Optimisation of the Distribution of Surgical Instruments over Trays

Cost Effectiveness and Quality Improvement of an Operating Theatre

Elske Paulien Florijn, BSc.

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Supervisors:

dr. ir. E.W. Hans, University of Twente, Enschede, the Netherlands

dr. ir. L.L.M. van der Wegen, University of Twente, Enschede, the Netherlands

ing. A. S. N. Vernooij, Academic Medical Centre, Amsterdam, the Netherlands

amc

University of Twente
Enschede - The Netherlands

VOORWOORD

Het is gelukt, na 6 jaar studie mag ik mezelf Master of Science noemen. Mijn studietijd heb ik ervaren als een zeer leuke tijd, zowel wat betreft studie als daarbuiten. Een zelf samengestelde minor nautische wetenschappen en een bestuursjaar bij Euros Zeilen hebben hier zeker aan bijgedragen.

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De volgende mensen uit het AMC kunnen niet onvermeld blijven. Mijn twee collega's Marijke Gerver en Jaap Boomsma bedankt voor alle gezelligheid en hulp. De operatieassistenten en chirurgen die meegewerkt hebben aan mijn onderzoek bedankt voor jullie inzet. Met name Devinia, Erika en Vena bedankt voor jullie inzet, zelfs op jullie vrije dagen.

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Elske Florijn,
Augustus 2008.

MANAGEMENT SUMMARY

During a surgery instruments are required, which are distributed over surgical instrument trays. Several problems are identified concerning these instrument trays: the tray types are too heavy, inconveniently arranged, and contain unused instruments. All instruments from a used tray require *cleaning and sterilising* (C&S) after surgery. Unused instruments on a tray cause unnecessary C&S costs, and also unnecessary costs for maintenance (C&S leads to wear), replacement, storage, and holding. Heavy and inconveniently arranged trays lead to sub-optimal working conditions for the OT assistants; they lift trays several times and should count all instruments for each surgery of each used tray.

The objective of this research is to develop a method to distribute surgical instruments over trays, in such a way that the costs are reduced and the working conditions for OT assistants are improved.

The literature about optimising the logistics of instrument trays is limited. We use the literature from similar disciplines and adapt it to the requirements of this problem. The research is set-up as follows. First, we define a model for the distribution of instruments over trays, the *tray optimisation problem* (TOP) model. Next, we gather the data from the OT department of the AMC, for the TOP model. OT assistants and surgeons are consulted to determine the required instruments per surgery type. Since this is very time-consuming, we restrict our research to 15 surgery types, 239 instrument types, and starting with 12 tray types. Finally, we use a *simulated annealing-based* algorithm to solve the TOP.

The simulated annealing algorithm assumes that the total costs are determined by the costs per tray type, costs for cleaning and sterilising instruments, and the costs for handling trays types, by the OT assistants.

The TOP model and SA method are implemented in a computer program called TrayOptimisation. The main result of the experiments with TrayOptimisation show possible cost reductions of approximately €125,000 per year, on only a

fraction (12) of the total number of tray types (550) in the OT department. It is expected that applying this method to the entire tray inventory can lead to cost savings up to millions of Euros.

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1 INTRODUCTION

The operating theatre (OT) department is one of the most expensive resources of a hospital. Of all patients in a hospital, 60-70% pays a visit to the OT department [1]. From both a cost and a quality care point of view, an efficient surgical process is of paramount importance. This report focuses on the reusable (non-disposable) instruments that are used during surgery, and sterilised thereafter. The surgical instruments are distributed over trays. This project investigates how to optimise the distribution of instruments over trays and is performed in the OT department of the Academic Medical Centre (AMC) in Amsterdam.

PICTURE 1 ACADEMIC MEDICAL CENTRE, AMSTERDAM

This chapter is structured as follows. Section 1.1 gives an introduction to the AMC. Section 1.2 describes the problem background. Section 1.3 gives the research objective. Section 1.4 defines the research questions. Section 1.5 gives the assumptions. Section 1.6 describes the methodology. Section 1.7 shows the report structure.

1.1 INTRODUCTION TO THE AMC [1]

Academic Medical Centre (AMC) is one of the largest hospitals in the Netherlands. AMC houses the university hospital and the medical faculty of the University of Amsterdam, as well as several institutes, such as the Netherlands Institute for Brain Research, and the medical department of the Royal Tropical Institute. Primary processes of the AMC are patient care, education and research.

AMC has around 1,000 beds. Each year, some 25,000 patients are admitted; there are 35,000 day admissions and over 350,000 outpatient visits. AMC employs approximately 7,000 staff members.

This research is performed in the operating theatre (OT) department of the AMC, in the department *logistics, quality, innovation and information (LKI)*. Appendix A shows the organizational chart of the AMC and its OT department.

1.1.1 Introduction to the OT department of the AMC

The OT department has 19 inpatient and 5 outpatient OTs. The inpatient OTs are located on the second floor, the outpatient OTs on the first floor. An elevator connects these two parts of the OT department, so personnel can walk from the inpatient to the outpatient part without leaving the OT department, and vice versa. The inpatient OTs are divided in three units; A, B, and C, which cover the surgical services as follows:

- *Unit A*: Cardiothoracic surgery, orthopaedic surgery, and traumatology
- *Unit B*: General surgery, paediatrics, neurosurgery, and vascular surgery
- *Unit C*: Plastic surgery, obstetrics and gynaecology, otolaryngology, urology, ophthalmology, oral and maxilla facial surgery.

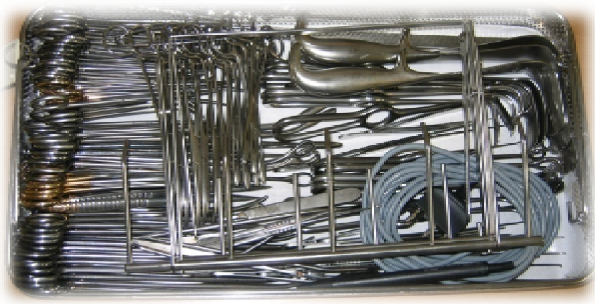
Each unit has its own storage for instrument trays, disposables, and individual instruments. The use and storage of *disposables* and *individual instruments* are outside the scope of this research and therefore not explained. The outpatient OTs uses trays from all units, because they only have a small storage.

1.1.2 Introduction to the department LKÏ

The objective of the LKÏ department is to support the primary process of the AMC by ensuring balanced and efficient processes in the OT department. Currently, LKÏ employs 21 staff members.

1.2 PROBLEM BACKGROUND

AMC performs approximately 17,000 surgeries per year using about 550 *different surgical instrument trays*. A surgery may require more than fifteen different trays, each containing up to 492 instruments. On average tray types contain about 45 instruments.



PICTURE 2 BIG BASIS TRAY, CONTAINS 107 INSTRUMENTS

The surgical instrument trays in the OT department of the AMC contain many instruments and are used for a lot of different surgeries. OT assistants complain about heavy and inconvenient arranged trays, caused by many instruments on a tray. Moreover, performing many surgery types with one tray type causes a low ratio of used versus total number of instruments, as the tray contains required instruments of all different surgeries. Furthermore, ongoing developments in surgery techniques cause changes to the inventory of trays: new instruments are added to existing trays or new trays are introduced. The introduction of new instruments in the OT department happens weekly.

All the above problems indicate that the current distribution of instruments over trays can be optimised. Figure 1 shows the problems concerning the current distribution; detailed explanation is given in chapter 2. The following subsections describe the main problems.

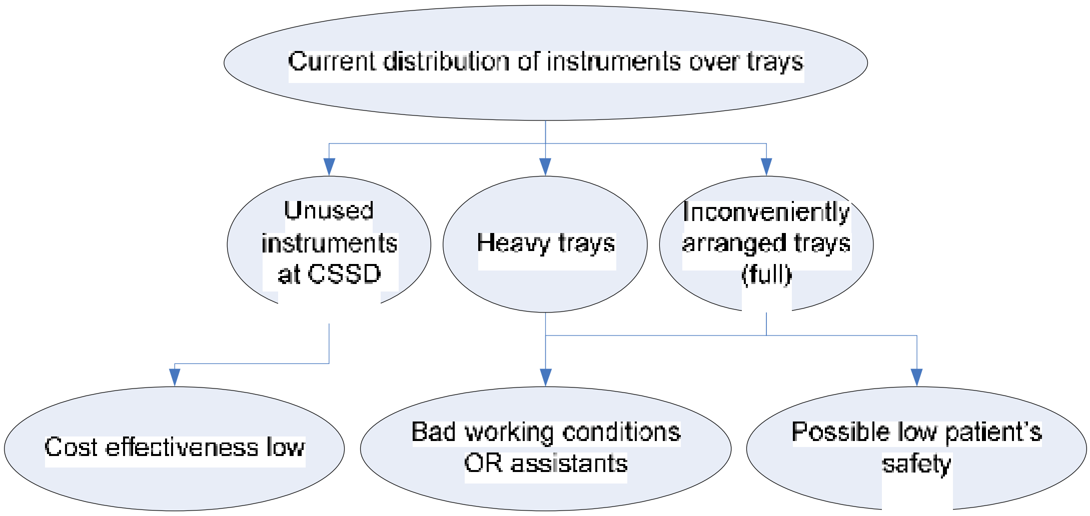


FIGURE 1 Overview problems

1.2.1 Cost effectiveness

The cost effectiveness of health care can be improved. A recent report [3] written on behalf of the state secretary of health care, suggests opportunities for improvement in logistics of goods and pharmaceuticals of one billion euro.

AMC's OT department tries to reduce the high costs caused by inefficiently distributed trays. These high costs arise when trays are prepared for surgery, while only part of the instruments of these trays is used. It is believed that over 60% of the instruments from the trays are returned without being used[1].

In 2007, the *central sterilisation service department* (CSSD) of the AMC cleaned and sterilised approximately 1.8 million[2] instruments. If we assume the unused percentage to be 60%, than the total number of *cleaning and sterilising* (C&S)

[1] Source: H. Lingeman, manager *CSSD*, Synergy Healthcare

[2] Source: Records of the *CSSD*. The sum of the turnover per tray multiplied by the number of instruments distributed in the tray.

unused instruments is approximately 1 million, leading to *costs of C&S of unused instruments* of approximately *one million euro*[3].

The *unused instruments* are not available for other surgeries that need those instruments. As a consequence, more instruments are required, which on its turn requires larger inventory. *Unused instruments* lead to high costs for C&S, maintenance (C&S leads to wear), replacement, storage, and holding.

1.2.2 Working conditions OT assistants

OT assistants suffer from stress and back problems, caused by *inconveniently arranged-* and *heavy* trays. OT assistants should count all the instruments before and after surgery, to make sure the tray is complete before and after surgery. Most OT assistants only count the instruments that are certainly required for the surgery. Whenever an instrument is not required for the particular surgery it is not counted or checked, this may be caused by the *inconveniently arranged* trays. Missing instruments may cause stress when during surgery it becomes clear that they are not available. The surgeon becomes agitated and the OT assistant needs to fetch the requested instrument from another tray in the storage, which may take about five minutes, if it is available in one of the storage rooms. This clearly leads to unnecessary delay of the surgery.

1.2.3 Patient's safety

Unavailability of instruments may affect the patient's safety as missing or malfunctioning instruments are not detected until they are actually needed. At this time the patient is already under anaesthetics. The surgery might still be *cancelled* if the missing instrument is not available in one of the storage rooms of the OT department.

[3] C&S a single instrument after use costs around 1 euro, source: H.Lingeman.

1.2.4 Conclusion

We have indicated three main problems concerning the current distribution of instruments over trays:

1. Heavy trays;
2. Unused instruments;
3. Inconveniently arranged trays.

This leads to:

- Low cost effectiveness;
- Bad working conditions for OT assistants;
- Possible lower patient's safety.

1.3 RESEARCH OBJECTIVE

To develop a method to distribute surgical instruments over trays, such that the costs are reduced and the working conditions for OT assistants are improved.

1.4 RESEARCH QUESTIONS

1. What are the current problems concerning the distribution of instruments over trays?
    a. How are the instrument distributed over trays?
    b. What are causes of the current problems?
2. What model can be used for defining the distribution of instruments over trays?
    a. What is the optimisation criterion, i.e. the objective function?
3. What data is required for distributing instruments over trays?
4. What strategy should be used for distributing instruments over trays?
    a. What optimisation technique(s) can be used?
5. What organisation implementation strategy should be used?
    a. How should new tray types be introduced in the OT department?

b. How can the distribution of instruments over trays be continually improved?

1.5 ASSUMPTIONS & RESTRICTIONS

- We do not consider disposables and individual instruments;
- We do not consider unavailability of trays;
- The CSSD is paid a fixed amount per year for C&S all instruments and trays. The assumption is made that lower C&S costs are realised when fewer instruments or trays or both are provided to the CSSD. The price per cleaned and sterilised instrument is assumed to be 1 euro inclusive VAT[4];
- Implant and prosthesis trays are not taken into account as these trays require a different approach;
- The current capacity for C&S in the CSSD is sufficient;
- Optimisation of the actual C&S process in the CSSD is not considered in this research;
- The required instruments for surgery are determined by OT assistants and surgeons. We assume that all mentioned instruments are required for each surgery of that type. We are aware that OT assistants and surgeons want more instruments than actually required, because fear exists of not having an instrument available, but as we do not have the medical knowledge to prove this or are able to determine which instruments are really required, we assume that all mentioned instruments are required.

1.6 METHODOLOGY

Surprisingly, there is hardly any literature about optimising the logistics of surgical instrument trays. Klundert, Muls and Schadd [4] investigate various logistical and mathematical concepts for optimizing the flow of sterile instruments between the sterilisation department and the OT department. They

[4] Source: H. Lingeman

conclude that, in theory, significant cost reductions are possible. Nilson [5] describes a straightforward quantitative methodology to determine appropriate inventories of equipment (trays) and instruments in an OT department. Other scientific papers about optimising the logistics of surgical trays are to the best of our knowledge not available. This indicates that, as Klundert, Muls and Schadd [4] also mention, the emphasis has been on the reliability of instruments, meaning proper C&S of instruments, instead of possible cost reductions by optimising logistics.

As literature about optimising the logistics of surgical trays is not abundantly available, we use literature from similar disciplines. We try to adapt this available knowledge and experience for the optimisation of the logistics concerning surgical trays.

1.7 REPORT STRUCTURE

This report is structured as follows. *Chapter 2* gives background information and the problem analysis of AMC's OT department. *Chapter 3* introduces the *tray optimization* (TOP) model. *Chapter 4* describes the data that is gathered in the OT department of the AMC. *Chapter 5* describes the solution approach. *Chapter 6* gives the computational results of the TOP. *Chapter 7* describes the organisational implementation strategy. The report finishes with the conclusion and recommendations.

2 BACKGROUND AND PROBLEM ANALYSIS OF AMC'S OPERATING THEATRE DEPARTMENT

The processes and control concerning the logistics of surgical instrument trays in the OT department of the AMC are explained in this chapter. This chapter is structured as follows. Section 2.1 describes the processes of trays through the OT department. Section 2.2 describes the control functions. Section 2.3 gives the problem analysis. Section 2.4 gives the conclusions of the problem analysis and defines the performance measures for optimising the distribution of surgical instruments over tray types.

2.1 PROCESSES OF TRAYS

Different processes concerning the surgical instruments trays take place in the OT department, see Figure 2. The processes are subsequently explained in the following paragraphs.

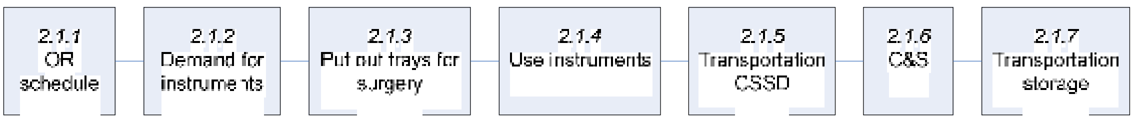


FIGURE 2 Processes trays at the OT department

2.1.1 OT Schedule

The OT planning and scheduling is divided in three parts:

1. The capacity planning
2. The staff planning
3. The patient planning

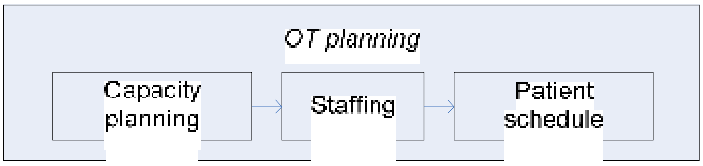


FIGURE 3 THE OT PLANNING

The *capacity planning* is based on the budget of surgical services. The budgets are translated into hours of OT time. The capacity plan is made for each month of the coming year. 80% of the capacity plan is fixed twelve months in advance; the remaining 20% is determined three months before execution. If possible, the planning takes into account criteria for better patient care and preferences of surgeons, such as planned holidays. Better patient care can be a day of the week as to be sure that the IC has a bed available for the patient or to ascertain that the patient leaves the hospital before the weekend. The capacity plan must be approved by the OT department's management team.

If the capacity plan is approved, the *staff planning is* determined for OT assistants and anaesthesia assistants. Anaesthesia assistants are all-round; meaning the assistants can be planned in each OT for any surgical service. The OT assistant planning is more complicated, as OT assistants can only be planned for surgical services they have been trained for. Currently, OT assistants are a bottleneck: OTs are sometimes closed because of a lack of OT assistants. The staff plan is made between six weeks and three months ahead of time. The final staff plan must be approved by the unit managers. The surgeons and anaesthesiologists make their own staff plan based on the capacity plan.

The *elective patient planning* is done by the surgeons and must be approved by the unit managers. Surgery times are based on the experience of the surgeons, meaning that estimates are used. Each Thursday, the elective patient plan for the next week is given to the unit managers. The unit managers check the plan on instrument and staff feasibility. If they do not approve, surgeries may have to be cancelled and rescheduled. The resulting empty OT is sometimes used for an emergency patient but otherwise the OT remains empty. The definitive patient plan for a day is determined the previous day at 10.00 a.m., by the senior OT assistants. The senior OT assistants mainly pay attention to the sequence of surgeries for that day.

2.1.2 Generate demand for instruments

The elective patient plan generates a demand for instruments as each surgery requires instruments. The instruments are not reserved for the planned surgeries, so planning too many surgeries requiring the same trays stays unnoticed. The approved patient plan for the next day is given to the OT assistants. They know which tray types are required for each surgery type, and which instruments are distributed in each tray type. The required tray types per surgery type are also documented in the surgery protocols that are stored in the storage room. Unfortunately, the surgery names of the patient plan do not correspond to the names in the surgery protocols, i.e. it is not possible to determine the required trays for the surgery, in the patient plan, from the records of the surgery protocols. The patient plan of the year 2007, contains approximately 1,700 different surgery names, while the put out protocols only contain about 200 surgery names.

2.1.3 Prepare tray types for surgery

The OT assistants of the late shift start putting out the trays at 1.30 p.m. for the next day. The OT assistants collect the required trays from the storage.

In the current situation, some tray types are stored on multiple units in the OT department. Tray types are used for multiple surgical services, so also for many different surgeries. This leads to a low number of different tray types, which is an advantage for the OT assistants, as they have to know which instruments are distributed in which tray types and the required tray types for each surgery type.

The OT assistants gather the trays on a trolley with a hand written paper on the trolley indicating the scheduled OT, the surgery, and the unavailable tray types. The required tray types which are unavailable for the first and second surgeries are put on a list which is brought to the CSSD. The trays on this list are given high priority C&S, which takes only 6 hours instead of the standard 12 hours.

PICTURE 3 STORAGE ROOM UNIT C

The required and available tray types are checked before the surgery starts; if a required tray type is unavailable, the surgery is delayed or cancelled.

2.1.4 Use instruments for surgery

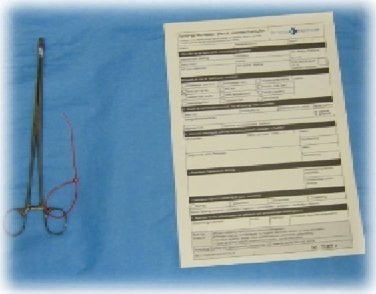
The OT assistant opens the trays, counts the instruments and arranges the instruments on the table for the surgeon. Sometimes, an OT assistant detects missing or malfunctioning instruments. The OT assistant files a complaint if this problem is caused by a mistake of the *CSSD*. If it is not a mistake of the CSSD a note is written on the accompanying form of the tray to make sure that the problem is solved at C&S. If a requested instrument is not available, the OT assistant will take the requested instrument from another tray in the storage room. If this occurs during the surgery it may disturb the progress of the surgery, and possibly the patient's safety.

PICTURE 4 PREPARE INSTRUMENTS FOR SURGERY

Sometimes the surgeon diagnoses another or different problem just before or during surgery, i.e. the performed surgery differs from the surgery in the patient plan. The performed surgery may require different instruments than the scheduled surgery. In this case the OT assistant rushes to the storage room to fetch the requested trays, required for the surgery. After checking the required and available instruments the surgery starts or continues. During the surgery the OT assistant hands instruments to the surgeon.

PICTURE 5 THE OT ASSISTANTS HAND THE REQUESTED INSTRUMENTS TO THE SURGEON

After the surgery, the OT assistants put the instruments back in the accompanying trays, and again check the trays on completeness. A red label is attached to malfunctioning instruments to indicate that they should be repaired or replaced.



PICTURE 6 RED LABEL ATTACHED TO INSTRUMENT AND COMPLAINT FORM FOR CSSD

2.1.5 Transportation from OT to the CSSD

The used trays are put in a trolley. The OT assistant brings the trolley to the room from which the CSSD picks up the trays. Any unopened tray, i.e. unused tray, is brought back to the storage room. The OT assistant scans the trays for time registration. The agreement with the CSSD is that they pick up the used trays every 30 minutes.

PICTURE 7 TIME REGISTRATION (LEFT) AND USED TRAYS IN TROLLEY (RIGHT)

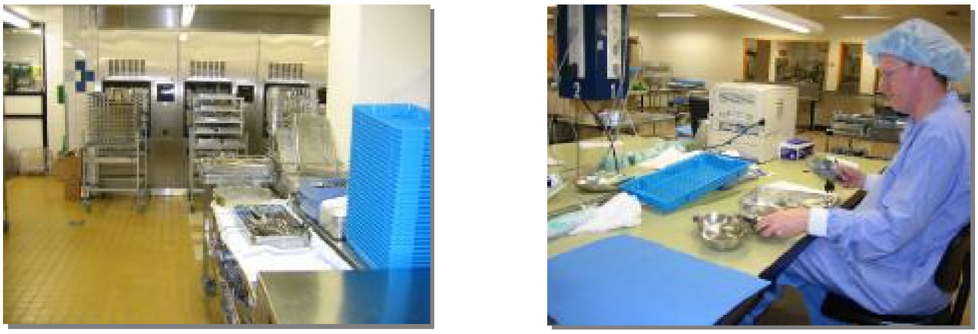
2.1.5.1 Synergy Healthcare

C&S is outsourced to a company called *Synergy Healthcare*. This company is situated in the OT department, on the same floor as the outpatient OTs. At present (2008), Synergy is paid a lump sum price for the annual C&S. In the near future, AMC will pay per cleaned instrument or package of instruments, the price per instrument for single C&S will be about 1 euro[5].

2.1.6 C&S trays

Currently, Synergy cannot handle the timely supply of instruments. C&S times are higher than the agreed 12 hours. It is almost impossible to retrieve this data from the records of the CSSD and unfortunately the OT department does not record this data. The CSSD admits that the agreed time for C&S is not always met[6].

The trays traverse a number of stations in the CSSD. Firstly, the trays and instruments are cleaned in the washing machines. Secondly, the instruments are checked for malfunctioning, distributed over trays, checked for completeness, and wrapped in paper.



PICTURE 8 WASHING MACHINES OF THE CSSD AND DISTRIBUTION OF INSTRUMENTS OVER TRAY

[5] Source: H.Lingeman and J. Veldhuis, expert in sterilised medical aids, AMC

[6] Source: H. Lingeman

Labelled instruments or forms of missing instruments are brought to the supervision medical aids department, which is responsible for repairing and replacing the malfunctioning instruments. The accompanying tray is put in quarantine. When the tray is complete again it is brought back to the CSSD. Some trays cannot be put in quarantine, because they cannot be missed in the OT department. In this case the tray is sterilised and an accompanying note is written on the sticker of the tray, as to indicate the missing instrument(s). Finally, the trays are put in the so-called autoclave where sterilisation takes place.

PICTURE 9 AUTOCLAVE OF THE CSSD AND THE TRAYS WAITING TO BE BROUGHT UPSTAIRS TO THE STORAGE ROOMS

2.1.7 Transportation from CSSD to storage rooms

The CSSD brings the trays to the OT department after sterilising. The OT assistants put the trays back in the storage room.

2.2 CONTROL OF THE PROCESSES

Various control functions influence the processes concerning the logistics of the surgical instrument trays:

- The composition of trays (subsection 2.2.1);
- The three dimensional planning of inventory (subsection 2.2.2);
- The stock policy (subsection 2.2.3);
- Repairs and maintenance of instruments (subsection 2.2.4);
- High priority C&S (subsection 2.2.5).

2.2.1 Tray composition

The trays are composed in such a way that they can be used on multiple units. The idea is that most surgeries use a basis tray and one or more supplementary trays. The basis trays are interchangeable between the units. Running out of a tray may not be a problem as it might be available at another unit. The trays contain many instruments to make sure that the same tray can be used for multiple surgeries, surgical services, and units. The unit managers and the surgeons together decide which new tray types or instruments are acquired, for example for the use of new techniques. Trial tray types are provided by the supplier. When the tray meets its expectations and the manager of the supervision medical aids department as well as the expert in sterilised medical aids approves, the tray is acquired. The trial period is usually a few months.

Clear procedures about adjusting tray types or acquiring new tray types do not exist.

2.2.2 Three dimensional planning of inventory in the storage rooms

The units have cupboards for the storage of trays. The trays are put in a rack. One rack offers space for one standard tray or two small trays. For each tray type space is reserved in the cupboard. The units have different number of cupboards and spaces for racks, see Figure 4.

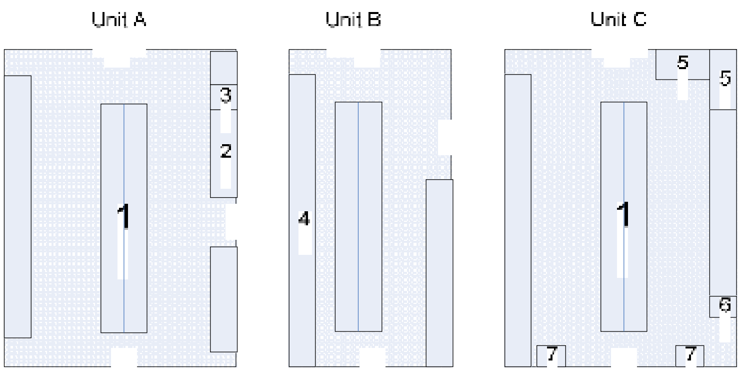


FIGURE 4 STORAGE ROOMS

The figure shows the storage rooms of the different units; A, B, and C. The numbered cupboards are the storage cupboards of trays, the other cupboards are for storage of disposables, individual instruments, and other necessities for OTs. Each numbered cupboard has different number of spaces for racks. Table 1 shows the number of available spaces in the cupboards. The cupboards with number 7 deviate, because these spaces are wider. Tray types that do not fit in the standard size are put in these spaces. Unit A and Unit C both have two cupboards numbered as 1.

Cupboard	Top to bottom	Left to right	# Spaces	Storage A	Storage B	Storage C
1	12	16	192	384		384
2	12	6	72	72		
3	3	1	3	3		
4	12	18	216		216	
5	12	3	36			72
6	12	1	12			12
7	15	1	15			30
	Total available spaces per storage			**459**	**216**	**498**

TABLE 1 NUMBER OF SPACES IN THE CUPBOARDS

2.2.3 Stock policy of number of available trays per type

Presently, there is no stock policy. The number of available trays per tray type depends on the budget of the surgical service, instead of on tray usage. Some trays are used 120 times per year, while others are used only 10 times per year. In the near future the stock policy will be defined[7].

2.2.4 Repairs and maintenance of surgical instruments

Instruments require maintenance and repairs. For example, a pair of scissors must be sharpened once in a while, and other instruments must be lubricated once in a while. Procedures about maintenance of instruments do not exist, while instruments do require:

[7] The project "supervision and maintenance" started. One of the objectives is to formulate procedures for determining appropriate stock levels.

- Daily maintenance and functional checks;
- Periodic preventive maintenance;
- Corrective maintenance (repairs).

The project "supervision and maintenance" has started in November 2007, to develop procedures for repairs and maintenance.

The OT assistants identify malfunctioning or missing instrument in the OT. The CSSD identifies malfunctioning or missing instruments after cleaning the instruments. Malfunctioning instruments or "missing instruments forms" are brought to the supervision medical aids department by the CSSD. The depreciation time of an instrument is on average 10 years, the dispersion is between 4 and 30 years[8].

2.2.5 High priority C&S of trays

The standard time for C&S is 12 hours, but the OT department has the possibility of putting trays on high priority C&S, meaning that C&S is performed in only 6 hours. Over 3% of all the trays has the high priority C&S label[9]. The decision about which trays are labelled high priority is made by the unit managers. A formal procedure does not exist.

The OT assistant decides which trays get the once-only label high priority C&S. This decision is based on the required trays for the next day. Unavailable trays, for the first and second surgery for each OT, get the once-only label high priority C&S. Approximately 100 trays per day[10] get the once-only label for high priority C&S.

[8] J. Veldhuis and A.S.N. Vernooij, chief supervision medical aids department.

[9] Source: H. Lingeman (records of the CSSD).

[10] Source: H. Lingeman

2.3 PROBLEM ANALYSIS AND PERFORMANCE MEASURES FOR OPTIMISATION

In this section the problems concerning the distribution of surgical instrument trays are outlined through an analysis of the involved processes and control functions. This section is structured as follows: subsection 2.3.1 describes problems concerning processes in the OT department, and subsection 2.3.2 describes problems concerning the control function in the OT department.

2.3.1 Problems analysis for processes

2.3.1.1 Prepare tray types for surgery

OT assistants have to lift the required trays for each surgery several times from floor level to waist level. Moreover, they remember the assigned tray types per surgery type

Putting out more tray types for a surgery leads to more time for the OT assistants to prepare the instruments for surgery, as:

- The OT assistants have to find each tray type assigned to a surgery type in the storage rooms;
- Each tray type assigned to a surgery type is brought to OT, opened (with care for sterility reasons), and checked for completeness.

The time of the OT assistants is scarce and expensive. This leads to the conclusion that it is better if OT assistants put out as few as possible tray types. Taking into account the maximum weight of a tray type, as putting out fewer tray types with weight above the maximum weight is not an improvement of the current situation.

2.3.1.2 Use instruments for surgery

OT assistants should count all the instruments before and after surgery. This is often not performed due to the inconvenient arrangement of the trays, which makes the counting of instruments a time-consuming task.

The number of missing instruments is large, both in the OT department and in the CSSD. Unfortunately it is not possible to indicate where the instruments go missing, in the OT department, at the CSSD, or both. The OT assistants are one of the reasons for missing instruments, as one of the OT assistants told us:

"If I find a pair of scissors that is not sharp then I will throw it into the trash bin"

2.3.2 Problem analysis for control function

2.3.2.1 Composition of tray types

The basis tray types contain many instruments, because all surgical services need their basis instruments in the basis tray types. The collaboration between surgical services leads to flexibility in the total number of required trays types, but also to a lot of instruments on a tray type to allow that the tray type can be used on multiple units. The tray types contain instruments that are obsolete; in section 4.3.2 we show that 13% of the instruments distributed in the big basis tray are obsolete. Surgeons prefer certain instruments; these instruments are added to the corresponding tray type(s). New techniques are constantly developed, requiring new instruments to be added to the corresponding (basis) tray type(s). When a surgeon leaves the AMC or a surgery technique is not used anymore, the obsolete instruments are usually not taken out of the tray type(s).

Tray types contain many instruments. Tray types with many instruments may lead to a low number of instruments being actually used. If a tray is opened, all instruments, including unused instruments, require C&S. This leads to a *low ratio of used instruments against total C&S*; it is believed that over 60% of the instruments are returned to the CSSD without being used. The exact percentage is not known, as it is impossible for the CSSD to see how many instruments have actually been used from the trays. To determine the exact percentage, counting the number of unused instruments during surgeries must be performed in all OTs at the same time. This is very time consuming and therefore not performed at AMC. Moreover, unused instruments make a tray type unnecessary *heavy* and *inconveniently arranged, i.e. full*.

The employees of the CSSD also suffer from tray types containing too many instruments. After C&S, they have to make sure all instruments are in the tray; more instruments make it difficult to verify whether the tray is complete.

2.3.2.2 Size of tray types

At the time of carrying out this research, a different standard tray size is introduced. The old ISO standard trays are replaced by trays conforming to the smaller DIN standard. Table 2 shows the volume of the two standard tray sizes.

Instrument Tray	DIN (dm)	Volume DIN (dm3)	ISO (dm)	Volume ISO (cm3)
1	4.8 * 2.5 *6	7.2	4.6 * 3.2 * 6	8.8
½	2.4* 2.5 * 5	3.6	2.3 * 3.2 * 6	4.4
¼	1.2 * 2.5 * 6	1.0	1.15 * 3.2 * 6	2.2

TABLE 2 ISO AND DIN STANDARD TRAY SIZES

Some tray types are almost impossible to transfer to DIN standard, as they are already full; putting all those instruments in a smaller tray type is not possible without instruments sticking out of the tray. The trays are wrapped in paper before sterilisation takes place, the instruments sticking out may cause the paper to rip. When this happens, the tray cannot be used for surgery, and it must return to the CSSD for C&S.

2.3.2.3 Three dimensional planning of storage rooms

The current storage capacity is not sufficient. Table 3 shows the number of available spaces and the number of stored trays per storage room. A renovation of AMC's OT department will start in July 2008. The storage capacity will be increased during this renovation to be able to cope with the current total number of tray types. Increasing the total number of tray types, for example by fewer instruments per tray type, should be as small as possible. Otherwise, the storage capacity is still insufficient. The OT department is a closed department, so OT department space is scarce. Therefore elaboration of the storage capacity is not easily possible.

Storage room	Available spaces	Stored trays
Storage room A	459	479
Storage room B	216	233
Storage room C	490	509

TABLE 3 AVAILABLE SPACES VERSUS AVAILABLE TRAYS

2.4 CONCLUSION PROBLEM ANALYSIS, THE PERFORMANCE MEASURES

The OT assistants remember the assigned tray types per surgery type; fewer assigned tray types per surgery type leads to more convenient working conditions for the OT assistants. OT assistants lift each assigned tray type several times; lifting fewer tray types is more convenient for the OT assistants. More tray types for a surgery types lead to more time for the OT assistants to prepare the instruments for surgery, because:

- The OT assistants have to find each tray type assigned to a surgery type in the storage rooms;
- Each tray type assigned to a surgery type is brought to the OT, opened (with care to preserve sterility), and checked for completeness.

The time of the OT assistants is scarce and expensive, so fewer tray types assigned per surgery type is better, given that the weight and volume of all instruments distributed in a tray type are not higher than the maximum weight and volume of a tray type.

The current capacity of the storage rooms is (already) insufficient; creating more tray types implies that elaboration of the current storage rooms is inevitable. The

OT assistants know the contents of the tray types; fewer tray types are preferred by the OT assistants and leads to better performance of the OT assistants.

Unused instruments on a tray result in unnecessary C&S costs. As hospitals try to reduce high costs, unnecessary C&S of instruments should occur as few as possible.

The performance measures, based on the problem analysis, are defined as follows:

1. *The number of tray types;*
2. *The number of unused instruments;*
3. *The average number of assigned tray types per surgery.* Surgery types that are regularly performed should have as few tray types assigned as possible. The impact on the time of the OT assistants of putting out these tray types is high, as these tray types are put out often. While sporadic performed surgery types do not have great impact on the time of OT assistants, as these tray types are only put out sporadically. Therefore, the average number of assigned tray types for surgeries is taken into account.

3 MODEL FOR THE TRAY OPTIMISATION PROBLEM (TOP)

We propose a model for optimising the current distribution of surgical instruments over trays. This chapter is structured as follows. Section 3.1 gives a formal problem description of and introduces the tray optimization problem (TOP). Section 3.2 gives the mathematical TOP model.

3.1 FORMAL PROBLEM DESCRIPTION OF TOP

The *tray optimisation* problem (TOP) consists of the assignment of tray types to surgery types and determines the contents of each tray type, i.e. the instrument types and the number of instruments per instrument type.

3.1.1 Entities

We consider the following three entities:

1. Surgery types, S (index s)
2. Instrument types, I (index i)
3. Tray types, T (index t)

3.1.2 Parameters

The characteristics of *surgery types S*:

- Required instruments ($r_{s,i}$);
- Turnover per year (o_s).

The characteristics of the *instrument types I*:

- Weight (w_i);
- Volume (v_i);
- C&S costs (ε_2).

The characteristics of *tray types T:*

- Maximum weight of a tray type (MaxWeight);
- Maximum volume of a tray type (MaxVolume);
- Costs for a tray type in storage (ε_1);
- Costs for handling a tray (ε_3).

3.1.3 Decision variables

The decision variables are:

- Tray type contents ($C_{t,i}$), i.e. the number of instruments of type i assigned to tray type t;
- Tray to surgery type assignment ($A_{t,s}$), i.e. whether tray type t is assigned to surgery type s.

3.1.4 Objective function

We define three cost aspects to minimise:

1. Total number of tray types
   - A larger number of tray types leads to more storage and capital costs.
2. Number of instruments that require C&S in a year
   - C&S more instruments leads to more C&S costs.
3. Total number of trays that require handling time of the OT assistants
   - Handling more trays leads to more labour costs.

3.1.5 Restrictions

We define restrictions based on the problem analysis of chapter 2:

1. The sum of the weight of the instruments that are distributed in one tray type is lower than the maximum weight of a tray type;

2. The sum of the volume of the instruments that are distributed in one tray type is lower than the maximum volume of a tray type;
3. The required instruments for a surgery type are available for that surgery type in the assigned tray types.

3.1.6 Assumptions

We assume that:

1. Each surgery type requires at most one tray per tray type. Hence, it is not possible that a surgery type requires two trays from the same tray type;
2. Other costs, than those stated in the objective function are not considered. Other costs, for example, are: inventory, holding, and maintenance costs. AMC has not defined an inventory model, to determine appropriate number of available trays per tray type. Moreover, the required data for taking other costs into account lacks, such as:
   - The storage costs per tray;
   - The depreciation time per instruments and for tray types;
   - The maintenance costs per instrument;
   - The costs per instrument.

3.2 MATHEMATICAL MODEL FORMULATION

3.2.1 Entities

1. S = {1...k} → Entity of all surgery types, input;
2. I = {1...n} → Entity of all instrument types, input;
3. T = {1...m} →-Entity of all tray types, output.

3.2.2 Parameters

Input parameters:

(1) o_s : Turnover of surgery s for one year ;

(2) $r_{s,i}$: Number of required instrument type i for surgery type s;

Instrument type characteristics:

(3) w_i : Weight of instrument type i;

(4) v_i : Volume of instrument type i;

(5) ε_2 : Costs for C&S an instrument;

Tray type characteristics:

(6) MaxWeight : The maximum weight of a tray type;

(7) MaxVolume : The maximum volume of a tray type;

(8) ε_1 : The costs of a tray type;

(9) ε_3 : The costs of handling a tray.

3.2.3 Decision variables

1. $A_{t,s}$: Assigned tray type t to surgery type s;

   $$A_{t,s} = \begin{cases} 1 \text{ if tray } t \text{ is assigned to surgery } s \\ 0 \text{ else} \end{cases}$$

2. $C_{t,i}$: Number of instruments of type i in tray type t.

3.2.4 Objective function

1. Costs of total number of tray types:

   $$(|T * \varepsilon_1)$$

2. Costs of instruments that require C&S:

   $$(\sum_s \sum_i ((\sum_t A_{t,s} * C_{t,i}) * o_s) * \varepsilon_2)$$

3. Costs of trays that require handling:

   $$(\sum_s (\sum_t A_{t,s} * o_s) * \varepsilon_3)$$

By adding these three factors we obtain an integral costs objective function:

$$\text{Min}\ (\ T\ *\ \varepsilon_1) + \ \left(\textstyle\sum_s \sum_i ((\sum_t A_{t,s} * C_{t,i}) *\ o_s) *\ \varepsilon_2\right) + (\ \textstyle\sum_s (\sum_t A_{t,s} *\ o_s) *\ \varepsilon_3\ )$$

3.2.5 Restrictions

1. The weight of a tray type is less than the maximum weight of a tray type:
   $\sum_i (w_i * C_{t,i}) \leq MaxWeight \quad \forall t$
2. The volume of a tray type is less than the maximum volume of a tray type:
   $\sum_i (v_i * C_{t,i}) \leq MaxVolume \quad \forall t$
3. The required instruments for a surgery type are available for that surgery type on the assigned trays type:
   $r_{s,i} \ \leq \ \sum_t (A_{t,s} * C_{t,i}) \quad \forall$ i,s

As defined above, the model contains non-linearity, namely the multiplication of $C_{t,i}$ and $A_{t,s}$. This non-linearity makes it impossible to simply solve the problem by using a linear programming solver. Chapter 5 describes the solution approach which we propose for solving the TOP.

4 DATA GATHERING

This chapter describes how the data is gathered from the OT department of the AMC. This chapter is structured as follows. Section 4.1 describes which data is required. Section 4.2 describes the results of the data gathering. Section 4.3 shows the analysis of the gathered data. Section 4.4 shows the performance of the dataset. Section 4.5 determines the cost coefficients for the TOP model. Section 4.6 gives the conclusions.

4.1 REQUIRED DATA FOR OPTIMISATION OF SURGICAL INSTRUMENT TRAYS

Section 3.2.2 indicates the (input) parameters that are used in the TOP model. For these parameters we gather data:

- Turnover per surgery type (o_s);
- Required instruments per surgery type ($r_{s,i}$);
- Volume per instrument type (v_i);
- Weight per instrument type (w_i);
- The maximum weight of a tray type (MaxWeight);
- The maximum volume of a tray type (MaxVolume);
- The costs of a tray type (ε_1);
- Costs for C&S an instrument (ε_2);
- The costs of handling a tray (ε_3).

4.2 OVERVIEW OF DATA GATHERING RESULTS

Data gathering in the AMC is hampered as the required data is not readily available. The surgeons and OT assistants know the required instruments per surgery. As the stock-taking of the required instruments per performed surgery type (about 1700 surgery types in 2007[11]) takes too much time for the scope of

[11] Source: The patient plan of 2007

this research, we choose to optimise the distribution of instruments over trays for a selection of the tray types. This selection constitutes our dataset.

4.2.1 Selection of tray types for the dataset

One tray type, the big basis tray, causes most of the problems in the OT department of the AMC. This tray type causes problems for transforming to DIN size. Moreover, this tray is mentioned by each expert as problematic, because it contains many unused instruments, is heavy, and inconveniently arranged.

The big basis tray contains 107 instruments and is used 2538 times per year. The big basis tray is used for the surgical services: orthopaedic surgery, traumatology, general surgery, vascular surgery, obstetrics and gynaecology, and urology. The use of the big basis tray for the surgical services traumatology and orthopaedic surgery is outside the scope of this research, as these surgical services deal with a high level of uncertainty about which instruments are required for surgery. Moreover, a new tray type has been introduced for these surgical services, the orthopaedic basis tray, which resulted into using the big basis tray sporadically.

We choose to optimise the big basis tray with all other tray types that are used in combination with the big basis tray for the surgical services: general surgery, vascular surgery, obstetrics and gynaecology, and urology. The accompanying tray types are only used in combination with the big basis tray, with one exception: the *small basis tray* that is also used for other surgery types without using the big basis tray. Table 4 shows the tray types and surgery types that are part of the dataset.

The entities are defined as follows:

- Surgery types → {1..15}
- Instrument types → {1..239}
- Tray types (current) → {1..12}

Example of surgery per group	Required trays	Specialty	Turnover
Laparoscopic small surgeries	Big basis tray	General surgery	325
Mamma	Big basis tray, small basis tray	General surgery	199
Relaparotomie	Big basis tray, abdominal tray	General surgery	449
Whipple	Big basis tray, abdominal tray, liver tray	General surgery	193
Proctolocolectomie	Big basis tray, abdominal tray, ileo tray	General surgery	206
Oesophagus resection	Big basis tray, abdominal tray, thorax tray	General surgery	80
Abdominal radical uterusextirpatie	Big basis tray, Wertheim tray, *Gynaecology* tray	Obstetrics and gynaecology	115
Locale excise vulva	Big basis tray	Obstetrics and gynaecology	56
Abdominal uterusextirpatie	Big basis tray, Gynaecology tray	Obstetrics and gynaecology	106
Cryocoagulatie	Big basis tray	Urology	75
Urethra Implant	Big basis tray, urology tray	Urology	82
Orchidectomie	Big basis tray	Urology	56
Endarterectomise	Big basis tray, vascular tray, micro vascular tray	Vascular surgery	96
Kidney transplant	Big basis tray, vascular tray, micro vascular tray	Vascular surgery	100
Aorta iliac	Big basis tray, vascular tray, aneurysm tray	Vascular surgery	95

TABLE 4 DATASET FOR THE OT DEPARTMENT OF THE AMC

4.2.2 Turnover per surgery type

The patient plan contains different surgery names for the same surgery type, as surgeons are free to use any surgery name for the surgery they are going to perform. We use expert opinions, of the OT assistants, to indicate which surgery names from the patient plan belong to which surgery type. From the patient plan the turnover per surgery type is determined. Table 4 shows the turnover per surgery type.

4.2.3 Required instruments per surgery type

The required instruments per surgery type are determined jointly by the OT assistants and surgeons. Starting with the surgical service general surgery, we asked three experienced (senior) OT assistants of this surgical service to indicate the required instruments per surgery type on the *tray type lists*, i.e. the list with the contents (instruments) distributed in the tray type. It turns out that the instrument names on the tray type lists are not the same as the instrument names that are used by the surgeons during surgery. The OT assistants doubted about which instrument types from the lists were required for the surgery types. Therefore, the gathered data concerning the required instruments per surgery is not reliable when the *tray type lists* are used. The OT assistants showed big differences in the required instruments per surgery type; they only corresponded for approximately 70%.

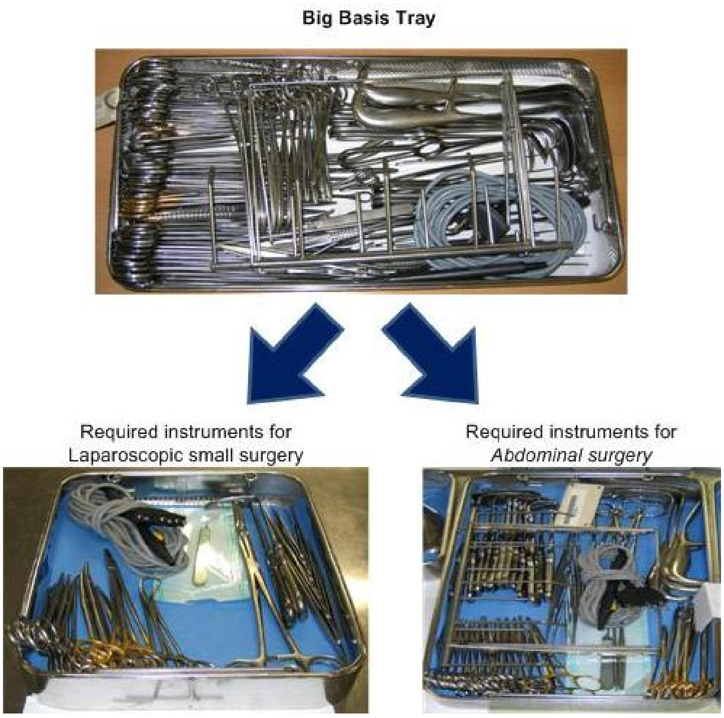
We decided to open all the required tray types for each surgery type and again asked all three OT assistants, to indicate the required instruments per surgery type. At this point, the OT assistants took each instrument type from the tray types and discussed with each other whether and when this instrument type is used. Sometimes the OT assistants did not agree about the required instruments; we consider these instruments to be required for the surgery type. The stock-taking of the required instruments for the other surgical services are performed in same way as for general surgery.

We also asked the surgeons to indicate the required instruments per surgery type. At least one OT assistant attended these meetings to help the surgeon, as (most of) the surgeons find it hard to indicate what they require for which surgery type.

The required instruments determined by the OT assistants corresponded for more than 95% to the required instruments determined by the surgeons.

4.2.3.1 Example required instruments per surgery type

The available instruments per surgery type are sometimes more than twice as many as the required instruments per surgery type. An example is given in picture 10, it shows for two surgery types the available instruments in the *big basis tray* and the required instruments for these surgery types from the *big basis tray*.



PICTURE 10 INSTRUMENTS ON BIG BASIS TRAY VERSUS USED INSTRUMENTS FOR SURGERY

4.2.4 Volume and weight of instrument types and tray types

Characteristics of instrument types are not available at all. This data is available at the supplier, but as the OT department is currently searching for a new supplier, it is not possible to ask this data[12]. Assumptions are made about the characteristics of instrument types. The maximum volume and weight of tray types are not based on the actual weight or volume of the instruments distributed in a tray type. The assumption is made that each tray type may only contain a certain maximum number of instruments.

4.3 ANALYSIS OF THE DATASET

The contents and turnover per tray type of the dataset are stored in a database by the CSSD. This section describes analyses of the dataset for the surgical service general surgery, analysis the obsolete instruments distributed in all the tray types of the dataset, and determines the performance of the dataset.

4.3.1 Analysis of the dataset for the surgical service general surgery

The surgical service *General surgery* uses tray types from the dataset for various surgeries, as is seen in Table 5. This table also shows the number of required instruments per surgery type, the total number of available instruments, the total unused instruments per year, and the percentage of unused instruments.

For this surgical service, each year 101,960 instruments are cleaned without being used.

[12] Source: A.S.N. Vernooij

Surgery	Required	Available	Unused		Unused %
Laparoscopic small surgeries	25	107	(82*325=)	26,650	77%
Mamma's	54	179	(125*199=)	24,875	70%
Relaparotomie	88	147	(59*449=)	26,491	40%
Whipple	107	195	(88*193=)	16,984	45%
Proctolocolectomie	103	168	(65*206=)	13,390	39%
Oesophagus resection	115	202	(87*80=)	6,960	43%
Total	**492**	**998**		**101,960**	**51%**

TABLE 5 REQUIRED INSTRUMENTS VERSUS AVAILABLE INSTRUMENTS

4.3.2 Obsolete instruments in dataset

Table 6 shows the number of obsolete instruments per tray type for the entire dataset. The percentages are striking as these instruments are never used for any surgery type. These instruments are brought to the CSSD for C&S, repaired (by the supervision medical aids department) when broken, and replaced when missing all for nothing. The average of obsolete instruments per tray type is as high as 21%, for the selected dataset.

The small basis tray is not taken into account in this analysis as this tray type is also used for other surgeries in combination with other tray types than the big basis tray.

Tray Type	Total instruments	Total obsolete instruments	% obsolete
Big basis tray	107	14	13%
Ileo tray	21	4	19%
Abdominal tray	40	3	8%
Liver tray	48	26	54%
Thorax tray	34	22	65%
Wertheim tray	32	6	19%
Gynaecology tray	30	5	13%
Urology tray	32	4	13%
Micro vascular tray	18	0	0%
Vascular tray	60	11	18%
Aneurysm tray	20	3	15%

TABLE 6 OBSOLETE INSTRUMENTS PER TRAY

One of the obsolete instrument types of the big basis tray is the Matthieu needle holder. One of the OT assistants told us:

> *"I often throw the Matthieu needle holder in the trash bin, as it is not used by surgeons anymore, only one surgeon sometimes asks me if I can give it to him, but then I tell him that we do not have this instrument anymore"*

This instrument type is obviously obsolete, but when OT assistants throw them in the trash bin, they are replaced by the supervision medical department, as the CSSD must complete the tray before it is sterilised and taken back to the storage room. Moreover, replacing missing instruments takes time, as the CSSD has to bring the entire tray type to the supervision medical department, and this department needs some time to retrieve a new instrument. All this time the tray is not available for any surgery.

4.4 PERFORMANCE OF DATASET

Table 7 shows the performance of the current situation.

Performance measure	Current distribution
The total number of trays	12
The average required trays per surgery	2.2
The unused percentage	46%
Number of unused instruments	159,885
The average number of instruments in a tray per tray	43.5
The maximal number of instruments in a tray	107

TABLE 7 COMPARING CURRENT AND NEW CONFIGURATION

The unused percentage of 46% does not imply that the unused percentage of 60% mentioned earlier in this report is incorrect, because the 46% assumes that all determined instruments are required for *each* surgery. For example when a certain pair of tweezers is required only rarely for a certain surgery, the 46% implies that the number of unused instruments for this pair of tweezers is zero, while actually it is more than zero, as it is not always required. The 60% does take these instruments as unused into account.

4.5 COSTS COEFFICIENTS

The following input parameters of the cost coefficients, defined in chapter 3 are:

1. Cost for one tray type
2. Cost for C&S one instrument once
3. Cost for handling a tray once

The *cost for one tray type* is hard to determine, as this cost aspect does not take the number of trays per tray type into account. The average number of trays per tray type is approximately 2.5 trays. The costs for one tray is on average approximately €4,000. We assume that the cost for one tray type is the average number of trays per tray type times the average cost per tray. Hence, the costs are €10,000 per tray type. Sensitivity analysis is performed on the value of this cost aspect in chapter 0.

The *cost for C&S one instrument* is 1 euro; the CSSD determined this price.

The *cost for handling one tray* once for a surgery type is based on the time it takes for an OT assistants to prepare one tray type for surgery. This time is for finding the tray type in the storage room, bringing it to the OR, preparing the instruments for surgery, bringing the tray type to the room from which the CSSD picks up the used trays, and for putting the tray types back into the storage room after C&S it. We estimate the costs for handling one tray type once to be approximately 20 euro.

4.6 CONCLUSION DATA GATHERING

The required data for the TOP model is not directly available in the OT department of the AMC.

The characteristics of surgery types are determined by the OT assistants and surgeons together. Striking is the high coincidence, more than 95%, between surgeons and OT assistants about the required instruments per surgery type.

Striking about current distribution of instruments over trays is the high number of obsolete instruments per tray type; the average is 21% per tray type.

The characteristics of instrument types are not available at all, the assumption is made that tray types may contain a maximum number of instruments.

The cost coefficients for the objective function of the TOP model are:

1. Cost for one tray type : €10,000
2. Cost for C&S one instrument once : €1
3. Cost for handling a tray once : €20

5 SOLUTION APPROACH

This chapter is structured as follows. Section 5.1 shows the simulated annealing algorithm, which we propose for solving the TOP. Section 5.2 describes the software implementation.

5.1 SIMULATED ANNEALING

TOP contains set covering as a sub problem. The set covering is NP hard [19]. Hence, TOP may also be considered NP hard. A formal proof is outside the scope of this report.

NP hard C.O. problems are generally solved heuristically. A constructive heuristic first generates a feasible solution, and a local search heuristic is then often used to improve that solution iteratively. A so-called neighbourhood structure defines the 'neighbour solutions' (a.k.a. 'swaps') of the initial solution that are obtained by altering the initial solution in a predefined way. Local search heuristics evaluate such neighbourhood solutions quickly, and use the computer's computational power to evaluate many candidate solutions in little time. As a result, improved solutions are often obtained quickly.

The main advantages of local search methods are their general applicability and flexibility. A disadvantage is that they are heuristics, i.e., they may not find the optimal solution. The risk of sub-optimality is reduced by choosing a method that can escape from a local minimum. Simulated annealing is such a method.

We choose to use the *simulated annealing* (SA) algorithm as a local search method. Appendix B gives the formal description of SA algorithms and provides background information about the algorithm. A strong feature of the SA algorithm is that it does not rely on the choice of the start solution, i.e. the algorithm's performance is regardless of the initial solution. A typical feature of SA is that, besides accepting improvements in costs, it also accepts deteriorations in costs. These deteriorations are often accepted in the beginning of the algorithm and are less often accepted as time passes. In the end no deteriorations are accepted anymore, and SA then works as a steepest descent local search method, which only accepts solution improvements. This feature makes it possible for SA to escape, to some extent, from local minima.

SA requires an initial solution and a neighbourhood structure. These are defined in the following subsections.

5.1.1 Initial solution

The only requirement of the initial solution is that it is a feasible solution. As stated before, the algorithm is not strongly dependent on the initial solution; therefore a simple heuristic is used for finding a feasible initial solution.

This heuristic proceeds as follows. Create tray type(s) for each surgery type. We first determine the minimum number of required tray types for a surgery type, depending on the weight and volume of the required instruments for this surgery type. Then we fill the tray types with all required instruments for this surgery type.

5.1.2 The neighbourhood structure

To move from the current solution to a neighbourhood solution we may choose one of the following points of view:

- *The tray type point of view* aims to minimise the number of tray types, has little influence on the used instruments, and no influence on the total used tray types;
- *The surgery type point of view* aims to minimise the used instruments and the total used trays, and has no influence on the number of tray types;
- *The instrument type point of view* aims to minimise all aspects in the objective value.

In the following subsections 5.1.2.1 to 5.1.2.3 we describe our neighbourhood generating mechanisms within these three points of view respectively. In subsection 5.1.3 we describe how we select a neighbourhood generating mechanism in each iteration.

5.1.2.1 *Tray Type* point of view:

- Pick one random tray type and put all the instruments of this tray type in new individual tray types;
- Pick two random tray types and put the overlapping instrument types, the maximum number of instruments contained in one of the two tray types, in a new tray type. Delete the overlapping instrument types from the randomly picked tray types;
- Pick two random tray types and merge them entirely. The new tray type contains the maximum number of instruments contained in one of the two tray types. The merge is only performed if the volume or weight does not exceed the maximum volume or weight of a tray type;
- Pick two random tray types, A and B, and put overlapping instrument types in tray type A. Delete the overlapping instrument types from tray type B. The maximum number of instruments from tray type B is only put in tray type A if the weight or volume does not exceed the maximum volume or weight of a tray type;
- Randomly pick a tray and copy the entire tray; all the instrument types, number of instruments per instrument type and the assigned surgery types.

5.1.2.2 *Surgery type* point of view

- Pick random one surgery type and put the required instruments in as few as possible (new) tray type(s);
- Pick random one surgery type, if this surgery types requires more than one tray type, than randomly pick two tray types and merge them entirely.

The merge is only performed if the volume and weight does not exceed the maximum volume or weight of a tray type;

- Pick random one surgery type, if the required instruments fit in one tray then create a new tray type for this surgery type with all required instruments.

5.1.2.3 Instrument type point of view

- For all instrument types check if they are used for more than one surgery type. If the instrument type is only used for one surgery type, than create a new tray type for this surgery type with all required instruments that are only used for this surgery type. Delete the instruments of the new tray type(s) from all other tray types;
- Create a new tray type, and put the instrument types that are used for most surgery types in the new tray, the number of instruments per type is the maximum used per surgery type, until the tray is full (volume or weight restriction);
- Create a new tray type and put the instrument types that are distributed in most tray types in the new tray type, the number of instruments per type is the maximum that is distributed in the tray types containing this instrument type, unit the tray is full (volume or weight restriction).

5.1.3 Selection of neighbourhood generating mechanism

In each iteration we randomly select one of the neighbourhood generating mechanisms described in subsections 5.1.2.1 to 5.1.2.3. Subsection 6.2.2 shows the result of an experiment that determines the success ratio per swap type, i.e. point of view.

During the SA execution empty or obsolete tray types may be found. Also tray types may contain obsolete instruments and tray types may be assigned to a surgery type that does not require any instruments distributed in that tray type. We dispose of these tray types and instruments.

5.2 SOFTWARE IMPLEMENTATION

This section describes how the SA algorithm is implemented in the program TrayOptimisation. Subsection 5.2.1 describes the data structure that is used. Subsection 5.2.2 explains the simulated annealing parameter setting.

5.2.1 The data structure of TrayOptimisation

The required data for the optimisation of trays is stored in a Microsoft Office Access database. The TOP model and the solution approach are implemented in the program TrayOptimisation Borland Delphi 7.0. TrayOptimisation loads the initial solution from the database and saves the new solution in the database as a new configuration, in the table TrayConfiguration. Figure 5 shows the database structure.

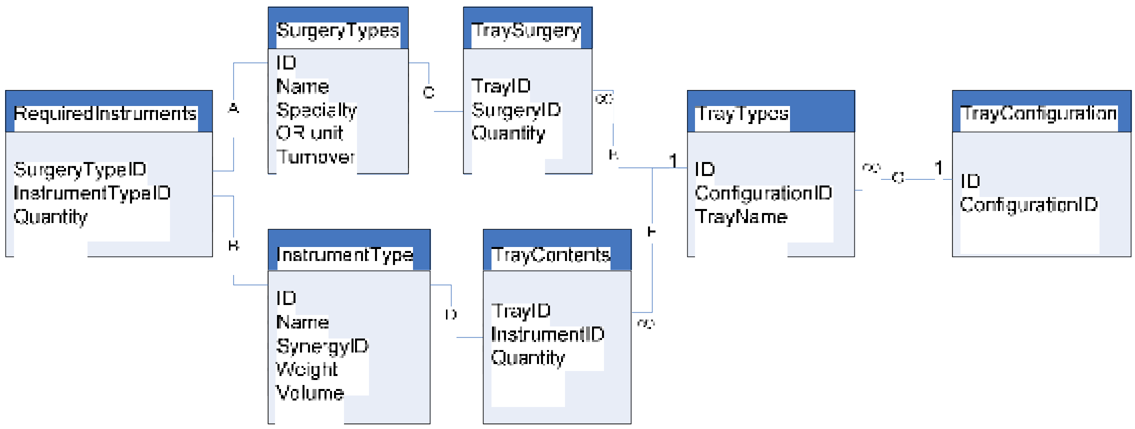


FIGURE 5 DATABASE STRUCTURE

The lines in the database structure (Figure 5) define the relations between the different tables and cross tables. When lines have a 1 or ∞ symbol it means that the relation is one or ∞, if there is not a symbol then the relation is ∞ both ways. The lines are interpreted as follows:

A Each surgery type requires one to infinite many instrument types, and a required instrument is used for one to infinitely many surgery types;

B Each instrument types is required for one to infinitely many surgery types, and the required instruments contain each instrument type one to infinite times;

C Each surgery requires one to infinitely many tray types, and each tray type can be used for one to infinitely many surgery types;

D Each instrument type is one to infinitely many times distributed into a tray type, and each tray type contains one to infinitely many instrument types;

E Each surgery type can only require a certain tray type once, and a tray type can be used for one to infinitely many surgery types;

F A tray type can contain one to infinitely many instruments, and the contents of one tray type can only belong to one tray type;

G One configuration contains infinitely many tray types, and a tray type can only belong to one configuration.

5.2.2 The SA parameter setting

In order to apply the SA algorithm the various parameters must be determined that specify the cooling schedule, background information about the cooling schedule is provided in Appendix B. The values of these parameters can have a significant impact on the algorithms effectiveness. Unfortunately, there is no procedure to determine an optimal cooling schedule. We use an empirical procedure and guidelines from the literature [14].

The following parameters are used in the SA algorithm:

- *Start temperature (1000)*, the initial temperature is chosen such that the initial acceptance ratio is sufficiently high to generate random walks in the initial phase of execution;

- *Decrease factor (0.99)*, *length Markov Chain (150)*, and *lower bound temperature (0.5)* are chosen such that the SA converges after approximately one hour.

6 COMPUTATIONAL RESULTS

This chapter describes the results of the experiments with the software implementation of the proposed method, TrayOptimisation, for the dataset of the OT department of the AMC. This chapter is structured as follows. Section 6.1 describes the design of the various experiments that are performed. Section 6.2 shows the results of the experiments. Section 6.3 gives a discussion of the results of the experiments. Section 6.4 gives the conclusion of the results.

6.1 EXPERIMENT DESIGN

6.1.1 Introduction

Before optimising the TOP for the dataset, we first perform a few experiments.

In chapter 4 we made estimation for the value of the cost per tray type (ε_1). The first experiment is sensitivity analysis on this cost parameter. The cost parameter is assumed to be €10,000 we analyse what happens to the solution if this value (slightly) differs.

In chapter 5 we defined the neighbourhood structure, three swap types, i.e. point of views, are defined:

1. Instrument type point of view
2. Surgery type point of view
3. Tray type point of view

We perform an experiment to determine the success ratio per swap type, i.e. both the number of times that this swap type is accepted and the number of times that this swap type leads to a new best solution is determined.

In chapter 4 we explained that the characteristics of instrument types are not available in the OT department of the AMC. We assume that the number of instruments distributed in a tray type indicates whether the volume and weight restrictions are met. The value for the maximum number of instruments in a tray type (M_i) is estimated. In the dataset the value for M_i is 107 instruments, distributed in the big basis tray. This tray type is too heavy and inconveniently arranged, so M_i should be chosen such that it is smaller than 107. The CSSD claims that about 60 instruments per tray type is the optimal value[13]. We chose to perform experiments with the values for M_i between 50 and 110 instruments, with an interval of 5 instruments. We also perform an experiment for the current value of M_i and compare the solution to the solution of the current distribution. After these experiments the value for M_i is determined, based on the experiments and on the input from the CSSD.

6.1.2 The dataset

The dataset defined in subsection 4.2.1 is optimised. We use the following attributes and parameters.

6.1.2.1 Attributes

The entities, defined in subsection 3.1.1, are as follows:

- The number of surgery types (S) is 15 → {1..15}
- The number of instrument types (I) is 239 → {1..239}
- The number of tray types (T) is zero, as this is an output of the TOP model. Currently the number of tray types is 12 → {0..0}

6.1.2.2 The cost coefficients for the objective function

The following cost coefficients, determined in section 4.5, are used in the objective function:

- Cost of one tray type (ε_1) : €10,000
- Cost of C&S one instrument once (ε_2) : €1
- Cost of handling one tray type once (ε_3) : €20

[13] Source: H.Lingeman. Synergy healthcare is a big C&S company with department in many hospitals in the UK. The number of instruments per tray type is based on the experiences of Synergy healthcare in the UK.

The value of the objective function is: the number of tray types * ε_1 + number of used instruments * ε_2 + number of handled trays *ε_3.

6.1.2.3 The cooling schedule for simulated annealing

The following cooling schedule, determined in section 5.2.2, for simulated annealing is used:

- *Start temperature* →*1000*
- *Decrease factor* →*0.99*
- *length Markov Chain* →*150*
- *lower bound temperature* →*0.5*

6.2 EXPERIMENT RESULTS

6.2.1 Sensitivity analysis for value of ε_1

The value for ε_1 is varied between €7,500 and €12,500 with an interval of €500. The value for M_i is not determined yet, so we assume it to be 60, as the CSSD claims that this is the optimal value for M_i. Table 8 shows the results for the various values of ε_1. The number of tray types does not show an unexpected high increase or decrease for small changes in ε_1. We use the value of €10,000 for ε_1.

Epsilon 1	# Tray types
7500	19
8000	18
8500	19
9000	18
9500	18
10000	17
10500	18
11000	18
11500	18
12000	18
12500	16

TABLE 8 RESULTS OF SENSITIVITY ANALYSIS FOR ε_1

6.2.2 Success ratio per swap type

Table 9 shows the success ratio per swap type. The second column shows the ratio of accepted swaps, the third column shows the ratio of swaps that led to the best solution so far.

Swap type	Not accepted	Accepted	Best solution so far
Tray type point of view	76.7%	23.3%	100.0%
Surgery type point of view	40.0%	60.0%	0.0%
Instrument type point of view	100.0%	0.0%	0.0%

TABLE 9 SUCCESS RATIO PER SWAP TYPE

From this table we may conclude that the swaps of the instrument type point of view do not influence the solution at all. This swap type is not used for determining the best solution. The tray type point of view is the only swap type that leads to new best solution so far, but the swaps are often (77%) not accepted. The surgery type point of view is more often accepted then the tray type point of view, but does not lead directly lead to a best solution so far.

6.2.3 Determination of value for M_1

Table 10 shows the results of the experiments with various values for the maximum number of instruments per tray type.

The objective function decreases as M_i increases. Figure 6 gives a clear view of this decrease. If M_i increases more instruments may be distributed per tray type. Increasing M_i gives more possibilities for minimising the objective function. When M_i is small the number of instruments per tray type is low, because it is limited to M_i. If M_i is high than the number of instruments per tray type is probably high, but it may also be low if that gives a better solution. Hence, increasing M_i gives the program more flexibility for minimising the objective function.

M_t	# tray types	#instruments used	# trays used	objective value
50	22	217705	4050	534065
55	20	213214	4297	499154
60	18	220555	4217	484895
65	17	206374	3850	453374
70	16	208499	3855	453599
75	17	212285	3755	457385
80	14	225917	3755	441017
85	14	220167	3851	437187
90	11	235753	3306	411073
95	11	225076	3224	399556
100	11	218800	3224	393200
105	11	216495	2719	380875
107	10	226243	2719	380623
110	10	223136	2719	377516

TABLE 10 RESULTS OF TOP MODEL FOR VARIOUS VALUES OF MAXIMUM INSTRUMENTS PER TRAY TYPE

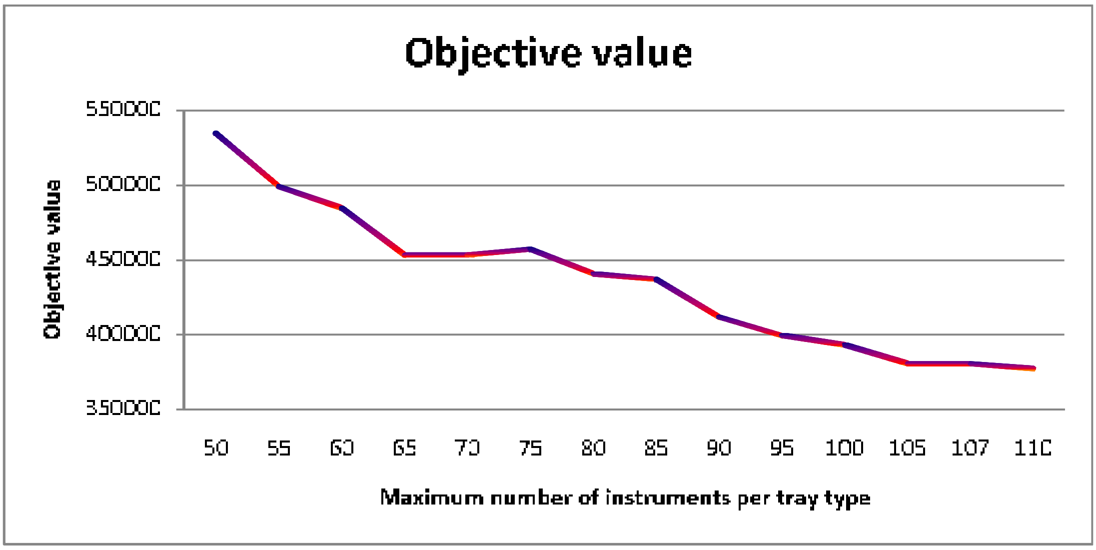


FIGURE 6 OBJECTIVE VALUE WITH VARIOUS VALUES FOR MAXIMUM NUMBER INSTRUMENTS PER TRAY TYPE

The influence of the maximum number of instruments per aspect of the objective value is shown in the following charts.

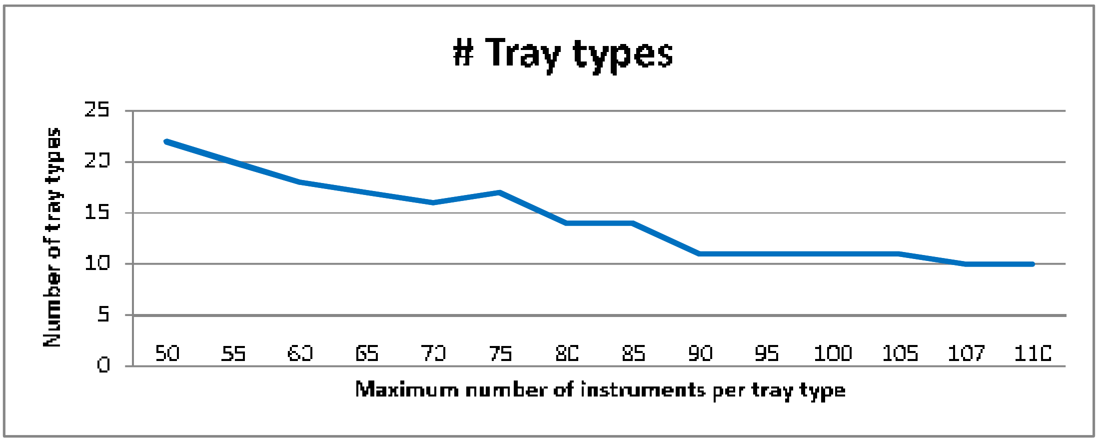


FIGURE 7 IMPACT OF MAXIMUM NUMBER OF INSTRUMENTS ON NUMBER OF TRAY TYPES

Figure 7 shows that the number of tray types decreases as M_i increases. When M_i increases, i.e. more instruments may be distributed in a tray type, less tray types are required, as the required instruments per surgery type fit into less tray types.

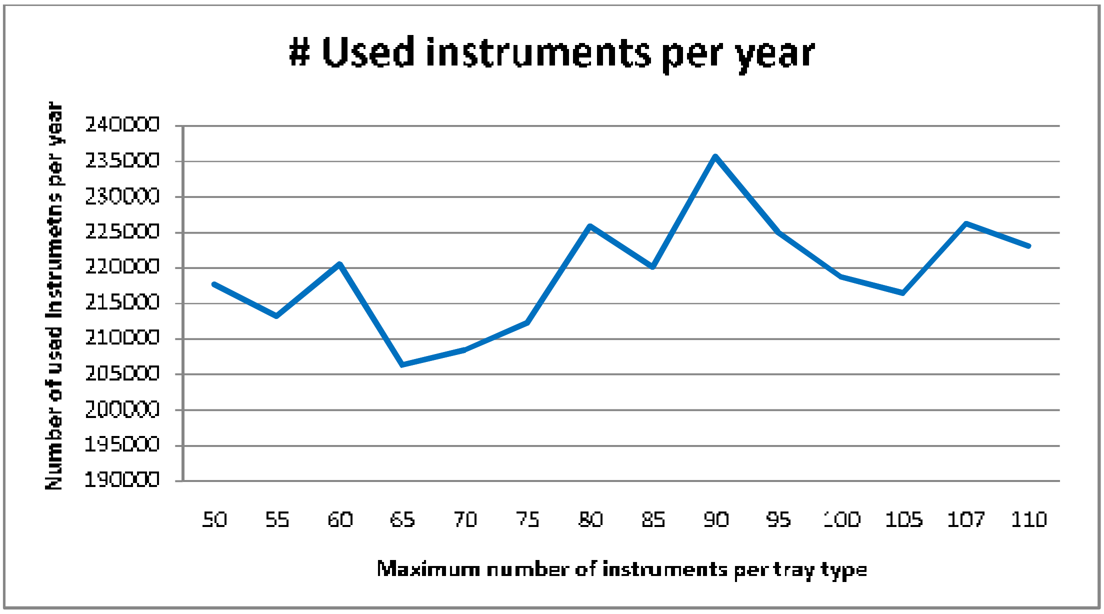


FIGURE 8 IMPACT OF MAXIMUM NUMBER OF INSTRUMENTS ON NUMBER OF TRAY TYPES

Figure 8 shows that the number of used instruments fluctuates as the maximum number of instruments per tray type increases. This chart indicates that the number of used instruments may increases significantly if the number of tray types reduces by one or if the number of used tray types decreases. The cost for C&S one instrument is very low compared to the other two cost factors, therefore deteriorations in used instruments are easily compensated if one of the other two cost aspects improves.

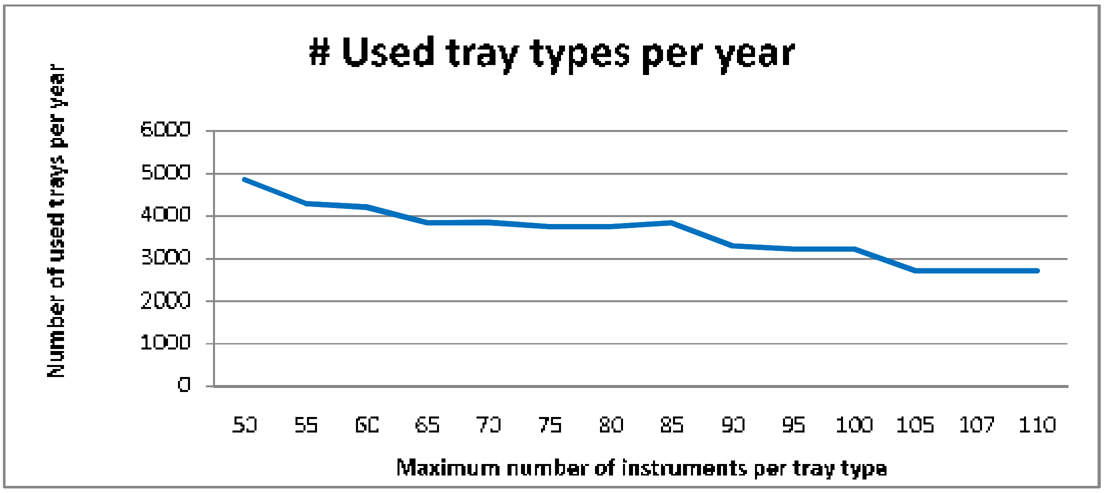


FIGURE 9 IMPACT OF MAXIMUM NUMBER OF INSTRUMENTS ON NUMBER OF USED TRAY TYPES

Figure 9 shows that the number of used tray types decreases as the maximum number of instruments per tray type increases. More instruments are distributed in a tray type, so the required instruments per surgery type fit in fewer tray types, so fewer tray types are required per surgery type.

6.3 DISCUSSION RESULT

According to the CSSD, the maximum number of instruments should be around 60. The chart, of the objective value, shows a high decrease from 60 -65 maximal instruments on a tray type. We chose the maximum instruments on a tray type to be 65 instruments. Table 12 shows the tray types, the number of instruments distributed in each tray type, and the assigned surgeries per tray type. The surgery types are numbered as indicated in Table 11.

1	Laparoscopic small surgeries	9	Abdominal uterusextirpatie
2	Mamma	10	Cryocoagulatie
3	Relaparotomie	11	Urethra Implant
4	Whipple	12	Orchidectomie
5	Proctolocolectomie	13	Endarterectomie
6	Oesophagus resection	14	Kidney transplant
7	Abdominal radical uterus extirpatie	15	Aorta iliac
8	Locale excise vulva		

TABLE 11 NUMBER PER SURGERY TYPES

Tray type	# instruments	Surgery type(s)
1	64	6
2	56	5,6
3	53	4
4	62	4,5
5	62	7,9
6	65	11,15
7	59	2,10,12
8	65	7,9
9	64	13,15
10	57	13
11	64	2
12	23	2
13	65	8
14	21	1
15	64	14
16	61	14
17	65	11,15

TABLE 12 SOLUTION OF TOP MODEL

6.3.1 Cost reductions after organisational implementation of new tray types

Table 13 compares the current solution with the best solution and with the best solution with maximum instruments per tray type of 107, the current situation.

max # instruments in tray	# tray types	# used instruments	# used trays	objective value
65	17	206374	3850	453374
107	13	226243	2719	380623
Current situation (107)	12	357899	5118	580259

TABLE 13 COMPARISON CURRENT AND BEST SOLUTION(S)

The possible cost reduction are approximately (580259 – 453374 =) €125,000 per year.

6.4 CONCLUSIONS COMPUTATIONAL RESULTS

The experiments performed to determine the success ratio per swap type shows that the instrument type point of view is not used for finding the best solution. Moreover, only the tray type point of view gives best solutions so far.

The maximum number of instruments per tray type influences the best solution. An increase in the maximum number of instruments per tray type leads to decrease of the objective value. We choose the maximum number of instruments per tray type to be 65.

The computational results show a significant improvement compared to the current situation. The best solution gives possible cost reductions of at least €125,000 per year, on only a fraction (12) of the total number of tray types (550) in the OT department. It is expected that applying this method to the entire tray inventory can lead to cost savings up to millions of Euros.

7 ORGANISATIONAL IMPLEMENTATION OF NEW TRAY TYPES

This chapter describes the implementation strategy for introducing new tray types and proposes using the continuous improvement method for continuous improvement of the contents of tray types. Section 7.1 describes the strategy for the implementation of new tray types. Section 7.2 describes how continuously improvement of the contents of tray types is possible. Section 7.3 gives the conclusion about the implementation.

7.1 IMPLEMENTATION STRATEGY FOR NEW TRAY TYPES

The implementation involves the use of managerial, administrative, and persuasive abilities to ensure that the chosen alternative is carried out. The ultimate success of the chosen alternative depends on whether it can be translated into action. Employee resistance to change is often the cause of failing to translate the best alternative into action. Force field analysis is a tool to help analyse the change forces. It assumes that change is a result of the competition between driving and restraining forces. As restraining forces are reduced or entirely removed, behaviour will shift to incorporate the desired changes [7].

This section is divided into two parts. Subsection 7.1.1 explains the reasons for employee resistance. Subsection 7.1.2 describes force field analysis and shows how this is used for the implementation of new tray types in the OT department. Subsection 7.1.3 describes the implementation of the first new tray type in the OT department of the AMC.

7.1.1 Reasons for employee resistance [7]

"The best procedure before implementation of the best alternative is not to ignore the employee resistance, but to diagnose the reasons and design strategies to gain acceptance by the users" (D.L. Barton and I. Deschamps, 1988).

Surgeons are afraid of losing their power about the available instruments during surgery, for example fear exists for standardisation. Currently, the surgeons decide which instruments they want to use. As a result, for example in the surgical service gynaecology, each surgeon prefers its own instruments. Therefore many, almost the same, instruments are available at each surgery, which are unused for most of the time as only one surgeon uses these instruments.

7.1.1.1 Lack of understanding and trust

"Employees often do not understand the intended purpose of a change or distrust the intentions behind it"

Fortunately, the OT assistants understand the intended purpose of changing the current contents of trays. They are happy about the better working conditions as a result of the new configuration. Some of the surgeons in the OT department of the AMC distrust the intentions of changing the contents of the trays. The past years various projects have started to reduce costs, most of these projects fail or make the working conditions worse. Therefore one of the surgeons of the AMC literally said:

"If this is a project to reduce costs, than I will not cooperate"

7.1.1.2 Uncertainty

"Uncertainty is the lack of information about future events; it represents a fear of the unknown"

Fear exists among OT assistants and surgeons for unavailability of trays and instruments during surgery. The current contents of trays are not optimal, but they know which instruments are available on which tray types. If a tray is unavailable, which happens regularly, they know where to find other trays that contain the required instruments. When a new configuration is implemented, fear exists of missing instruments in required trays, unavailability of required trays, and not knowing where to find required instruments if a required tray is unavailable. Moreover, unavailability of required instruments, leads to cancelling surgery.

7.1.2 Force Field Analysis

Force field analysis is a tool to help analyse the change forces. Change is a result of the competition between driving and restraining forces. Performing the force field analysis starts with making a force field diagram that contains the restraining and the driving forces (Figure 10).

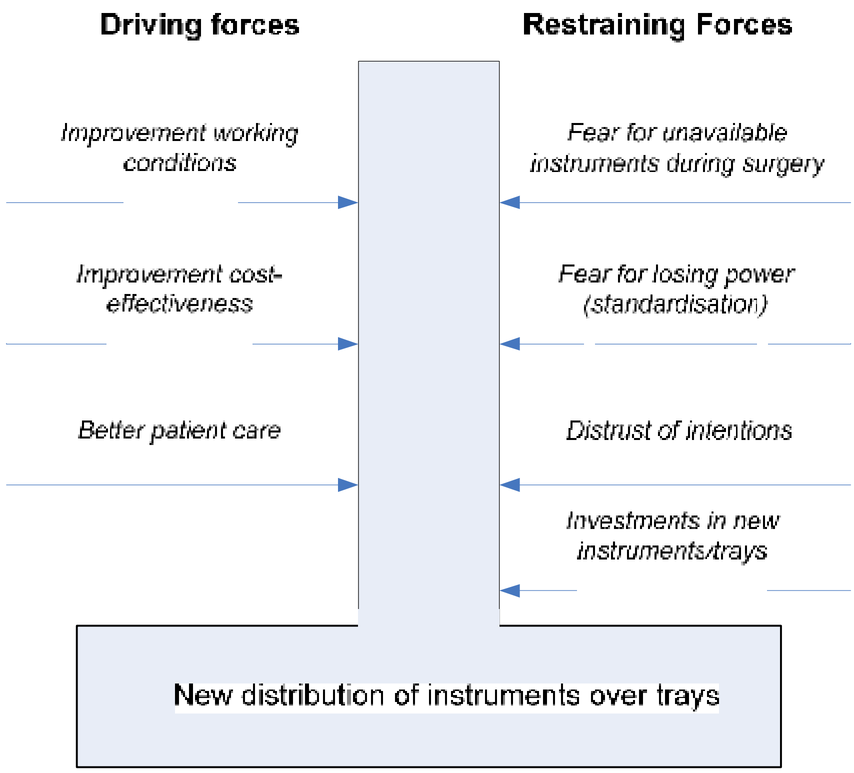


FIGURE 10 FORCE FIELD DIAGRAM

The following step is to reduce or remove the restraining forces; various tactics exist for reducing employees' resistance. The investments in new trays and or instrument are reduced by proving that the gains in the near future are higher than the required investment at this moment. The following tactic, participation [23], is used to overcome the resistance of OT assistants and surgeons.

7.1.2.1 Participation

OT assistants and surgeons are both asked to participate in determining the required instruments per surgery. This is a time-consuming approach, but the fear of instrument unavailability during surgery significantly reduces. A drawback of the participating approach is that both OT assistants and surgeons want more instruments than actually required, as safety stock. In the future, the required instruments per surgery must be re-evaluated and when possible adjusted. For now, it can be seen as a negotiation about reducing the resistance by allowing more instruments than actually required. The OT assistants are educated in using the new tray types by the participating OT assistants. During business meetings, new trays are shown and explained. The introduction of new trays should be a slow process, meaning that not all trays are changed at the same time, but only one to a few per time unit, for example each two weeks.

At this point the driving forces outweigh the restraining forces; behaviour will shift to incorporate the desired changes. The contents of the tray types can be changed.

7.1.3 Implementation first new tray type in the OR department of the AMC

We introduced one new tray, the "Struma tray". The required instruments for surgeries requiring this tray were discussed with three OT assistants and the surgeon that performs most of these (struma) surgeries. The tray type has been successfully implemented; currently three struma trays are used in the OT department of the AMC.

Before this new tray, two trays (of which one is the big basis tray) had to be put out for the struma surgery. Now only one, conveniently arranged, tray type, the Struma tray, has to be put out, which significantly improves the working conditions for OT assistants. This big basis tray is no longer required for this surgery, but is still required for all other surgery types mentioned in Table 4, chapter 4.

The costs savings, for C&S, are also high as only 61 instruments require C&S when this surgery is performed (199 times in 2007), instead of 182 instruments in the old situation. As the C&S costs per instrument are approximately 1 euro, the savings in C&S costs amount to almost 25,000 euro per year, as a result of creating this new tray type. The trial struma tray is used for six weeks, after which three struma trays were drawn up.

PICTURE 11 PARTICIPATION OF OT ASSISTANTS

7.2 CONTINUOUSLY IMPROVING THE DISTRIBUTION OF INSTRUMENTS OVER TRAYS

The required instruments per surgery type are changing constantly, also the surgery types change regularly. Each week new instrument types are introduced in the OT department of the AMC. Therefore, we think that a continuous focus on the subject of distributing surgical instruments over trays is important. To achieve such a continuous focus we recommend using the continuous improvement method.

7.2.1 Continuous improvement (Kaizen) [24]

It is not the rate of improvement which is important in continuous improvement; it is the momentum of improvement. The successive improvements may be small as long as some kind of improvement takes places every month, week, quarter, or whatever period is appropriate.

Continuous improvement is the idea that improvement can be represented by a never-ending process of repeatedly questioning and re-questioning the detailed working of a process. In our case the performed surgery types and the required instruments accompanying these surgery types. This cyclic nature is summarised by the idea of the Plan Do Check Act (PDCA) improvement cycle:

- Plan → analyse the required instruments per surgery type and compare this to the available instruments per surgery type. The program TrayOptimisation determines new optimal distribution for tray types. The output is a plan of action, the new tray types, for improving the distribution of instruments over the tray types. This does not imply that all surgery types and all tray types should be improved at once; more realistic is the idea of improving part of the distribution each month (or whatever time period is workable).
- Do → implementation of the new tray types, the implementation should take the aspects explained in section 7.1 into account. For example, force field analysis should be performed.
- Check → the new tray types are evaluated and the realised performance improvement is compared to the expected improvement.
- Act → if the new trays are successful, then the new tray types are no longer seen as trial trays. If the new tray types are not successful, then the lessons learned from the trial tray types are formalised before a new cycle is started.

7.3 CONCLUSION IMPLEMENTATION

The implementation of change often fails, because the chosen alternative cannot be translated into action. Employee resistance is a major factor in the implementation step; employees have various reasons for resisting change, for example fear of the unknown. Force field analysis is performed to determine the competition between driving and restraining forces. As restraining forces are reduced or entirely removed behaviour will shift to incorporate the desired changes. Various tactics exist for reducing the restraining forces of employee resistance. Participation is selected for reducing the resistance of OT assistants and surgeons, meaning that these employees participate in the research and implementation. As the restraining forces reduce, the driving forces outweigh them, which led to a successful implementation of the first new tray type in the OT department of the AMC.

The concept of continuous improvement will help the OT department of the AMC to continuously keep the focus on optimisation of the surgical instrument trays distribution. To make sure that introducing new instrument types or surgery techniques will not lead to a sub-optimal distribution of instruments over tray types.

CONCLUSIONS AND RECOMMENDATIONS

The objective of this research is to develop a methodology to efficiently distribute surgical instruments over trays. This chapter gives the conclusion about the developed method and the use of this method in the OT department of the AMC. Moreover, this chapter gives recommendations about further research in optimising the logistics concerning surgical instrument trays and gives general recommendations for the OT department of the AMC.

CONCLUSIONS

The distribution of instruments over trays can be significantly improved using the proposed method of this research.

We have indicated three main problems concerning an inefficient distribution of surgical instruments over trays in the *operating theatre* (OT) department of the AMC:

1. Heavy trays
2. Unused instruments
3. Inconveniently arranged trays

This leads to:

- Low cost effectiveness
- Bad working conditions for OT assistants
- Possible lower patient's safety

Surprisingly there is hardly any literature about optimising the logistics of surgical instrument trays. Therefore, we use literature from similar disciplines and adapt this available knowledge and experience for the optimisation of the logistics concerning surgical instruments trays.

We defined three performance measures for the optimisation, based on the problem analysis of AMC's OT department:

1. The number of tray types
2. The number of unused instruments
3. The average number of assigned tray types per surgery type

We define the *tray optimisation problem* (TOP) as the assignment of tray types to surgery types and the determination of the contents per tray type, i.e. the distributed instruments per tray type. We created the TOP model that minimises the number of tray types, the number of available instruments in used trays for one year, and the number of used trays for one year. The restrictions for the TOP model are: the weight and volume of a tray type may not exceed the maximum weight or volume of a tray type, and the required instruments for a surgery type must be available in the assigned tray types per surgery type.

We gathered data in the OT department of the AMC. The required instruments per surgery type are determined by consulting both surgeons and OT assistants. Striking is the high agreement between surgeons and OT assistants about required instruments for surgery. This implies that OT assistants know very well the required instruments per surgery type, and therefore may be consulted for future data gathering concerning the required instruments per surgery type. The characteristics of instruments, the weight and costs per instruments are not directly available. We assume that the tray types have a maximum number of instruments (65), instead of looking at the weight and volume of instrument types.

The number of obsolete instruments distributed in tray types in the OT department of the AMC is very high. On average 21% of the instruments distributed in tray types is obsolete, for the selected dataset.

TOP is a NP hard combinatorial optimisation problem. These problems are often solved heuristically, which is likely to lead to sub-optimality. This risk is reduced by a using a method that can escape from local minima. One of these methods is the local search method simulated annealing algorithm, which we chose for solving the TOP problem.

The TOP model and the solution approach, simulated annealing, are implemented in the program TrayOptimisation using Borland Delphi 7.0. The required data for the optimisation of trays is stored in a Microsoft Office Access database.

The main result of the experiments with TrayOptimisation show possible cost reductions of approximately €125,000 per year, on only a fraction (12) of the total number of tray types (550) in the OT department. It is expected that applying this method to the entire tray inventory can lead to cost savings up to millions of Euros.

RECOMMENDATIONS

We divide the recommendations in several parts. The first part recommends further research in the subject of optimising the distribution of instruments over trays. The second part gives recommendations for the OT department of the AMC to optimise logistic processes in the OT department, other then the contents of instrument trays. The third part gives recommendations about data storage in the OT department of the AMC. The fourth part gives recommendations about educating the OT assistants about costs of tray and instrument usage.

Optimising the distribution of instruments over trays

Further research in the area of optimising the distribution of instruments over trays should be performed by investigating and elaborating TrayOptimisation and by continuously focusing on the subject of efficiently distributing instruments over trays. The main missing aspect of TrayOptimisation is the cost aspect in the objective function.

We recommend the OT department of the AMC to use continuous improvement for further and continuous optimisation of the contents of the surgical instrument trays.

Optimising logistic processes in the OT department of the AMC

Various studies may help the OT department to optimise logistic processes. We recommend performing the following seven studies:

1. There is no inventory model, i.e. a procedure about the available trays per type. Analysing the turnover per tray and the number of available tray types gives a strange result. Some trays are used over 100 times per year, while others are used only 20 times per year. Therefore, we recommend a study to determine the appropriate stock levels of trays per type. After determining the stock levels this data can be used as an input for TrayOptimisation, hence, the costs can than be taken into account in the objective value, as calculating the costs of a configuration is possible. Of course the costs per instrument should then also be available.
2. Currently the entire stock of trays is stored in the OT department. As the OT department is a closed department, the space is scarce. The current storage capacity is insufficient, therefore we recommend to perform a study to investigate the possibilities and influences of storing (part of) the trays in a storage room outside the OT department.
3. The outpatient OTs uses the trays from the inpatient OTs. Therefore, the OT assistants of the inpatient OTs often have to deal with unavailable trays, while the trays were available at the start of their shift. The other way around is the same, OT assistants of the outpatient OT put out the trays in trolleys for the next day, it often occurs that when the trolleys are brought to the outpatient OTs trays are missing, because an OT assistant of the inpatient OT used the tray for another surgery. This leads to much irritation and therefore we recommend a study to be performed to determine the influences of the outpatient OTs using the inpatient trays and investigate the possibilities for an own storage room for the outpatient OTs.

4. Currently, the patient plan is made by the surgeons. They do not consider the available instruments. When a surgery is planned, the required trays are not reserved for that patient. Therefore, planning too many surgeries requiring the same instruments often stays unnoticed. We recommend a study to investigate if the current patient planning is good, and the possibilities of reserving required trays when the surgery is planned. To make sure that the required trays for a surgery are available.
5. During this research the individual instruments are not taken into account. Currently, it is not clear when an instrument should be distributed in a tray or put in the storage as an individual instrument. Therefore we recommend performing a research to find out when it is appropriate to distribute an instrument over a tray or as individual instrument.
6. The implant and prosthesis trays are not taken into account in this research. During this research we found out that these trays are different than the normal instrument trays. We recommend performing a separate research on optimising the contents of implant and prosthesis trays.
7. Many trays have the label of high priority C&S (>3%). Moreover, many trays (about 100 per day) get the once only high priority C&S. High priority C&S of trays disrupt the standard processes at the CSSD. Therefore, we recommend performing a study to determine when trays should get the high priority label, once or standard, as there currently is not a clear procedure.

Data storage in the OT department of the AMC

The required instruments per surgery type are currently not stored. We recommend storing this data and keeping these records up-to-date, obsolete instruments are detected easily and should then be immediately removed from the tray types.

OT assistants put the sterilised tray types back in the cupboards of the storage room. The printed location on the sticker of the tray types indicated where the tray type should be stored. The OT assistants usually do not look at the sticker, but put the tray type in an empty space. When the tray type is required again the OT assistants can not find the tray type. We recommend to up-date the location of each tray type regularly, and to make sure that all trays have their own location in one of the storage rooms.

Education about costs of instrument and tray usage

The personnel should be better educated about costs of using trays and instruments. Most of the OT assistants and surgeons do not know the high costs involved in opening a wrong tray, throwing away instruments, C&S tray, and etcetera.

REFERENCES

[1] http://www.OECD.org

[2] http://intranet.amc.nl (April 2008).

[3] Bakker P. (2004), *"Sneller beter" (in Dutch)*, Report, Dutch Ministry of Health.

[4] Klundert J., Muls J.P. and Schadd M. (2006), Optimizing sterilized logistics in hospitals.

[5] Nilsen E. (2006), Managing equipment and instruments in the operating room.

[6] Carter M. (2002), *Diagnoses: Mismanagement of resources,* OR/MS Today, Vol 29, No 2.

[7] Daft R.L. (1997), *Management*, fifth edition, 268-283 and 364-386

[8] Daft R.L. (2001), *Organization Theory and Design,* seventh edition, 399-419.

[9] Archer E.R. (1980), *"How to make a business decision: An analysis of theory and practice",* Management review, 69:2, 54-61.

[10] Mintzberg H., Raisinghani D and Theoret A (1976), "The structure of "Unstructured" decision processes", Administrative Science Quarterly, vol 21, No 2, 246-275.

[11] Heerkens H.(2004), "A methodological checklist for the High-tech marketing project", TSM Business School.

[12] Fineman S.J. (1978), *"An analysis of the logistics of supplying and processing sterilized items in hospitals",* Computers & Operations Research research, Vol 5, 47-54.

[13] Lyles M.A. and Thomas H. (1988), *"Strategic problem formulation: biases and assumptions embedded in alternative decision-making models",* Journal of management studies, 25:2.

[14] Aarts E.H.L. and Korst J.H.M. (1989), *"Simulated Annealing and Boltzmann Machines"*, Wiley, New York.

[15] Kirkpatrick S., Gelatt C.D., and Vecchi M.P. (1983), *"Optimization by Simulated Annealing,* Science, volume 220, number 4598, 671-680.

[16] Schuur P.C. (2005), *"DOBP Combinatorische optimalisering" (in Dutch)*, syllabus, 5-13.

[17] Schuur P.C. (2005), *"DOBP Complexiteit" (in Dutch)*, syllabus, 18-20.

[18] Gademan A.J.R.M (1998)., *"De operationele besturing van magazijnsystemen" (in Dutch).*

[19] Garey, M.R. and Johnson, D.S. (1979), "*Computers and Intractability: A Guide to the Theory of NP-Completeness",* ISBN 0-7167-1045-5.

[20] Winston W.L. (1994), *"Operations Research",* International Thomson publishing, Third edition, 770-881.

[21] Westbrook R. (1994), *"A new paradigm for research in production and operations management"*, International journal of operations & production management, volume 15, number 12, 6-20.

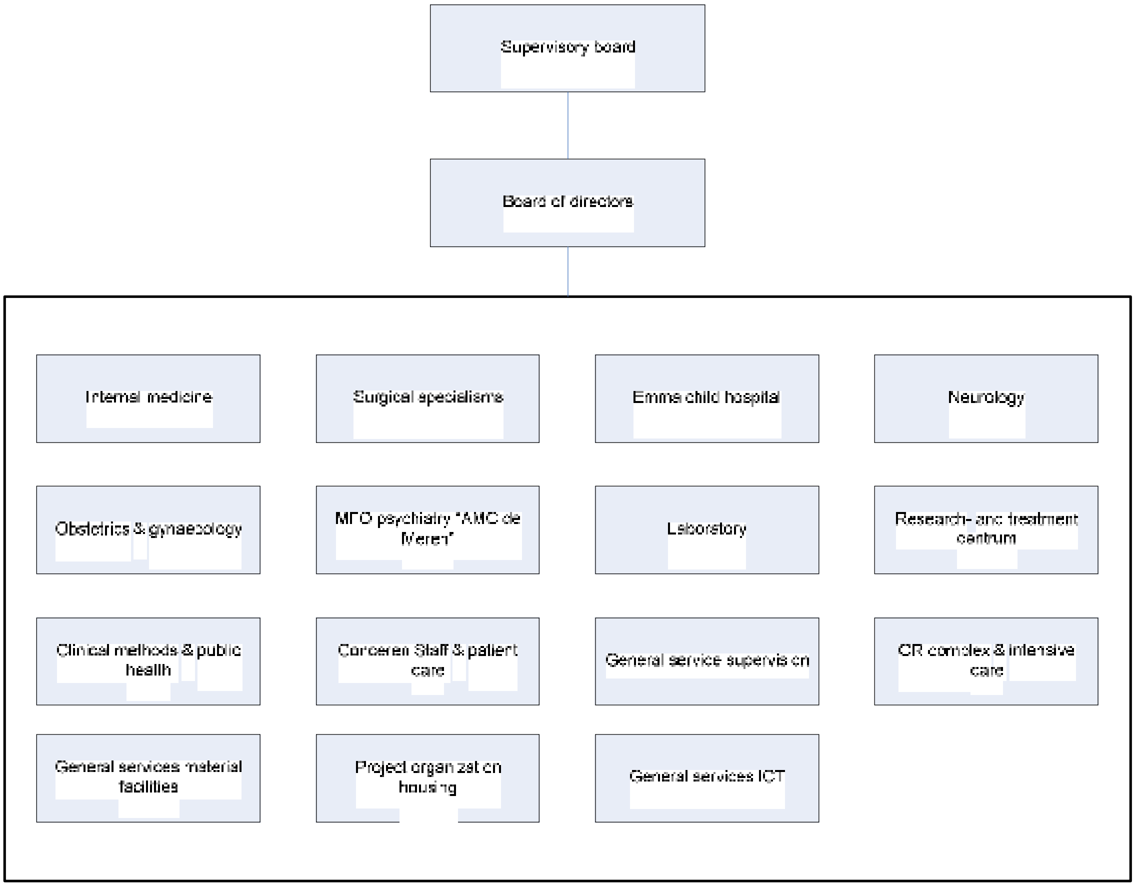
[22] Burnes B. (2004), *"Kurt Lewin and the planned approach to change: a Re-appraisal"*, Journal of management studies, volume 41, number 6.

[23] Nutt P.C. (1986), *"Tactics of implementation"*, Academy of management journal 29, 230 – 261.

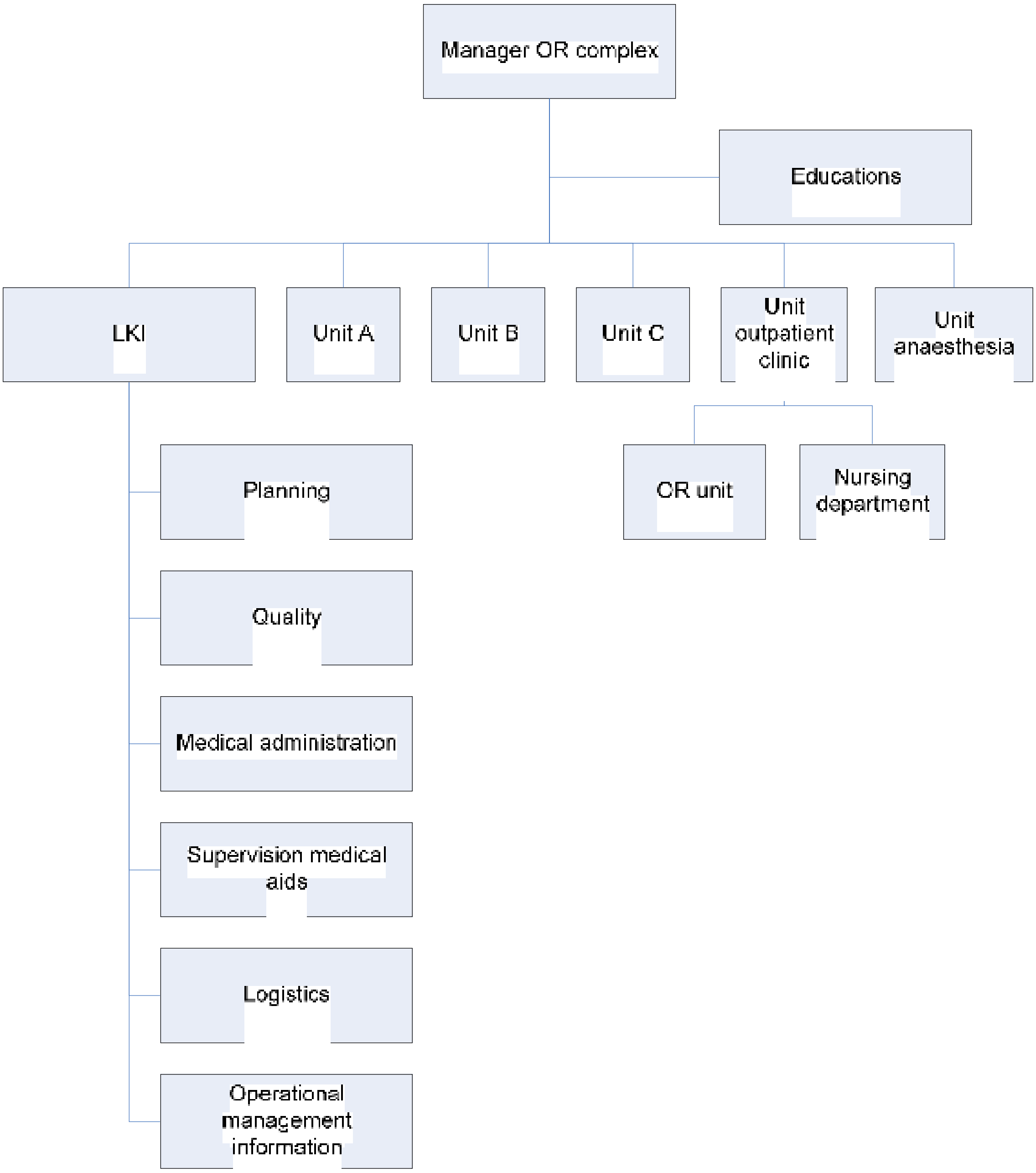
[24] Slack N., Chambers S. and Johnston R. (2004), *"Operations management",* Prentice Hall, fourth edition, 652-657.

APPENDIX A ORGANIZATIONAL CHART: AMC AND OT DEPARTMENT

AMC



OR complex:


Manager OR complex
Educations
LKI
Unit A
Unit B
Unit C
Unit outpatient clinic
Unit anaesthesia
OR unit
Nursing department
Planning
Quality
Medical administration
Supervision medical aids
Logistics
Operational management information

Appendix B SA ALGORITHM

The concept of SA in C.O. problems is independently described by S.Kirkpatrick, C.D. Gelatt and M.P. Vecchi in 1983 and by V.Cerny in 1985. The concept is based on a strong analogy between the physical annealing process of solids and the problem of solving large C.O. problems.

In condensed matter physics, annealing is known as the thermal process for obtaining low energy states of a solid in a heat bath. The process contains two steps:

1. Increase the temperature of the heat bath to a maximum value at which the solid melts;
2. Carefully decrease the temperature of the heat bath until the particles arrange themselves, randomly, in the ground state of the solid.

In the liquid phase all particles of the solid arrange themselves randomly. In the ground state the particles arrange in a highly structured lattice and the energy of the system is minimal. The ground state of the solid is obtained only if the maximum temperature is sufficiently high and the cooling is done sufficient slow. Otherwise the solid will be frozen into a meta-stable state rather than into the ground state.

In the SA algorithm each point in *S* of the search space is analogous to a state of some physical system, and the function *E(s)* to be minimised is analogous to the internal energy of the system state. The goal is to bring the system, from an arbitrary initial state, to a state with minimum possible energy.

The analogy between a physical many-particle system and a C.O. problem is:

- The solutions in a C.O. problem are equivalent to states of a physical system; a change in the state is reached by picking a neighbour solution randomly.
- The cost of a solution is equivalent to the energy of a state.

When the costs of the neighbour solution stay the same or are less than the current solution, than the switch is accepted. When the costs of the neighbour solution are more than the current solution, then the switch is accepted with a certain chance, dependant of the increase of the costs function and of the "temperature". The parameter which plays the role of the temperature is called the *control parameter*. The acceptance probability is defined as follows:

$$\mathbb{P}_c\{\text{ accept } j\} = \begin{cases} 1 & \text{if } f(j) \leq f(i) \\ \exp\left(\frac{f(i) \leq f(j)}{c}\right) & \text{if } f(j) \geq f(i) \end{cases}$$

Where $c \in \mathbb{R}^+$ denotes the control parameter.

Initially, at large values of the control parameter, large deteriorations will be accepted, as c decreases, only smaller deteriorations will be accepted, and finally, as the value of c approaches 0, no deteriorations will be accepted at all, which makes it at this time identical to some form of local search. The SA algorithm can therefore be viewed as a generalisation of local search.