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Modeling and Emulation of Hcpn-based Dynamic Auxiliary Diagnosis System

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Abstract: The quality of a diagnosis system impacts the living quality and even life of patients. But regular software testing tools have difficulty in testing and evaluating the quality of a complex diagnosis system. Modeling and evaluation of a diagnosis system based on the Hierarchical Colored Petri Net before its development is highly necessary, feasible and forward-looking and can help detect loopholes and deficiency in the system and can provide informative support to the diagnosis of illness and designers of medical information system at large. Different treatment options are generated for patients with similar physical conditions but varied willingness in emulation tests on CPN tools 3.4.0. Upon comparison with 20 actual cases of the Henan Provincial People's Hospital, such system generated treatment options are substantially in line with that of the actual cases. A Gastric Cancer Dynamic Auxiliary Diagnosis System is designed in accordance such modeling and algorithm as detailed in this thesis and is proven to function regularly.

Key words: Hierarchical colored petri net, gastric cancer, treatment option

INTRODUCTION

Medical Information System has largely changed the conventional diagnosis model in that it has helped to alleviate the workload of doctors and nurses, reduce the ratio of medical errors and enhance the efficiency of hospitals. Nowadays, more and more diagnosis and research institutes are researching and developing medical information systems.

Ferrizzi *et al*. (2008) have designed a medical information system to manage a cancer databank (Petter and Fruhling, 2011). Stacie Petter and Ann Fruhling have conducted an online investigation to evaluate an emergency medical information system with contents covering system quality, information quality, use of the system, object of using the system, user satisfaction, effects on persons and organization etc (Ferrizzi *et al*., 2008). Gang Du and Zhibin Jiang have modeled and optimized the clinical pathway of osteosarcoma via the Petri Net (Du *et al*., 2011). Jrgensen has modeled a number of actual cases via the Petri Net, which provided necessary data support for the development of a diagnosis system and further proved the Petri Net has vast generality and marked advantage in modeling medical information systems (Jorgensen, 2003).

Instances 1-4 above have solved the basic problems in the design and development of a medical information system and have provided developers with successful examples and references. However, they also have deficiencies. As so many factors are involved, the tumor diagnosis system is hard to design. Currently, there are only a few tumor diagnosis systems. Instance 2 is not forward-looking as the evaluations are conducted after the system had commenced operation. Whether the centralized way of research of clinical pathway in Instance 3 is scientific or not is yet to be proved and it also failed to conduct further researches on the design of the diagnosis later on. Instance 4 modeled the clinical pathway and provided necessary data for the development of a diagnosis system but its few diagnosis schemes are mostly designed for doctors without taking the willingness of patients into account, thus hard to implement.

If anything does not go as expected after the system is established, the system may need to be re-developed all over again and medical accidents may have already been caused. Therefore, emulation tests of the feasibility and correctness of diagnosis procedures of a medical system before its development with the aim to detect and avoid errors or deficiency in its design and procedures will benefit its ensuing developments and successful operation and ultimately to the provision of technical support to diagnosis works.

The process of diagnosis of tumors is knowledge intensive and the diagnosis scheme itself is complex and difficult to memorize. In the meanwhile, the course of tumor diseases is complicated and highly variable within a long period of time. Under such circumstances, a

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rational and scientific diagnosis scheme is vital to save the life of patients and to guarantee their living quality. Usually, many factors need to be taken into consideration in the diagnosis of tumors. Firstly, the current physical conditions and state of illness of the patient need to be considered as the most important factors. Secondly, the willingness of the patient and their families also needs to be considered because the degree of cooperation of the patient has a direct influence on the ultimate effect of the treatment. Normally, the patients would consider the effect, expenses, time and the side effects etc of the treatment. In actual diagnosis, a doctor usually considers all such factors as a whole and makes a treatment option in consultation with the patient or their family so as to achieve the best treatment effect. Against such a background, this thesis, taking gastric cancer as the subject of research, proposes a new dynamic auxiliary diagnosis system which can change with the change of state of illness of patients and can be inputted by both the doctors and patients.

The diagnosis of gastric cancer involves doctors and nurses of various departments of a hospital as a typical example of flow of work. Petri Net as an effective tool for the description of flow of work has been broadly applied to many fields of work (Xiao *et al*., 2012). As a classical Petri Net has some limitations in describing complex systems, researchers have extended it to Random Petri Net, Time Petri Net, Colored Petri Net and a series of other advanced Petri Nets (Xiao and Zhong, 2011). Such advanced Petri Nets have stronger description and modeling capacity but their simulation, validation and analysis capacities are also consequently weakened (Ou-Yang and Winarjo, 2011; Xiao and Zhong, 2011). This paper mainly verifies the correctness of the procedures of our proposed dynamic gastric cancer diagnosis system against actual cases, as well as models the diagnosis system via the Hierarchical Colored Petri Net in accordance with actual needs.

HIERARCHICAL COLORED PETRI NET

Colored Petri Net, as an enhancement of the classical Petri Net, has a complete set of theoretical system and stronger description capacity for the modeling and analysis of a complex system (Ardissono *et al*., 2006).

Definition 1: Colored Petri Net (CPN) is a set of nine elements, CPN = {Σ, P, T, A, N, C, G, E, I} (Yang *et al*., 2010; Jensen and Kristensen, 2009).

Where:

- Σ is a nonempty set of colors
- P is a finite set of places
- T is a finite set of transitions and $P \cap T = \varnothing P \cup T \neq \varnothing$
- A is a finite set of arcs, $A \subseteq (PHT) \cup (THP)$
- N is a node function, where N: $A \rightarrow (PHT \cup THP)$
- C is a color function, where C: $P \rightarrow \Sigma$
- G is a guardian function: G: $T \rightarrow expr$ and:

$$\forall t \in T: \text{Type}[G(t)] = \text{Bool} \wedge \text{Type}[\text{Var}(G(t))] \subseteq \Sigma$$

- E is an arc expression function, where and:

$$\forall a \in A: \text{Type}[E(a)] = C(p)_{MS} \cap \text{Type}[\text{Var}(G(t))] \subseteq \Sigma$$

- I is an initial function, where: I: $P \rightarrow expr$ and:

$$\forall p \in P, \text{Type}[I(p)] = C(p)_{MS}$$

Hierarchical Colored Petri Net integrates the data structure and its hierarchical decomposition. It derives a complete description of the system by way of gradual elaboration from the top down or gradual combination from the bottom up. It can solve the problems caused by the large scale of modeling as faced by the classical Petri Net (Ou-Yang and Winarjo, 2011; Wang and Dagli, 2008; Staines, 2008).

Definition 2: HCPN = (S, Sn, SA, PN, PT, PA, FS, FT, PT).

Where:

- S is a finite set of pages, where every $s \in S$ is a CPN and:

$$\forall s_1, s_2 \in S: s_1 \neq s_2 \Rightarrow (P_{s1} \cup T_{s1} \cup A_{s1}) \cap (P_{s2} \cup T_{s2} \cup A_{s2}) = \varnothing$$

- $SN \subseteq T$ is a set of substitution transition nodes
- SA is a page allocation function, where: SA: $SN \rightarrow S$
- $PPN \subseteq P$ is a set of port nodes
- PT is a port type function, where, PT: $PN \rightarrow F$, F = {in, out, i/o, general}
- PA is a port allocation function. As defined in SN, the dual relationship between the socket node and port node is:

$$\forall t \in SN: PA(t) \subseteq X(t) \times PN_{SA(t)}$$
$$\forall (p_1, p_2) \in PA(t): [PT(p_2) \neq \text{general} \Rightarrow ST(p_1, t) = PT(p_2)]$$

$$\forall t \in SN: \forall (p1, p2) \in PA(t): [C(p_1) = C(p_2) \wedge I(p_1) = I(p_2)]$$

- FS is a finite set of combinations and:

$$\forall fs \in FS: \forall p1, p2 \in fs: [C(p_1) = C(p_2) \wedge I(p_1) = I(p_2)]$$

- FT is a combination type function, a function from the definition of combination set to [global, page, instance]. Both the combination node of pages and set of local nodes belong to one page:

$$\forall fs \in FS: [FT(fs) \neq global \Rightarrow \exists s \in S: fs \subseteq P_s]$$

- PT is a multi-set defining home page

CONCLUSION MODELING AND EMULATION OF DYNAMIC AUXILIARY DIAGNOSIS SYSTEM BASED-ON HCPN

Basic procedures of gastric cancer dynamic diagnosis system: It can be seen from Fig. 1 that the treatment of gastric cancer involves many doctors and nurses of the Inpatient Department, various examination departments, Department of Medical Oncology, Department of Surgical Oncology and Department of Radiotherapy etc. On the other hand, in making a patient-oriented treatment option the willingness of the patients needs to be fully considered. Therefore, the choice of patients should be inserted into the diagnosis procedures as exemplified as follows:

- Patient checks in for hospitalization at the Admission Office
- Patient goes to various examination departments for checkup
- Physician of Medical Oncology Department evaluates the state of illness of the patient against the examination results and proposes a number of treatment options for the selection of the patient or makes a treatment option in consultation with the family of the patient:

- Initial treatment stage
- Patient gets rest and recuperation
- Patient re-admits for hospitalization and, repeat procedure Eq. 3-4
- Postoperative treatment stage
- Repeat procedure Eq. 5-6
- Follow-up visit of the patient and the palliative treatment stage
- Wind up of the treatment

MODELING OF DYNAMIC AUXILIARY DIAGNOSIS SYSTEM BASED-ON HCPN

Coloring: To model the proposed dynamic auxiliary diagnosis system, the Σ in Definition One under Item 2 needs to be further specified. In the above analysis of procedures for the treatment of gastric cancer, a set of colors is defined, a number of subsets of which is further specified as follows.

Color set of patient:

- Colset PTT=product p_ID*P_NAME*P_CON*STAGE
- To record the patient's case number, name, physical conditions and treatment stage

Color set of patient, physical condition:

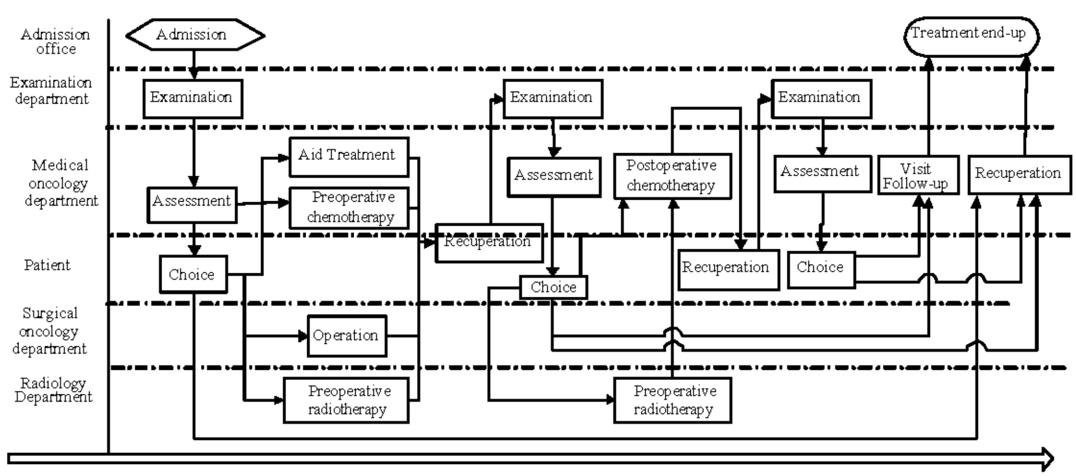

Fig. 1: Procedures for treatment of gastric cancer

- Colset CONDITION= product HEALTH*T*N*M
- The patient's physical condition includes the patient's recent physical conditions, such as blood routine and function of liver and kidney and development stage of their tumors as expressed by Period T, N, M

Color set of treatment option

- Colset SCHEME=product S_ID* S_TYPE* S_DETAIL*TIME*COST* WHOQQL
- Mainly to record the details of a treatment option, such as reference number of the option, the type of treatment, e.g. radiotherapy or chemotherapy; detailed description of the option, the expense and time needed for one course of treatment, the average score of living quality of other patients used the option, side effects of the option. WHOQQL refers to the score of living quality of the patient which is mainly assessed according to the WHOQQL-100 as issued by the World Health Organization

Color set of willingness of patient

- Colset WISH=STRING
- Mainly to record the willingness of the patient, including their requirements with respect to expense, therapeutic effect, living quality, time and side effects etc

Color set of course of disease

- Colset DA= STRING
- To record the doctor's advice, mainly the treatment option

Hierarchy: A top level Petri Net can be derived as the below Fig. 2 from the procedures of dynamic auxiliary diagnosis of gastric cancer and the basic definitions of HCPN.

As can be seen from Fig. 2, the procedures are complicated in that checkup, evaluation and selection precede each treatment stage. To simplify the procedures for following modeling and analysis, the procedures in Fig. 1 need to be revamped. As the Colored Petri Net can color different transitions and tokens of the same type, the Petri Net thus can be greatly simplified. By applying such a function, a new top level Petri Net can be derived as the following Fig. 3 by combining the colored transitions and tokens of the same type in Fig. 2.

By comparing Fig. 2 and 3, it can be found that the procedures are simplified and the description is clearer. The top level petri net consists of a number of non-basic transitions which need to be further specified. Take examination transition therapy and post chemotherapy as example, they can be further extended to sub Petri Nets as shown in the below Fig. 4 and 5.

Accessibility test: Accessibility Test refers to bounded test and activity test of the Petri Net. The simplified Dynamic Auxiliary Diagnosis Petri Net can be tested by the Accessibility Figure. The accessibility testing of Petri Net as shown in Figure Three can be represented in the following Fig. 6.

From the above Fig. 6, it can be seen that such Petri Net is bounded and accessible without deadlock and the procedures are reasonable and feasible.

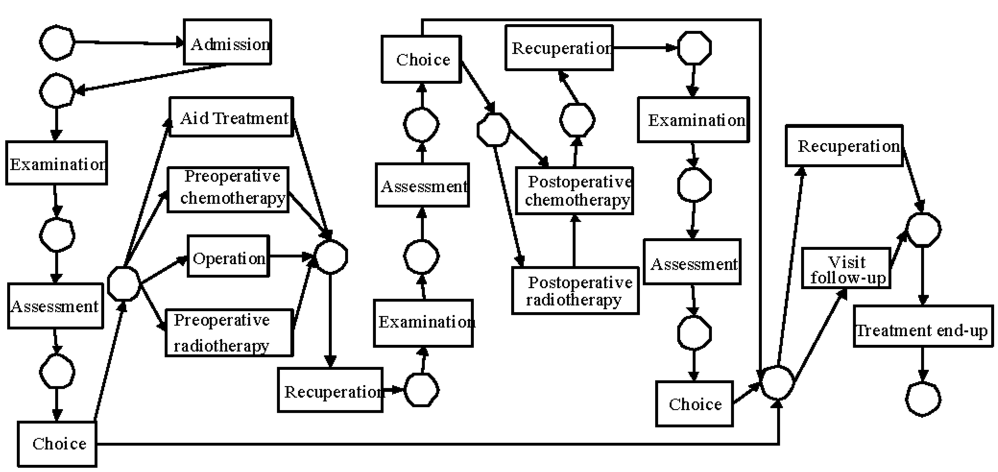

Fig. 2: Top level petri net of dynamic auxiliary diagnosis system

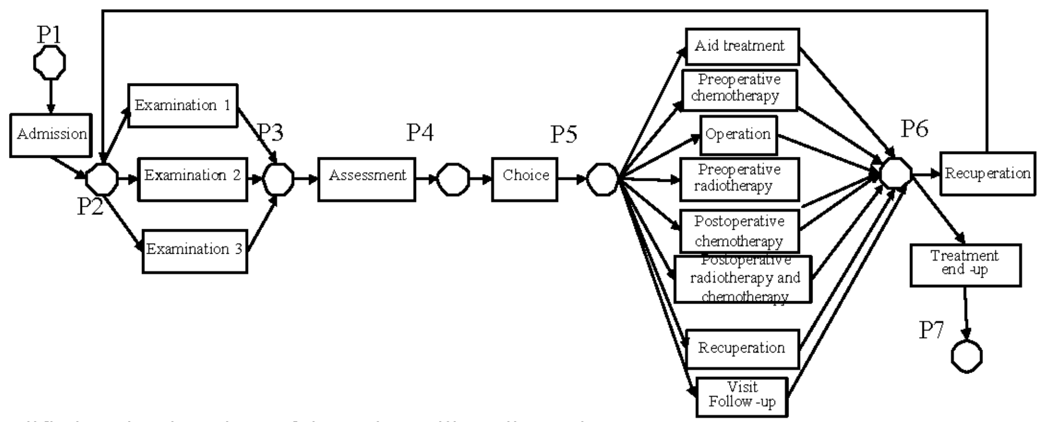

Fig. 3: Simplified top level petri net of dynamic auxiliary diagnosis system

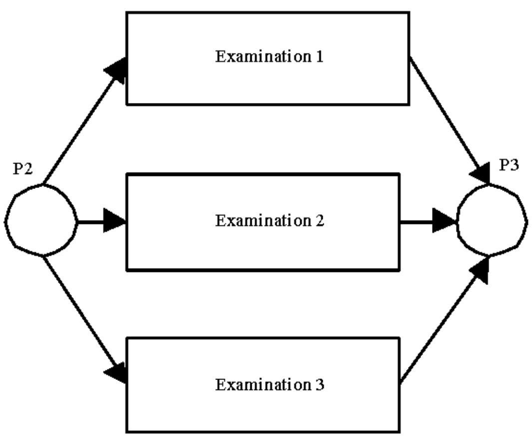

Fig. 4: Examination sub-petri net

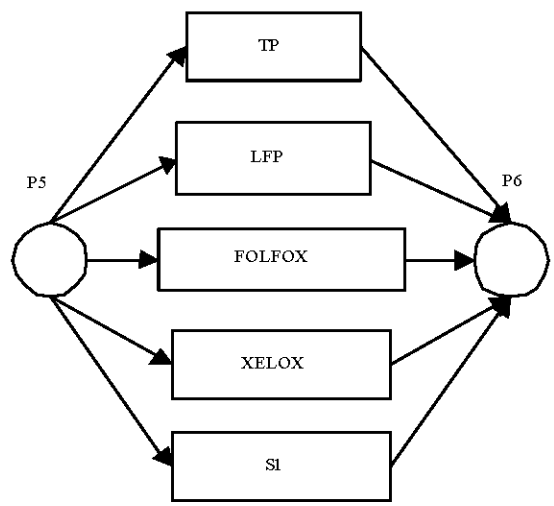

Fig. 5: Post-surgery chemical therapy sub-petri net

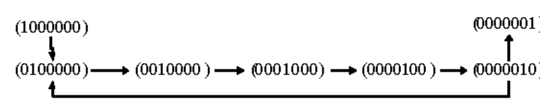

Fig. 6: Accessibility figure of dynamic auxiliary diagnosis system

Key algorithm: The "selection" transition in Fig. 3 requires taking the physical conditions and willingness of the patient into consideration as a whole in selecting the ultimate treatment option. The selection of option includes a key algorithm. Such algorithm initially makes a treatment option according to the physical conditions of the patient and if a parallel treatment option exists, selects the option as per the willingness of the patient. The algorithm is represented as follows:

Step 1: Read the treatment stage of the patient and record it as "stage"

Step 2: Read the patient,s treatment option for the stage and record the number of options as count_s1±, if count_s1=1, choose the option, otherwise go to Step Three

Step 3 Read the patient's Period T, N, M, select treatment options as per the patient's Period T, N, M and record the number of options as "count_s2", if count_s2=1, choose the option, otherwise go to Step Four

Step 4: Complete the reading of the willingness of the patient and record it as "wish"

- If "wish = Shorter Period of Time First", then read "t"-the time needed for one course of

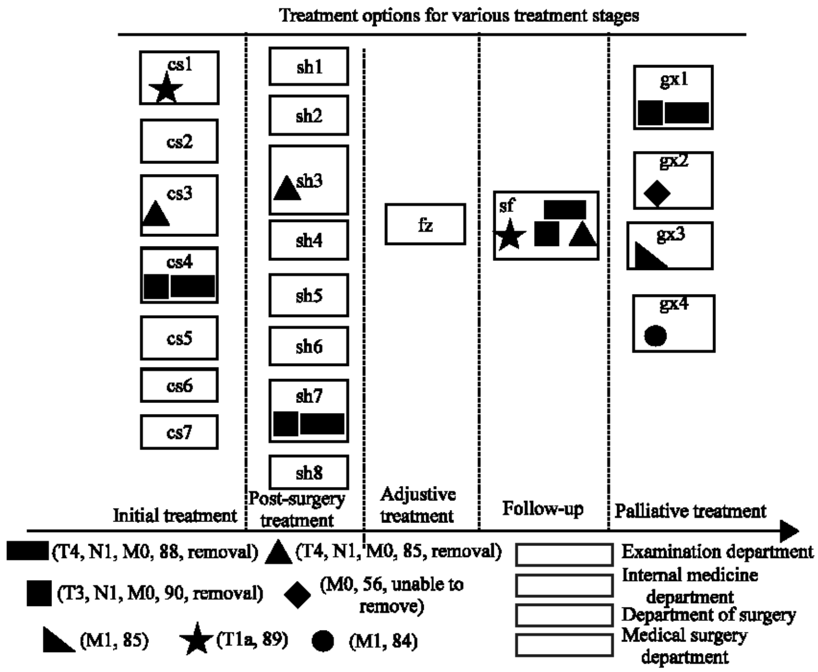

Fig. 7: Emulation results of dynamic auxiliary diagnosis system

Table 1: Selection among parallel options

Patient	Physical Condition	Option	Patient's willingness	Evaluation	Selected
▬	T4, N1, M0, 88, Tumor may be resected	sh3, sh4	Preclude Surgery		sh4
▲	T4, N1, M0, 85, Tumor may be resected	cs3,cs4,cs5	Early Treatment	$t_{cs3\_start}>$ $t_{cs3\_start}>$ t_{cs3_start}	cs3
▲	T4, N1, M0, 85, Tumor may be resected, R0	sh3, sh4	(Effect/Expense) First	$(e/c)_{(sh3)} > (e/c)_{(sh4)}$	sh3
▲	T4, N1, M0, 85, Tumor may be resected, R0	sh4, sh5	Low expense, short hospitalization time	$c_{sh4}\tilde{}c_{sh5}$	
■				$t_{sh4}>t_{sh5}$	Sh5
◆	T3, N1, M0, 90, Tumor may be resected	sh3, sh4	Afraid of Surgery		sh4
■	M0, 56, Tumor can not be resected	cs6, cs7	Living Quality First	$s_{CS7} > s_{CS6}$	cs7
■	M1, 85		Full Treatment		Gx3
●	M1	gx1, gx4	Preclude Chemotherapy		gx4

treatment in parallel options and select the option with the least "t" as the ultimate option;

- If "wish = Less Expense First", then read "c"-the cost needed for one course of treatment in parallel options and select the option with the least "c" as the ultimate option
- If "wish=Living Quality First", then read "s"-the score for living quality in parallel options and select the option with the highest "s" as the ultimate option
- If "wish" has multi choices, then select as per their priority until the ultimate treatment option is ascertained

EMULATION EXPERIMENT AND ANALYSIS

The proposed dynamic auxiliary diagnosis system is modeled and emulated on CPN tools 3.4.0 with a number of patients to be diagnosed. The physical condition and treatment options for various treatment stages of the patients are as Fig. 7.

It can be seen from the above Fig. 7 that the system generated treatment options for various treatment stages as per the physical conditions and willingness of the patients and generated different treatment options for different patients. Even for patients with similar physical conditions but different willingness, different options were generated for them. Parallel options shown in the above Figure involve factors like living quality, time and cost etc. There are a number of choices of options available for patients at various stages as indicated as Table 1.

It can be seen from Table 1 that patient ▬ and ■ get different ultimate treatment options from patient ▲ as a result of their different willingness despite the fact that they have similar physical conditions.

Upon comparison with 20 actual cases of the Henan Provincial People's Hospital, the above seven system generated treatment options are substantially in line with that of the actual cases. This proves the modeling of the diagnosis procedures is successful.

We have so developed a Gastric Cancer Auxiliary Diagnosis System based on the abovementioned model and algorithm. After a series of tests, the system is proven to be functional, effective and accurate.

CONCLUSION

This thesis has modeled and analyzed the procedures of a Dynamic Auxiliary Diagnosis System based on HCPN and has proved such procedures as reasonable and feasible. It is proven that HCPN is an effective tool for modeling of systems and HCPN-based modeling can standardize and simplify the procedures of a complex system. The successful operation of the Gastric Cancer Auxiliary Diagnosis System as established in this paper further verifies the effectiveness and feasibility of HCPN as a modeling tool. The proposed Gastric Cancer Auxiliary Diagnosis System is proved to be an effective and feasible diagnosis system that can provide informative support and reference for the selection of treatment options and ultimately can alleviate the workload of doctors and nurses.

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