have not been fully recognized.

Knowledge-Based Systems technology has already delivered significant commercial benefits.(6) This technology is now useful, easy to use, and reliable. According to Peters,(7) "any business leader who is not learning about Knowledge-Based Systems today and sticking a tentative toe or two in its waters, is simply out of step, dangerously so." Furthermore, Knowledge-Based Systems have the ability to automate laborious decision-making processes by presenting a number of scenarios and producing a particular conclusion.(8) As the Knowledge-Based technology matures, hospitals can no longer afford not to make use of this technology in order to reduce the time and cost of resource utilization and control. Soliman *et al.*(9) have presented a number of factors that could influence the introduction of Knowledge-Based Systems. These factors are applicable to Patient Dependency Systems in hospital settings.

Knowledge-Based Systems have been accepted by users because of their ability to provide explanations and justifications for their results. Explanations are constructed by transforming expert rules into lines of reasoning that users can inspect on demand. A line of reasoning shows how a starting set of assumptions and a set of rules produce a particular conclusion. Therefore Knowledge-Based Systems offer the best mechanism for storing, updating, and retrieving decisions made regarding patients' care because they can utilize a set of complex *Rules* for identifying the most appropriate level of care to patients.

Processes requiring judgment play a critical role in the overall management of patients' care. They are responsible for the key decision points and for the bulk of the benefit to patients. Such tasks require judgment for which Knowledge-Based Systems are a proven automated technology. With the critical role played by judgmental processes and their inherent complexity, it is essential to identify these processes within the Patient Dependency System and use Knowledge-Based Systems to automate them. Dependency Knowledge-Based Systems can complement the work of nurses, freeing them to do more challenging and higher value activities and can be used to achieve:

- retention of in-house nursing expertise even after the nurse expert has left the hospital;
- greater innovation by allowing creative nurses to explore, understand, discard, and rework many alternative paths to a patient's care;
- greater decision-making consistency by having the Patient Dependency Knowledge-Based application serve as a common tool in all wards in a hospital;
- increased cost-effectiveness in the transfer and dissemination of existing knowledge.

Nurses may obtain timely advice on patients' needs even when the specialist staff are not available. Moreover, periodic revisions of the knowledge base ensure that the information provided is up to date. Although a Patient Dependency Knowledge-Based System does not fully replicate the skills and expertise of nurse specialists, its implementation can substantially reduce their loads of caring for patients' needs.

Karlsson[10] identified several driving forces for a competitive strategy. These include the utilization of best knowledge in different areas in hospital management. This has been supported by Bottoms,[11] who predicted that organizations will soon experience a major transition from the utilization of traditional Information Technology tools such as Electronic Data Interchange (EDI), to a much more comprehensive strategy using Knowledge Engineering. All of these factors indicate that Knowledge-Based Technology has the potential to impact greatly and support the corporate strategy of health care organizations.

The Patient Dependency Knowledge resides in a sophisticated Knowledge Base, which is distinct from the conventional processing mechanisms. Traditional information systems seek to create information reports by accumulating, organizing, and processing data. In the Patient Dependency Knowledge-Based System decisions made regarding staffing on the basis of patients' needs are so complex that they need to be made efficient and regulated by means of a *Decision Regulator*.

## THE DECISION REGULATOR CONCEPT

The *Decision Regulator* is a control concept, which is closely associated with the movement of decisions and information within the Patient Dependency Knowledge-Based System. The regulator concept permits decisions on information and staffing duties to be made in response to any small variations between patients' needs and the availability of nursing staff.

The Decision Regulator concept can be used to convert the decisions into a set of structured rules so that Knowledge-Based Systems can monitor and report the status, trends, and changes of information and patients' needs. Figure 2 below illustrates how the set of decisions used in the Patient Dependency Knowledge-Based System is converted into a set of rules through the *Decision Regulator*.

At the initial stages the Patient Dependency Knowledge-Based System uses these results to group the critical indicators of care under three categories (Direct Care Indicators, Indirect Care Indicators, and Unit Related Indicators). The system then formulates a list of major categories of activities, which becomes the critical indicators of care and makes up the basic module in the Patient Dependency Knowledge-Based System. The Knowledge-Based System automatically groups the timing results under these categories. It should be noted that continuously updating the data could result in altering the membership of these categories.

Nursing staff decisions made are entered and stored in the System's Knowledge Base for later re-use in similar situations. As the system progresses and new data are entered, these Critical Indicators are further divided into two types[1]: (a) Type

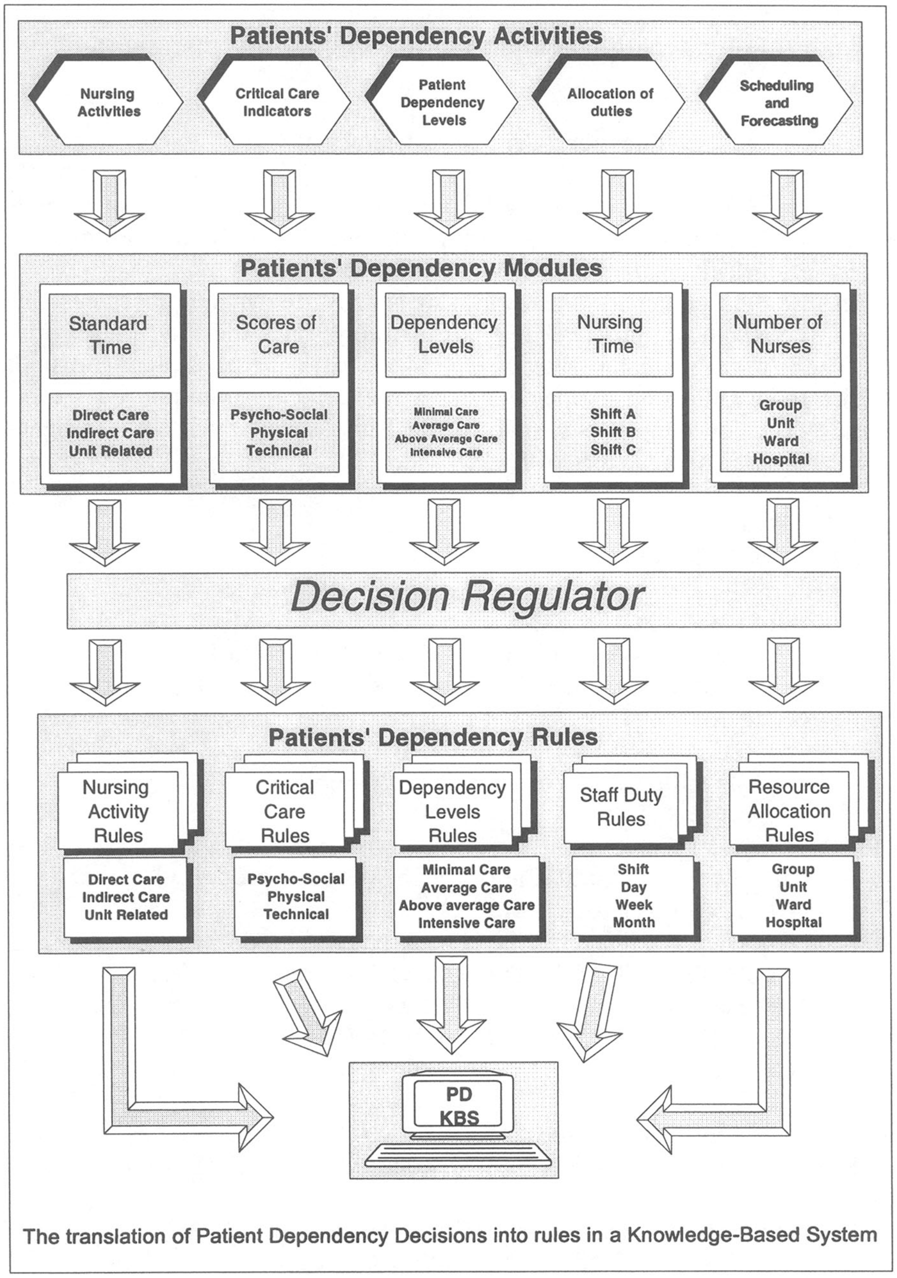


**Fig. 2.** Illustration of the Decision Regulator Concept.

A Indicators and (b) Type B Indicators. This is necessary to ensure that the comprehensive set of criteria is consistent with the duties of the nursing staff.

## Rules for "Critical Indicators of Care"

Soliman[1,2] has shown that the "Critical Indicators of Care" can be used as the basis for calculating the dependency levels and ultimately the staffing requirement for a particular patient.

Because the frequencies of each nursing activity are dynamically calculated and updated, the results are more reliable. Furthermore, since the Frequencies and Average Time of each nursing activity are calculated using all stored and updated data, the re-identification of the weights of the Critical Care Indicators becomes necessary. The following is a sample of the Rules used to select the weights for each of the Critical Indicators of Care:

```
RULE 1: {Psycho-Social Care}
  For ALL INDICATORS
    IF (Care_Type = psychosocial) THEN {Check Frequency}
        ELSE GO_TO Rule 2
      IF (Frequency = High) THEN {Check Nurse Time}
        ELSE SELECT NEW INDICATOR {Repeat Rule 1}
          IF (Nurse_Time = High) THEN USE {i.e. Select Indicator Weight}
            ELSE SELECT NEW INDICATOR {Repeat Rule 1}
        GO_TO Rule 2

RULE 2: {Physical_Care}
    IF (Care_Type = Physical_Care) THEN {Check Frequency}
        ELSE GO_TO Rule 3
    IF (Frequency = High) THEN {Check Nurse Time}
        ELSE SELECT NEW INDICATOR {Repeat Rule 2}
      IF (Nurse_Time = High) THEN USE {i.e. Select Indicator Weight }
        ELSE SELECT NEW INDICATOR {Repeat Rule 2}
        GO_TO Rule 3

RULE 3: {Technical_and_Miscellaneous}
    IF (Care_Type = Technical_and_Miscellaneous) THEN {Check Frequency}
        ELSE GO_TO Rule 4
    IF (Frequency = High) THEN {Check Nurse Time}
        ELSE SELECT NEW INDICATOR {Repeat Rule 3}
      IF (Nurse_Time = High) THEN USE {i.e. Select Indicator Weight }
        ELSE SELECT NEW INDICATOR {Repeat Rule 3}
        GO_TO Rule 4
```

The user can modify the length and boundaries of the period of time by changing the default values of FROM and TO. During the specified period all data from all the three shifts are processed and analyzed for: (a) Total Frequency of Occurrence, (b) Minimum Time Recorded, (c) Maximum Time Recorded, (d) Mean Time, and (e) Standard Deviation.

In addition to the above rules there is a suite of lengthy and complex rules that drive the reasoning engine of the Knowledge-Based System to provide the decision-maker with a number of scenarios and their possible outcomes. These rules and data are stored in the Knowledge and Data Bases as shown below.

## PATIENT DEPENDENCY DATA BASE

Data are entered and stored in the Patient Dependency Data Base. The on-line facility enables staff to enter as frequently as necessary all nursing activities related to the same patient. Two types of entries can be made, Yes or No, to confirm or otherwise that the activities took place. The frequency of the activity is also entered for each of the Critical Indicators of Care. The system also displays default information such as Ward Name, Date, and Total Number of Staff in the three shifts. The user with the appropriate authorization level can edit this information.

## PATIENT DEPENDENCY KNOWLEDGE BASE

At the beginning of the Learning Stage, all decisions made regarding Patients' Care and the allocation of staff duties are stored for later reuse. The Knowledge-Based System presents the experts with a number of scenarios requiring decisions.

Once patient data and decisions are entered, the system automatically calculates the Dependency Levels and displays the staffing levels required to provide care for the patient under consideration.

## KNOWLEDGE REPRESENTATION

Knowledge is represented in the system through four models, namely, (a) Elicitation model, (b) Structure model, (c) model of Expertise, and (d) Design model. These models are interrelated explicitly within the system to give the full benefits for problem solving, documentation, maintenance, and explanation.

### The Elicitation Model

The knowledge (in the form of decisions, protocols, policies, etc.) gained from the expert in the *Elicitation Phase* is described and used to define the elicitation model which is the basis of the structure model.[12]

## The Structure Model

The Structure Model consists of the following four contexts, which are used for capturing the functional aspects of the system: (1) The Concept Context which defines the domain terminology; (2) The Activity Context which defines the task decomposition; (3) The Data Flow Context which defines the data flow between the sub-tasks; and (4) The Ordering Context which defines the Control Flow.

In addition, the activities in the Patient Dependency are defined in a Process Context. The Contexts of the Structure Model are represented in the inference layers of the Model of Expertise.(13)

## The Model of Expertise

The Model of Expertise includes all functional requirements of the system. The nonfunctional requirements, such as efficiency of the problem-solving method, maintainability of the system or persistency of data, are also considered. The function of the system is described in the Model of Expertise using first-order logic and dynamic logic for each layer of the Model of Expertise.(14)

## The Design Model

Decisions are captured within the design model, which interacts with the Model of Expertise. The Design Model allows description of data structures, algorithms, and mathematical models.(15)

Transposing the Patient Dependency functions (such as patients' data, nursing activities, and dependency levels) in a Concept Context enhances the problem-solving capabilities of the Knowledge-Based System. This close relationship with the Concept Context allows the experts to reason about real patient needs.

In other words, the Patient Dependency functions are represented in the Knowledge-Based System by:

- Four views, namely: **Data View, Function View, Nurse View** and, to realize the connection between these views, the **Control View.**
- Integration of several modeling methods, such as Entity Relationship Models and Object Oriented Approaches.
- The Concept Context which distinguishes between the four views of the Patient Dependency which are described in different layers of abstraction as follows:

1. The **Data View** describes patients, their attributes, and patient-staff relations. Furthermore, the data view contains events that can initiate and control segments in the Patient Dependency.

2. The **Function View** contains functions that are part of the Patient Dependency. It also determines, through the creation and change of objects and events, which complex function can be decomposed into more elementary ones.

3. In the **Nurse View** the relations between patient needs and the staffing required are modelled.

4. The task of the **Control View** is the integration of the first three views. The most important entities here are functions and events which are linked together to form the so-called *Event-Driven Patient Dependency*.

The Knowledge-Based System models the control flow of the Patient Dependency and links the relevant entities generated by all the views. Accordingly, functions are easily connected to their input and output data which are located in the Data View to model the Data Flow. The following figure (Fig. 3) illustrates the conceptual components of the Patient Dependency Knowledge-Based System.

## CONCLUSIONS

Experience has shown that the manual Patient Dependency method is expensive to maintain, as it requires time and effort to support. Considerable savings and benefits may be obtained if some of the Patient Dependency functions are computerized using Knowledge-Based Systems.

The Patient Dependency Knowledge-Based System is a computer software application, which seeks to replicate the problem-solving and decision-making approaches of the nursing experts. The Patient Dependency Knowledge-Based System manipulates facts, relationships between those facts, and heuristics (or rules of thumb) within a narrow and bounded patients' dependency area. During its development, a vast body of task-specific knowledge from a human is transferred into a computing environment. In contrast, traditional information technologies process alphanumerics using well-defined sequential algorithms. This means that Knowledge-Based Systems are best suited for procedure-intensive tasks, which involve the processing of large volumes of data such as Patient Dependency data.

Although many of the Knowledge-Based Systems' benefits are difficult to quantify, empirical support linking expert systems with cost savings and improved quality has been reported.[6] Increasing application of Knowledge-Based System technology will amplify a number of Knowledge-Based Systems' related social concerns.[16,17] Managers will certainly need to consider a wide range of socioeconomic factors when making decisions related to the impact of this technology. Knowledge-Based Systems technology enables human resource scarcities to be overcome through "smarter" work.[18] Many other reports indicate that KBS is helping to deliver higher quality outputs which result in increased customer satisfaction.

This technological evolution has prompted growth in the investment in Knowledge-Based Systems. This will ultimately lead to the rise of the "intelligent" hospital, where Artificial Intelligence-based products are used to achieve better quality of care, higher productivity, and profits. The Patient Dependency Knowledge-Based System can be considered an "intelligent assistant" rather than an actual expert-level decision-maker.

Knowledge-Based Systems promise higher rates of return than earlier generations of information technologies, such as EDP and DSS (Decision Support Systems). However, they typically require a larger initial investment and have a longer

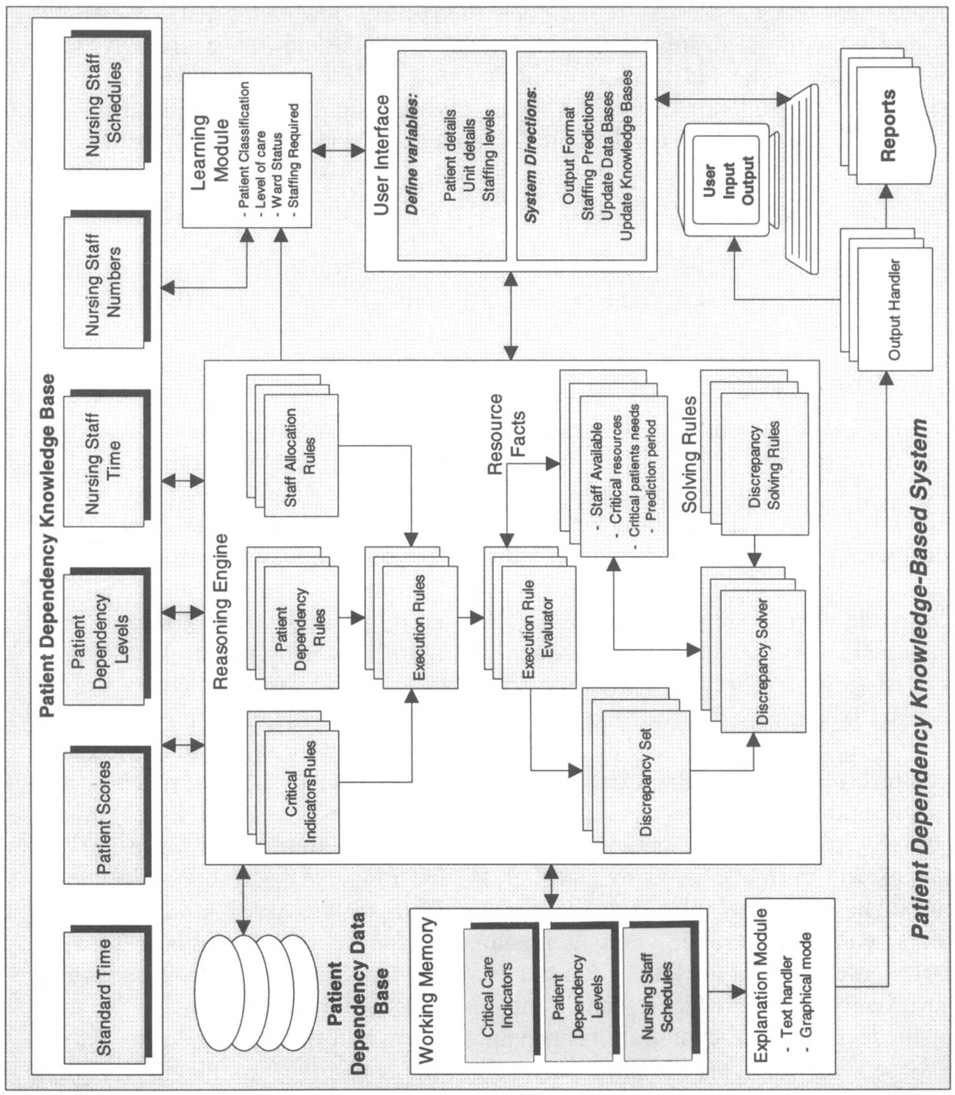


**Fig. 3.** The conceptual Patient Dependency Knowledge-Based System.

payback period.[16,19,20] The investment in this new technology can be considered similar to buying a call option on a financial security. It has been noted that such a pledge promotes organizational learning while providing the flexibility to undertake specific revenue-generating projects in the future.[8]

Patient Dependency Knowledge-Based Systems could revolutionize health care delivery, enabling both increased quality of care and lower costs. Today's exponentially rising health care costs make that transition predictable.

In conclusion, the use of Knowledge-Based Systems in hospitals will make major advances into redefining health care away from physically driven processes and toward an information-intensive system. The extent to which hospitals are cognisant of the Knowledge-Based System's multi-mission capabilities in itself does not in any way guarantee the successful implementation of a flexible strategy; rather, strategy, organizational design, and incentives must match the new opportunities offered by Knowledge-Based System's multidimensional and complex offerings.

## RECOMMENDATIONS

It is recommended that the impact of introducing the Patient Dependency Knowledge-Based System on the performance of hospitals be studied. It is envisaged that the introduction will result in social and employment concerns. This needs to be addressed.

The effectiveness of using the Patient Dependency Knowledge-Based System needs to be examined closely in a new study. The application of a Critical Path approach to enhance the Patient Dependency Knowledge-Based System needs to be evaluated in a separate study.

## ACKNOWLEDGMENTS

My sincere thanks to Dr. Margaret Wilkins for invaluable advice and proof reading the manuscript.

## REFERENCES

1. Soliman, F., Improving resource utilization through patient dependency systems. *J. Med. Sys.* 21(5):291-302, Oct 1997.
2. Soliman, F., Automation of patient dependency systems. *J. Med. Sys.* 22(4):225-236, Aug 1998.
3. Wong, S., A Study of Patient Dependency System, Master of Business Thesis. University of Technology, Sydney, 1995.
4. Hay, M., and Nelson, L., Client satisfaction: A needs approach. *J. Psychosocial Nurs.* 26:23-30, 1988.
5. Hoffman, F., Schaefer, T., and Zuraikal, N., Setting nursing hours standards, (part 1) *J. Nurs. Admin.* 16:13-16, 1986.
6. George, J., and Tyran, C. K., Expert systems and organisations: predictions and evidence, *Account. Manag. Infor. Technol.* 3:173-89, 1993.
7. Peters, T., *The Rise of the Expert Company,* Random House, New York, pp. vii–xiii, 1989.
8. Dos Santos, B. L., Justifying investments in new information technologies. *J. Manag. Infor. Sys.* 11(3):71-90, 1991.

9. Soliman, F., and Clark, J., The System Value as a critical success factor for managing the introduction of Knowledge-Based Systems. *Proceedings of the 7th World Conference on Globalisation and Entrepreneurship, ENDEC,* Supplement Proceedings, December 5-7:74-82, 1996.
10. Karlsson, C., Knowledge and material flow in future industrial networks. *Int. J. Operat. Prod. Manag.* 12(7/8):10-23, 1992.
11. Bottoms, D., Keeping up with the Joneses. *Industry Week* 244(11):55-8, June 1995.
12. Neubert, S., Model construction in MIKE (Model Based and Incremental Knowledge Engineering), current trends in knowledge acquisition—EKAW'93. *Proceedings of the 7th European Knowledge Acquisition Workshop*, Toulouse, France, LNAI 723, Springer, Berlin, 1993.
13. Landes, D., and Studer, R., The treatment of non-functional requirements in MIKE, *Proceedings of the 5th European Software Engineering Conference (ESEC'95),* Barcelona, Spain, LNCS 989, Springer, Berlin, 1995.
14. Schreiber, G., Wielinga, B., and Breuker, J. (eds.), KADS. *A Principled Approach to Knowledge-Based System Development, Knowledge-Based Systems, 11,* Academic Press, London, 1993.
15. Landes, D., Design KARL—A language for the design of Knowledge-Based Systems. *Proceedings of the 6th International Conference on Software Engineering and Knowledge Engineering (SEKE'94),* Jurmala, Lettland, pp. 78-85, 1994.
16. Sviokla, W., Expert systems and their impact on the firm. *J. Manag. Infor. Sys.* 6(3):65-84, 1990.
17. Zuboff, S., *In the Age of the Smart Machine—The Future of Work and Power,* Basic Books, New York, 1988.
18. Broderick, R., and Boudreau, J. W., Human resource management, information technology, and the competitive edge, *Acad. Manag. Exec.* 6(2):7-17, 1992.
19. Andrews, B. V., *Successful Expert Systems: Twenty-Four Studies of British Organizations with Expert Systems in Successful Operation,* FT Business, London, 1989.
20. Feigenbaum, E., McCorduck, P., and Nii, H. P., *The Rise of the Expert Company,* Random House, New York, 1989.