Simulation Gaming in Hospital Environments

Creating a Simulation Environment to Show that Information Sharing Works

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ABSTRACT

Information sharing in hospitals often faces problems, reducing overall hospital coordination. This research takes a look at information sharing and why it presents problems in hospital processes. It includes a look at the prisoner’s dilemma. A ‘NetLogo’ environment is used to implement a simulation game considering sharing of beds between departments to show the effectiveness of information sharing. Next the testing and validation of the simulation game is described. The simulation game is a valid tool for showing that information sharing creates an increase in hospital revenue and effectiveness.

Keywords

Simulation gaming, simulation game, hospital environment, information sharing, coordination problems, iterated prisoner’s dilemma, NetLogo.

1. INTRODUCTION

Hospitals tend to end up in four different, disconnected organizations. These are: “community”, “control”, “cure” and “care”, symbolizing the board, the managers, the physicians and the nurses [1]. This increases difficulty of coordinating a hospital. Furthermore, the formal hierarchy of hospitals tries to put managers above physicians, but in reality, the physicians have a professional status that is above that of all other players (increased by their uniqueness of being harder to replace than any of the other players), often using their position for their own interests [1,2]. This professional status is used to assume authority in areas where the person in question is actually not an authority.

These above are united by dedication to this field, a desire to advance (scientific) knowledge by means of research and development and urgency in times of crises, where saving lives is the first priority. One of these increase defragmentation and cooperation, because all groups there have the same interests and same sense of shared purpose; as soon as these are gone, cooperation again deteriorates [1]. A good example of the general lack of coordination are the discussions involving the ‘DBC’ (the entire route a patient goes through from diagnosis to being declared cured). Long negotiations with all involved parties are used to determine a definite price for the treatment. Especially when parties in a hospital itself act in their own interests, this process can be prolonged [3].

The way coordination in hospitals works at the moment is by means of standardization of skills and knowledge. When the situation requires urgency and quick decision making, the strength of this system shows an near-complete automatic coordination of work (physicians and nurses do what’s best in an immediate situation to save lives) [4]. However, this also leads to the drawbacks described above. Therefore the methods of coordination should be changed to a system of mutual adjustment and the standardization of norms, informally called an “informed communication embedded in a strong culture” [5]. Informal and open communication is one of the keywords here.

The American St. Charles Medical Centre has effectively broken the barriers between these different groups [2]. Formal authority has been relinquished; the hospital is instead relying on functional relations. It has led to 40% less management tasks, taking the manager’s tasks to back where they belong, instead of trying to coordinate all the different groups, each with their own interests. Instead of physicians, nurses are in charge. As they say: (sic) “The nurse is in charge, the physician facilitates.” [2]. This has decreased the number of accidents and near-accidents, because before when nurses saw them occurring they were afraid of damaging a physician’s authority, or were otherwise delayed by the ‘walls’ between them and the other parties. This shows it brings down the number of adverse events, which in The Netherlands 5.7% of the patients experience [5].

There is a project called “Sneller Beter”, in which the “Gelre ziekenhuis” in Zutphen, The Netherlands, is a participant. Among other things, this project takes some of the successful principles of the St. Charles Medical Centre and tries to apply them to hospitals in The Netherlands. One of the secondary focuses of this project (after taking on a patient focused approach), is the setting of high demands to provision of information, as well as its timeliness, completeness and accuracy. This shows that the need for sharing of information in hospitals is ever increasing [3]. The increased need for control of costs goes straight against the lack of transparency in costs and turnovers in hospitals. Not having this kind of information decreases the effectiveness of policies on commercial as well as process level [3].

Important to note is that a lot of the information presented and the research done applies to Dutch hospitals. It may or may not be applicable to hospitals in other countries, unless specifically stated.

This paper first considers the problem statement in section 2. Section 3 introduces us to the research questions, the what and why of the research. Section 4 considers the methodology of the research. Subsection 5.1 goes into gaming theory, using the prisoner’s dilemma to describe the way of the information sharing can be looked at in game theory. Subsection 5.2 covers the problems that hospital processes face with information sharing. Section 6 is about simulation and game rules, considering why we are using a simulation. Section 7 considers the implementation of a prototype of the artifact. Section 8 will be the validation of the prototype. Section 9 will give
conclusions. Finally, section 10 will provide suggestions for future research.

2. PROBLEM STATEMENT

Hospitals are separated into a financial side (management) and an operational side (care). This separation exists to make sure doctors treat their patients as best as they can instead of trying to treat as many patients as possible or just treat the patients with the best chances of survival to gain maximal financial benefits. It is exemplified by this quote: (sic) “But it should be understood that the organization is set up to protect the doctor from behaving as economic man.” [6]. This separation is the reason hospital departments use budgets.

In reality, hospital departments are in constant competition over scarce resources. They all want as much access as possible to resources such as machinery, equipment and time in operation chamber. Information sharing is often problematic. It seems to be obvious that information sharing leads to a more effective and efficient use of resources. Even though, departments are often afraid of sharing information. They have good reason to believe that sharing information will lead to them getting cut in their budget, or leading to less access to e.g. machinery or time in operation chamber (because they needed the operation chamber less time this week, even though they might need it more next week). Because of budget issues, privacy issues, and time issues, information sharing commonly faces many problems. Subsection 5.2 will consider specific hospital processes and their troubles with information sharing.

As sharing information is more effective (as explained in the introduction), there is a solution to the problem of departments not sharing information: training medical personnel in sharing more information. The board and management need ways to change the mindset of the organization’s stakeholders in order to increase acceptance for sharing information. Patients and secretaries might want to stick to a different hospital, where they at least know the way of working. Specialists and physicians will be afraid to lose a lot of their power [2].

This is where simulation gaming comes in. Simulation games provide a means of modelling a real world environment, thereby showing that information sharing is beneficial. Section 6 gives us more information about simulation gaming.

3. RESEARCH QUESTIONS

The research will focus on simulation gaming considering information sharing in hospital processes. From this and the above we infer the following main research question:

*Can we create a simulation game that shows that information sharing in hospital environments is beneficial?*

With the word suitable we mean that the simulation game needs to resemble a part of the information sharing process in hospital environments.

The first thing we need to define is what type of information sharing we will use in our simulation game. Something that we might use could be the same in a hospital environment as in other company environments, but might differ as well. The prisoner’s dilemma is a problem in game theory that can be used for situations where entities gain benefits from cooperating or suffer if a party involved does not do so. This is something that we might be able to use to model information sharing. It poses the following question:

*How can we use the prisoner’s dilemma to model information sharing in a hospital process?*

Something else we want to find out is why hospitals have problems with information sharing in the first place. If we can find a hospital process that has problems with information sharing, we can model this process in our simulation game. The model needs to be simple, as well as accurate. There needs to be some kind of competition between different departments or hospital groups, where some kind of information sharing can take place. This leads to this question:

*Why do hospital processes present problems with information sharing?*

We now need to translate the solutions to the above into a simulation. There needs to be a simulation of information sharing. It is important to consider what variables and what values we use to model all information in the simulation. We can for example use point-based values for different information. The simulation will need to emulate the real information sharing in hospital environments. After we have a simulation, we need to turn it into a game, to get players to actively participate in our simulation. We will for example introduce competitive elements to try to encourage player participation, as well as giving motivation to look for the best possible case (which will obviously be lots of actors sharing information). The above translates to the following question:

*How do we model a hospital information sharing problem in a simulation game?*

4. METHODOLOGY

In order to answer the main question, the research consists of three main parts. The first part is the investigation about what type of information sharing we will represent, as well as what hospital process we will use for our model. The second part consists of the actual creation of a simulation game based on the model and type of information sharing. Finally, this simulation game will be tested and evaluated.

Hevner [7] gives us several guidelines for design science, to which this research adheres as best as possible. Because of the limited scope of this research, only the following are actually relevant:

- The design-science research must provide an artifact in the form of a construct. This paper outlays the artifact that has been designed as part of this research in section 7.

- The problem must be relevant to a problem domain. This paper demonstrates why the research done and why the solution described is relevant to the problems hospital processes face with information sharing, the second part being described in section 5.

- The artifact must be evaluated. The evaluation of the produced artifact will be shown in section 8 of this paper.

- The design must be communicated “effectively both to technology-oriented as well as management-oriented audiences” [7]. Management-oriented audiences require knowledge of why they should use the artifact for their organization, whereas technology-oriented audiences need knowledge of how to implement the artifact. This paper does the work of presenting the research done in ways such as that it is suitable to the two relevant groups described above.

The first step we will take is a look to what type of information sharing we can represent in the model. This choice relies on
what model we have chosen. Even more, the choice of our model can change based on whether our model can represent a type of information sharing that we find satisfying. To look at what different types of information sharing currently exist and can exist in hospital environments, the prisoner’s dilemma will be used as an analysis tool.

The next step to take in order to answer the main research question is looking at what hospital processes have problems with information sharing. Several processes will be discussed, and a choice will be made between them about which to use for our model. Information sharing has to be a relevant aspect of the case.

After the above, the simulation design will start, with the creation of simulation rules. The simulation design will provide a model for our simulation game. The simulation game will allow different settings considering information sharing between the players, as well as show different scenarios of information sharing. Game rules will be created to promote players to actively participate in the game, thereby providing interaction between the player and the simulation. It is not supposed to be a passive simulation, so different options to settings, as well as interaction with the simulation during run time of the simulation game will be made possible.

We need a simulation game environment to implement our model. NetLogo “is a programmable modelling environment for simulating natural and social phenomena” [8]. We will use NetLogo to simulate information sharing in a hospital process. The next step is implementing our simulation game in this NetLogo environment. Both the rules of simulation (the model) and the game (the interaction) will be implemented into one simulation game.

To check whether the simulation provides a correct solution, the game will be evaluated. A number of tests will be developed to determine whether the model is a correct representation for information sharing in hospital environments, as well as to determine if the model actually proves that information sharing in hospital environments is beneficial to being less open with information. The tests will validate the correctness of the hypothesis that a simulation game is indeed suitable for proving that information sharing in hospital environments is beneficial, thereby answering our main research question.

After this, the feedback gathered will be used to make small improvements to settings of the simulation game and present conclusions. The paper will finish with recommendations to application of the simulation game, as well as research to future modifications and adaptations.

5. CASE AND INFORMATION
This section deals with the first part of the research: choosing the type of information sharing and hospital process.

5.1 Information Sharing
This subsection describes information sharing by means of the prisoner’s dilemma in game theory.

It would be easy to say information sharing is beneficial to all parties involved, especially when the parties involved are expected to be cooperating with each other. It could help increase the ‘up-time’ of things like the operation chamber or CT and MRI-scans. As stated above however, departments involved are often weary about this. Subsection 5.2 presents several hospital processes, along with the information sharing scenarios that are occurring.

What exactly is information sharing? On an abstract level it means that one department shares data with another. The departments can share different types of information, but to keep our simulation simple, we take a look at cases with just one type of information being shared. In a recurring situation departments can choose to share information every time, or they can choose to share information based upon whether the other department shares their information. One department can also randomly choose to share information, or not at all. Something that can provide a context for information sharing is the prisoner’s dilemma.

The prisoner’s dilemma is a problem in game theory. It can be used for situations where entities gain benefits from cooperating or suffer if a party involved does not do so. The best overall possible solution involves all parties cooperating. It can however be difficult for parties involved to cooperate due to costs and trust issues involved and the amount of coordination required, and therefore the optimal situation (cooperating) is often not achieved.

An inherent problem in a lot of real world and hospital situations is that not sharing information strictly dominates (is statistically better than) sharing information [9, p.10]. This means that if one party does not have information about what the other party will do, it will objectively choose not to share information. If both parties cooperate (share information), they both benefit. If one party chooses to cooperate and the other does not, the party that cooperates loses all advantages of sharing information, while the other party gains the other’s information and can benefit from it. If both parties choose not to cooperate they do not get the benefit of cooperation. If a party does not know what the other party does, the best option is to not share information, because that way it will have the best chances of getting the most benefit.

In our version of the prisoner’s dilemma, we will use an iterated version. Here, the game is played repeatedly and players can use knowledge of previous ‘meetings’ (opportunity on information sharing) in order to figure out what to do the next ‘meeting’ [10]. For example, a department cooperating with another department on an occasion can choose not to cooperate anymore when he sees that the other department does not cooperate. This makes it harder for parties to build trust when not cooperating in the first place, which is comparable to real life situations. Also, as soon as one of the parties ‘betrays’ (i.e. does not cooperate) others whilst cooperating before, the other department will be weary of cooperating with that party again on future occasions.

5.2 Hospital Processes
This subsection deals with why hospital processes experience problems with information sharing and the selection of one of these processes for the simulation game.

Several different hospital processes came up in discussions with researchers who have knowledge in the field of information sharing in hospital environments. Often it is clear that sharing information is beneficial to not sharing information. This subsection will show why these processes do give problems with information sharing. These processes can be used to apply the information sharing ideas of the previous subsection. After a discussion of these a choice will be made about which case we simulated, as well as why. The different cases are:

- Operating patients with multiple health problems.
- Operation room.
- Picking up patients for operation room.
• Radiology department, usage of CT and MRI-scans.
• Reservation of beds in a nursery department.

Operating patients with multiple health problems: e.g. whenever a patient with lung and heart problems needs to have heart surgery, the heart surgeon needs to know if the patient has any lung problems that might result in complications during surgery. He has to ask the doctor with the patient’s file on lung problems for any information regarding the patient’s lung problems. He will then have to wait to receive the file to perhaps change his way of operating to decrease the chance of complications. Increasing the number of people who have access to a patient’s file can cause privacy issues, but also a decrease of the workload of the surgeon and of the amount of time required to prepare for the operation.

The usage of the operation room is based on historic events. A department that has had the operation room for a number of hours this week will get the same hours next week, even though it might need the operation room less hours, or more hours, than this week. Departments are afraid that if they claim fewer hours, when they need more again they will not get them, because last time they needed only fewer hours.

Picking up patients for operation room: whenever a patient needs to be picked up for an operation, the assistant goes to the nursery where the patient is located and asks for the patient to be picked up. The patient is then retrieved and delivered to the assistant, who then brings the patient to the operation room. If the assistant would be given more information about the patient, such as where the patient is located, less people are needed to retrieve the patient, which would also happen faster. Downsides include privacy issues.

Every timeslot, e.g. a day, a CT and MRI-scan, or machinery in the radiology department are turned to a certain setting. This timeslot, all scans that require this setting are done. After the timeslot, the scanner is changed to a different setting. This means that if the day a scanner with a specific setting is filled, another patient requiring a scanner tuned this way will have to wait for a number of days (often in the hospital) before the scanner is tuned back to the setting he needs. This also happens if a doctor requires a patient to get a scan while the next day the scanner is set in the way the patient needs is still several days away. It is more efficient if the departments share information on what scan they need, so that the scanner is not set in a specific way for a timeslot, but is only set that way for as long as there are patients who need this setting, and then changed. This reduces waiting times for patients, as the machine is changed back to the setting they need maybe days earlier.

Reservation of beds in a nursery department: sometimes several departments use the same nursery, e.g. in the intensive care. They reserve beds for their patients, some of which they know will come, others which they do not know of in advance. There is a competition between departments for getting as many beds as possible, because treating more patients leads to bigger budgets. Sharing information about the amount of beds not used but reserved, and sharing those beds will allow departments to make more efficient use of beds.

Coincidentally, the choice was made to use the last item on the list: the reservation of beds as the hospital process we will model. This is because in our opinion this is easiest to model and implement within the allotted time for the research, and is easy to extend when time allows it. Also, we had a good idea of how to model and implement this, giving this case a head start as opposed to the other cases.

6. SIMULATION GAME
This section deals with the second part of the research: the development of the simulation and game rules.

Something that can be used to solve our above problem is a simulation game (non-entertainment game). Simulation games emanate the real environment as well as stimulating competition. About why a simulation game, [11,12] give different explanations based on an extensive literature review, that can be used in this case too. A summary of these explanations is that simulation games have potential with presenting real environments, as well as increasing acceptability of offered solutions. Furthermore, [11] reports that in another case the seriousness of the problem (lack of information sharing) and potential benefits of the solution (improved information sharing) start to become more obvious through a game as well.

A simulation game creates an environment where the board and management can test how and what kinds of increases of information sharing affects performance, and stakeholders such as doctors can be persuaded to accept them, by showing them that increasing communication and information sharing facilitates an overall increase of effectiveness (sharing is better than not sharing). Because of the above, a simulation game is suited in helping with training medical personnel in sharing more information.

In our hospital process, the reservation of beds, sharing information relates to the sharing of beds that are reserved but unused. Translating the prisoner’s dilemma to our case, if we take two departments they both have two options: sharing information and not sharing information. When they both share, they both win, because they will be able to use each others beds when needed. If one department shares while the other does not, the department will be able to use the beds of the other departments, but not the other way around. If they both do not share, they both lose out on the benefit of being able to use each other’s beds. The above leads to the outcomes of table 1, with one department set out horizontally and the other vertically. The table shows relative increases in benefits when parties share. Sharing beds will not lead to double figures of revenues, but to an increase that needs to be taken into account nonetheless.

<table>
<thead>
<tr>
<th>Share</th>
<th>Not share</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,3 – 1,3</td>
<td>1,1 – 1,3</td>
</tr>
<tr>
<td>1,3 – 1,1</td>
<td>1 – 1</td>
</tr>
</tbody>
</table>

Table 1. Prisoner’s dilemma information sharing options

Important to note is that the mentioned increase in revenue is a chance at an increase in revenue. Only by taking a very large amount of turns sharing (limit towards an endless amount) there will be a clear increase in revenues when information is shared as opposed to not shared. This reasoning also shows why sharing information is not directly seen as being more beneficial and is not clear for every actor involved, as with a small amount of turns sharing or not sharing there is not a clear benefit in sharing information.

An advantage of sharing that needs to be taken into account is that if a department shares its beds now while the other department needs them, it leads to a decrease in the waiting list of the other department. Then, as soon as the department needs beds, the other department might have them available, because it could have cleared its waiting list by then with help of the
other department. This also explains why when one department shares while the other does not, the first department still has the chance of getting an opportunity of gaining from it.

The first step of creating the model is translating the hospital process of reserving beds to a model. We use beds as our starting point. We want to model the three different statuses of beds: empty, reserved and occupied. To keep the model simple, we use two departments. Every department has a waiting list that keeps track of the number of patients that need a bed but does not have one available yet.

We want to create a setting in which some of the time the two departments will have ample beds to lower waiting lists to zero, whereas other times waiting lists will be created and increase. For our simulation we make use of rounds. Every round, a set of predefined steps takes place, and players are allowed to change settings.

The options we use for our game rules are the options share and not share. This means that a department can choose to share beds it has reserved but not occupied that round, or choose not to do so. Each round, each department is able to choose which option they want.

The goal of the game is to earn as much revenue as possible. Benefits are obtained by treating patients, whereas costs are made by using beds, where using a reserved bed costs less than using a bed that was not reserved by the specific department. Revenue is calculated per department, as well as in total (adding the revenue for each department). A penalty is added for treating patients from the waiting list, instead of treating new patients. Hospitals always strive to keep waiting lists as small as possible, and this model enforces that behaviour. Each round, revenue is calculated per department in this way:

\[
100 \times (\text{new patient treated}) + 70 \times (\text{patient treated from waiting list}) - 10 \times (\text{reserved beds by this department}) - 20 \times (\text{used non-reserved beds by this department}) - 3 \times (\text{non-occupied beds})
\]

Each round, each occupied bed has a 50% chance of becoming empty (the patient is cured or deceased). The amount of new patients per department per round is calculated like this:

\[(\text{Base amount of new patients} + \text{random number between and including 0 and 9})\]

Each 50th round, per department the base amount of new patients is randomly set to 10, 20 or 30. Whenever both departments have a base amount of 10 new patients, there are ample of beds and any waiting list will decrease. If both departments have a base amount of 30 new patients, all beds will be occupied quickly and waiting lists will likely arise and/or increase, whereas if both departments have a base amount of 10 new patients, waiting lists will decrease and beds will be left empty after the waiting lists have disappeared.

A department makes reservations based on the mean of the last 10 incoming patients, reserving 5 extra beds in case there will be extra patients:

\[(\text{Sum of incoming patients of last 10 rounds}) / 10 + 5\]

If the amount of available beds is smaller than the amount of beds the two departments want to reserve, the available beds are divided between the two departments based on a ratio between their reservation requests.

The number of wasted beds is the number of beds reserved by a department and not occupied, while the other department still has patients in the waiting list.

7. ARTIFACT IMPLEMENTATION

This section describes the implementation of the artifact developed by this research. The design as an artifact is described in [7]. The class model of the game can be seen in Figure 1. Each bed can be either available, occupied or reserved. Furthermore the game keeps track of the number of patients in the waiting list.

Playing the game in NetLogo 54 times gives a view such as the one in Figure 2. It shows an example of the representation of beds. Beds are represented by squares with colours or different shades denoting each bed’s status (here a black square is a bed occupied by one department, a very light grey square is a bed occupied by another department, a grey square is a bed reserved by that same department, and the white squares denote empty beds). This view has a total of 121 beds (the amount we used throughout our simulation game).

Each round (called ‘tick’ in NetLogo), the following happens:

1. A semi-random amount of new patients for each department is set.
2. Each reserved bed is set to available bed.
3. Each occupied bed has a 50% chance that it will become available.
4. Each department reserves beds, if the reservation option is turned on.
5. Beds will be occupied by each department, based on reservations first. The free rooms are distributed randomly, until there are no more patients in the waiting list or new patients, or no more free (or reserved) beds. Left over new patients will be added to the waiting list of the department.
6. A department will receive beds reserved by the other department if it needs them and the other department has the sharing option turned on.
7. The number of wasted beds is calculated.
The following monitors are present, to keep track of a number of important variables over time:

- The amount of beds used per department, as well as in total.
- The amount of patients in the waiting lists per department, as well as in total.
- The amount of wasted reserved beds (unused reserved beds that could have been used by the other department).
- The average amount of wasted reserved beds (amount of wasted beds divided by the amount of rounds).

8. VALIDATION

This section will describe the validation and evaluation of the simulation game. The evaluation method used is an experimental one, with the actual validation being done by means of a simulation [7]. We deemed this the most effective and efficient way of testing given the strict time constraints of the research, while still using a rigorous testing method.

Our simulation is a stochastic simulation. A stochastic process is an experiment in which the outcomes will not necessarily be the same, even with equal inputs and circumstances [13].

We assume all patients are treated as new patients (not from the waiting list). The following expected values (per department) have been determined [13]:

- The expected number of new patients per round is \( 24.5 \).
- The expected number of reserved beds per round is \( 29.5 \).
- The expected number of occupied beds after each round after an equilibrium between the emptying and occupying of beds has been reached is \( 98 \).

We let the simulation game run for \( 10000 \) steps. This we deem a number large enough to eliminate total randomness. Next, we determine the expected value \( E(X) \) of the total revenue. This is the sum of the average value of the revenue per department per round (see section 6) times 2 (number of departments) times \( 10000 \) (number of rounds):

\[
E(X) = (100 \times 24.5 + 70 \times 0 - 10 \times 29.5 - 20 \times 0 - 3 \times (121 - 98)) \times 2 \times 10000 = 41720000
\]

The validation of the simulation game is done in four steps. First, the different scenarios are discussed. Second, the test setting is described. Third, the outcomes are shown. Last, the evaluation of the testing is done.

8.1 Scenarios

For our validation we will consider four different scenario’s of information sharing in the simulation game. For simplicity, we will consider a department choosing in advance whether he shares information or not. We want to show the extreme options, so we will disallow any department changing in between:

- Neither department shares beds.
- The first department shares beds, the second does not.
- The second department shares beds, the first does not.
- Both departments share their beds.

The second and third scenario listed above are equal to a case in which one of the departments shares its beds where the other does not. It does not matter which department shares and which does not, for our tests we can take these two cases and consider them as one case.

8.2 Test setting

Thus, we come to three different test settings:

1. Neither department shares beds.
2. One department shares beds, the other does not.
3. Both departments share their beds.

We suspect that the total revenue will be highest when both departments share their beds, and that the total revenue for a single department will be higher when the other department shares its beds as opposed to when the other department does not share its beds.

Considering the information in this section so far, we formulate the following hypothesises:

1. The total revenue will be close to the expected value.
2. The first test setting will have a lower average total revenue than the second and third test settings.
3. The second scenario will have a lower average total revenue than the third test setting.

We have run the simulation game for \( 10000 \) rounds. We have done this 40 times for each test setting. If more time was available, more extensive testing would have been done. However, each test itself took up a considerable amount of time, and interpretation of test data cost time too.

8.3 Outcomes

The different test settings are called 0-share, 1-share and 2-share, for the amount of departments that share beds. As table 2 in Appendix A and figure 3 below show, (rounded) average total revenue for test setting 1 is \( 39133654 \), for test setting 2 it is \( 39333690 \) and for test setting 3 it is \( 40621711 \). Furthermore, the department that does not share has a lower average total revenue by around \( 2000000 \) than the department that does share (test setting 2).

We can now calculate with 95% chance a confidence interval for \( E(X) \) with this formula [13]:

\[
((\text{avg})x - c \times (s/sqrt(n)), (\text{avg})x + c \times (s/sqrt(n)))
\]

If we take a look at the total revenue per round, this leads to the following 95%-confidence intervals for \( E(X) \) for the different test settings, per round (rounded, for calculations see table 3 in Appendix B):

1. \( E(X) = (3897, 3930) \)
2. \( E(X) = (3921, 3946) \)
3. \( E(X) = (4045, 4079) \)

We can calculate with a 95% chance the confidence interval for \( \text{var}(X) \) with the following formula [13]:

\[
((\text{avg})x \times(1-\text{avg})x/n - c \times s^2/n, (\text{avg})x \times(1-\text{avg})x/n + c \times s^2/n)
\]
Using this formula we get 95%-confidence intervals for \( \text{var}(X) \) (see table 3 in Appendix B for calculations). The standard deviation is then calculated by taking the root for each value of the intervals. We can say that the standard deviation for the test settings lie, per round, in the following intervals (rounded by 2 decimals):

1.  (40,64; 63,59)
2.  (30,20; 47,25)
3.  (42,35; 66,26)

1. \( \frac{(n-1)s^2}{\sqrt{2n}} \), \( \frac{(n-1)s^2}{c_1} \)
2. \( \frac{(n-1)s^2}{\sqrt{2n}} \), \( \frac{(n-1)s^2}{c_2} \)
3. \( \frac{(n-1)s^2}{\sqrt{2n}} \), \( \frac{(n-1)s^2}{c_1} \)

The information sharing simulation game that has been developed by this research is an effective tool for showing that it actually shows that information sharing is beneficial and leads to bigger revenues and more efficient hospitals. The prisoner’s dilemma is a problem in game theory, where entities benefit from cooperating. We used an adapted version of this problem for our research. Not sharing information in a hospital dominates sharing information. Both parties have to be convinced to share information or they will not. We use an iterated version of the prisoner’s dilemma, which means the game is repeatedly played.

Hospital processes often experience problems with information sharing. Often there are privacy issues involved, but at other times they consist of budget issues. Departments are afraid that they will lose hours in operation rooms if they are open about what times they need the operation rooms, especially when they have an idle week. Other times they are afraid their budgets will be cut and other departments will take those beds instead and get a bigger part of the overall hospital budget.

We have used the NetLogo simulation environment for creating a simulation game. We have created simulation rules to include more than two departments. The prisoner’s dilemma is a problem in game theory, where entities benefit from cooperating. We used an adapted version of this problem for our research. Not sharing information in a hospital dominates sharing information. Both parties have to be convinced to share information or they will not. We use an iterated version of the prisoner’s dilemma, which means the game is repeatedly played.

8.4 Evaluation
This subsection will evaluate the hypotheses discussed in subsection 8.2, and will

1. The total revenue will be close to the expected value.
The expected total revenue was calculated in section 8 as 41 720 000. The values that came out of the tests were (rounded, per test setting): 39 133 655, 39 336 91 and 40 621 711. The largest difference is a difference of (41 720 000 - 39 133 655)/41 720 000 * 100% = 6.199%. In our simulation there have been patients that were treated from the waiting list, reducing revenue (departments get reduced revenue from patients treated from the waiting list). There will be times that patients will be treated in non-reserved beds instead of in reserved beds. Also, the amount of incoming new patients varies over time. If it is low, revenue will be lower, whereas a higher amount of new patients will be sure to increase revenue (while if they will be treated from the waiting list revenue will be cut and other departments will take those beds instead and get a bigger part of the overall hospital budget).

2. The first test setting will have a lower average total revenue than the second and third test settings.
The revenue values that came out of the tests were (rounded, per test setting): 39 133 655, 39 336 91 and 40 621 711. The difference in revenue between 1-share and 0-share is 200 035,8, which is: 0,51%. The difference between 2-share and 0-share is 1 488 056: 3,80%. There is only a small difference between the first and second test setting. This could be because of the relatively small amount of testing done. Future research could be done about why this difference is small.

About the difference between the first and second test setting, a difference of 3,80% seems to be little, but in fact all parties involved will always look to reduce costs as much as possible. 3.80% of a budget is therefore a large amount, especially when there is a lot of money involved.

3. The second test setting will have a lower average total revenue than the third test setting.
The second test setting has an average total revenue of 39 336 91, the third test setting has a total amount of revenue of 40 621 711. The difference is 4 288 020, which is a difference of about 3,28%. This confirms that there is indeed a difference between whether one or both departments share.

With the three hypothesis confirmed, and with the difference between all departments sharing and no department sharing a good amount of revenue, the testing shows that the simulation game is indeed a tool worthy of future usage and further research. It shows that information sharing increases both hospital revenue and effectiveness, having benefits from both management as well as care perspectives.

9. CONCLUSIONS
The information sharing problem was introduced. It was discussed in depth, leading to research questions.

The prisoner’s dilemma is a problem in game theory, where entities benefit from cooperating. We used an adapted version of this problem for our research. Not sharing information in a hospital dominates sharing information. Both parties have to be convinced to share information or they will not. We use an iterated version of the prisoner’s dilemma, which means the game is repeatedly played.

Including more than two departments.

Information sharing strategies for departments.

10. FUTURE RESEARCH
Due to very strict time constraints of this research, some aspects of the research could have been done more extensively. There are several things that we would have done if we had more time, which are discussed below.

There are a number of options for our simulation game itself that could be looked at in future research. These include:

- Including more than two departments.
- Information sharing strategies for departments.

9. CONCLUSIONS
The information sharing problem was introduced. It was discussed in depth, leading to research questions.

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We have used the NetLogo simulation environment for creating a simulation game. We have created simulation rules that NetLogo can work with. Next we validated this simulation in that it actually shows that information sharing is beneficial and leads to bigger revenues and more efficient hospitals.

The information sharing simulation game that has been developed by this research is an effective tool for showing that hospital revenue and effectiveness is increased by information sharing. It has benefits from both management as well as care perspectives. It can be a helpful tool in training medical personnel in sharing more information.

10. FUTURE RESEARCH
Due to very strict time constraints of this research, some aspects of the research could have been done more extensively. There are several things that we would have done if we had more time, which are discussed below.

There are a number of options for our simulation game itself that could be looked at in future research. These include:

- Including more than two departments.
- Information sharing strategies for departments.
• Revenue penalty for having patients in waiting list, depending on time of patient in waiting list.

Our game simulation is ready for use as a management or learning tool. The simulation game has only been tested by means of simulation, not by means of a controlled experiment. Therefore it is very interesting to see what happens when this simulation game is tested using a controlled experiment [7]. Even more exciting would be the evaluation of usage of the simulation game as such as a training method.

The information sharing simulation game developed by this research focuses on one aspect of hospital information sharing. Future research could also be done on one of the other hospital processes described in subsection 5.1. This research could focus on information sharing in one of those areas and create a simulation game for it, or find other ways to tackle those problems.

Another option for future research is to investigate why the difference between the first and second test setting is low. The second test setting does show a higher revenue, but it is a small increase.

ACKNOWLEDGMENTS
My thanks go out to D.C.F. Rothengatter for being my supervisor. He has tremendously helped with checking my schedule as well as motivating me when I needed it. His feedback has been extremely helpful and the endless number of meetings we had really helped a lot in putting this paper together. I thank C. Amrit for some early feedback as well as pointing to the existence of the NetLogo environment. Thanks to track supervisor A.B.J.M. Wijnhoven for being critical on all points imaginable. Even though sometimes some criticism were felt to be a bit over the top, in the end it has helped a lot. D. Scheerens, thanks for some pointers in the right direction when I needed to get some focus. I would like to thank all participants in the review session for giving (general) useful comments and in particular W. Vegter for taking an extra look at a draft version of my paper. Thanks to all other reviewers for their criticism, which helped immensely in improving the final version of this paper.

REFERENCES
### Table 2. Total revenue of tests

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**Total average revenue**

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Increase (amount): 200035,8  1488056

Increase (%): 0,51116054  3,802496897

(increases both compared to 0-share)
APPENDIX B: CONFIDENCE INTERVALS

This appendix contains two tables with calculations for the 95% confidence intervals for the expectation value and the variance of the three different test settings. Both are taken for 10,000 rounds.

### Table 3. 95% confidence interval for the expectation value E(X) for 10,000 rounds

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### Table 4. 95% confidence interval for variance var(X) for 10,000 rounds

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