The Net Optimization Problem

A Heuristic Approach

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Abstract

For every operation hospitals need surgical instruments. These instruments are usually grouped together in a special net. In a hospital there are different types of these nets, each net type has a different composition. The optimization of the net compositions and the inventory level of each net type is called the *Net Optimization Problem (NOP).* This paper will use a heuristic approach for the NOP. The heuristic will use an iterative process of making new net types, assigning net types to operations, calculating the costs and comparing the cost to the previous solution. To check the performance of the heuristic, the solution was compared to the solution of Glorie(2008)

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Content

1 Introduction

Everyday hospitals have to carry out different type of surgeries. This can range from removing an appendix to a complicated brain surgery. For the different types of operations surgeons need different types of instruments. In hospitals these instrument are grouped together in special nets. These nets can be used for one type of operations or even more. There is also the probability that a surgery needs more than one net type, otherwise it does not have the required instruments. After a surgery the nets have to be made sterile again and be made ready for another operation.

Of course these nets do not come free of cost. Every time a net is sterilized the hospitals have to pay sterilization costs. Also the instruments in the nets have certain costs, which have to be paid. For example the purchase cost of an instrument. Finally the hospitals also have to pay storage costs for the nets. Per year hospitals could save a lot of money by improving the sterilization cycle.

A way to improve the sterilization cycle is to optimize the net compositions and the inventory of these nets. Optimizing the inventory of these nets means determining how many of each net composition has to be held in inventory. This problem is called the *Net Optimization Problem (NOP).* This paper will use a heuristic approach to determine the net compositions and how many of each net should be held in inventory.

The NOP could be seen as a covering problem. Each operation has a certain demand of instrument types and these demands must be covered in order to have a feasible solution. To cover an operation demand several nets, containing the requested instrument types, have to be assigned to the operations. If an operation uses only a part of a net, the remaining part cannot be assigned to another operation on the same day. Once a net is opened the instruments are no longer sterile. The number of nets that are going to be used to cover an operation depends on the composition of each net. The total cost depends on the net compositions and the number of net compositions in inventory.

We hope that the developed heuristic can produce reasonably good solutions.

1.1 Paper overview

In section 2 an overview of other researches in hospital logistics is given and the research question is stated in section 3. In section 4 an explanation of the data will be given, what data is available to us. Section 5 will explain how our heuristic works and the results will be shown in section 6. In section 6 we will also compared our results with the results of Glorie(2008). Section 7 will contain our conclusion.

2 Literature

In 2007 there was a research done by Van de Klundert, Muls and Schadd(2007) in hospital logistic. The research was mainly about improving the sterilization cycle of hospitals. In their paper they suggested several methods to reduce sterilization cost. One of these methods is to optimize the net composition. Experiments of solving the ILP of the NOP indicated that the NOP is NP-hard.

In 2008 Glorie(2008) did a follow up research on the NOP. Glorie(2008) used column generation to find better net compositions to reduce the sterilization cost. With his algorithm Glorie(2008) has shown that he could easily solve small and medium size problems. Glorie(2008) could not guarantee that the solutions were also optimal, but has shown that the cost for hospitals can be reduced. Larger size problems were difficult to solve with his algorithm.

Because hospital logistics is a fairly new research area, there are not many articles about NOP available. There are other researches about hospital logistic. Lapierre and Ruiz(2007) presented a supply chain approach on the inventory of hospitals. They focused on the scheduling decisions instead of the multi-echelon inventory decisions. Scheduling decisions like, when to buy a product, when to replenish the shelves, when does each employee work and such. They developed two models, an inventory cost minimization and a balance schedule that divides the workload over the days. However they could also not guarantee optimality for their solutions.

Another research in hospital logistics was done by Little and Coughlan(2008). They used a constraint based model. This model optimizes the stock level for all products with regards to the available space, the frequency of delivery time of a product and the service level of a product. They had two objectives for their model. The first one was maximizing the minimum service level. The second one is maximizing the average service level. Their model was trialled in a hospital, but they stated that the model does not take unpredictable events into account, like emergencies where people need surgery right away.

There are models to improve hospital logistics, but there is still a lot that can be done to improve hospital logistics even further.

3 Research question

The purpose of this research is:

To construct instrument nets with the help of a heuristic and determine how much of each instrument net a hospital has to keep in inventory such that the demand within the planning period is met. The use of net types and keeping them in inventory come with certain costs. The hospital also wants these costs to be as low as possible.

To solve the NOP three sub-problems have to be solved:

- Which instrument nets have to be included?
- How many of each net is needed?
- What are the costs of using the instrument nets?

4 Data

The data consists out of five datasets. The number of operations and instrument differs for each dataset and is shown in the next table:

Dataset	Number of Operations	Number of Instruments
1	56	39
2	123	59
3	120	122
4	228	62
5	120	122

Table 1: Size of datasets

Further each dataset contains:

- A planning schedule of the operations, which contains:
    - On which day does an operation take place
    - Which instruments are needed and how many are needed
- The cost of an instrument
- The weight of an instrument
- The volume of an instrument
- The maximum allowed number of net types
- The maximum allowed weight of nets
- The maximum allowed volume of nets

Just like Glorie(2008) the transportation costs are not taken into account in the cost of an instrument. The instrument cost only consists of the storage cost of an instrument and its deprecation cost.

In the dataset the weight of an instrument or the volume of an instrument is not always defined, there is no value appointed to the weight or volume of an instrument. Because these values were not defined, we assumed that these values were zero or close to zero and therefore set them to zero.

A data piece that was missing was the sterilization time. The sterilization time, is the time needed to sterilize a net. For this research we assumed that the sterilization time is a day. This means that a net can only be used once a day, but hospitals can have more than one of net, with the same composition, in inventory.

5 Heuristic

The heuristic is based on the ILP of Glorie(2008) provided in Appendix A. The heuristic consists out of four steps. The first step is the initialization, also called step 0. In the initialization step a feasible starting point will be created. Step 1 is making combinations with pair of nets, which leads to new instrument nets. Step 2 is assigning nets to operations and determining how many of each instrument net is needed. The final step, step 3, is calculating the cost of the planning made in step two and updating the solution.

The heuristic will make use of an iterative process to make the best possible solution. The initialization step will only be done once and step 1 to 3 will be repeated. During each iteration a number of nets (this number has to be determined by the user himself) will be added to the initial solution, created in step 0, until no better solution can be found.

5.1 Initialization

In the initialization step a feasible solution will be created for the NOP. The most basic solution is to put every instrument in its own net. This means that if a hospital uses a hundred different types of instruments, there will also be a hundred different net types. Net types are instrument nets and each net type has a different composition from the others. For example the nets with the instruments *(a), (b)* and *(a,b)* are three different net types. The basic net types will be put together in a net set. A net set is a collection of net types.

Of this net set the total cost needs to be calculated. The total cost of a net set consists of the total instrument cost, the total storage cost and the total sterilization cost. The instrument costs are the depreciation cost plus the storage cost of an instrument. Note that the instrument costs could differ per instrument. A scalpel does not need to have the same costs as a needle. To calculate the total instrument cost for the net set, first the maximum number of each instrument over the planning period has to be determined. This can be determined by determining the maximum number of each instrument needed on a day and then taking the maximum over all days. Next multiply each instrument with its instrument cost and add them up.

The storage cost is the cost of holding one net in inventory. It is assumed that the storage cost for every net type is the same, so the size of a net does not matter. For the total instrument cost the maximum number of each net type for the starting net set was determined. The total number of nets in inventory is the sum of these values and the total storage cost is the total number of nets in inventory times the storage cost.

The sterilization cost is the price for sterilizing a net after usage. To calculate the total sterilization cost, the number of net usage has to be calculated. For each day the maximum number of each instrument was determined. Adding these numbers together and multiplying it with the sterilization cost gives the total sterilization cost.

With the total instrument cost, total storage cost and total sterilization cost determined, the total cost can be calculated by summing these three costs.

Now we will try to make a net set, whose total cost is lower than our current total cost. For creating new nets set, the current best net set will be used as base and thus this net set will called the base net set. For the first iteration this will be the net set, where each instrument has its own net type.

5.2 Step 1: Combining Net Types

Step 1 is making new net types and merging them separately with the base net set. Out of the base net set two net types will be picked and combined to form a new net type. Every pair of possible combinations of the base net set will made and will be tested against the following restrictions:

- The volume of a net cannot surpass the maximum allowed net volume
- The weight of a net has to be lower than the maximum weight of a net
- The number of net types cannot exceed the maximum allowed number of net types

If one of the first two restrictions is violated the combination of the two net types is invalid. If the third restriction is violated a penalty, in terms of costs, will be given for each net type that exceeds the maximum allowed number of net types. The penalty has to be high enough that the next iteration will always have lower costs and thus is always better. The approved combinations will be added individually to the base net set. Thus if there are n possible combinations, there will be n new net sets.

5.3 Step 2: Covering Operations

The second step is to determine which net types of a net set, constructed in step 1, are going to be used to cover the operations and how many of each net type is going to be used. However the number needed of each net type does not always have to be recalculated for all net types. For some net types the number of how many of a net type is needed can be taken from the base net set. This will be clarified with the following example.

In this example there are six instruments *a, b, c, d, e* and *f*. After three iterations the net types with the compositions: *(a,b)*, *(a,d)* and *(b,c)* are created. In the next iteration the net types with *(a,b)* and *(a,d)* are going to be combined to make a new net type with the composition: *(2a,b,d).* The number needed for each net type has only to be recalculated for the net types containing instruments *a, b, c* or *d*. The net types containing instruments *a, b* and *d* are directly influenced by the new combination. It could happen that by adding the new combination to the set, less of other net types are needed. The net types containing instrument *c* also have to be recalculated because the combination has an indirect influence on it. By adding the combination to the set, the combination *(b,c)* could no longer be needed and it is perhaps cheaper to use only *(c)*. The net types containing the instruments *e* and *f* do not have to be recalculated, because the combination does not have any effect on them.

5.3.1 Covering Percentage

To determine which net types are going to be used, the *Covering Percentage* of a net type will be used. The *Covering Percentage* of a net type can be calculated as followed:

$$Covering\ Percentage = \frac{Number\ of\ Instruments\ Covered\ By\ a\ Net}{Total\ Remaining\ Instrument\ Demand}$$

The *Number of Instruments Covered By a Net* is the sum of the maximum instrument cover per the day. For example, there is the following planning schedule:

Operation Number	Instrument Requirements	Day	Operation Number	Instrument Requirements	Day
1	3a,b	1	**6**	a,2c	2
2	3a,b	1	**7**	a,b,c	2
3	a,b,c	1	**8**	a,b,c	2
4	a,2c	2	**9**	c	3
5	a,2c	2	**10**	a,2c	3

Table 2: Planning schedule for Covering Percentage example

There are also two net types, net type 1 and net type 2. Net type 1 consists only of instrument *a* and net type 2 contains two times instrument *c*. Next the *Number of Instruments Covered By a Net* has to be calculated for both net types. For the *Number of Instruments Covered By a Net* the maximum instrument cover for each day needs to be calculated for each net type and add together. This is given in table 3.

Day	Maximum Instrument Cover Net Type 1 *(a)*	Maximum Instrument Cover Net Type 2 *(2c)*
1	1	1
2	1	2
3	1	2
Total	3	5

Table 3: Maximum instrument cover of net type 1 and 2 per day

The lower row in table 3 gives *the Number of Instrument Covered By a Net*. A net can be used multiple times during the planning period, but only once a day. It was assumed that the sterilization time of a net is one day. However if the planning period is one day, a net cannot be used multiple times during a planning period.

The *Total Remaining Instrument Demand* is the number of instruments that has not been covered yet. Thus the *Covering Percentage* is the percentage of the total remaining instrument demand that is fulfilled by a net type. The *Covering Percentage* of the two nets is:

Covering Percentage Net Type 1 *(a)*	Covering Percentage Net Type 2 *(2c)*
0.10	0.17

Table 4: Covering Percentage of net type 1 and 2

The *Covering Percentage* of net type 2 is higher than the *Covering Percentage* of net type 1, but this is actually quite logical. Net type 2 is a larger net type which means it can cover more instruments. If more instruments are covered the *Covering Percentage* goes up and only large net types will be chosen. This could have a negative effect on the cost, because two smaller net types could be cheaper than one large net.

5.3.2 Weighted Covering Percentage

To negate the effect that larger net will have a larger probability of being chosen a weight variable will be used. The weight will be defined as followed:

$$W = \frac{Number\ of\ Instruments\ Covered\ By\ a\ Net}{Total\ Possible\ Cover}$$

$$Total\ Possible\ Cover = Number\ of\ Instruments\ in\ Net * Number\ of\ Days\ a\ Net\ is\ Used$$

The *Weighted Covering Percentage* is given by:

$$Weighted\ Covering\ Percentage = \frac{Number\ of Instruments\ Covered\ By\ a\ Net}{Total\ Remaining\ Instrument\ Demand} * W$$

The *Number of Instruments Covered By a Net* is used as denominator for the weight, because otherwise smaller nets are more favorable. A large net types will usually also have a larger *Total Possible Cover*, which means if the *Number of Instruments Covered By a Net* is not put in the denominator the weight of larger nets could always be smaller than the weight of smaller nets. The *Weighted Covering Percentage* of the this example is given in table 5.

	Net Type 1 ***(a)***	**Net Type 2** ***(2c)***
Covering Percentage	0.10	0.17
Weight	1	0.83
Weighted Covering Percentage	0.10	0.14

Table 5: Weighted Covering Percentage

Judging from the *Weighted Covering Percentage* net type 2 will be picked over net type 1. Next the instrument demand of the operations which uses net type 2 has to be adapted. In this example the demand of operations 3, 4 and 10 has to be adjusted. These are the operations, where net type 2 can cover the most instruments. The new demand looks as followed:

Operation Number	**Instrument Requirements**	**Day**
3	a,b	1
4	a	2
10	a	3

Table 6: Adjusting demand

The demand is adjusted by removing the instruments, which are covered by the net type. In case of a tie, like on day 2 where operation 4 and 5 both have the same maximum cover for net type 2, the net will be assigned to first operation on the list. The first operation on the list is the operation with the lowest operation number (see table 2).

Repeat this procedure of calculating the *Weighted Covering Percentage* for every net type in a net set, picking the largest *Weighted Covering Percentage* and adjusting the demand, until all operations are covered. When all operations are covered, we know which net types of a net set are going to be used and also how many of a net type is going to be used. Step 2 has to be done for every net set made in step 1.

5.4 Step 3

The final step is to calculate the total cost for every net set and update the base net set. Now the total cost consists of the total instrument cost, total storage cost, total sterilization cost and the penalty cost of violating the maximum net type number. The calculation for the total instrument cost, total storage cost and total sterilization cost is almost the same as for the initialization. The difference is in the calculation of the number of each instrument needed, number of nets in inventory and the number of net usage is different than in the initialization step.

The number of an instrument needed is the sum of the number of that instrument in each net type times how many of that net type is needed. The number of nets in inventory is the sum of the number of each net type in a net set that is needed to cover all operations. In the step 2 the number of nets assign to each operation was determined. Adding these numbers together gives the number of net usage. The penalty cost is the number of net types that exceeds the limit times the penalty. As mentioned earlier the penalty has to be high enough to make sure that net types will be combined in the next iteration, which will result in lower costs.

5.4.1 Update Base Net Set

To update the base net set, the total costs of every net set is compared to each other. In the initialization step the number of net types that has to be added to the base net set, (say that number is equal to x) had to be determined. Out of all net sets, the top x net sets with the lowest total cost will be picked. From these net sets the net type that was added in step 1 will be taken, with other words the combinations that were merged with the base net set. These combinations will then be added together with the base net set and will be called the combination net set.

For the combination net set will also be determined which net types are going to be used and how many of them. Next the total cost of the combination net set will be calculated. The total cost of this combinations net set will be compared to the total cost of the base net set. If the total cost of the combination net set is lower than the total cost of the base net set, the combination net set will be taken as the new base net set. If this is not the case the current base net set is the best possible solution.

5.4.2 Removing Net Types

Removing net types from a net set only happens in case the total cost of the combinations net set is lower than the previous base net set. For example, the new base net set consists of the following net types:

Net types	Number Needed
(a)	1
(b)	0
(c)	3
(a,b)	0
(a,d)	2
(b,c)	0
(a,2b,c)	1

Table 7: Example removing net types

The second column represents the number of net types needed to cover the demand. In this example the net types with instruments *(a,b)* and *(b,c)* are deleted, because these net types are not needed. The net type with instrument *b* is not deleted. The net type with instrument *b* is the smallest net needed to make a combination with the instrument *b*. Without this net type, combinations for instrument *b* always require other instruments. The other instruments could be unnecessary and thus they add extra costs. It is necessary to delete net types, because for one the calculation time of the heuristic increases with every net type in a set. With more net types it means more possible combinations, which leads to more net set and for every net set step 2 and 3 has to be done. Second reason is that the number of net types may not exceed a certain limit. If nets are not deleted, the number of net types does not go down. For the smallest net types, the nets containing only one instrument look at how much of them is needed. If that number is zero, that net type must be excluded in the number of net types.

After the unused net types are deleted, the program should go back to step 1 until the total cost of the combination net set is higher than the total cost of the base net set.

5.5 Overview

Step 0 (Initialization): Create the net set in which every instrument has its own net type. Calculate the total cost of this net set if this net set is used to cover the operations demand. Use this net set as a base net set for the next steps.

While: Total cost can be lowered **Do**

> **Step 1:** Make every possible pair of net type combinations, the net types have to come out of the base net set. Check if every combination adheres to the given restrictions. Add the approved combinations separately to the base net set. Thus if there are n approved combinations, there will be n net sets.
>
> **Step 2:** Determine which net types of a net set is needed and how many of each net type is needed using the *Weighted Covering Percentage.* Do this for every net set created in step 1.
>
> **Step 3:** Calculate the total cost of each net set. Compare the cost the net set and pick the top x, where x is the number of net types that will be added to the base net set per iteration, net set with the lowest cost. Out of these x net sets pick the combination net types, the net types created in step 1, and add them together in the base net set. Determine for this net set which net types are going to be used and how many of each net type. Calculate the total cost and compare this to the cost of the base net set. If the cost is lower, use the current net set as the new base net set. Delete unused net types out of the new base net set.

End While

6 Results

The program was programmed in Matlab R2008a. A Intel® Core™2 Quad CPU Q6600 @2.40GHz was used to run the program.

With the first dataset the number of net types that is added to the base net set is determined. The number of net types that will be added after iteration will be determined by lowest total cost. The following five possibilities will be taken into account: 1, 10, 20, 30 or 40 combinations will be added to the set. For the first dataset the following results were obtained:

Number of net types added to the base net set	Total cost
1	39142
10	39753
20	38238
30	39640
40	39321

Table 8: The cost by adding 1, 10, 20, 30 and 40 to the base net set

We also notice that if more nets are added, the calculation time per iteration, so the calculation time for step 1 to 3, increase but the overall calculation time decreases. However if there are too many net types added at once the overall calculation time increases. As stated earlier as the number of net types in the base net set increases, more combinations are possible. For each possibility a net set has to be created and for every net set a planning has to be made and the total cost have to be calculated.

Next the program was checked with the example Glorie(2008) used.

Operation	Instrument requirement	Day		Operation	Instrument requirement	Day
1	c, e	1		11	$3a, 2c, 3d$	2
2	c, e	1		12	c, e	3
3	c, e	1		13	$2b, d$	3
4	$3a, 2c, 3d$	1		14	$2b, d$	4
5	$2b, d$	2		15	$2b, d$	4
6	$3a, 2c, 3d$	2		16	$2b, d$	4
7	$2b, d$	2		17	c, e	4
8	c, e	2		18	$2b, d$	5
9	$2b, d$	2		19	$3a, 2c, 3d$	5
10	$3a, 2c, 3d$	2		20	$2b, d$	5

Fig 1: Example from Glorie(2008)

Our Solution	Glorie(2008) Solution
651	646

Table 9: Results of the example of Glorie(2008)

Compared to Glorie(2008) solution, our solution is not better. However the difference between the solutions is 0.8 percent and this was found acceptable.

Now the program will be used to find the solutions for the given datasets. Because the calculation time of the program is too long, solution for dataset 3, dataset 4 and dataset 5 could not be calculated.

For the first dataset the total cost for the hospital was: 38238. The net compositions and the number needed of each net composition can be found in Appendix B. For the second dataset the total cost was: 79574. The total cost per iteration for both dataset can be found in Appendix C. These results are also put in a graph in figure 2 and figure 3 on the next page.

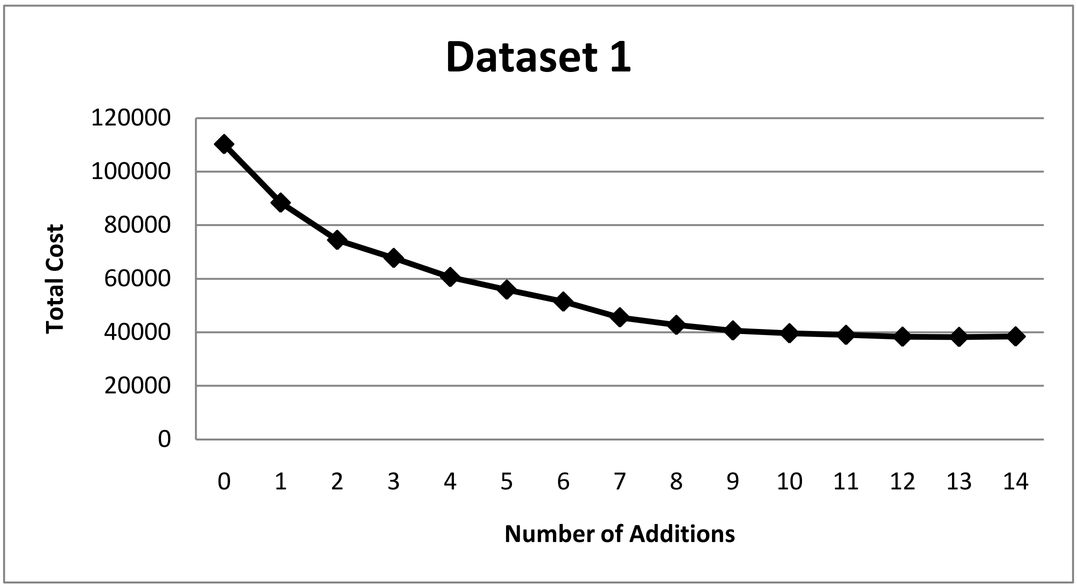

Fig 2: Results dataset 1

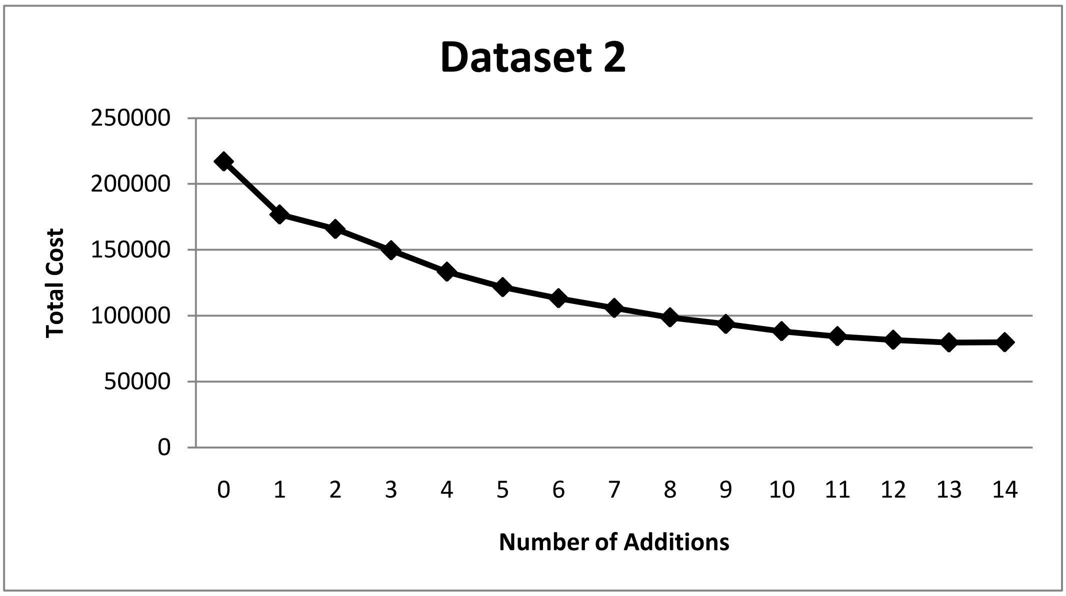

Fig 3: Results dataset 2

The *Number of Additions* is the number of times net sets are added to the base net set. One could also see this as the number of times steps 1 to 3 are repeated.

The following table will compare our results with results obtained by Glorie(2008).

	Our Solution	Glorie(2008) Solution	Difference in Percentage	Calculation Time	Number of Steps
Dataset 1	38238	36756	4%	01:35:41	558224
Dataset 2	79574	66991	18.9%	11:29:08	2566452

Table 10: Results from dataset 1 and 2

The *Number of Steps* is the number of combinations that is evaluated by the program. By looking at table 10 we can conclude that the total cost can be reduced even more.

By looking closer at the results the 4 percent difference in cost can be explained by the number of instrument the net set contains. Our solution uses 30 extra instruments. An extra instrument means extra cost. We also use one net extra, however the extra storage cost of this net is small compared to the extra costs generated by the extra instruments. The extra costs are mostly created by the extra instruments.

Dataset 1	Us	Glorie(2008)
Number of Nets	18	17
Number of Instruments	218	188

Table 11: Number of nets and Instrument of dataset 1 compared with Glorie(2008)

For dataset 2 the difference is larger namely 18.9 percent. Comparing the number of nets in inventory, our solution holds 22 more nets in inventory. Also the number of instruments that is used larger than that of Glorie(2008), to be exact in our solution there are 47 extra instruments. Both the extra nets as the extra instruments contribute to the difference in cost. But we also think it is safe to say that because more nets are used, the sterilization cost is also higher. All nets that is kept in inventory is used at least once, otherwise there is no reason to keep these nets. Thus an extra net also means extra sterilization cost.

Dataset 2	Us	Glorie(2008)
Number of Nets	67	45
Number of Instruments	399	352

Table 12: Number of nets and Instrument of dataset 2 compared with Glorie(2008)

7 Conclusion

The goal of this paper was to develop a heuristic method that would produce a reasonably good solution for the NOP. The heuristic consist of four steps. First the initialization where a basic solution is created. The second step is where new net types are created using two net types out of the base net set. In step 3 the net types of net set are assigned to the operations. In the final step the total cost for every net set is calculated and the solution is updated.

The heuristic could not fulfill his goal. The solutions the heuristic produce were in comparison with the solution of Glorie(2008) worse. The total cost of Glorie(2008) lies lower than our solution. Also the calculation time of the heuristic is too long. Due to this only the first two datasets could be solved, but the target was to solve all five datasets. The column generation heuristic of Glorie(2008) is better than our iterative heuristic.

The program still needs a lot of improvement. For starters the calculation time must be improved. A possible way to reduce the calculation time is to check if certain instruments are complementary with other instruments. For example when a patient needs to be stitch, the doctor needs a needle and a wire. If these two instruments are frequently used together it is perhaps better to start with a net that contains both these two instruments instead of having these two instruments in separate nets. By combining frequently used instruments together, there are fewer base net types, which results in less combination possibilities, which reduce the calculating time.

The weight to solve the NCP could also be research. The current weight adds nets to set based on how much a net can cover. But perhaps a better weight is to choose the nets on the number of usage.

Also the number of net types added to a set could be looked. In this paper we add 20 net types. However this number is only based on the first dataset, because this one had the smallest calculation time. For other dataset it could be possible that if more than 20 net types, the total cost is lower.

An extension for this heuristic could be to add emergency operations. In reality operation are not always planned. For example, when major accident happens and a person needs to be operated immediately. That person does not have to wait be schedule, but will be operated on right away. For these emergency operations hospitals also have to have enough equipment available.

Hopefully these ideas could help improve the program.

8 References

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9 Appendix

9.1 Appendix A

Sets

$T = days\ in\ the\ planning\ period$
$I = instrument\ types$
$J = operations$
$J^t = operations\ executed\ on\ day\ t$
$K = net\ types$
$L = net$

Decision variables

$Y_{jk} = the\ number\ of\ nets\ of\ type\ k\ used\ for\ operation\ j, j \in J, k \in K$
$$Z_{kl} = \begin{cases} 1\ if\ net\ l\ is\ of\ type\ k, k \in K, l \in L \\ 0\ otherwise \end{cases}$$
$$Z_k = \begin{cases} 1\ if\ net\ type\ k\ is\ used, k \in K \\ 0\ otherwise \end{cases}$$

Parameters

$w_{ik} = the\ number\ of\ instruments\ of\ type\ i\ contained\ in\ a\ net\ of\ type\ k, i \in I, k \in K$
$d_{ij} = the\ number\ of\ instruments\ of\ type\ i\ needed\ for\ operation\ j, i \in I, j \in J$
$a_i = the\ fixed\ periodic\ cost\ of\ instruments\ of\ type\ i, i \in I$
$c_1 = the\ fixed\ periodic\ net\ related\ cost$
$c_2 = the\ sterilization\ cost\ per\ net$
$r_k = the\ maximum\ allowable\ number\ of\ different\ net\ types$

Model

$$min \sum_{i \in I} \sum_{k \in K} \sum_{l \in L} a_i w_{ik} Z_{kl} + \sum_{k \in K} \sum_{l \in L} c_1 Z_{kl} + \sum_{j \in J} \sum_{k \in K} c_2 Y_{jk}$$

$$\sum_{k \in K} Y_{jk} w_{ik} \geq d_{ij} \quad \forall (i \in I, j \in J)$$

$$\sum_{j \in J^t} Y_{jk} \leq \sum_{l \in L} Z_{kl} \quad \forall (t \in T, k \in K)$$

$$\sum_{k \in K} Z_k \leq r_k$$

$$Z_{kl} \leq Z_k \quad \forall (k \in K, l \in L)$$

$$\sum_{k \in K} Z_{kl} \leq 1 \quad \forall (l \in L)$$

$$Y_{jk} \in \mathbb{N} \quad \forall (j \in J, k \in K)$$

$$Z_{kl}, Z_k \in \{0,1\} \quad \forall (k \in K, l \in L)$$

9.2 Appendix B

Instrument Number	Net types																	
1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	4	0	0	1
2	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	3	0
3	0	0	0	0	0	2	0	0	0	0	0	0	1	2	0	0	0	0
4	0	0	0	4	0	8	0	0	0	0	2	0	0	8	0	0	0	0
5	0	0	0	8	0	0	0	0	0	4	0	0	0	4	0	0	1	0
6	0	0	0	3	2	0	0	0	0	0	1	0	0	3	0	0	4	0
7	0	0	0	4	2	1	0	0	0	0	0	0	0	3	0	0	2	0
8	0	0	0	0	0	0	0	1	2	0	0	3	0	0	0	0	0	0
9	1	0	0	2	0	2	0	0	0	1	0	0	2	2	0	1	0	0
11	0	0	0	2	0	0	0	0	0	1	0	0	0	1	0	0	0	0
12	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	1	0	0	0	0	0	0	0	4	0	0	0
15	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
19	0	0	0	0	0	0	0	0	2	0	0	2	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
21	0	1	0	4	0	0	0	0	0	2	0	0	0	3	0	0	0	0
23	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	1
24	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	2	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
32	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0	1	0	0	2	0	2	3	0	0

34	0	0	0	0	0	0	0	2	0	0	0	2	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0
36	0	0	0	0	0	4	0	0	0	0	0	0	0	4	0	0	0	0
38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
44	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	2
45	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
55	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0
57	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
68	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0
73	0	0	0	0	0	6	0	0	0	0	0	0	0	6	0	0	0	0
74	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0
78	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
80	0	0	0	0	0	5	0	0	0	0	0	0	0	5	0	0	0	0
82	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0
98	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0
Number of Nets Needed	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

9.3 Appendix C

Dataset 1

Iteration number	Total Cost
0	110203
1	88363
2	74446
3	67719
4	60602
5	55897
6	51436
7	45564
8	42744
9	40664
10	39624
11	39008
12	38338
13	38238
14	38445

Dataset 2

Iteration number	Total Cost
0	217114
1	176771
2	165762
3	149598
4	133314
5	121584
6	113177
7	105757
8	98646
9	93615
10	88154
11	84349
12	81612
13	79574
14	79766