In hospitals, the anesthesia preoperative evaluation clinic (APEC) is an integrated service designed to give patients an in-depth understanding of their scheduled operations and help physicians evaluate operative risks when preparing anesthetic care plans. APEC services can increase patient satisfaction and quality of care and decrease hospital operational costs and the number of last-minute surgical cancellations.1-3 Led by the anesthesiology department, the APEC helps anesthetists evaluate patient risk factors toward scheduled surgeries.1,4-7 and is a crucial clinical assessment. This evaluation includes risks associated with the patient’s physical status, functional capacity, and type of planned surgery. Additionally, the risks of cardiac complications and stroke as defined by medical guidelines and literature should be embedded in the evaluation to help decrease postoperative morbidity and mortality.8-11 After the evaluation, anesthetists can calculate the patient’s surgical risks and decide on a proper anesthetic care plan. Because this decision crucially affects quality of care, anesthetists must receive...
adequate patient information and updated risk factor calculation algorithms. Many hospitals have utilized IT to computerize the APEC and enhance the performance of clinic procedures. However, the computerized APEC systems used in most hospitals focus mainly on administrative functions, such as displaying patient records, collecting patient information, improving routine clinical documentation, and supporting organizational billing accuracy.

The APEC support system we describe here focuses more on the functionality of risk factor calculation algorithms than on administrative functions. This APEC support system provides a guideline-based clinical assessment procedure for anesthetists to stratify patients’ risk factors, calculate operative risks, and recommend an anesthesia care plan. The system architecture was designed and developed with multitier IT so that it can be systemically updated with the latest medical guidelines and literature without requiring users to change user interfaces. The completed system was tested by a group of anesthetists at Chang Gung Memorial Hospital, a research hospital located in southern Taiwan.

Method
The APEC support system designed in our study aims to facilitate a guideline-based risk factor estimation capacity that gives anesthetists the latest medical references and encodes the recommended risk factor information in their routine clinical procedures. Thus, anesthetists will have the latest medical information for preoperative anesthesia assessments, and the anesthesiology department will have cohesive knowledge about clinical practices for quality care. The multidisciplinary development team formed for this study included one experienced anesthetist, two medical informatics experts, and one software engineer. The design scenario was based on the clinical operations of the anesthesiology department at Chang Gung Memorial Hospital.

APEC Support System Design
Our study aimed to integrate dynamic medical references related to anesthetic risk factors with a relatively static user interface in a fast-paced clinical environment. System functionality needed to support anesthetists with the latest medical references, interfaces for stratifying patient risk factors, and the results of estimated risk of scheduled surgeries. Providing domain knowledge with respect to risk factor estimation and developing a system architecture for future operation and maintenance were our two main concerns for the design.

Domain knowledge. The system includes three domain knowledge references to support clinical activities. The first is the Goldman Revised Cardiac Risk Index (RCRI), which identifies six risk factors: high-risk surgical procedures, a history of ischemic heart disease, a history of congestive heart failure, a history of cerebrovascular disease, preoperative treatment with insulin, and preoperative renal treatment. According to the presence of 0, 1, 2, or ≥ 3 predictors, the rate of major cardiac complications was estimated as 0.4, 1.0, 2.4, and 5.4 percent, respectively. The second reference is a stroke risk prediction medical reference that depicts stroke risk after various surgical procedures. The third is a structured and stepwise risk-prediction procedure, released by the American College of Cardiology and the American Heart Association (ACC/AHA); this guideline estimates the risk factors as urgency of surgery, patient’s active cardiac conditions, risk of surgery, patient’s functional capacity, and clinical conditions.

During the process, anesthetists can interact with patients, review patients’ current physical status, decide the adequate risk for each step, or go back to previous steps when and if new evidence becomes available. The three guideline-based risk factor assessment steps are then calculated and finalized as an anesthesia evaluation report. Anesthetists can review or revise the estimated risk, add their opinions, and decide on a proper anesthetic care plan for patients.

System architecture. The APEC support system is not very complex, nor is it a large-scale deployment. However, the system’s operational environment requires friendly user interfaces in a fast-paced clinical setting, and the system needs a structure that is easy to maintain and update with the latest medical references; it must also be able to revise the risk-calculation algorithm embedded in the risk-assessment steps with minimal effort. To meet these operational conditions, a three-tier system architecture from software engineering was adopted to allow flexibility in system development and maintenance. The system has...
• a user interface tier to provide anesthetists with a stepwise risk assessment function and a knowledge maintenance function;
• a business rule tier to collect risk factors input by anesthetists, calculate identified risks based on the medical references in the data storage tier, and present the estimated results on the user interface tier; and
• a data storage tier to record patients’ clinical information and append it to their medical records.

Medical references are also maintained in the data storage tier. Each tier can be designed and developed separately and then integrated later to form a whole system. When and if new requirements emerge, each tier can also be maintained or revised individually. Thus, the latest medical references can be included in the data storage tier without changing the user interface, and the risk calculation algorithm can be revised in the business rule tier. Figure 1a depicts the user interface workflow, the business rule steps, and the medical references in the architecture’s data storage tier. Figure 1b illustrates how new medical references are included in the system.

A series of friendly user interfaces was developed to facilitate risk assessment for anesthetists. Although anesthetists might have different levels of knowledge and experience with certain medical conditions, the guideline-based workflow can provide the latest risk information and the necessary evaluation procedure reminders. For instance, Figures 2a and 2b offer information on the latest cardiovascular and stroke risk factors. Figure 2c reminds the user of the evaluation procedures regarding patient physical conditions and lists sample questions anesthetists should use to interact with patients. Figure 2d presents the risk calculation results with a recommended anesthesia plan.

**APEC Support System Evaluation**

After medical domain knowledge was integrated into the system, it was ready to be evaluated in a real-world setting.

**Anesthetist enrollment.** With 26 anesthetists, the anesthesiology department at Chang Gung Memorial Hospital was selected to participate in the acceptance test of the APEC support system. This department is a busy clinical environment, and enrolling all anesthetists for the system evaluation was a challenge. The evaluation procedures were coordinated with the department and lasted three days in a real-world clinical situation. The APEC support system was installed on the same computer as the hospital information system, but a separate monitor was used for projection. A trained research assistant oriented anesthetists to the system functions before the
The first patient came in for evaluation. The anesthesiologists then used the system to assess patients’ risk factors and plan surgery. When the day’s clinical session was over, an acceptance questionnaire was given to the anesthesiologists to assess their perceptions of the APEC support system. During the three-day period, 14 anesthesiologists completed system evaluations and questionnaires.

Evaluation model. System acceptance was evaluated using the technology acceptance model (TAM), which has been widely used to test the acceptance level of new systems in many healthcare domains. TAM can be used to better understand causal relationships with regard to user perceptions toward different system aspects and to estimate the system’s acceptance level.18,19 The model utilizes several constructs for assessment. Perceived usefulness (PU) indicates the degree to which a user believes that using the system would enhance his or her job performance. Perceived ease of use (PEOU) depicts the degree to which a user believes that using the system would be free of additional effort. PU and PEOU are used to estimate the intention to use (ITU), which indicates the degree to which a user accepts the system. The TAM questionnaire is available as a Web extra at https://extras.computer.org/extra/mit2017010027s1.pdf.

Results
As mentioned, 14 out of 26 anesthesiologists (53.85 percent) in the department participated in the acceptance test. Of these 14 anesthesiologists, eight were male (57.14 percent), and six were female (42.86 percent). Ten held bachelor’s degrees (71.43 percent), three had master’s degrees (21.43 percent), and one held a doctoral degree (7.14 percent). Ages ranged from 31 to 56 years old, with a mean of 38.7. The years of anesthesia experience ranged from 5 to 27 years, with a mean of 11.6. All anesthesiologists knew the ACC/AHA guideline, and 13 used it as supportive information for patients’ risk factor assessment.

Acceptance Test
The test results indicate that the majority of anesthesiologists perceived the system to be useful and easy to use in supporting their APEC operations, and they intended to use the system in the future. Figure 3 shows anesthesiologists’
responses in terms of PU, PEOU, and ITU. The mean and standard deviation of PU, PEOU, and ITU were 14.28/1.83, 7.14/1.09, and 14.78/2.39, respectively.

The correlation analysis indicates that PU and PEOU are significantly positively correlated with ITU. PEOU also has a significant positive correlation with PU. Table 1 displays the means and standard deviations of each construct as well as the correlations among the constructs.

The regression analysis depicted that PU correlated to ITU with a coefficient estimate of 0.337, which is significant with a p-value of 0.0367; and PEOU correlated to ITU with a coefficient estimate of 0.315, which is significant with a p-value of 0.0068. Together, the correlation of PU and PEOU to ITU is also significant, with two coefficient estimates of 0.023 and 0.0260, where the corresponding p-values are 0.0766 and 0.0157, respectively. The regression analysis results, with corresponding p-values, are shown as follows:

\[
\begin{align*}
\text{ITU} &= 2.38 + 0.337\text{PU} \quad (p = 0.0367) \\
\text{ITU} &= 2.48 + 0.315\text{PEOU} \quad (p = 0.0068) \\
\text{ITU} &= 0.023\text{PU} + 0.260\text{PEOU} \quad (p = 0.0766; 0.0157)
\end{align*}
\]

We use t statistics to test the significance of the predictor variables in equations 1 through 3. For the two-side test, the p-value is defined as \( p = P(|T| > |t^*|) \), where \( T \) stands for the student T-distribution with a corresponding degree of freedom, and \( t^* \) stands for the value of the test statistics. The p-value for each term tests the null hypothesis that the coefficient is equal to zero (no effect). A low p-value (< type 1 error; \( \alpha \)) indicates that we can reject the null hypothesis. Hence, the predictor variables in the three regression models are all significant for \( \alpha = .10 \).

**Discussion**

The APEC support system was designed to facilitate anesthetists’ risk factor assessment in their clinical environments. Instead of emphasizing clinic administrative routines, such as displaying and storing patients’ medical records, the system focuses on knowledge and decision support. The results from the TAM acceptance evaluation indicate that the functionalities designed and the algorithms embedded in the system were perceived to be useful for conducting clinical risk assessment. Moreover, the system’s workflow and interface designs also obtained high PEOU mean scores, indicating that the anesthetists perceived the system to be easy to use. The correlation analysis results indicate positive high correlations between PU, PEOU, and ITU constructs, suggesting that the anesthetists have high intention to use the APEC support system in their clinical environments. The linear regression analysis also indicates that the increases in the system functionality’s usefulness and the system interfaces’ ease of use significantly increase anesthetists’ intention to use the system.

From a software engineering perspective, the three-tier system architecture is not a new or difficult design. Most software developers can use off-the-shelf web application languages and relational database tools to develop such a system. However, the real challenge lies in the communication between domain experts and software developers. The experienced anesthetist in our study patiently explained to the software developers the risk factor calculation algorithm from the guidelines and described the necessary clinical user interfaces. The software developer had to learn the domain knowledge terminology and expose herself to the busy clinical environment during development. The system underwent several revisions before going online for practical evaluation. After evaluation, a further revision will be required before the system can be fully deployed in the clinic.

![Figure 3. Anesthetists’ level of agreement on perceived usefulness (PU), perceived ease of use (PEOU), and intention to use (ITU). For this evaluation, 1 = strongly disagree, 2 = disagree, 3 = no comment, 4 = agree, and 5 = strongly agree.](image)
Obviously, our study lacked this full deployment, which would show how the system could integrate with the hospital’s main health information system. In our evaluation, the anesthetists had to review patient medical records from a different screen, copy risk assessment information from the APEC support system, and paste this information back into the patient’s medical record. Three out of 14 anesthetists (21 percent) commented on the integration issue in the open-ended questions. However, 11 out of 14 anesthetists (79 percent) also commented that the system is effective in handling their clinical activities. Overall, the results show that the three-tier system architecture for developing a guideline-based APEC support system can advance our knowledge and experience for promoting other preoperative anesthesia-related systems in the future.

The study responds to a real clinical requirement with the development and evaluation of the APEC support system. The major difference between our system and other anesthesia information management systems is its focus on the support functionality, which facilitates domain knowledge management for the anesthetists and the anesthesiology department. The anesthetists can receive the latest medical information for their risk factor assessments, and the department can obtain cohesive clinical activities for quality care. Future research will focus on a full deployment of the system in clinical environments and analyze the system performance from both operational and organizational perspectives.

References


**Shu-Man Chang** teaches in the Center for General Education at Chang Gung University, Taiwan. Her research focuses on computer-aided engineering, life and medical sciences, social networking, and health promotion. Contact her at amanda@mail.cgu.edu.tw.

**Yan-Yuen Poon** is an attending anesthesiologist at Kaohsiung Chang Gung Memorial Hospital, Taiwan. His current research focuses on the interaction of the sympathetic and parasympathetic systems in diabetes as a predictor for anesthesia risks. Contact him at elephant423@yahoo.com.tw.

**Chun-Yi Lin** teaches in the Department of Information Management at Chang Gung University, Taiwan. His research interests include health information management, quality management, production management, and data mining. Contact him at chunyi@mail.cgu.edu.tw.

**Yung-Hsiu Lin** teaches in the Department of Information Management at Chang Gung University, Taiwan. His research focuses on service description and modeling of healthcare applications. Contact him at lin021060@gmail.com.

**Ping Pete Chong** taught in the College of Business and Design at Ming Chi University of Technology, Taiwan. His research interests were in the modularization and integration of business systems, content design, and theory and applications of the Pareto Principle.

**Her-Kun Chang** is a joint professor in the Graduate Institute of Business and Management and the Department of Information Management at Chang Gung University, Taiwan. His current research interests include health information management, distributed information processing, data mining, and mobile technology-enabled services. Contact him at hkchang@mail.cgu.edu.tw.