



UNIVERSITY
OF WOLLONGONG
AUSTRALIA

University of Wollongong
Research Online

Faculty of Engineering and Information Sciences -
Papers: Part B

Faculty of Engineering and Information Sciences

2017

The effect of nursing participation in the design of a critical care information system: a 4 case study in a Chinese hospital

Yanhong Qin

Hospital of PLA, Beijing

Ranyun Zhou

Hospital of PLA Beijing

Qiong Wu

Hospital of PLA Beijing

Xiaodi Huang

Hospital of PLA Beijing

Xinli Chen

Hospital of PLA Beijing

See next page for additional authors

Publication Details

Qin, Y., Zhou, R., Wu, Q., Huang, X., Chen, X., Wang, W., Wang, X., Xu, H., Zheng, J., Qian, S., Bai, C. & Yu, P. (2017). The effect of nursing participation in the design of a critical care information system: a 4 case study in a Chinese hospital. *BMC Medical Informatics and Decision Making*, 165 (17), 1-12.

Research Online is the open access institutional repository for the University of Wollongong. For further information contact the UOW Library:
research-pubs@uow.edu.au

The effect of nursing participation in the design of a critical care information system: a 4 case study in a Chinese hospital

Keywords

care, critical, system:, 4, hospital, information, chinese, case, participation, nursing, design, effect, study

Disciplines

Engineering | Science and Technology Studies

Publication Details

Qin, Y., Zhou, R., Wu, Q., Huang, X., Chen, X., Wang, W., Wang, X., Xu, H., Zheng, J., Qian, S., Bai, C. & Yu, P. (2017). The effect of nursing participation in the design of a critical care information system: a 4 case study in a Chinese hospital. *BMC Medical Informatics and Decision Making*, 165 (17), 1-12.

Authors

Yanhong Qin, Ranyun Zhou, Qiong Wu, Xiaodi Huang, Xinli Chen, Weiwei Wang, Xun Wang, Hua Xu, Jing Zheng, Siyu Qian, Changqing Bai, and Ping Yu

1 Journal: BMC Medical Informatics and Decision Making

2

3 Title page

4 Title: The effect of nursing participation in the design of a critical care information system: a
5 case study in a Chinese hospital

6 Short title: Participatory design of a critical care information system by nurses in China

7

8 Yanhong Qin^{1*}, Ranyun Zhou^{2*}, Qiong Wu², Xiaodi Huang³, Xinli Chen¹, Weiwei Wang¹,
9 Xun Wang¹, Hua Xu¹, Jing Zheng¹, Siyu Qian⁴, Changqing Bai¹, Ping Yu⁴

10

11 Yanhong Qin ¹Department of Pulmonary & Critical Care Medicine, 307th Hospital of
12 PLA, Beijing 100071, China. qinyanhong1023@sina.com

13 Ranyun Zhou ²Department of Nursing, 307th Hospital of PLA, Beijing 100071, China.
14 zhoury307yyhlb@163.com

15 Qiong Wu ²Department of Nursing, 307th Hospital of PLA, Beijing 100071, China.
16 hkhl2yz@163.com

17 Xiaodi Huang ³Department of Biomedical Engineering, 307th Hospital of PLA, Beijing
18 100071, China. hxdpunk@163.com

19 Xinli Chen ¹Department of Pulmonary & Critical Care Medicine, 307th Hospital of
20 PLA, Beijing 100071, China. 572469084@qq.com

21 Weiwei Wang ¹Department of Pulmonary & Critical Care Medicine, 307th Hospital of
22 PLA, Beijing 100071, China. 1013855013@qq.com

23 Xun Wang ¹Department of Pulmonary & Critical Care Medicine, 307th Hospital of
24 PLA, Beijing 100071, China. 1260996156@qq.com

25 Hua Xu ¹Department of Pulmonary & Critical Care Medicine, 307th Hospital of PLA, Beijing
26 100071, China. 1697907561@qq.com

27 Jing Zheng ¹Department of Pulmonary & Critical Care Medicine, 307th Hospital of
28 PLA, Beijing 100071, China. studentzj0921@163.com

29 Siyu Qian ⁴Centre for IT-enabled Transformation, School of Computing and Information
30 Technology, University of Wollongong, Wollongong NSW 2522, Australia.
31 sq992@uowmail.edu.au

32 Changqing Bai ¹Department of Pulmonary & Critical Care Medicine, 307th Hospital of
33 PLA, Beijing 100071, China. mlp1604@sina.com

1 Ping Yu ⁴Centre for IT-enabled Transformation, School of Computing and Information
2 Technology, University of Wollongong, Wollongong NSW 2522, Australia.
3 ping@uow.edu.au

4

5 *These authors contributed equally as the first authors.

6

7 Corresponding author 1: Ping Yu, Centre for IT-enabled Transformation, School of
8 Computing and Information Technology, University of Wollongong, Wollongong NSW 2522,
9 Australia. ping@uow.edu.au

10 Corresponding author 2: Changqing Bai, Department of Pulmonary & Critical Care
11 Medicine, 307th Hospital of PLA, Beijing 100071, China. mlp1604@sina.com

12

13

14

1 **Abstract**

2 **Background:** Intensive care information systems (ICIS) are continuously evolving to meet
3 the ever changing information needs of intensive care units (ICUs), providing the backbone
4 for a safe, intelligent and efficient patient care environment. Although beneficial for the
5 international advancement in building smart environments to transform ICU services,
6 knowledge about the contemporary development of ICIS worldwide, their usage and impacts
7 is limited. This study aimed to fill this knowledge gap by researching the development and
8 implementation of an ICIS in a Chinese hospital, nurses' use of the system, and the impact of
9 system use on critical care nursing processes and outcomes.

10 **Methods:** This descriptive case study was conducted in a 14-bed Respiratory ICU in a
11 tertiary hospital in Beijing. Participative design was the method used for ICU nurses, hospital
12 IT department and a software company to collaboratively research and develop the ICIS.
13 Focus group discussions were conducted to understand the subjective perceptions of the
14 nurses toward the ICIS. Nursing documentation time and quality were compared before and
15 after system implementation. ICU nursing performance was extracted from the annual
16 nursing performance data collected by the hospital.

17 **Results:** A participative design process was followed by the nurses in the ICU, the hospital
18 IT staff and the software engineers in the company to develop and implement a highly useful
19 ICIS. Nursing documentation was fully digitized and was significantly improved in quality
20 and efficiency. The wrong data, missing data items and calculation errors were significantly
21 reduced. Nurses spent more time on direct patient care after the introduction of the ICIS. The
22 accuracy and efficiency of medication administration was also improved. The outcome was
23 improvement in ward nursing performance as measured by ward management, routine
24 nursing practices, disinfection and isolation, infection rate and mortality rate.

1 **Conclusions:** Nurses in this ICU unit in China actively participated in the ICIS development
2 and fully used the system to document care. Introduction of the ICIS led to significant
3 improvement in quality and efficiency in nursing documentation, medication order
4 transcription and administration. It allowed nurses to spend more time with patients to
5 improve quality of care. These led to improvement in overall nursing performance. Further
6 study should investigate how the ICIS system contributes to the improvement in decision
7 making of ICU nurses and intensivists.

8 **Keywords:** Critical care, intensive care, ICU, information system, electronic health records,
9 EHR, nursing documentation, nurse, implementation, user-centred design, participatory
10 design, evaluation

11

1 **Background**

2 With rate up to 70%, failure of health information technology (HIT) project is a widespread,
3 significant problem [1]. The “design and reality gap” underpins HIT failure [2]. The socio-
4 technical nature of HIT calls for its design and development to be user centred [3]. Therefore,
5 user participation, better tools for modelling the relevant healthcare processes and better
6 management of the development project are recommended to reduce the risks for HIT failure
7 [3].

8 The first intensive care unit (ICU) in China was established in Beijing in 1982 [4]. Although
9 intensive care medicine was only officially recognized by the Ministry of Health as a clinical
10 specialty in 2009 [2], many ICU units have been established in hospitals around the country
11 since then [1]. In line with the international trend of ageing population and high demand for
12 specialised, high quality hospital services [5], intensive care is also the fastest growing
13 hospital specialty in China.

14 Although only a “young” speciality in the family of hospital health care, the processes of
15 intensive care nursing have been steadily improving, as have other specialties in Chinese
16 hospitals. The driving force has been the government health reform program [6] underpinned
17 by the hospital accreditation standards. Internationally, nurses in ICU face high levels of
18 stress due to the challenges of meeting the complex needs of critically ill patients and their
19 families [7]. Therefore, many hospitals in China are implementing strategies and innovations
20 to optimize nursing processes to improve efficiency and patient and society satisfaction.

21 Translation of knowledge into rational care is as essential and pressing as the development of
22 new diagnostic or therapeutic devices, and is arguably even more important [8]. However, a
23 lack of information required for clinical and managerial decisions has been one of the major
24 problems in ICUs internationally [9, 10]. As the major assembly point for critically ill
25 patients in a hospital, each patient in the ICU will generate a large volume of data.

1 Information and communication technology (ICT) has and will continue to play an important
2 role in managing the data to improve patient care [8] in daily clinical services [5]. Together
3 with engineering strategies, ICT provides an excellent opportunity to improve the design of
4 hospital care [5].

5 Despite its importance, Lapinsky et al. found the use of fully integrated intensive care
6 information systems (ICIS) was still not common in 2008 [11]; only 46% of ICUs in 50
7 hospitals in Canada introduced medication administration records, even fewer (26%) used
8 computerised nursing notes.

9 Several authors have suggested that computerised nursing information systems are among the
10 optimal choices to improve nursing care in ICUs [5, 12]. Bosman et al. found that the use of
11 an ICIS in patients after cardiothoracic surgery alters nursing activity; it reduces time for
12 documentation and increases time for patient care [13]. Hoekstra et al. found that
13 computerized potassium control, integrated with the nurse-centred GRIP program for glucose
14 regulation, is effective and reduces the prevalence of hypo- and hyperkalaemia in the ICU
15 compared with physician driven potassium regulation [14]. Nyholm et al. suggested that the
16 use of nurse checklists in a bedside computer-based information system may elevate nursing
17 alertness to avoid secondary insults and help in the evaluation of patients' conditions [15].

18 Conroy et al. found evidence of improvements in the delivery of essential daily care
19 processes after introduction of a valid e-checklist to the morning ward rounds in an ICU [16].

20 Yusof finds that most nursing staff have a positive perception of an ICIS in reducing
21 documentation and data access time, and giving them more time with patients [17].

22 To date there is no refereed paper reporting ICIS development, implementation, usage and
23 impact from Asian countries including China. The international research community have no
24 knowledge about whether and how ICIS is introduced and used by nurses in China, and what
25 are the impacts of Chinese nurses' use of ICIS on their work practices and performance. Lack

1 of this knowledge is a serious impediment for the international advancement of intensive care
2 as a medical specialty and ICIS as an effective tool to support intensive care services.
3 Critical care research in China is still in its infancy [4]. Although many ICU units in China
4 have been or are in the process of computerising their clinical care processes to improve
5 quality, safety and productivity, these clinical ICT innovations need to be rigorously
6 evaluated to ensure they deliver the intended benefits and avoid the potential hazards and
7 unintended negative consequences reported elsewhere [18, 19]. Therefore, taking a case study
8 approach, this research investigates the active participation of nurses in the design,
9 development and implementation of an ICIS in a Chinese hospital, and the effect of the ICIS
10 introduction on nursing care processes and outcomes. In order to provide a clear conceptual
11 model of the nurses' participation in the ICIS design, we first review the literature on
12 participatory design.

13 **Participatory design**

14 The goal of participatory design is to establish a more human, creative and effective
15 relationship between the actors involved in technology's design and its use so as to generate a
16 user-friendly digital ecosystem [20]. The participation of the intended users, including
17 managers, internal design professionals, and users, in technology design is seen as one of the
18 preconditions for good design in an organisational context [21]. The three key participatory
19 design issues [22] are (1) the politics of design, (2) the nature of participation, and (3)
20 methods, tools and techniques for carrying out such projects. The four major steps of
21 participatory design projects are (1) initial exploration of work, (2) discovery processes, (3)
22 prototyping [23], and (4) organizational implementation [3].

23 *The politics of design*

24 The organizational contexts are important for the success of participatory design projects [22].
25 These include the distribution of power in the workplace, the rationales for participation and

1 the ways that differently positioned actors within an organization influence technology design
2 and implementation [24].

3 *The nature of participation*

4 The nature of participation can be conceptualised in three dimensions: (1) access to relevant
5 information [25], (2) the opportunity for taking an independent position on the problems, and
6 (3) participation in decision making [3]. Design professionals need knowledge of the actual
7 use context and workers need knowledge of possible technological options. These types of
8 knowledge are developed most effectively through active cooperation between workers and
9 designers within specific design projects. Although the projects are likely to be initiated by
10 the managers or design professionals, a real commitment by the actors at various levels of an
11 organisation over the direction and outcome is required for project success [21]. This calls for
12 careful consideration of the choice of user participants and the forms of participation. The
13 choice can be made in consideration of the motivations for participation, the scope of
14 participation, and the resources allocated for the project. In addition, the relations between
15 those actively take part in the project and those who do not should be carefully considered
16 and attended to throughout the project so as to sustain the influence of the project beyond its
17 immediate lifecycle [26].

18 *Methods, tools and techniques for participatory design*

19 Many participatory design methods have been developed, such as cooperative experimental
20 systems development method, prototyping experiments, and work-oriented design.

21 Cooperative experimental systems development method is characterized by a focus on active
22 user involvement throughout the entire development process [11]. Prototyping experiments
23 closely couple with work situations and use scenarios to transform results from early
24 cooperative analysis/design to targeted object-oriented design, specification and realization;
25 and design for tailorability. A “work-oriented design” approach advocates a combination of
26 field studies of work with case-based prototyping [27].

1 Tools and techniques are needed to facilitate designers to learn the everyday work practices
2 of potential users, for workers to learn about the technical options, and for both to connect
3 current and future work practices with envisioned new technologies. The useful tools and
4 techniques for work analysis include visualization, reviewing written materials,
5 questionnaires, interviews and ethnographic techniques [3]. Visualizations are useful for
6 representing the relations between technology and work [28], the same as questionnaires and
7 interviews [3]. Reviewing written materials and observing current technologies in use can
8 inspire the design of potential technical solutions. Ethnographic techniques such as open
9 ended interviews and observations can generate insights into workers' tacit knowledge and
10 develop shared views on the work.

11 The tools and techniques for system design include scenarios, mock-ups, simulations of the
12 relation between work and technology, future workshops, design games, case-based
13 prototyping and cooperative prototyping [29, 30]. These tools and techniques can avoid the
14 overly abstract representations of traditional design approaches and allow workers and
15 designers to more easily experiment with various design possibilities in cost effective ways.
16 Gronback et al. [30] advocate the use of cooperative prototyping where users and designers
17 collectively explore the functionality and form of applications as well as their relations to the
18 work in question. This type of cooperation requires access to adequate prototyping tools, and
19 the availability of workers' actual work materials for case-based prototyping. The prototypes
20 act as "catalysts" and "triggers" in discussion about the relations between work and
21 technology, leading to mutual learning.

22 **Methods**

23 **Case study site**

24 The case study site is the 14-bed respiratory ICU in the Department of Pulmonary & Critical
25 Care Medicine in 307th Hospital of PLA in Beijing, China. The hospital is a tertiary hospital

1 with 1,500 beds. The Respiratory ICU was established in 2009, the same year intensive care
 2 was recognised as a medical specialty by the Chinese Ministry of Health. In total, there were
 3 27 nurses in the specialty. The demographic profiles of the nurses are listed in Table 1. The
 4 nurses worked in two 12 hour shifts, day shift and night shift.

5 **Table 1. Demographic information of the registered nurses in the ICU in May 2016.**

Age (Years)	No. of persons (%)
20 – 25	7 (26%)
26 – 30	17 (63%)
30 – 40	3 (11%)
Sex	
Female	23
Male	4
Nursing education level	
3-Year higher education diploma	14 (52%)
4-Year Bachelor	13 (48%)
Nursing work experience	
<=3 years	6 (22%)
3 – 5 years	15 (56%)
>5 years	6 (22%)

6

7 **The development of the ICIS**

8 *Project initiation*

9 The first author, who was the Director of Nursing (DON) in the ICU, expressed her wish of
 10 introducing certain information system to reduce the burden of nursing documentation, and to
 11 “return nurses to patients” with the Chief Information Officer (CIO) in the hospital in 2012.
 12 After initial market research including site visits to two hospitals in Beijing with
 13 sophisticated IT systems and discussions with various HIT vendors, YQ, CB and the CIO
 14 came to the conclusion that there was no readily available ICIS that could meet the needs of
 15 the ICU nursing. The team had to develop an ICIS onsite.

16 *The project team*

17 The project team was coordinated by then CIO in the hospital. YQ was responsible to provide
 18 domain knowledge and resources, five nurses (22%) in the unit (XC, WW, XW, HX and JZ)
 19 participated in the project team. A manager in the company led the technical team. The team

1 members included one to two software engineers in the Department of Biomedical
2 Engineering in the hospital, all of the authors for the paper except SQ and PY, and three to
3 eight software engineers from the company at the various software development stages.

4 *The politics of design*

5 As the initiator of the ICIS development, the nursing team was actively driving the
6 development, providing the engineers with access to the ICU knowledge and resources. An
7 engineer could conduct ethnographic observation in the ICU upon informing the DON and
8 without disturbance to the unit operation. Excited by the opportunity of leading the
9 development of ICIS innovation in China, the CIO was highly enthusiastic, allocated one to
10 two biomedical engineers in the Department of Biomedical Engineering in the hospital to the
11 project, as well as the office space for use by the engineers in the company for software
12 development. Motivated by the opportunity to enter the market of ICIS, the management in
13 the company made the strategic decision to invest resources in building the ICIS, using the
14 hospital ICU as an experiment and test site. With the appropriate administrative position in
15 the organization, the CIO acted as the general manager for the project.

16 Therefore, a shared goal that united the three collaborating partners together was producing a
17 high quality ICIS to strengthen the position of nurses in their efforts to improve working
18 conditions and quality of work life. The initial nursing requirement for the system was
19 automating the nursing documentation system, real-time data capture from numerous ICT
20 equipment, and automatic generation of the one-page 24-hour special nursing care form.

21 *The nature of participation*

22 The common goal motivated the team to communicate, negotiate, compromise and
23 collaborate in the participative design process. To solve the challenge of ambiguity of
24 requirements and difficulty in understanding the view point of each other, the engineers and
25 the nurses really collaborated to understand each other. Patience, collegiality, and trust led to
26 high morale, mutual learning and development.

1 The nursing team provided the requirements for the system, including the nursing
2 documentation forms and data, the information flow and its accordance with nursing work
3 processes and exchange mechanism with other hospital information systems in the other
4 departments.

5 With better knowledge of the work practices of nurses, experience of automating hospital
6 work and cost associated with the automation, the biomedical engineers in the hospital drove
7 the requirements capture and analysis, and the translation of nursing needs to the language of
8 the software developers in the company.

9 The team regularly had participatory design meetings at the Department of Biomedical
10 Engineering in the hospital in the late afternoon for one to three hours. Any idea, issue or
11 suggestion was discussed, the information related to the project was transparently shared in
12 these meetings. Each individual team member took an independent position on the problems.
13 After discussion, the final decision was a rational choice based on the analysis of various
14 scenarios, weighing pros and cons of each scenario.

15 *The four stages of the project*

16 Stage 1. Initial exploration of work. This stage was quickly gone through in one-month time.

17 The CIO and two biomedical engineers in the hospital regularly visited the ICU unit, having
18 meetings with the DON and the nurses to understand the nurses' work activities, purposes,
19 procedures, routines, technologies used, and information exchange with other departments
20 using other hospital information systems.

21 Stage 2. Discovery processes. The biomedical engineers in the hospital used the ethnographic
22 techniques such as observing nursing work, reviewing written documents, and
23 communicating with nurses to understand the everyday work activities and actions of nurses
24 and to gain insights into nurses' tacit knowledge.

25 They learned nursing care processes and actions; first what nurses did, then divided the
26 nursing actions into modules and understood each action in a module. They recorded the

1 action, its rationale, and relationship with other actions or parameters; e.g., the relationship
2 between medication orders and patient's health conditions. Based on the learning, they
3 produced the requirements documentation.

4 The whole team worked together, either in the ICU or in the Biomedical Engineering
5 Department, to understand and prioritize work organisation and to agree on the technical
6 solutions. The team would discuss the documented requirements. To balance the speed of
7 development and the quality of software, the requirements were prioritised according to the
8 sequence of information flow and usage rate, i.e, how many users would use a function. The
9 functions with high usage rate were given higher priority for automation.

10 Tools such as diagrams, drawings and nursing scenarios were often used to visualize and
11 analyse the model of patient journey and information flow, the relationship between
12 technology and work in these meetings and to develop shared views on nursing work and
13 how the ICIS could be best designed to support the nursing work.

14 The participating nurses learned about the technical options through direct discussions with
15 engineers in the participatory design meetings, trialling on the prototype system and
16 referencing with their experience of using other common software applications such as
17 Microsoft Word and online activities.

18 Stage 3. Prototyping. The system development methods included cooperative experimental
19 systems development method, prototyping experiments and work-oriented design.

20 The first version of the prototype was quickly produced in two-month time, in February 2013.
21 As the product was a direct translation of paper records to electronic records, the nurses did
22 not see it as what they expected, i.e., an automatic system that would help nurses to manage
23 information. It was completely abandoned because nurses did not see it as usable. This
24 experience taught the engineering team that automation was not a simple replication of
25 manual process, but the best possible automation of information flow and output.

1 An incremental, modular development was conducted to ensure quality control for each step
2 of patient journey. A module was centred on satisfying the information needs for each step of
3 patient journey, such as patient admission, allocation of bed and medication order. Only after
4 a module was built, and has satisfactorily passed unit test and user test, would the
5 development progress to the next module.

6 Stage 4. Implementation

7 Between February and September 2013, the ICIS was incrementally used to record the
8 information for one patient by a nurse in the project team. The nurse recorded the patient
9 information both on paper and in the ICIS and checked the conformance between the two
10 types of records. The trial rolled from one patient to the second and third. Only after all the
11 deficits were ironed out and the software functionality and workflow met the needs of ICU
12 nursing, was the system fully implemented in the unit in September 2013. The system was
13 fully integrated into practice by December 2013.

14 The onsite engineer provided training to all nurses on usage of the system. This full-time,
15 onsite support was continued until July 2014. This had enabled any usage problems to be
16 resolved promptly on site, any technical glitches to be ironed out quickly and the
17 functionality of the system to be continuously improved. The nurses involved in piloting the
18 system also acted as trainers and champions to provide peer support to the other nurses.
19 There was strict procedure to follow on functional change and documentation. System was
20 only upgraded after thorough testing to ensure error free. Installation of the upgraded system
21 was usually conducted at mid-night on week days, avoiding the peak usage period of
22 weekends and Mondays.

1 **Measurement of the effects of the ICIS introduction on nursing services in the ICU**

2 Pre- and post-implementation comparison was conducted. The outcome data collected were
3 documentation time versus direct patient care time, auditing of paper vs electronic nursing
4 records, and annual hospital nursing performance data.

5 *Documentation time before and after implementation of the ICIS*

6 Pre-implementation data collection was conducted between May and September 2013, before
7 the ICIS was implemented in the ICU. The documentation time was acquired through self-
8 reporting by nurses in the day shift, from 8 am to 8 pm. In consideration of the frequent
9 occurrence of emergencies, an intrinsic feature of ICUs, a nurse was given five months to
10 record their own documentation time and direct patient care time per shift, then reported the
11 average time over five months to the Director of Nursing (DON) in the unit.

12 The post-implementation data was collected during March to August 2014, five months after
13 implementation of the ICIS, when most nurses were sufficiently experienced to use the ICIS
14 confidently.

15 *Nursing records auditing*

16 The nursing records were audited by the Director of Nursing (DON) as part of the routine
17 nursing documentation quality control process in the hospital. Ten to fourteen nursing records
18 were audited randomly every day to identify missing data, missing data items, calculation
19 errors and legibility. Missing data items were identified by a comparison of a patient's
20 records in a day with that of previous days.

21 Before the ICIS introduction, YQ audited 500 paper-based nursing records in July to August
22 2013. After the ICIS was fully implemented, she audited 450 electronic nursing records in
23 May to June 2014 again, as part of the routine procedure of quality assurance.

24 *Annual nursing performance data collection*

25 Nursing performance in each ward was formally evaluated by a quality assurance committee
26 on annual basis as an important nursing quality assurance mechanism in the hospital. Six
27 areas were assessed: ward management, routine practice, disinfection and isolation, nursing

1 documentation, infection rate and mortality rate. Each area was measured in several domains.
2 Each domain was, again, measured by several tangible items, each was assigned a score. The
3 total score of all items in all domains in an area was 100. For example, the area of
4 disinfection and isolation was measured by four domains: hand hygiene, sterilised goods
5 management, clinical item usage and management, and ventilator usage and management.
6 The domain of hand hygiene was again measured by five items: (1) A clear sign to notify the
7 procedure of hand hygiene and completeness of supplies for hand wash at the sink, 1 mark; (2)
8 Antiseptic agent to be placed close to the entrance of the monitoring ward, 1 mark; (3) Nurses
9 were fluent with the six-step hand wash procedure, 1 mark; (4) Washing hands promptly,
10 washing or antiseptic disinfection before and after contact with a patient, 3 marks; and (5)
11 Correct usage of various gloves, 1 mark. Likewise, other domains were also measured by the
12 specific, measurable items. With a standardised, reasonably rigorous method of data
13 collection, the annual nursing performance data provided a useful indicator of changes in
14 nursing care quality that might be related to the introduction of the ICIS.

15 **Ethics approval**

16 The study was approved by the Institutional Review Board of Affiliated Hospital of Academy
17 of Military Medical Sciences.

18 **Results**

19 **Overview of the ICIS functionality**

20 The system had the following functionality: (1) Seamless integration with the hospital
21 information system (HIS), picture archiving and communication system (PACS), laboratory
22 information system (LIS) and electronic medical records (EMR); (2) Automatic collection
23 and recording of data from bed-side monitoring devices and respirators via a centralised
24 transmitter; (3) Extraction of physician order entries from the HIS; (4) Bar-code verification
25 of a patient's identity and the medication to be administered for preventing medication errors;

1 (5) Generation of line charts of patient vital signs; (6) Automatic generation of a daily one-
2 page, 24-hour “Critical Care Chart”; (7) Provision of an interface for nurses to enter patient
3 intake and discharge records, body temperature, nursing records and medication management
4 records. Figure 1 presents an outline of the system.

5 The data captured from the monitoring devices included blood pressure, heart rate, breathing,
6 transcutaneous oxygen saturation, ventilator output, blood gas analysis parameters, and
7 various intake and output statistics. The system automatically conducted blood gas analysis,
8 calculated oxygenation index, hemofiltration and fluid intake and output balance. The
9 interval of data collection is one minute. The numerical data were presented in a one-page,
10 easy-to-read intuitive diagram called a Critical Care Chart (see Figure 2).

11 There were 20 types of quantitative evaluation of clinical effects built into the ICIS. The
12 critical disease assessment model in the ICIS included acute care physiology and chronic
13 disease evaluation (APACHE II score), sequential organ exhaustion evaluation system
14 (SOFA score), and comprehensive assessment of multiple organ dysfunction (MODS score).

15 Abnormal data captured from various monitoring devices, such as blood pressure outside
16 normal range, or out of range data entry, were automatically identified and alerted to nurses
17 by the ICIS. For example, the abnormal data collected from an electrocardiography would be
18 colour-coded to draw the attention of nurses to the need for further assessment. Nurses were
19 alerted to the depth of entrance of endotracheal intubation, if longer than the total length of
20 the tube by a pop-up window for further validation.

21 It is common that 10 to 20 medications are prescribed to a patient in the ICU. In the ICIS, in
22 order to standardise the process of medication administration, each medication in a physician
23 order entry was automatically classified as a long-term or temporary medication by the period
24 of medication. Long-term medications were further classified by the method of
25 administration into three types: (1) oral medication, (2) minor treatment, such as oxygen and

1 cardiopulmonary suctioning, and (3) injection, including intravenous and intramuscular
2 injection.

3 In accordance with the characteristics of nursing in the ICU, specific forms and charts were
4 designed in the ICIS to present real-time changes in vital signs. These included an
5 observational chart of vital signs, critical patient records, critical nursing charts, various
6 assessment forms and medication administration forms. The database was established to
7 collect, integrate, analyse and export data to the end users, nurses. The system also provided
8 search functions for all the data in the database. The data searched can be stored in an Excel
9 spreadsheet.

10 **Nurses' usage of the ICIS**

11 The system was used in three major functional areas of nursing: data capture and entry,
12 information output and medication administration. Nurses used mobile terminals on cart and
13 desktop computers to access data electronically. After introduction of the ICIS, paper was no
14 longer used by nurses in the ICU. The nurses who participated in the focus group discussions
15 all expressed satisfaction with the ICIS and the way it was implemented, grateful for the
16 support received from the onsite engineer. One nurse reported "The system was used to full.
17 The engineers provided all the functions in accordance with our requirements. We also used
18 all these functions." They all stated that whenever they had any problem using the system, the
19 problem was solved promptly.

20 **Impact of ICIS use on the nursing practice**

21 The major benefits of the ICIS were improved quality and efficiency of nursing
22 documentation, accuracy and efficiency of medication administration and overall nursing
23 service quality and efficiency.

24 *Improving quality of nursing documentation*

25 Errors often occurred when nurses were required to hand write and draw diagrams to present
26 the monitoring data. These could lead to inaccurate assessment of the condition of a critically

1 ill patient. Using the ICIS, 100% accurate monitoring data were automatically generated;
 2 improving the accuracy of patient assessment.
 3 Measured by the indicators of quality of nursing documentation including wrong data,
 4 missing data items, wrong calculations and legibility, the quality of electronic records
 5 significantly outperformed paper records. The rate of wrong data was reduced from 7.5% in
 6 the paper records to 1.6% in the electronic records. The rate of missing data dropped from
 7 18.5% in the paper to 3.7% in the electronic records. The rate of wrong calculation decreased
 8 from 16.8% to 2.8%. The electronic records were completely legible, whereas 110 illegible
 9 data items were corrected in the paper records (see Table 2).

10 **Table 2. A comparison of documentation errors in paper vs electronic records.**

Type of Records	Sample size	Data (n)		Data Item (n)		Calculation (n)		Legibility	
		Wrong (%)	Right	Missing (%)	Right	Wrong (%)	Right	Corrected	No Change
Paper	500	35 (7.5%)	465	78 (18.5%)	422	72 (16.8%)	428	110	390
Electronic	450	7 (1.6%)	443	16 (3.7%)	434	12 (2.8%)	434	0	450
Chi square		16.6		37.2		40.5		120.0	
p value		< 0.01		< 0.01		< 0.01		< 0.01	

11
 12 Nurses were satisfied with the simplicity of electronic recording. Using the ICIS, the nurses
 13 could quickly and accurately complete nursing documentation about the treatment process for
 14 a patient. Only objective data and nursing process data were recorded, clearly and accurately.
 15 The extent of subjective assessment was believed to be reduced.

16 *Reducing nursing documentation time and allowing more time on bed-side nursing tasks*
 17 Using paper, a nurse needed to handwrite monitoring data, which would take about 30
 18 minutes per shift; whereas using the ICIS, the data were automatically recorded and
 19 generated into tables and diagrams for use. This completely freed nurses from these tedious,
 20 mechanical tasks, eliminating recording and calculation errors.

21 Using paper, retrieving data was time consuming. Using the ICIS, data could be quickly
 22 retrieved from the database. This led to the reduction of nursing pressure and the

1 improvement of work efficiency (see Table 3). The nurses reported that they spent more time
 2 with patients, providing oral hygiene and skin care, teaching and comforting patients.
 3 According to the self-reported time usage data, using the paper records, a nurse would spend
 4 3.80 hours (n = 28, SD = 0.41) per 12 hour shift to complete nursing documentation. Using
 5 the ICIS, the documentation time was significantly reduced to 2.05 hours (n = 28, SD = 0.18,
 6 $t = 25.19, p < 0.001$).

7 When using the paper records, in a 24-hour period, a nurse spent 20.20 hours (n = 28, SD =
 8 0.40) on bed-side nursing tasks. After using the ICIS, a nurse spent 21.95 hours (n = 28, SD =
 9 0.18) on bed-side nursing tasks ($t = - 25.19, p < 0.001$), an increase of 1.75 hours in a 24-hour
 10 period.

11

12 **Table 3. A comparison of nursing documentation using paper vs electronic records.**

Item	Using Paper	Using ICIS
Recording the monitoring data	Hand writing, taking about 30 minutes per shift	Automatic generation of tables and diagrams
Reading patient's information	Inconvenient to find paper records	Easy to retrieve data in ICIS
Accuracy of data captured from the monitoring devices	Missing data despite best effort	100% accurate
Storage of data	Paper records are easy to lose	Long-term storage in the database in the server
Data retrieval	Takes time and effort	Fast and directly retrieved from the database

13

14 *Improving accuracy and efficiency of medication administration*

15 Using the ICIS, the whole process of medication administration was automated via barcode
 16 technology, including order transcription from the HIS system, verification and
 17 administration.

18 According to the clinical guideline, an order entry by a doctor first needed to be transcribed
 19 by a nurse to the nursing chart, then to be validated by the second nurse. Only after the two
 20 nurses both signed the medication chart to signal completion of the medication validation
 21 process could the order entry be sent to the pharmacy for dispensing.

1 In a doctor's prescription, the dosage was recorded as the total amount of medication for a
2 day. As a medicine was often needed to be administered several times for a patient in a day,
3 it required a nurse to calculate the dosage for each medication, a source of calculation error.
4 As the ICIS directly populated the order entry data from the HIS, it eliminated the process of
5 order transcription, an error prone process. The ICIS automatically presented the number of
6 times that a medicine needed to be administered based on pattern analysis of medication
7 administration for the common types of medicine. This provided an intuitive interface for a
8 nurse to enter the dosage data. The nurse was also given the flexibility of changing
9 administration time and dosage according to own discretion. Therefore, after implementation
10 of the ICIS, the whole process of medication administration was automated and standardised.
11 The error rate in transcription of medication prescription was believed to be reduced.
12 The ICIS also helped nurses to prioritize nursing treatment by the automatic classification of
13 medications. For example, if a medication was placed in the temporary category, it signalled
14 to a nurse that this medication had to be administered at the correct time. Long-term
15 medication needed to be administered in order, at a fixed time interval, whereas
16 administration of minor treatments, such as shoulder massage or oral hygiene care, could be
17 done after the completion of oral medication and injection. Therefore, the nurses felt that they
18 spent less time and less mental load on medication administration.

19 *Impact on quality of nursing services*

20 Data output from the ICIS was in various intuitive diagrams and charts, much more intuitive
21 and convenient for a nurse to monitor and accurately understand the disease change process.
22 The nurses reported that the saved time was used to observe the changes in a patient's
23 psycho-social status and to provide more personal care to the patients. The amount of oral
24 hygiene, personal care and physiotherapy treatment to the patients was also increased after
25 using the ICIS.

1 The study unit had always enjoyed high performance ratings in all mandatory nursing quality
 2 audit areas in the annual hospital nursing service evaluation (Table 4). The quantitative
 3 performance scores in all these areas improved after the introduction of the ICIS. The scores
 4 for ward management were improved from the baseline of 94.5 in 2012 to 99.7 in 2013, the
 5 year the ICIS was implemented. It increased to the highest level of 99.8 in 2014. The scores
 6 for routine nursing practice increased from 99 to 99.7, then 99.8 in the three years,
 7 respectively. The rate of improvement in disinfection and isolation was clear, from 94.1 in
 8 2012 to 96.9 in 2013, then 99.8 in 2014, respectively. The score in nursing documentation
 9 was improved to 99.96 in 2014, starting from the baseline of 97.3. Infection rates dropped
 10 substantially, from 29.3 in 2012 to 20.0 in 2013, then 16.1 in 2013. Mortality rates dropped
 11 from 12.6 to 9.4, then 8.5 in the three years, respectively (see Table 4).

12 **Table 4. A comparison of nursing performance before and after introduction of the**
 13 **ICIS.**

Item	2012 (Paper-records)	2013 (September, ICIS introduction)	2014 (Electronic records)
Ward management	94.5	99.7	99.8
Routine nursing practices	99	99.7	99.8
Disinfection and isolation	94.1	96.9	99.8
Nursing documentation	97.3	99.7	99.96
Infection rate	29.3	20.0	16.1
Mortality rate	12.6	9.4	8.5

14

15 **Discussion**

16 Knowledge about the contemporary development of the ICIS worldwide, their usage and
 17 impacts on nursing services is beneficial for international advancement in building smart
 18 environments to transform ICU services in different healthcare context. This case study
 19 contributes new knowledge about how nurses contribute to the participatory design of an
 20 ICIS to support critical care nursing in a Chinese hospital. It describes the development and

1 functionality of the ICIS, the nursing team's use of the system, and the impact of system use
2 on critical nursing care processes and outcomes. Both objective, performance evidence and
3 nurses' perceptions were gathered to provide a pre- and post-implementation comparison of
4 quality and efficiency of nursing documentation, quality and efficiency of medication
5 management, and impact on quality of nursing services.

6 Carayon et al. [31] find that factors related to technology design have significant effects on
7 ICU nurses' acceptance of electronic health records; however, there is little knowledge about
8 how ICIS is designed and developed. This case study presents participative design, a useful
9 approach for nurses to actively participate and contribute to the design and implementation of
10 a useful ICIS for intensive care nursing services.

11 The success of the system, including its fit with nursing work processes and information
12 needs was ensured by a committed, sustained collaboration in research and development of
13 the ICIS by the ICU nurses, the hospital IT department and the software company developing
14 the system. Once more, this case study proves that the active participation of the intended
15 users in HIT design facilitates good design (Kensing and Blomberg 1998). This effective,
16 interactive system development and implementation process have also contributed to a lack
17 of workforce resistance to IT introduction reported elsewhere [32]. The strong technical
18 support provided by the on-site engineer, as well as strong peer support from the workmates,
19 also met nurses' learning needs.

20 **Improving the quality of nursing records, reducing time for documentation and**
21 **increasing direct patient care time**

22 Similar to findings by Bosman [13, 17] and Yusof [17], the use of the ICIS by the nurses in
23 the study unit not only improved the quality of nursing records, but also reduced time spent
24 on documentation and increased direct patient care time. All of the RNs who participated in
25 the focus group discussions perceived that the nursing stress was reasonably relieved because
26 the ICIS replaced nurses in meticulous, repetitive monitoring data entry and had also

1 eliminated errors in this process. They were pleased to be able to spend more time to focus on
2 providing direct nursing and personal care to the critically ill patients. Only two nurses left
3 the ICU since the introduction of the ICIS in 2013 to 2016, suggesting that the nursing staff
4 in the unit was generally satisfied with work in the unit, as observed by PY, who was external
5 to the hospital. The nurses' feedback was in agreement with the previous finding that the
6 amount of time nurses spend with patients is linked to their job satisfaction, which is one of
7 the critical factors for nurse retention [33].

8 **Improving the medication management process**

9 Serious medication errors are common in hospitals and often occur during the process of
10 order transcription and medication administration [34]. Heavy nursing workload and
11 incomplete prescriptions are two significant risk factors for medication error [35]. Previous
12 studies have found that use of bar-code electronic medical records can substantially reduce
13 the rate of errors in order transcription and in medication administration [34, 36].
14 Standardisation of the order transcription and medication administration process was another
15 mechanism that had led to the reduction of medication administration error in the ICU, as
16 suggested by the previous study [35]. Although we did not have data about the change in
17 medication error in this study, the reduction of annual patient mortality rate in the study unit
18 in the year and one year after the ICIS introduction lend support to the improved quality and
19 efficiency of order transcription and medication administration. This supports the wide
20 adoption and usage of ICIS in medication management.

21 **Improving the quality of nursing care**

22 The organization of nursing work in the study unit was improved with the automation of
23 nursing documentation, particularly monitoring data collection, medication order
24 transcription and management. The tasks that are markers of good nursing care, such as oral
25 hygiene and skin care, teaching, and comforting patients [37], were increased.

1 **Limitation of the study**

2 The limitation of the study was that only one ICU was studied to provide a bird’s eye view of
3 the introduction of the ICIS in a Chinese hospital. A comparison of medication error rate
4 before and after the implementation of the ICIS could provide useful, direct evidence about
5 the effect of the ICIS on medication error, a key potential benefit of digitisation of ICU work.
6 The improvement in nursing care quality cannot be fully attributed to the introduction of the
7 ICIS. From its inception in 2009, only a few nursing staff left the ICU. Five-year daily hands-
8 on nursing practice had led to a steady progress in team building, communication,
9 improvement in individual nursing expertise, capacity and skill in intensive care nursing; an
10 important contributor to the steady improvement in nursing performance.

11 Management of daily activities in ICU is challenging; ICU intensivists and nurses often need
12 to make immediate ad hoc decisions to enable the optimal flow of activities [38]. Therefore,
13 further research can be conducted to understand how intensivists and nurses actually work
14 [39], and how to continuously build up the ICIS to support decision making of intensivists
15 and nurses in ICU.

16 **Conclusions**

17 Participatory design was a useful model for the nurses, the hospital IT department and the
18 software company to collaboratively research and develop a user-centred, intelligent ICU
19 environment. Use of the ICIS had brought benefits including improving quality and
20 efficiency of nursing documentation, accuracy and efficiency of medication administration,
21 overall improvement in nursing service quality, and improvement in working conditions and
22 quality of work life for the nurses. Further research can be focused on understanding how to
23 enhance the functionality of the ICIS to support decision making of intensivists and nurses,
24 and nursing performance measurement in ICU.

25 **List of abbreviations**

APACHE II score	Acute care physiology and chronic disease evaluation
-----------------	--

DON	Director of Nursing
EMR	Electronic medical records
HIS	Hospital information system
ICIS	Intensive care information system
ICT	Information and communication technology
ICU	Intensive care unit
LIS	Laboratory information system
MODS score	Comprehensive assessment of multiple organ dysfunction
PACS	Picture archiving and communication system
RN	Registered nurse
SOFA score	Sequential organ exhaustion evaluation system

1

2 **Declarations**

3• **Ethics approval and consent to participate:** The research was approved by the Institutional
4 Review Board of Affiliated Hospital of Academy of Military Medical Sciences. The ethics
5 committee approved the use of verbal consent for participation. All the interview and focus
6 group participants orally agreed to participate in the study.

7• **Consent for publication:**

8• Not applicable.

9• **Availability of data and material:** The original datasets generated during the current study
10 are not publicly available as they contain individual nursing performance data. The objective
11 measurement and nursing performance data was stored in the records of the Department of
12 Pulmonary & Critical Care Medicine in 307th Hospital of PLA, China. The audio records of
13 focus group discussions were stored in the password-protected office computer of PY.

14• **Competing interests**

15 The authors declare that they have no competing interests.

16•

17• **Funding**

18 This study did not receive any funding.

19• **Authors' contributions**

1 YQ, RZ, CB and PY contributed to project conceptualisation, manuscript drafting and
2 revision. PY collected the qualitative data. QW, XH, XC, WW, XW, HX and JZ contributed
3 to participatory design and implementation of the ICIS and quantitative performance data
4 collection. SQ contributed to qualitative data analysis, interpretation and critical revision of
5 the manuscript. All the authors approved the final manuscript.

6• Acknowledgement

7 We are grateful for the contribution of the RNs in the study ICU who participated in the focus
8 group discussions. Mr Boqiang Song, the former CIO in the hospital, is acknowledged for his
9 vision and leadership in developing the ICIS.

10 References

- 11 1. Leiviss J. Hit or miss: lessons learned from health information technology
12 implementations, 2nd ed. Chicago: AHIMA; 2010.
- 13 2. Heeks R. Health information systems: failure, success and improvisation.
14 *International Journal of Medical Informatics*. 2006;75:125-37.
- 15 3. Nykänen P, Karimaa E. Success and failure factors in the regional health information
16 system design process. *Methods of Information in Medicine*. 2006;45(1):85-9.
- 17 4. Du B, Xi X, Chen D, Peng J. Clinical review: critical care medicine in mainland
18 China. *Critical Care*. 2010;14(1):206.
- 19 5. Vincent J. Critical care - where have we been and where are we going? *Critical Care*.
20 2013;17:S2.
- 21 6. You L-m, Aiken LH, Sloane DM, Liu K, He G-p, Hu Y, et al. Hospital nursing, care
22 quality, and patient satisfaction: cross-sectional surveys of nurses and patients in
23 hospitals in China and Europe. *International Journal of Nursing Studies*.
24 2013;50(2):154-61.
- 25 7. Choi J, Bakken S, Larson E, Du Y, Stone PW. Perceived nursing work environment of
26 critical care nurses. *Nursing Research*.53(6):370-8.
- 27 8. Pickering BW, Litell JM, Herasevich V, Gajic O. Clinical review: the hospital of the
28 future - building intelligent environments to facilitate safe and effective acute care
29 delivery. *Critical Care*. 2012;16(2):220.
- 30 9. Mador RL, Shaw NT. The impact of a critical care information system (CCIS) on time
31 spent charting and in direct patient care by staff in the ICU: a review of the literature.
32 *International journal of medical informatics* 2009;78(7):435-45.
- 33 10. Steurbaut K, Colpaert K, Van Hoecke S, Steurbaut S, Danneels C, Decruyenaere J, et
34 al. Design and evaluation of a service oriented architecture for paperless ICU
35 tariffication. *Journal of Medical Systems*. 2012;36(3):1403-16.
- 36 11. Lapinsky SE, Holt D, Hallett D, Abdolell M, Adhikari NKJ. Survey of information
37 technology in intensive care units in Ontario, Canada. *BMC Medical Informatics and
38 Decision Making*. 2008;8:5.
- 39 12. Vahedian-Azimi A, Ebadi A, Saadat S, Ahmadi F. Intelligence care: a nursing care

- 1 strategy in respiratory intensive care unit. Iranian Red Crescent Medical Journal.
2 2015;17(11):e20551.
- 3 13. Bosman R, Rood E, Straaten HO, Spoe Jvd, Wester J, Zandstra D. Intensive care
4 information system reduces documentation time of the nurses after cardiothoracic
5 surgery. *Intensive Care Medicine*. 2003;29(1):83-90.
- 6 14. Hoekstra M, Vogelzang M, Drost JT, Janse M, Loef BG, van der Horst IC, et al.
7 Implementation and evaluation of a nurse-centered computerized potassium
8 regulation protocol in the intensive care unit - a before and after analysis. *BMC*
9 *Medical Informatics and Decision Making*. 2010;10(1):1-10.
- 10 15. Nyholm L, Lewén A, Früjd C, Howells T, Nilsson P, Enblad P. The use of nurse
11 checklists in a bedside computer-based information system to focus on avoiding
12 secondary insults in neurointensive care. *ISRN Neurology*. 2012:1-7.
- 13 16. Conroy KM, Elliott D, Burrell AR. Testing the implementation of an electronic
14 process-of-care checklist for use during morning medical rounds in a tertiary intensive
15 care unit: a prospective before–after study. *Annals of Intensive Care*. 2015;5(1):1-12.
- 16 17. Yusof MM. A case study evaluation of a critical care information system adoption
17 using the socio-technical and fit approach. *International Journal of Medical*
18 *Informatics*. 2015;84(7):486-99.
- 19 18. Shulman R, Singer M, Goldstone J, Bellingan G. Medication errors: a prospective
20 cohort study of hand-written and computerised physician order entry in the intensive
21 care unit. *Critical Care*. 2005;9(5):R516-R21.
- 22 19. Ammenwerth E, Shaw NT. Bad health informatics can kill - is evaluation the answer.
23 *Methods Inf Med*. 2005;44:1-3.
- 24 20. Suchman L. Forward. In: Schuler D, Namioka A, editors. *Participatory design:*
25 *principles and practices*. NJ: Lawrence Erlbaum; 1993: vii-ix.
- 26 21. Greenbaum J, Kynny M. *Design at work: cooperative design of computer systems*.
27 Hillsdale, NJ: Erlbaum; 1991.
- 28 22. Kensing F, Blomberg J. *Participatory design: issues and concerns*. *Computer*
29 *Supported Cooperative Work*. 1998;7:167-85.
- 30 23. Spinuzzi C. The methodology of participatory design. *Technical Communication*.
31 2004;52(2):163-74.
- 32 24. Blomberg J, Suchman L, Trigg R. Back to work: renewing old agendas for change. In:
33 Kyng M, Mathiassen L, editors. *Computers and design in context*. Cambridge, MA:
34 MIT Press; 1997: 201-38.
- 35 25. Kensing F. The trade unions influence on technological change. In: Briefs Uea,
36 editors. *Systems design for, with and by the users*. North Holland: 1983
- 37 26. Bødker S. Creating conditions for participation: conflicts and resources in systems
38 development. *Human-Computer Interaction*. 1996:215–36.
- 39 27. Blomberg J, Suchman L, Trigg R. Reflections on a work-oriented design project.
40 *Human-Computer Interaction*. 1996;11(3):237-65.
- 41 28. Eriksson H, Penker M. *Business modeling with uml*. 2000. Accessed 12 June 2017.
- 42 29. Kensing F. Generation of visions in systems development – a supplement to the
43 toolbox. In: Mathiassen L, editors. *Systems design for human development and*
44 *productivity: Participation and beyond*. Berlin, Germany: North-Holland Publishing
45 Co.; 1987: 285-301.
- 46 30. Grønbaek K, Kyng M, Mogensen P. Toward a cooperative experimental system
47 development approach. In: Kyng M, Mathiassen L, editors. *Computers and design in*
48 *context*. Cambridge, MA: MIT Press; 1997: 201-38.
- 49 31. Carayon P, Cartmill R, Blosky MA, Brown R, Hackenberg M, Hoonakker P, et al.
50 ICU nurses' acceptance of electronic health records. *Journal of the American Medical*

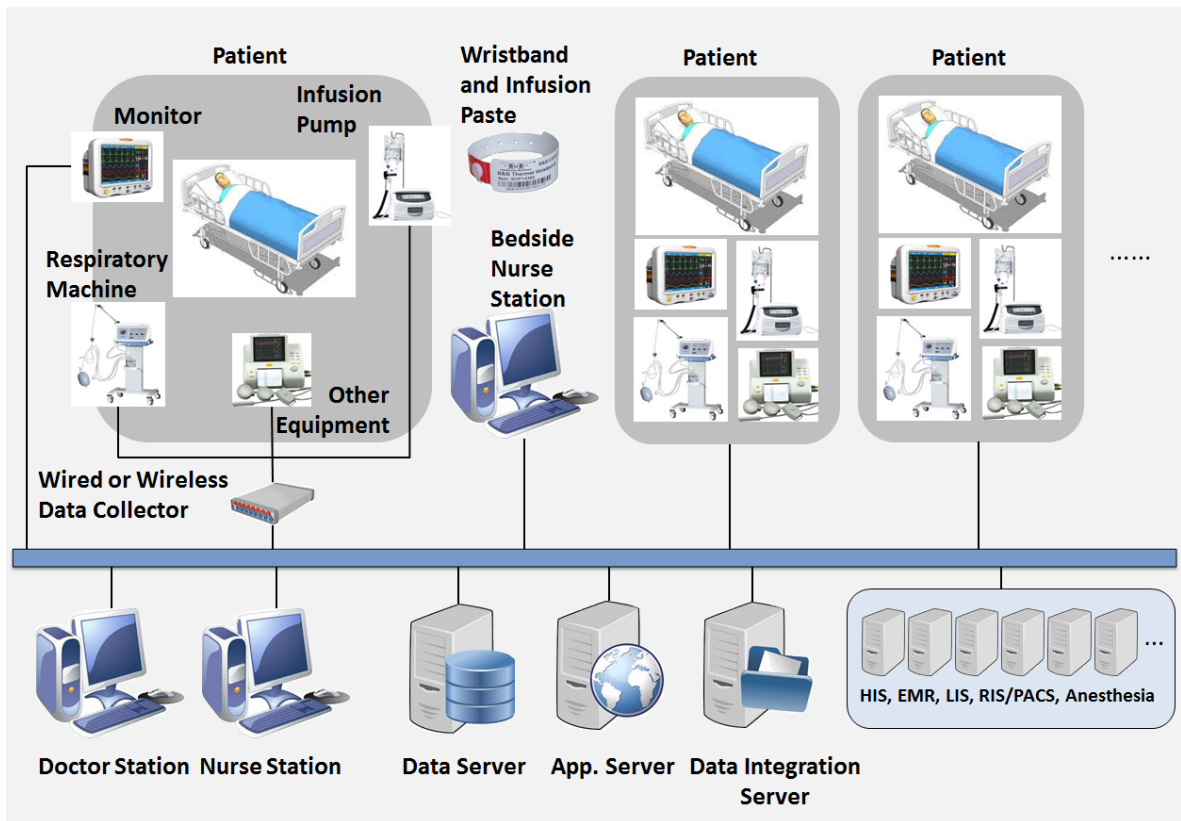
- 1 Informatics Association. 2011;186:812-9.
- 2 32. Holden RJ, Karsh BT. The technology acceptance model: its past and its future in
3 healthcare. *Journal of BIomedical Informatics*. 2010;43:440-55.
- 4 33. Hayes B, Bonner A, Pryor J. Factors contributing to nurse job satisfaction in the acute
5 hospital setting: a review of recent literature. *Journal of Nursing Management*.
6 2010;18(7):804-14.
- 7 34. Poon EG, Keohane CA, Yoon CS, Ditmore M, Bane A, Levtzion-Korach O, et al.
8 Effect of bar-code technology on the safety of medication administration. *New
9 England Journal of Medicine*. 2010;362(18):1698-707.
- 10 35. Tissot E, Cornette C, Limat S, Mourand J-L, Becker M, Etievent J-P, et al.
11 Observational study of potential risk factors of medication administration errors.
12 *Pharm World Sci*. 2003;25(6):264-8.
- 13 36. Bates DW. Using information technology to reduce rates of medication errors in
14 hospitals. *BMJ*. 2000;320(7237):788.
- 15 37. Aiken LH, Clarke SP, Sloane DM, Sochalski JA, Busse R, Clarke H, et al. Nurses'
16 reports on hospital care in five countries. *Health affairs (Project Hope)*.
17 2001;20(3):43-53.
- 18 38. Lundgrén-Laine H, Kontio E, Perttilä J, Korvenranta H, Forsström J, Salanterä S.
19 Managing daily intensive care activities: an observational study concerning ad hoc
20 decision making of charge nurses and intensivists. *Critical Care*. 2011;15(4):1-10.
- 21 39. Sevdalis N, Brett SJ. Improving care by understanding the way we work: human
22 factors and behavioural science in the context of intensive care. *Critical Care*.
23 2009;13(2):1-3.
- 24

25

26 **Figure legends**

27 Figure 1. System Outline.

28 Figure 2. ICU Critical Nursing Care Chart.




Page ____ Bed No ____ Name ____ Date of disease ____ Sex ____ Age ____ Patient No ____ Diagnosis ____ Year ____ Month ____ Day		General items												State of consciousness				Ventilator monitor							Catheter monitor				Blood glucose monitor		Signature												
Time	T °C	HR counts/min	R Counts/min	NBP mmHg	SpO2 %	Rhythm of heart	Aspiration of sputum	Turn over half/supine	Pain	ETCO2	Airbag pressure	O2 L/min	CVP mmHg	Ramsey sedation scale scores	Consciousness		Pupil R L	Mode	Depth of canula cm	FiO2 %	PAP	PEEP	PIP	VT	R	Humidification temperature °C	Gastric tube	Urinary catheter	Indwelling venous needles			CVC	Blood glucose mmol/L	Insulin u/h									
															EPAP	PSV					Pdeak	MV	Control	mmol/L	u/h																		

Ramsey Sedation Scale
 1 score: Anxious, agitated, restless
 2 score: Cooperative, oriented, tranquil
 3 score: Responsive to commands only

4 score: Brisk response to light glabellar tap or loud auditory stimulus
 5 score: Sluggish response to light glabellar tap or loud auditory stimulus
 6 score: No response to light glabellar tap or loud auditory stimulus

Pupil size (mm)



1 2 3 4 5

Sputum description
 Scanty
 Moderate
 Copious

White
 Yellow
 Green

Turn over record
 Right
 Left