Master thesis

Work Distribution of a Heterogeneous Library Staff - A Personnel Task Scheduling Problem

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LiTH - MAT - EX - - 04 / 04 - - SE

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Exam work: **30 hp**

Level: **A**

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Linköping: **June 2016**

Abstract

Here is where you can write your abstract. It may be very long, or it may be very short, the reason you have an abstract is for people not to be forced to read lots of crap.

But still, they will have to read your abstract. After all, the abstract is what everyone reads...

Keywords: Keyword One, Chemostat, Another Key-Word, Key, Clé, Mot de cle, Nyckelhål, XBOX, Dagens viktigaste nyckelord, and Keywords.

URL for electronic version:

http://urn.kb.se/resolve?urn=urn:nbn:se:liu:diva-77777

Acknowledgements

I would like to thank my supervisor, I would like to thank my supervisor, I would like to thank my supervisor, I would like to thank my supervisor...

I also have to thank, I would like to thank my supervisor, I would like to thank my supervisor, I would like to thank my supervisor, I would like to thank my supervisor...

My opponent NN also deserves my thanks, I would like to thank my supervisor, I would like to thank my supervisor, I would like to thank my supervisor...

Nomenclature

Most of the reoccurring definitions, symbols and abbreviations are described here.

Definitions

Plocklista	Text
Library on wheels	Text

Symbols

Y_0	The amount of the variable Y inserted into a system.
$\hat{Y}$	The unit-dimension of the variable Y, for example $\hat{t} = 1s$.
$\bar{Y}_i$	A steady state (number i) value of Y.
K_i	Constants used in kinetic expressions, for example K_I.
$\mathbf{A}$	The system matrix.

Abbreviations

Exp	Text
Info	Text
PL	Text
PTSP	Text
SMPTSP	Text
CPI	Competitive Product Inhibition (or Inhibited)
CSI	Competitive Substrate Inhibition (or Inhibited)
CSTR	Continuous Stirred Tank (bio)Reactor
MMI	Michaelis-Menten Inhibition (or Inhibited)

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Chapter 1

Introduction

1.1 Background

At a library absence can cause problems, both due to lack of personnel as well as due to the qualifications required to perform a task varies. If a worker were to be unavailable a day because of a meeting or being ill it would require for a stand-in to fill the vacancy. Therefore, it is of great interest to have a schedule with as many skilled stand-ins as possible to overcome such disturbances. Furthermore, the library personnel have certain demands and preferences as to how a satisfactory working schedule should be. For instance, it is neither preferable to work more than one evening each week nor work more weekends than required.

1.2 Problem description

1.2.1 Main objectives

Main objective is to create a schedule with as many stand-ins as possible, so that all days have a maximum amount of stand-ins. Diversity during the week and repetivity of the schedule each week is also desired.

1.2.2 Requirements on weekday activities

During weekdays, there is a worker demand at the stations Exp, Info, Plocklista and Library on wheels. ¡TABLE OF DEMAND¿. Plocklista is unique in the sense that its duration is longer than one shift. It is modeled as the three first shifts of a weekday.

In addition there is the Library on wheels, which has a different demand of workers depending on odd and even weeks.

1.2.3 Requirements on weekend activities

There are three different weekend stations: Exp, Info and Hageby. Working a weekend also means working friday unless you are scheduled to work in Hageby.

1.2.4 Diversity in skill

There are essentially two types of workers in a library. Librarians and assistants. The competence of the workers looks as follows: ¡TABLE OF DIFFERENT COMPETENCES¿

A subset of the librarians can handle the Library on wheels and all are expected to take shifts at Hageby.

1.2.5 Personnel availability and task assignment limitations

The staff at the library have certain times of availability. Every day, a person can perform at maximum one task. Plocklistan is limited to once a week.

Personnel is only allowed to work one weekend out of five. The following week, the worker is free on the times requested by the worker. Also, some workers have specific

1.2.6 Inner work

The goal of this thesis is to distribute given tasks to the heterogeneous workforce at the library of Norrköping. Each task is either classified as an outer or an inner service where an outer service is when a librarian needs to interact with visitors. Inner services can in some rare cases require a predetermined person to be assigned to a specified time or day.

Demands and requests are to be fulfilled to the furthest extent possible. Weekends are included in the scheduling problem, which adds more constraints regarding the number of contiguous working days. However, the librarians are permitted a few exceptions from these laws regarding days of rest.

The main purpose of the thesis is to create a schedule robust enough to withstand absence, such that outer services always are assigned to a qualified and available worker. This is visualized as having a list of available stand-ins for each shift.

There are a limited number of workers at the library and they make the resources that are to be distributed. Each individual has a set of *skills* and *competences*. Competences refer to the capability of being assigned the different outer services; Expedition, Norpan, Information desk, Library on wheels and Hageby as well as different inner services. The set of skills an individual can possess are described in Table 1.1. In total there are 39 workers available.

The outer services can be seen as assignments which requires available workers to be assigned to them. Each outer service is specified to a certain station, time and date. They also have a fix length and occur on a regular basis every ten weeks, which makes it possible to create a periodic schedule with a period of ten weeks.

Furthermore, outer and a few inner services can be characterized by different properties, which are represented in Table 1.2.

In addition to the properties mentioned above, there are several requirements that have to be met. These can be divided into job, robust and other requirements and are listed in Table 1.3 below.

Table 1.1: Personnel

Skills	**Description**
Work degree	0-100 %
Type of employment	Librarian/Assistant
Competence	Inner and outer services the worker is qualified for
Weekly rest	Which days the worker has requested after working a weekend
Other requests	Does not work evenings etc.

Table 1.2: Outer and inner services

Outer service	**Property**
	Start time, end time, week and duration
	Station
	Number of qualified librarians demanded
	Number of qualified assistants demanded
Inner service	**Property**
	Start time, end time, week and duration
	Type
	Number of qualified librarians demanded
	Number of qualified assistants demanded

Table 1.3: Requirements

Job requirements	**Description**
1	A maximum of one outer service is to be distributed to each person and day.
2	Remaining work time is individually distributed on assignments such as reshelving bo
3	Weekend work are to be evenly distributed between the workers available on weekend
4	Working a weekend includes work on saturday and sunday the same week.
5	One evening shift on a weekday per person each week except when weekend work is r
6	Every ten weeks the schedule is to be repeated.
7	It is recommended for each week to be as similar as possible.
Robust requirements	**Description**
1	Each outer service require at least one stand-in.
2	The stand-ins have to be qualified for the tasks they are stand-in for.
3	Focus is to maximize the lowest number of stand-ins of any task.
Other requirements	**Description**
1	Department and general meetings are to be held once per five weeks.

There are also additional requirements of the resulting schedule made by the workers at the library. Two examples would be that a handful staff members are unable to work weekends as well as some personnel are unable to work in the evenings.

1.3 Problem categorization

The problem can be formulated as a personnel tasks scheduling problem for a heterogeneous workforce since the main objective is to distribute tasks to workers during their available times. The workforce is heterogeneous as certain tasks can only be performed by librarians or is restricted to a certain subset of the personnel. Another aspect of the problem is the cyclic nature of the personnel schedules, which gives a degree of freedom in availability of personnel.

Chapter 2

Literature review

Emelie

The scheduling problem has been studied since the 1950's as a mathematical optimization problem and involves creating a feasible and satisfactory schedule for either workers or machines performing tasks. According to Ernst et al. the complexity of the scheduling problem has not in itself become more advanced with time. However, the mathematical models used to solve the scheduling problems have become more realistic and refined. This together with more powerful computational methods, makes it possible today to solve scheduling problems in a more satisfactory way, taking into account softer values such as worker satisfaction and worker fatigue [1].

In the paper [1] the scheduling problem is classified into different subcategories. A few relevant areas for our work include task based demand scheduling, days off scheduling, shift scheduling, tour scheduling and task assignment.

Task based demand scheduling involves the process of distributing a fixed number of tasks which need to be performed over a workforce. The workforce can either be fixed, as in our case, or subject to minimization in the objective function.

Days off scheduling involves scheduling staff and assigning a days off as required by work time regulations. This problem is often found together with shift scheduling which involves choosing the most suitable shifts for a workforce. The combination of the two is called tour scheduling and will be discussed later in this report. The big difference between our problem and tour scheduling is that in our problem we are not allowed to choose the free days of the workers, only in what week to assign them, and there is no shift work.

The problem which is most similar to our problem is, however, task assignment. This problem and different variations of it will be discussed in section 2.1.

2.1 Tour Scheduling Problem with a heterogenous work force

Emelie

The Tour Scheduling Problem (TSP) involves creating work shifts with days off for a work force. According to Loucks and Jacobs, the vast majority of all tour scheduling problems up to 1991 were with a homogeneous workforce, that is under the assumption that any worker could perform any assigned task [2]. The authors discuss a tour scheduling problem where the objective is to construct weekly schedules for each worker which also show the specific task assignments. The problem is studied in the context of fast food restaurants, where certain personnel is qualified only for certain stations in the restaurant. In such industries, the demand of staff differs between different weekdays and different times of the day. Two things differ between workers, their availability for work and their qualification. Furthermore, the workers working times are not fixed, but are composed of a number of consecutive tasks assigned during a block of time during a day.

The representative problem studied in the article involves creating a one-week schedule for 40 workers in a fast food restaurant, available for eight different tasks with a seven-day, 128-hour workweek. Several synthetic problems are studied in the article, all, however with minimum shift lenght three hours, maximum shift length eight hours and five maximum number of work days.

A similar problem to the one descibed by Loucks and Jacobs is studied by [3]. The article focuses on a particular fast food restaurant in Korea, which is made a representative of fast food chains in general. One big difference between this study and the previous one is the identification of part-time and full-time workers, between which the ratio of scheduled personnel should always be 6:4. Although a tour is scheduled also in this problem, the properties of the tour is different from Louck and Jacobs as the shifts are already divided into periods 8:00-12:00, 12:00-14:00, 14:00-21:00 and 21:00-23:00 while the latter schedules on an hourly basis. Further, a tour is defined as working five consecutive days, as opposed to the previous article. The task assignment dimension is lacking in this article, making it less similar to the problem described in this report.

In both articles the main objective is to minimize overstaffing and understaffing, which will both have severe consequences for the fast food chain. This is not relevant to our problem as we have a fixed work force. In the example studied by Loucks and Jacobs there is also a goal to meet staff demand on total working hours. This is modeled as a secondary goal and is similar to our goal of creating even and fair schedules.

The greatest difference between the problem studied by Loucks and Jacobs and our problem is the composition of shifts. Both problems have heterogeneous worker qualification and availability and both deal with task assignment for schedules with a fluctuating worker demand. Since our problem only concerns librarians and assistants, there are fewer skill groups. Compared to the problem studied by [3], there is more similarity in the shift design as the library also has four different shifts. However, our problem is a task asssignment problem and does not affect working times.

In some cases, a problem can be a combined tour scheduling and task assignment problem or can be divided into these two solution stages, as is the case in [**?**]. "An integer linear programming-based heuristic for scheduling heterogeneous, part-time service employees" , 2011

2.2 Personnel Task Scheduling Problem

Claes

In many practical instances production managers will face the Personnel Task Scheduling Problem (PTSP) while scheduling plant operations. It occurs when the rosterer or shift supervisor need to allocate tasks with specified start and end times to available personnel who have the required qualifications. Furthermore, it also occurs in situations where tasks of fixed times have been assigned to machines. Decisions will then have to be made regarding the amount of maintenance workers needed and which machine the workers are assigned to. [4]

There are several variants to the PTSP. These have been studied in an article by [4] who gives a list of attributes that commonly appear in a PTSP and are listed in Table 2.1 below. There are furthermore traits that always appear in a PTSP; tasks with fixed start and end time are to be distributed to staff members that possesses certain skills, allowing them to perform a subset of the available tasks. The start and end time of their shifts are also predetermined for each day.

One variant, which also is the most simple, is mentioned in [4] and is called the *Feasibility Problem* where the aim is to just find a feasible solution. This requires that each task is allocated to a qualified and available worker. It is also required that a worker can not be assigned more than one task simultaneously as well as tasks can not be pre-empted, meaning that each task has to be completed by one and the same worker.

In Table 2.1 one can see attributes of PTSP variants. The nomenclature of the attributes T, S, Q, O refer to the *Task type*, *Shift type*, *Qualifications* and *Objective function* respectively.

Table 2.1: PTSP variants

Attribute	**Type**	**Explanation**
T	F	Fixed contiguous tasks
	V	Variable task durations
	S	Split (non-contiguous) tasks
	C	Changeover times between consecutive tasks
S	F	Fixed, given shift lengths
	I	Identical shifts which are effectively of infinite duration
	D	Maximum duration without given start or end times
	U	Unlimited number of shifts of each type available
Q	I	Identical qualification for all staff (homogeneous workforce)
	H	Heterogeneous workforce
O	F	No objective, just find a feasible schedule
	A	Minimise assignment cost
	T	Worktime costs including overtime
	W	Minimise number of workers
	U	Minimise unallocated tasks

With this definition of PTSP attributes many of the most basic problems and a few more complex ones can be described. It is, however, not possible to describe all of the numerous types of PTSP using these nomenclatures.

By combining attributes it is possible to obtain more complex variants of the PTSP. An example would be the PTSP[F;F;H;A-T-W] mentioned in [4] where multiple objectives are used. This problem has fixed contiguous tasks, fixed shift lengths, heterogeneous workforce and three objective functions; assigment costs, work time with overtime included and requirements to minimize the number of workers respectively. This objective function is then a linear combination with different parameters used to prioritize them against each other.

Our problem would be most related to the PTSP[F;F;H;F]. The difference is the objective function, since we are looking to maximize the number of qualified stand-ins each day as well as maximize employee satisfaction by meeting their recommendations. This can not be described with the type of attributes given in Table 2.1 above because we have no costs, a fix number of workers and no unallocated tasks when a feasible solution is found.

Different variants of PTSP are given names in the literature. One example is when the shifts and qualifications are identical (S=I and Q=I) and the objective function is to minimize the number of workers that are used (O=W). This variant, PTSP[F;I;I;W], has been published as the *"fixed job schedule problem"* and is described in Section 2.5 below [4].

2.2.1 Applications

This type of problem can be found when developing a rostering solution for ground personnel at an airport. Such a problem can be dealt with by first assigning workers to days to satisfy all the labour constraints, followed by assigning the tasks to the scheduled workers.

Similar problems of type PTSP related to airplanes can also be found when scheduling for either airport mainteance staff (leading to either PTSP[F;I;H;U-A] or PTSP[F;I-U;H;W]), staff that do not stay in one location, such as airline stewards, or planes to gates.

Another application, which has been frequently studied, can be found in classroom assignments. Based on demands such as the amount of students in a class or the duration of the class, different classrooms have to be considered. Requirements of certain equipment, e.g. for a laboratory, may also greatly limit the available rooms to choose from.

For classroom assignment there are no start or end times for the shifts, as they represent the rooms. The aim would be to find a feasible assignment of classrooms and therefore the type of problem would be PTSP[S;I;H;F] with the possibility of adding preferences to the objective function. An example of a preference would be to assign the lessons as close to each other as possible on a day, preventing travel distances between classes for teachers and students.

2.3 Shift Minimisation Personnel Task Scheduling Problem

Claes

A close relative to the PTSP is the Shift Minimisation Personnel Task Scheduling Problem (SMPTSP) and is a special case in which the aim is to minimize the cost occuring due to the number of personnel (shifts) that are used. The same traits are valid in this problem as in the PTSP; workers with fixed work hours are to be assigned tasks, with specified start and end times, that they are qualified for.

In article [5] they "... concentrate mainly on a variant of the PTSP in which the number of personnel (shifts) required is to be minimised.". In doing so, it is possible to determine the lowest number and mix of staff a company should have to complete the tasks at hand and still be operational. They also presumed that the pool of workers are unlimited for either skill group, which is not the case in our problem due to the limitations on the number of librarians and assistants.

When there are a large number of workers available with qualifications to perform different tasks and it is needed to ensure all tasks for that day are performed SMPTSP can be applied. The PTSP and SMPTSP are therefore useful day-to-day management tools that commonly occurs in many practical instances where tasks are allocated on a daily basis.

SMPTSP is almost identical to another problem introduced by Kroon et al. [6] which is called the Tactical Fixed Interval Scheduling Problem (TFISP) and is described in Section

It is shown in [6] that SMPTSP is a complex problem even if the constraint regarding preemption were to be removed. However, if the qualifications of the workers were identical it would become an easily solvable problem [5].

2.4 Work load allocation and worker satisfaction

Emelie

Trötthet och utttråkad. Något vi borde ta med i litteraturen enligt Torbjörn, fast inte leta källor på det.

Source: "Employee positioning and workload allocation", Eiselt, Marianov, 2006 "Scheduling part-time and mixed-skilled workers to maximize employee satisfaction" Mohammad Akbari 2012

"Scheduling part-time personnel with availability restrictions and preferences to maximize employee satisfaction" Srimathy Mohan 2008

2.5 Fixed/flexible job scheduling problem (FJSP)

Maybe...

Identical skill of the workers/machines and indentical skill requirements of the operations to execute.

Problem defined in: "Algorithms for large scale Shift Minimisation Personnel Task Scheduling Problems" M. Krishnamoorthy http://www.sciencedirect.com/science/article/pii/S0377221711010

Problem: "A metaheuristic for the fixed job scheduling problem under spread time constraints" André Rossi, http://www.sciencedirect.com/science/article/pii/S0305054809002251 (Fixed job)

Cemal Özgüven http://www.sciencedirect.com/science/article/pii/S0307904X11004173 (Flexible job) Processors with a ready time, due date etc. (??)

2.6 Methods

2.6.1 TSP with inhom workforce

Solution methods to compare (similar problems):

"Task assignment and tour scheduling": Loucks and Jacobs, 1991

"Scheduling Restaurant Workers to Minimize Labor Cost and Meet Service Standards" Choi, Hwang and Park, 2009

"An integer linear programming-based heuristic for scheduling heterogeneous, part-time service employees" Heterogenous work force, tour scheduling. Using two objective functions Hojati and Patil, 2010

for another definition as PTSP[F;I;I;W], see "The Personnel Task Scheduling Problem" by Krishnamoorty and Ernst, 2001

Chapter 3

Implementation insights

Chapter 4

The ideal CSTR: the chemostat

In this chapter we study exponential growth, the logistic. . . .

4.1 Some simple models of biological growth

4.1.1 Exponential growth

If $\mu = \text{constant} > 0$, we get $X(t) = X_0 e^{\mu t}$.

4.1.2 The logistic equation

Let us assume that $\frac{dX}{dt} = \mu \cdot X$, with $\mu = \mu(S) = k \cdot S \ldots$

$$\begin{cases} \frac{dX}{dt} = kSX & (a) \\ \frac{dS}{dt} = -\alpha kSX & (b) \end{cases}$$

$$\frac{dX}{dt} = r(1 - \frac{X}{B})X \tag{4.1}$$

An explicit solution to (4.1) is: $X(t) = \frac{X_0 B}{X_0 + (B - X_0)e^{-rt}}$, if $0 < X_0 < B$. It can be found by separating variables in equation (4.1)

4.2 The chemostat

A chemostat is made of two main parts; a nutrient reservoir, and a growth-chamber, reactor, in which the bacteria reproduces.

$$\begin{cases} \frac{dX}{dt} = \mu(S)X \overbrace{-X\frac{F}{V}}^{\text{new}} \\ \frac{dS}{dt} = -\alpha\mu(S)X \underbrace{-S\frac{F}{V} + S_0\frac{F}{V}}_{\text{new}} \end{cases} \tag{4.2}$$

$$\mathbf{A} = \begin{pmatrix} 0 & \sigma\alpha_1 \\ -\frac{1}{\alpha_1} & -\sigma - 1 \end{pmatrix}$$

The invariant line: conclusions

Model	Monods Chemostat	CSI-CSTR
μ	$\frac{S}{1+S}$	$\frac{S}{1+S+\frac{S^2}{K_I}}$
$\frac{dX}{dt}$	$\alpha_1 \frac{S}{1+S} X - X$	$\alpha_1 \frac{S}{1+S+\frac{S^2}{K_I}} X - X$
$\frac{dS}{dt}$	$-\frac{S}{1+S} X - S + \alpha_2$	$-\frac{S}{1+S+\frac{S^2}{K_I}} X - S + \alpha_2$
XNC	$S = \frac{1}{\alpha_1 - 1}$	$S = \frac{K_I(\alpha_1-1)}{2} \pm \sqrt{(\frac{K_I(\alpha_1-1)}{2})^2 - K_I}$
SNC	$X = \frac{(\alpha_2 - S)(1+S)}{S}$	$X = \frac{(\alpha_2 - S)(1+S+\frac{S^2}{K_I})}{S}$
limit	–	$K_I \to \infty$

The other three models, the chemostat, the MMI-CSTR and the CPI-CSTR are quite similar in comparison to the CSI-CSTR.

Monods chemostat does not “feel” this inhibition and does not care...

This document is an example of BibTeX using in bibliography management. Three items are cited: *The LaTeX Companion* book [7], the Einstein journal paper [8], and the Donald Knuth's website [9]. The LaTeX related items are [7, 9].

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Appendix A

The Linearized stability

A.1 The Linearization

$F(x)$, a one-variable function of x can be Taylor-expanded around a fix X. We get $F(X+x) = F(X) + F'(X)x + O(x^2)$. For small perturbations of x around X we get the linearization: $F(X+x) \approx F(X) + F'(X)x$, containing only the constant and the linear terms.

For functions of two variables $F(X+x, S+s)$ and $G(X+x, S+s)$:

$$\begin{cases} F(X+x, S+s) = F(X,S) + F'_X(X,S)x + F'_S(X,S)s + O((x+s)^2) \\ G(X+x, S+s) = G(X,S) + G'_X(X,S)x + G'_S(X,S)s + O((x+s)^2) \end{cases}$$

```
function chemostat_inhibited(alpha1, alpha2, xp0, sp0, xc)
%
%chemostat_inhibited Displays a phaseportrait, nullclines
%   and an Euler-path of an inhibited Chemostat.
%   chemostat_inhibited(alfa1, alfa2, np0, cp0, nc) will run if
%   alpha1 > 1/xc, thus there is a reproduction.
%   alpha2 > 1/(xc*alpha1-1), thus there is sufficient stock-nutrition.
%   xp0 > 0 , you can not have a nonpositive population.
%   sp0 > 0 , you can not have a nonpositive concentration.
%   xc  > 0
%
%   The blue arrows represent the vectorfield.
%   The black lines are two of the three nullclines.
%   The black dotted line is the invariant line (no solution crosses it).
%   The red line is an Eulerpath, starting in + and ending in *.
%
%   Try the following:
%   chemostat_inhibited(5, 3, 0.2, 0.3, 6)
%
%   by Per Erik Strandberg, 2003-2004.
%

% Start-condition:
%------------------
if ((alpha1>1) & (alpha2>0) & (sp0>0) & (xp0>0) & xc>0),

    if (alpha2<1/(alpha1-1)),
        disp(' ')
        disp (' (HINT: Only the trivial steady state, alpha2 is too small...)')
    else
        disp(' ')
        disp (' (HINT: Two steady states, alpha2 is quite large...)')
    end
```

```
% The illegal indata case:
%---------------------------
else
    disp('   chemostat_inhibited.m by Per Erik Strandberg, 2003-2004.')
    disp('   Did not Finish OK. (You used illegal indata.)')
    disp(' ')
    disp('   For syntax help type: help chemostat_inhibited .')
    disp(' ')
end
```