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ORIGINAL PAPER

Computer Simulation Within Action Research: A Promising Combination for Improving Healthcare Delivery?

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Abstract Action research (AR) is increasingly being used to study the improvement of healthcare delivery. Ensuring that all the stakeholders in the AR are willing to take action, however, can be difficult. Especially in healthcare contexts, action plans may challenge the autonomy of the healthcare professionals and the positions of the different stakeholder groups. Does the use of computer simulation techniques within the AR promote action taking by all the stakeholders? We performed an AR experiment with computer simulation in a university hospital's emergency department in the Netherlands. A simulation model was designed that replicated the actual healthcare delivery process in the study setting. Together with representatives from the medical and nursing staff and department management, we used the model to discuss improvement actions. The team designed an improvement scenario that fundamentally rearranged the task division between the physicians and the nurses. The promising projections in the simulation model motivated the team to try the scenario in reality. The implementation was successful, although it generated much concerns and discussion. The new task division successfully improved patient length of stay (LOS) in the ED. The results achieved by the single team turned out to have lasting effects on the other stakeholders in the ED. Our AR experiment with computer simulation promoted action taking by all the stakeholders. Computer simulation within AR is a promising combination for improving healthcare delivery.

Keywords Action research · Computer simulation · Emergency department · Healthcare delivery · Organisational improvement

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Introduction

Action research (AR) is increasingly being used in healthcare settings. It is regarded as a promising way to study and improve the organisation and delivery of healthcare services (Nichols et al. 1997; Bridges and Meyer 2000; Meyer 2000; Fulop et al. 2001; Huxham 2003; Hall 2006; Walsh et al. 2008). In AR, practitioners and researchers collaborate to address problem situations and simultaneously produce new knowledge and better insights (Susman and Evered 1978; Checkland and Scholes 1990; French and Bell 1990; Gill and Johnson 1991; Westbrook 1994; Eden and Huxham 1996; Coughlan and Coghlan 2002). The research takes place in an ongoing process of action planning, action taking and evaluating, leading to further action planning and so on. In this process, the researchers provide theoretical backgrounds and problem analysis approaches, while the practitioners contribute their knowledge and experience of what works in their setting.

In our own research program in healthcare technology management, we have encountered several difficulties practising AR (Rosmulder et al. 2006, 2009). These all seem to concentrate on the action taking phase. In more than one AR project, it turned out that one group of stakeholders was unwilling to try the suggested changes—despite extensive efforts to involve all of them in the change process. As the contribution of all the groups was essential to make the change happen, the AR project ended at the action taking phase. A promising improvement idea then failed to be tried and learned from. The literature provides several explanations why changing the delivery of healthcare is so hard to achieve. First, the organisation of healthcare delivery is outside the physicians' main scope of interest. Their job is to concentrate on medical interventions and individual patients (Glouberman and Mintzberg 2001a). Second, the division of tasks in healthcare is strictly separated between different groups of professionals. The physicians manage the cure, the nurses manage the care and the administrators manage the control in the hospital (Mintzberg 1997; Glouberman and Mintzberg 2001b). Proposing changes to the healthcare delivery implies challenging the established positions of the stakeholder groups (Mitchell et al. 1997) and the autonomy of the individual healthcare professionals (Fitzgerald and Teal 2003). Third, AR combines research and action in an ongoing process of action planning, action taking and evaluating (Eden and Huxham 1996). This kind of continuous experimentation runs counter to the common approach in medicine of first doing research and then implementing changes with a solid evidence base only (Walshe and Rundall 2001). Considered together, all three explanations provide the different stakeholder groups with a reason to withdraw their cooperation at any time: "we are not interested, we feel that our professional position and autonomy is threatened, and we are rightly worried that our patients may be at risk".

Searching for a way to promote action taking by all the stakeholders, we decided to use computer simulation techniques. In a computer simulation model, users replicate the dynamic behaviour of a system on the computer. The computer can then project the effects of different improvement scenarios without changing the actual system. Currently available computer simulation software is user-friendly and robust, making it easy to apply for change-oriented purposes. We planned to use computer simulation within the AR in two steps. First, to design a computer model together with the stakeholders in the AR. The model should replicate the actual healthcare delivery process in their work setting. Second, to explore improvement scenarios with the stakeholders and project the effects in the model. We anticipated the following outcomes:

1. The use of the simulation model invites all of the stakeholders to think in terms of organising healthcare delivery. It forces them to jointly think about and discuss the current way of working. This promotes shared understanding of the problem situation (Rouwette et al. 2002; Kerkhoff 2006) and involvement in the change process (Richardson and Andersen 1995; Lane et al. 2003; den Hengst and de Vreede 2004; Scholl 2004).
2. The ability of the simulation model to project the effects of changes before implementation creates a kind of evidence base that better fits the medical mindset (Shojania and Grimshaw 2005; Neuhauser and Diaz 2007; Leykum et al. 2009). Promising projections motivate the stakeholders to take action in the real-life situation.

To our knowledge, the idea of using computer simulation to facilitate AR is relatively new and little reported in the literature. We have found no studies that describe the outcomes of research projects in which simulation models were used for change. This article describes an AR experiment in which computer simulation was used to improve healthcare delivery. An improvement scenario was explored that presented a fundamental change to the task division between medical and nursing professionals. Our research question was: does the use of computer simulation promote action taking by all the stakeholders involved in the AR?

Methods

Study Setting and Research Situation

This study was carried out in the emergency department (ED) of a 1,000-bed university hospital in the Netherlands. The ED is designated as level-one trauma centre and receives about 32,000 patients per year. Because of increasing patient visits, long waiting times for patients and problematic availability of ward beds, improving ED patient flow is currently a main hospital policy objective. Unsatisfied with the improvisational nature of problem solving in the hospital (see Spear 2005), the medical director of the ED expressed a desire for scientific analysis and theory about organising care processes. Collaboration in a doctoral research project was established with an industrial engineering department of a technical university. From the standpoint of the university, this presented a unique opportunity to investigate the benefits of the new approaches to operations in healthcare. Based on unsuccessful implementation of process improvement in an exploratory study (Rosmulder et al. 2006), it was decided to proceed in an AR mode (Rosmulder et al. 2009). A traditional, mechanistic-oriented AR approach was chosen (Coghlan 2003), in which researchers and members of the study setting worked together to address problematic patient flow in the ED. The traditional approach was suitable because the prime focus of the research was to address problem situations experienced by the organisation, as a social system (Checkland and Scholes 1990; French and Bell 1990). The focus was not on the personal and professional development of the individual stakeholders involved in the AR, as is custom in more modern, organistic-oriented approaches (Coghlan 2003).

The Subject of the Simulation Model

The researchers used a transformation-process perspective as the theoretical basis for modelling patient care, see Fig. 1. A transformation process changes inputs like raw

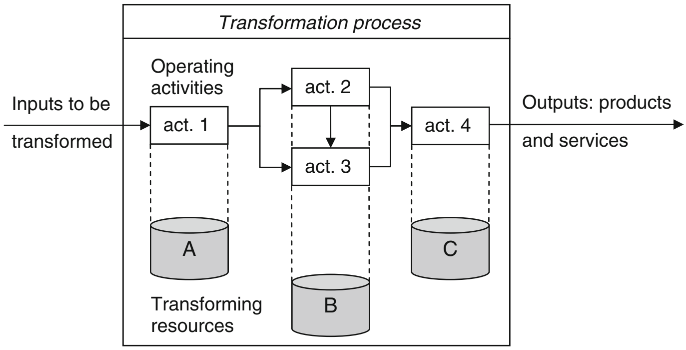

Fig. 1 A model of a transformation process

materials, customers, and information into outputs: products and services. Such a process consists of interrelated operating activities that are needed to complete the transformation (Miller and Rice 1967), and transforming resources that perform or enable the operating activities (Slack et al. 2004). These include people, machines, and facilities. It has been demonstrated that smarter configurations of transforming resources and operating activities can improve the performance of transformation processes in terms of speed, cost, quality, and efficiency in various industries (Hayes et al. 2005). Improvements were achieved, for example, by removing all operating activities that did not add value for customers, and modifying the remaining activities to proceed without interruption (the concept of lean manufacturing, see Womack and Jones 1996). When we now consider an ED, the transformation process involves turning patients arriving in acute situations into patients recovering from treatment or admitted to the hospital. Medical and nursing staff use treatment rooms, equipment and materials to perform physical examinations, X-rays, and various kinds of treatment. Patient symptoms designate the exact combination of operating activities that is needed (Thompson 1967); the healthcare professionals decide how, when, and in which order these activities are performed. Several applications of the lean manufacturing concept in emergency care delivery processes have demonstrated promising results (Simmons 2003; King et al. 2006; Dickson et al. 2009a, b).

Strategy to Design and Use the Simulation Model

The researchers realised that the design of the simulation model would play a crucial role in the AR experiment. To promote their willingness for action taking, all the stakeholders in the AR should accept the model and have confidence in its structure and outcomes (Richardson and Andersen 1995; Lane et al. 2003; Scholl 2004). It was therefore essential that the design of the simulation model and the development of the improvement scenarios was carried out in close cooperation with the members of the study setting. The researchers planned the following course of action.

1. *Convince the key stakeholder to use computer simulation*. The medical director of the ED is a key stakeholder for research access and initiation of change. Convince this person to use computer simulation for improvement based on the transformation-process perspective. Together, define the primary outcome measure of the simulation model.

2. *Make a conceptual model of the care delivery process*. Collaborate with the key stakeholder to analyse the current care delivery process in the ED. Describe the configuration of operating activities and transforming resources in a conceptual model. Share this with other stakeholders, i.e. members from the medical and nursing staff, for approval and modification.
3. *Build the computer model.* Make a computer simulation model based on the conceptual model. This requires data or assumptions about the duration and variability of operating activities, the number and availability of transforming resources, the arrival rates of patients and the combinations of activities they require. Acquire these data from the work setting and share the assumptions for approval and modification. Verify if the simulation model operates as intended and assess the accuracy of model output. Present the final model to the key stakeholder and the members from the medical and nursing staff for evaluation of its dynamic behaviour. Establish that they understand the general modelling assumptions and accept the model as a valid representation of the actual working situation.
4. *Explore improvement scenarios.* Invite representatives from the medical and nursing staff to join the collaboration with the key stakeholder. Together, explore promising alternatives to the current configuration of operating activities and transforming resources. Project the effects of the process improvement scenarios in the simulation model.
5. *Apply a promising scenario*. If all of the stakeholders consider an improvement scenario desirable and feasible to implement (Checkland 1985), take the necessary actions to realise it. Monitor possible unintended effects with regard to patient safety.

Evaluation of the Outcomes

This study involved an experiment to investigate if the use of computer simulation promoted action taking by all the stakeholders involved in AR in a healthcare setting. The ideal outcome of the experiment would be that the stakeholders did indeed take action to realise the improvement scenario, or indicate a willingness to support it in other ways. And if action was in fact taken, that the outcomes of the healthcare delivery process would improve as projected by the model. This required a measurement of the model's primary outcome measure before and after the experiment.

Execution of the Experiment

Preparations; Defining the Primary Outcome Measure

The researchers met with the medical director to discuss the idea of using computer simulation for process improvement. This idea appealed to him, because of the ability to project the effects of changes beforehand. The researchers explained their perspective, or worldview (Checkland and Scholes 1990), on the subject of the simulation model. He agreed to use the transformation-process perspective because it captured the essence of the care delivery. A team was formed to design the simulation model, which included the medical director of the ED, the doctoral student/action researcher, a professor in operations management, a professor in operations research, and a MSc student responsible for model programming. The design team decided to program the model with so-called discrete-event simulation software. Discrete-event simulations of care delivery processes in EDs are quite common (Saunders et al. 1989; Huddy et al. 1999; Connelly and Bair 2004; Hung et al. 2007). The researchers used the EMPlant (Tecnomatrix) software package, which is one of the scientific and educational standards for simulating production processes. The medical director of the ED considered long waiting times for patients as the most urgent problem to be addressed. The design team therefore defined patient length of stay (LOS) as the primary outcome measure. Patient LOS is the total time patients spend in the ED, which consists of time during which operating activities are performed and waiting time. It is one of the key outcome measures for patient satisfaction and process efficiency in the medical literature.

Making the Conceptual Model

The action researcher and the MSc student set out to make a conceptual model of the care delivery process. They joined the medical and nursing staff to observe their activities and understand the way of working. They also accompanied patients during their stay in the ED. There are several patient populations with different processing in Dutch EDs. After discussing the initial findings, the design team decided not to include all patient populations in the conceptual model of the ED. The model's scope was defined around the largest patient group in the ED, the self-referred patients. This group made up 60% of the total patient population. The configuration of transforming resources assigned to self-referred patients was simple: there was always one staff physician, one emergency nurse, and up to five treatment cubicles available 24 h per day. The physician and nurse were not responsible for treating other emergency patients, and the cubicles were assigned for their use exclusively. The thus limited scope made the design of the simulation model less complex, and it also facilitated the experiment by restricting the number of stakeholders involved. The student made a flowchart of the healthcare delivery process for the self-referred patients, see Fig. 2. The flowchart was placed in the refreshment room of the ED, with an invitation to everyone to comment. The final version was completed after several modifications.

Designing the Computer Model

The design team used the flowchart to define eight different patient flows that would form the basis of the simulation model, see Fig. 3. The flows resulted from combining three characteristics relating to patients' use of transforming resources. First, arrival: self-referred patients who walk into the ED take a seat in the waiting area; patients arriving by ambulance are immediately assigned to a treatment cubicle. Second, need for diagnostics: if patients require diagnostics such as X-rays or laboratory examinations, processing and transport time are consumed. Third, departure: most self-referred patients are discharged and leave the ED, but some require additional treatment and/or admission. These patients are transferred to residents in the ED, which involves waiting time and a relocation.

The design team defined a basic sequence of operating activities for each of the patient flows. A task list was programmed that triggered the correct sequence in response to the arrival of a patient. It assigned transforming resources to activities in real time, allowing for immediate changes in priority. Two sources ($n = 666$ and $n = 323$) from the study setting were used to simulate the arrival rates of patients. Exponential distributions (Law and Kelton 2000) were created that captured the natural variability in the patient arrival

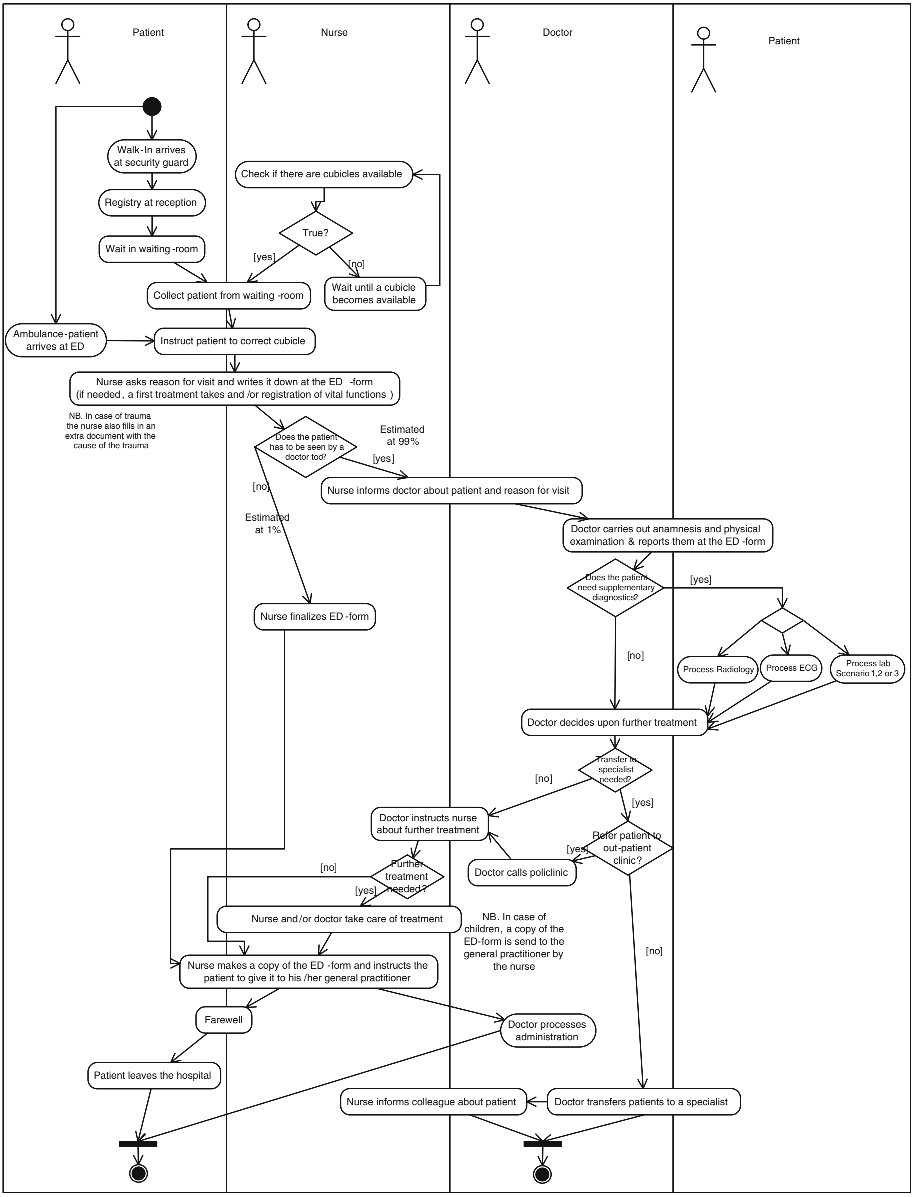

Fig. 2 Care delivery flowchart for self-referred patients in the ED

rate throughout the day. The durations of the operating activities were modelled primarily with gamma distributions (Winston 1994). The student performed several time study observations to gather the required data ($n > 20$ for each activity). The medical and nursing staff were asked to estimate the shortest, longest, and most occurring durations for activities that proved too complex and time-consuming to observe. Existing sources could be used for radiology and laboratory turnaround times ($n = 91$ and $n = 285$).

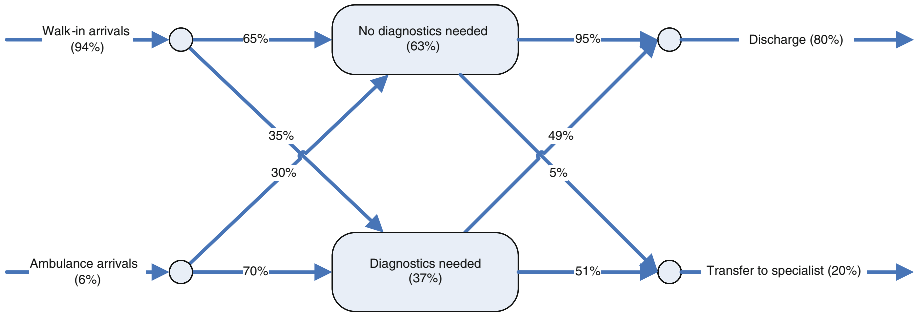

Fig. 3 Flows of self-referred patients through the emergency department, based on resource use

Table 1 Actual and modelled mean lengths of stay (min) compared

Flows (in order of largest size)	Modelled LOS	Actual LOS	Difference
1. Walk-in, no diagnostics, discharge	80	56	24
2. Walk-in, diagnostics, transfer	135	99*	36
3. Walk-in, diagnostics, discharge	145	105	40
4. Walk-in, no diagnostics, transfer	74	26*	48
5. Ambulance, diagnostics, transfer	92	101*	−9
6. Ambulance, diagnostics, discharge	102	118	−16
7. Ambulance, no diagnostics, discharge	36	68	−32
8. Ambulance, no diagnostics, transfer	28	50*	−22
Overall	100	74(*)	26(*)

* indicates estimate

Elements of the modelled working order were checked by the medical and nursing staff to ensure a close resemblance to daily practice. All program modules were documented as flowcharts with explanatory comments explaining the logic. To verify that the programmed code operated as intended, the student performed sensitivity analyses (Sargent 1992). The robustness of the programming was stress-tested under varying numbers of operating resources and different patient arrival rates. In addition, distributions for operating times and arrival rates were replaced with mean values. Inconsistencies that occurred during the analyses were corrected. To assess the accuracy of the model, over 40,000 patient visits were simulated using the so-called replication-deletion method (Law and Kelton 2000). The average patient LOS from these data was compared with the most recent source of data available in the ED ($n = 506$), see Table 1. The model overestimated the overall average patient LOS with 26 min (35%). Average LOS for walk-in patients was overestimated while it was underestimated for ambulance arrivals. Unfortunately, comparison was hampered because of inconsistencies between the data sources, so that several estimates were needed.

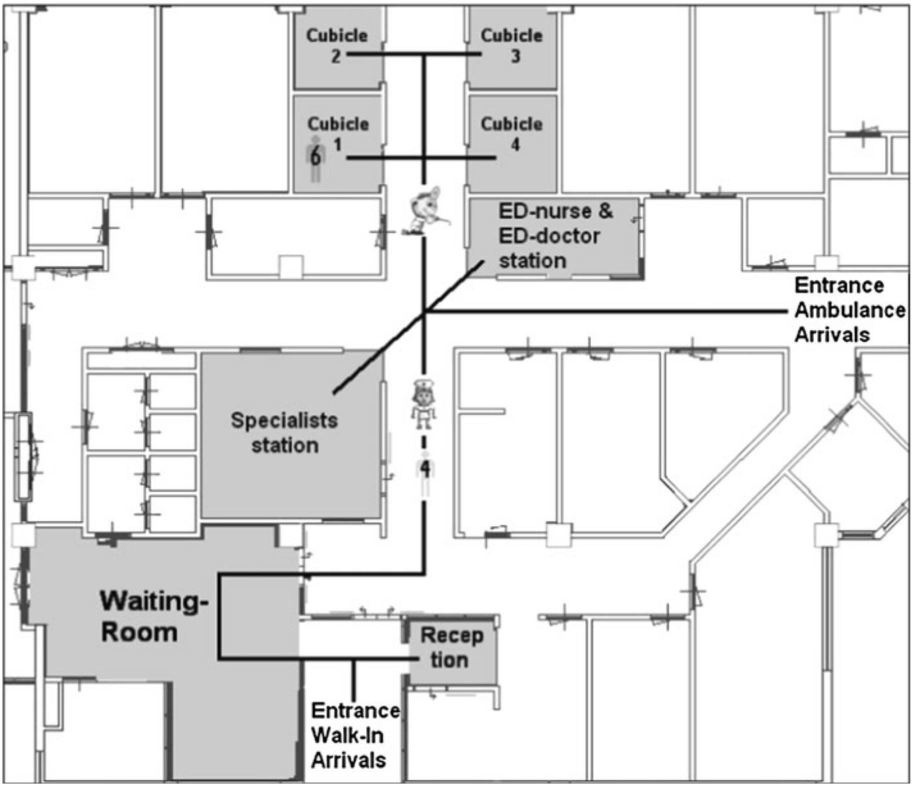

Fig. 4 Simulation model screenshot. NB: It displays a nurse in the hallway, taking a patient of flow 4 into a treatment room. The *black lines* indicate paths along which nurses, physicians and patients move

The design team presented the final working model to the members of the study setting. In an animation, the ED nurses and physicians could see their simulated counterparts moving across the model's visual interface. The exact department layout was used, see Fig. 4. The medical and nursing staff were asked to evaluate the animated representation for accuracy, completeness and specificity to setting. They had not previously evaluated the model's dynamic behaviour. The medical and nursing staff judged that the displayed movements and working order accurately represented the actual working situation. They responded enthusiastically to the presentation and brought up several improvement suggestions. There were no arguments about the design of the model. The design team concluded that the model's performance was acceptable, even though output accuracy could be improved. The work of this team was now finished.

Exploring Improvement Scenarios

At this point in the AR experiment, a team of researchers and the medical director of the ED had designed a simulation model that was enthusiastically received and accepted by all stakeholder groups as valid. It was now time to start using the model for action taking. The action researcher formed a new team with department management and representatives from the medical and nursing staff who were enthusiastic about collaborating in the research process. This "action team" included a staff physician, two emergency nurses, the medical director and the head nurse of the ED, the doctoral student/action researcher and also a BSc student who programmed the improvement scenarios in the simulation model. First, and most naturally, the action team talked about general improvement scenarios that involved adding transforming resources such as extra physicians and nurses, and reducing diagnostic turnaround times. The effects were calculated in the model, projecting reductions in patient LOS. The team especially appreciated having this predictive functionality of the simulation model at hand. However, implementation of these scenarios was deemed unfeasible by department management for economic reasons. The team then studied the model's animation of the care delivery process for self-referred patients. The model showed repeating waiting lines for patients during their stay in the ED. Discussing about ways to remove some of these waiting lines, the team observed that the physician and the nurse carried out their activities in an individual and successive fashion. This needlessly interrupted the patients' care delivery process. The staff physician and the emergency nurses realised that they could carry out their activities more in parallel; they could change their existing task division to improve the patients' care delivery. The team had learned to see that process improvements were possible without adding resources. This direction was certainly deemed desirable.

The team redesigned the professional task division for the self-referred patient group (in terms of "The Subject of the Simulation Model" section: they altered the configuration of transforming resources and operating activities). In the new situation, the triage nurse, who assesses the urgency of emergency patients upon arrival, would also initiate diagnostics such as laboratory examinations and X-rays. In the usual situation, diagnostics were only initiated by staff physicians. This occurred much later in the care delivery process: only after the patient was triaged, then waited for an available treatment room, and finally was seen by the physician. By bringing operating activities forward, the new task division promised to better utilise patient waiting time and thus reduce patient LOS. The effects of the improvement scenario were projected in the simulation model; with some effort, the BSc student altered the programming so that X-rays and laboratory examinations were initiated in the model directly after the triage. The scenario projected a promising 24-min reduction (24%) of average patient LOS, see Table 2. The results were even more promising for patients who required diagnostics. Motivated by this outcome, the action team proceeded to see if the scenario was feasible in practice.

Table 2 Modelled average patient length of stay (min) compared, model baseline to scenario

Group	Modelled LOS
Baseline, overall	100
Scenario, overall	76
Difference	−24
Baseline, no diagnostics	78
Scenario, no diagnostics	58
Difference	−20
Baseline, diagnostics	135
Scenario, diagnostics	102
Difference	−33

Implementing the Scenario

The action team prepared a pilot for the improvement scenario. A protocol was made that the triage nurse could use to initiate diagnostic examinations for the most common patient conditions. It was also agreed that the staff physician would provide quick assistance to the nurse in case of doubt. The emergency nurses and the staff physician then successfully piloted the new task division over two shifts. In their experience, the improvement scenario was feasible and beneficial for patient LOS. As a response, however, other staff physicians and members of the radiology department expressed concerns. They had seen or heard that the triage nurse had carried out an activity that was normally performed by the medical staff. This fundamentally changed the generally accepted professional task division in the ED, which had remained virtually unaltered since the hospital's opening in 1981. In their opinion, the initiation of diagnostics by triage nurses threatened the quality of patient care: it could possibly produce unnecessary diagnostic examinations and inadequate imaging requests.

The action team decided to integrate the concerns and perform a real experiment with more representatives from the medical and nursing staff. They asked two of the staff physicians who had expressed concerns and several previously uninvolved emergency nurses to participate. Ten experimental shifts (day and evening) with the new task division were scheduled. Outcome data would be collected on patient LOS and the quality of care. After two of these shifts were completed, a large difference occurred in the collaboration by the physicians. The newly joined doctors continued to bring up concerns and were generally unwilling to try the new way of working. The experiment was halted and the medical staff was gathered to discuss the concerns together with the medical director of the ED and the action researcher. In the meeting, it turned out that only the staff physician on the action team really wished to adopt the improvement scenario. His colleagues refused further participation, expressing a heartfelt "initiating diagnostics belongs to our responsibilities, the nurses cannot properly do it". Despite efforts of the action team to further involve the physicians in the experiment and stress the potential benefits to patient care, their standpoint remained.

The action team realised that the AR experiment could not proceed in its original form: not all of the stakeholders were willing to take action directly. The team decided to continue in a more indirect way: the one staff physician and the nurses would complete the experiment. If they could achieve the projected reduction of patient LOS while maintaining the quality of care, then these results could help promote the willingness of the other stakeholders. Ten new experimental shifts were scheduled and then implemented without problems. A total of 198 self-referred patients were included in the experiment. Table 3 shows the average patient LOS during the experiment and before the experiment (based on the source used to assess the accuracy of the simulation output). The action team realised a 14-min overall reduction (14%) of average patient LOS. The reduction was 27 min for self-referred patients who required diagnostics. This confirmed the trend projected by the simulation model, although the improvement was less than predicted. The outcome data confirmed that the quality of care was maintained. In the experience of the staff physician and the nurses on the action team, the care delivery process was faster and more efficient. They also perceived the new task division as more intensive and interactive compared to the usual situation. For more details on the methods of measurement, see Rosmulder et al. (2010).

Table 3 Actual average patient length of stay (min) before and during the experiment

Group	Actual LOS	*n*
Pre intervention, overall	97	506
Post intervention, overall	83	198
Difference	−14 ($p = 0.05$)	
Pre intervention, no diagnostics	64	309
Post intervention, no diagnostics	52	105
Difference	−12 ($p = 0.03$)	
Pre intervention, diagnostics	148	197
Post intervention, diagnostics	121	93
Difference	−27 ($p = 0.02$)	

Results

In this study, an AR experiment with computer simulation was performed to improve healthcare delivery for self-referred patients in a university hospital's emergency department. A team of researchers and the medical director of the emergency department designed a computer simulation model using locally available data and several straightforward observations and assumptions. All important modelling decisions were shared with the medical and nursing staff in the study setting. The model was accepted by all stakeholder groups as a valid representation of the actual work situation. A second team, consisting of the action researcher, the ED medical director and head nurse, a staff physician and two emergency nurses, used the simulation model to explore several improvement scenarios. Without any problems, this action team designed a scenario that fundamentally rearranged the task division between the physician and nurses. Based on the promising reduction of patient LOS projected by the simulation model, the scenario was brought into practice. This generated a lot of discussion and concerns, especially from other staff physicians in the ED. Convinced of the positive effects of the new task division, the action team proceeded to implement the improvement scenario over a number of experimental shifts. The outcome data of the successful implementation demonstrate that patient LOS was reduced and the quality of care was maintained. The simulated projections were confirmed to a large extent. The action team concluded that the improvement scenario could improve the delivery of patient care for more than 20,000 self-referred patients each year.

Up to the phase of scenario implementation in the AR experiment, the collaboration between the researchers and practitioners had been relatively free of engagement. This changed abruptly when the action team piloted the new task division. What had started as projections in a distant computer model now became directly visible on the work floor. In their enthusiasm to take action, the action team had underestimated how fundamentally different the new task division was for their colleagues—who had not shared in the exploration of improvement scenarios. This elicited discussions among the physicians, nurses and managers about the values behind the process of delivering healthcare in the ED. Especially the other staff physicians were challenged in their professional position and autonomy. They remained unwilling to further participate in the experiment. This clearly demonstrates how easily proposed changes to the healthcare delivery can be halted in the AR.

With time, the results achieved by the single action team turned out to have lasting effects on the other stakeholders in the ED. When the results of the experiment were presented to the medical and nursing staff, the emergency nurses responded enthusiastically. Several of them became inspired to take spontaneous action and tried the new protocol in the triage on their own initiative. They indicated that it made the nursing task more interesting. The nursing staff in general supported the improvement scenario. The results of the experiment made a number of staff physicians change their standpoint about the new task division. This process took several years: at the time of the experiment, their standpoint was that all diagnostic examinations could be initiated only after a physician had seen the patient; later, they indicated that the nurses could initiate some diagnostics at the triage to speed up the care delivery. The majority of the medical staff became supportive of the new task division, which was also a result of personnel changes. As a follow-up from the experiment, the physicians and nurses implemented regular staff meetings to discuss their professional collaboration. The medical director and head nurse of the ED gained sufficient insights from the experiment to put department-wide implementation high on the improvement agenda. They had learned that the new task division reduced waiting time for patients, improved teamwork and efficiency for the professionals, and maintained the quality of care. We conclude that in this single AR experiment with computer simulation, the willingness for action taking by all the stakeholders was promoted—albeit in different forms.

Discussion

To action researchers (with or without an industrial engineering background), the use of computer models is a way to involve practitioners in the research process. Our study demonstrated that if the researchers program the model and share the most important modelling decisions, then the healthcare professionals and managers will confide in the outcomes and projections of the simulation model. It was not complicated to design a simulation model for change-oriented purposes. The use of existing sources of data and several straightforward observations and assumptions was sufficient. The decision to limit the scope of the simulation model proved useful for keeping the model design simple and the change process manageable. We found it important to separate the responsibilities for programming the model and supervising the change process. The modeller's primary concern is the valid representation of reality, the action researcher's primary concern is the creative group process of using the model to improve practice. The two roles of facilitator and modeller are distinct and need to be embodied by different individuals (Vennix et al. 1992).

The members of the study setting who participated in the action team indicated several reasons why the experiment succeeded. The model provided one communication channel for the different groups to talk about the organisation of their activities to deliver patient care. This contrasted to the traditional way of discussing healthcare delivery from a medical, nursing or management perspective only. The exploration of improvement scenarios with the action researcher gave the team members a focus of what could be improved. The simulated projections provided an evidence base of what would and would not work under the local conditions in the study setting, which in turn motivated the staff physician and emergency nurses to take action. This shared process of consensus-building toward feasible action proved essential in the experiment, and is something that nicely fits with the Dutch cultural characteristics. A final reason for the successful implementation was the fact that the new task division could be safely and easily tried within the established general way of working. This model line approach (Spear 2005) was a useful way of organising the improvement of healthcare delivery within the department.

A question that rises is whether the measured improvement of patient LOS did not actually result from the experimental situation itself (Hawthorne effect) or from the deliberate selection of participants who were already enthusiastic. There are three counterarguments that can be brought up. First, the creation of an experimental situation alone does not promote willingness of the different stakeholders to engage in action taking. With our efforts to involve all stakeholders, we managed to achieve change with one team only—those who were involved in exploring improvement scenarios. Second, the outcome data demonstrate that the intervention to initiate diagnostic examinations earlier on explains most of the improvement in patient LOS. The most compelling argument however is the following. The improvement scenario that we developed in this study is not original: the intervention of initiating diagnostics at triage is known as "advanced triage" (Cheung et al. 2002; Seguin 2004; Wiler et al. 2010). Several countries including the United States have already successfully adapted this way of working (Hoffenberg et al. 2001; Wiler et al. 2010). In the process of developing it, the members of the study setting learned that the improvement scenario already existed in the international context. If the managers or the researchers had directly proposed to implement this scenario from the beginning, the healthcare professionals would most likely not have cooperated. The advanced triage challenged their assumed positions too much. The use of the computer in the change process made joint discussions about the professional task division possible, which was needed to allow implementation of the scenario.

To our knowledge, this study was the first application of computer simulation that explicitly aimed to change everyday healthcare practice. Simulation studies have concentrated primarily on the accuracy of the model output and on policy recommendations based on simulated projections (e.g. Saunders et al. 1989; Connelly and Bair 2004; Hung et al. 2007; VanBerkel and Blake 2007). It remains unknown whether recommendations were in fact implemented to improve the real-life situation, and whether the results were successful (Scholl 2004). A recent literature review reports that computer simulation models are hardly used in healthcare to support management decision making (Van Sambeek et al. 2010). Other relevant work studied collaborative model design without the change component (Lane et al. 2003), or was performed outside of the healthcare sector (Vennix et al. 1996; den Hengst and de Vreede 2004).

Our promising investigation merits further research on the use of computer simulation models to facilitate AR in emotionally-charged and risk-filled contexts such as healthcare. The experiment in this study can be repeated on a larger scale, with a random selection of participants into experimental and control groups. It is also worthwhile to involve more (teams of) stakeholders from the beginning in the exploration of improvement scenarios. Our decision to do this with only a single action team could have reduced the cooperation with others later on. In general, healthcare studies with computer simulation techniques should be more aimed at improving practice. The use of simulation software that is especially oriented toward healthcare settings is probably a good choice for this. We used a package that was a standard for simulating transformation processes in industry. In addition to healthcare-friendly software, learning to use flowcharting techniques can also help healthcare professionals and managers to better describe and understand the delivery of care. More research is finally needed on the socio-psychological processes taking place when groups of professionals redefine their ways to divide and coordinate tasks, and especially on how these can be influenced.

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