OPTIMIZED SCHEDULING OF ACADEMIC TIMETABLES:

A MATHEMATICAL APPROACH

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Degree of Master of Science

Department of Mathematics

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Sri Lanka

December 2016

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by

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Dissertation Submitted in Partial Fulfillment of the Requirement of Master of Science Degree in Financial Mathematics

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December 2016

DECLARATION OF THE CANDIDATE

I declare that this is my own work and this dissertation does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

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(M. T. M. Perera) Date:

(138904 R)

DECLARATION OF THE SUPERVISOR

I hereby recommend that I have supervised the above candidate an accepted this as the dissertation for the master in science degree in Financial Mathematics.

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DEDICATION

I dedicate this to my father and mother, for their unconditional support with my studies and the guidance and encouragement through all my walks of life.

ACKNOWLEDGEMENTS

First and foremost, I would like to express my sincere gratitude to my supervisor Dr. G. H. J. Lanel for the continuous support of my M.Sc. research, for his patience, motivation and immense knowledge. His guidance helped me in all the time of research and writing of this dissertation.

Besides my supervisor, I would like to thank Mr. T. M. J. A. Cooray the second supervisor and the coordinator of the M.Sc. program, for his encouragement and insightful comments.

My sincere thanks also goes to all academic staff at the department of Mathematics, University of Moratuwa for their continuous support of my M.Sc. studies and sharing the knowledge, and also I must be thankful to all the academic staff at the department of Mathematics, University of Sri Jayewardenepura which is my working place, for their encouragement and support throughout these three years.

I must be thankful to the management staff in the faculty record room for providing me the necessary data without any hesitation.

I thank my friends in 2013 batch of M.Sc. program in Financial Mathematics for the stimulating discussions, for and for all the fun we have had in the last two years.

Last but not the least, I would like to thank my family: my parents for giving birth to me at the first place and supporting me spiritually throughout my life.

M. T. M. Perera

ABSTRACT

Timetabling problem is a well-known problem commonly addressed by the researches over the decades using different techniques. With the advancement of the technology, the research direction has been narrowed to automate timetabling. Graph theoretic approach, linear programming, neural networks and artificial intelligence techniques have been used in literature.

This study focuses on university course timetabling problem, which intends to model the semester timetable of the Faculty of Applied Sciences at University of Sri Jayewardenepura, which currently does not possess an automated timetabling system.

It has been used an Integer Linear Programming model which attempts to assign group of course units to a time period where each group is a result of a graph coloring approach. A greedy algorithm has been used to color the vertices of the graph by the use of mathematical software. The variables in the model have defined to be binary integer variables. Branch and bound method has been used as the solution technique for the integer linear program. With the large number of variables and constraints the solution technique required large number of iterations. Hence a mathematical software has been used to implement the branch and bound method. Limited number of lecture halls, large number of subject combinations and growing number of student registration have made the problem very tight which results thousands of variables and constraints to the model. The quality of the solution depends on the location of the time period assigned to the set of course units. Hence the objective function is defined to optimize the allocation of time periods to course units.

The model results a feasible solution which has reduced the maximum idle time of students to three hours and it can be implemented with the lecture halls currently available in the faculty of Applied Sciences, University of Sri Jayewardenepura. The model is flexible and allows to change the constraints depending on the faculty requirements and other factors, and if necessary, construct alternative schedules.

Key words: *Course Timetabling, Graph Coloring, Integer Linear Programming*

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LIST OF ABBREVIATIONS

ARM- Aquatic Resource Management

BIO- Biology

CHE- Chemistry

CSC- Computer Science

ECN- Economics

EMF- Forestry and Environmental Science

FAS - Faculty of Applied Sciences

FSC- Food Science and Technology

ICT- Information and Communication Technology

ILP – Integer Linear Programming

LP - Linear Programming

MAN- Management Science

MAT- Mathematics

NP- Non Polynomial

PBT- Plant Bio Technology

PHY- Physics

PST- Polymer Science and Technology

STA- Statistics

USJP- University of Sri Jayewardenepura

ZOO- Zoology

CHAPTER 1

INTRODUCTION

1.1 Background

The Figure1.1 shows a timetable of a certain bus depot for the early morning hours. It clearly shows how three buses, $GA-3520, HP-5003, JX-4078$have been allocated routes between the bus stations A, B and D and the departing time at each station. By looking at it, one can understand which bus will depart at which station and its departing time. It is clear that same bus has not been assigned to two routes at once and also two buses have not been allocated to the same route at the same time.

One should be able to get more information about a scheduling, through a timetable at once. Thus a good timetable will always give lot of information to a user and it must be clear and understandable.

Bus Number	Time of departure	Departing	Arrival
GA-3520	5.40 a.m.	Depot	A
GA-3520	6.00 a.m.	A	B
HP-5003	6.00 a.m.	B	A
JX-4078	6.40 a.m.	B	D
GA-3520	7.25 a.m.	B	D
HP-5003	8.20 a.m.	B	A

Table1.1: Sample transport timetable

Timetabling problem involved in allocation of certain resources suchas people, rooms or vehicles to a given set of objects as time periods, routes, etc.such a way that it will satisfy some preferences as much as possible subject to some constraints which has been defined as a combinatorial optimization problem and known to belong to the class of problems called Non Polynomial (NP)-complete, i.e., no method of solving it in a reasonable (polynomial) time [16].

Timetabling problems can be identified in variety of fields such as, employee timetabling, sports fixtures timetabling, timetabling oftransport services, etc.But a huge part of the literature on timetabling are driven by scheduling issues inuniversities or schools, which canbe defined to be the problem of assigning number of coursesinto a limited number of time periods[1].

Burke, Kingston and de Werra [3] gave a definition of general timetabling, which covers many cases as follows:

A timetabling problem is a problem with four parameters: T, a finiteset of times; R, a finite set of resources; M, a finite set of meetings; and$C$, a finite set of constraints. The problem is to assign times and resourcesto the meetings so as to satisfy the constraints as far as possible.

There are three main classes of academic timetables [16]:

- School Timetabling: The week scheduling for all the classes a school,avoiding teacher meeting two classes in the same time, and viceversa.
- Course Timetabling: The week scheduling for all the lectures ofa set of university courses, minimizing the overlaps of lectures ofcourses having common students.
- Exam Timetabling: The scheduling for the exams of a set of universitycourses, avoiding overlapping exams of courses having commonstudents, and spreading the exams for the students as much as possible.

1.2 University Course Timetabling

Among those three types of academic timetabling, the university course timetabling problem looks for the best schedule, according to some criteria, in which every element in a set of resources, which may contain lecturers, groups of students, classrooms or laboratories. A set of constraintsdefines the terms of availability of the different components, so determining the schedulerules, that is, how the resources must be allocated [17]. Not like school timetabling, university courses can havecommon students, and room availability and their capacity become constraints of the problem.

The timetabling process is long and contains many stages before placing courses into time periods. One needs to reduce a given timetabling problem to a mathematical model, which can then be solved. Hence to automate the university course timetabling process, one must consider this entire process. Such problems are subject to many constraints that are usually divided in to two categories hard constraints and soft constraints which can be described as follows.

Hard constraints

These are strictly imposed. A feasible timetable must satisfy those hard constraints defined by the user. Following are the most commonly used hard constraints in literature.

- For each time period there should be sufficient resources (e.g. rooms, lectures, instructors, etc.) available for all the events that have been scheduled for that time period.
- Uniqueness: No resource (students or staff) can be demanded to be in more than one place at any one time.
- Completeness: all courses planned for every group of students must appear in the timetable, with the right amount of time periods.

Soft constraints

These are desirable but not absolutely essential. In real world situations it is, of course, usually impossible to satisfy all soft constraints [5]. A feasible timetable is optimal in the level of satisfaction of the soft constraints. Soft constraints depend on the institutional requirements. Examples for soft constraints can be stated as follows:

- Students should not have lectures of the same course in consecutive periods or on the same day.
- The idle time of students must be minimized.
- Students must not have lectures on more than three consecutive periods.

This study focuses on university course timetabling problem. Specifically the timetable of Faculty of Applied Sciences (FAS) at University of Sri Jayewardenepura (USJP). The faculty does not possess an automated timetabling system, as in the most academic institutions in Sri Lanka. At the beginning of each academic semester the management and the technical staff is doing minor changes in the pre-designed time table in order to meet the requirements.

Atthe beginning of FAS with few departments with low number of students and low number of degree programs, timetabling was not a tedious process. But with the increasing number of students, differentiation of subject combinations and limitations of the lecture halls and laboratories have make it a very difficult task. Most of the times both students and academic staff are not satisfied with the timetable they are given. So it is very useful to construct an automated system which creates a good feasible and efficient timetable satisfying all parties as much as possible.

1.2.1 Existing timetabling system in the FAS

The FAS of the University is one of the oldest among the faculties of sciences in Sri Lanka. At present there are nine academic departments which are departments of Mathematics, Physics, Chemistry, Statistics, Computer Science, Food Science and Technology, Zoology, Botany and Forestry.

In the meantimesome departments are offering courses for more than one subject as the department of Mathematics is offering Mathematics and Management science;Information and Communication Technology and Computer science from department of Computer science, Department of Zoology is offering Zoology with Biologyetc. Totally there are 15 different subjects which are offering with more than 100 academic staff members, over 1500 undergraduate students.

The different subjects offered in the facultyare listed in the following.

- Chemistry (CHE)
- Mathematics (MAT)
- Physics (PHY)
- Computer Science (CSC)
- Statistics (STA)
- Management Science (MAN)
- Information and Communication Technology (ICT)
- Zoology (ZOO)
- Aquatic Resource Management (ARM)
- Plant Bio Technology (PBT)
- Food Science and Technology (FSC)
- Polymer Science and Technology (PST)
- Biology (BIO)
- Forestry and Environmental Science (EMF)
- Economics (ECN)

The undergraduate program of FAS consists of three years of studies for the general degree program and four years of studies for the special degree program. At present FAS offers fifteen different subjects with twenty four subject combinations each composed with three different subjects for undergraduate students who are following a general degree. In each subject, there are compulsory courses and elective courses. Students have the freedom to select electives to cover up the credit requirements. However elective courses are not offered to the first year students, while for the third years more elective courses are offered. Hence there are about

200 course units being offered by the nine departments in the faculty in each semester with limited number of lecture halls.

Table 1.2 shows the above mentioned subject combinations.

Combination	Subject1	Subject2	Subject3
B01	CHE	ZOO	PHY
B02	CHE	ZOO	PBT
B03	CHE	ZOO	EMF
B04	CHE	EMF	PBT
B05	CHE	ZOO	ARM
B06	CHE	ARM	BIO
B07	CHE	MAN	PBT
B08	CHE	MAN	ZOO
B09	CHE	FSC	BIO
B10	CHE	ICT	BIO
B11	ARM	MAN	ZOO
B12	CHE	MAN	ARM
C01	CHE	EMF	MAN
C02	CHE	PHY	PST
C03	CHE	PHY	EMF
P01	CHE	MAT	PHY
P02	CHE	MAT	STA
P03	MAT	PHY	STA
P04	CHE	MAN	MAT
P05	MAN	MAT	PHY
P06	CSC	MAT	STA
P07	CSC	MAT	PHY
P08	MAT	STA	ECN
P09	MAT	PHY	ICT

Table 1.2: List of subject combinations(source: FAS prospectus-2015)

From Monday to Friday from 8.00 a.m. to 6.00 p.m. there are about 45 lecturing hours per week. Among the course units mentioned above, some require two consecutive hours of lectures per week while some other require one hour, depending on the credit value of the course unit. Hence the system must be able to handle such situations properly. Some of the courses require practical sessions of two to three hours per week with minimum capacities of laboratories. Due to such limitations, students are grouped and several practical sessions are repeated over the week. In this perspective the teacher and the instructors become constraints. So the timetabling problem involved in assigning each course to a number of time periods and class rooms such a way that no lecturer, student and lecture hall is used more than once per time period. This process shows how the real world problems are much more complicated thanwhat appears in a mathematical model.

With the new constructions there are about 17 lecture halls available in the faculty with different capacities which can mainly divided in to three categories as large (category1), medium (category2) and small (category3), where large halls have the capacity for more than 250 students and medium halls with the capacity for around 100 to 250 students and for small size lecture halls having capacity for less than 100 students. Table 1.2 represents the above mentioned categorization of lecture halls and the table 1.3 gives the list of subjects which can be conducted in those lecture halls.

Large	*Medium*	*Small*
S1	*A1*	*C2*
NFC1	*B1*	*C3*
C1	*F1*	*F2*
	NFC3	*M1*
	P1	*M2*
	BLT1	*P2*
		NFC3
		C5

Table 2.3: Categorization of lecture halls (Source: FAS records 2015-Dean's office)

Large	*Medium*	*Small*
CHE	*ARM*	*CSC*
MAT	*BIO*	*ECN*
	EMF	*STA*
	MAN	*FSC*
	PHY	ICT
	PBT	*PST*
	ZOO	

Table 1.4: Categorization of subjects (Source: FAS records 2015-Dean's office)

1.3 Objectives

The main goal of any timetabling process is to produce a timetable not only conflict free but also good quality as well to enhance the students' performances.

- It has identified that there is a higher absenteeism for lectures which will directly affect the students' performances. They must be motivated to attend the lectures by providing an efficient timetable.
- An efficient and feasible timetable must reduce the students' idle time between lectures while scheduling lectures at more productive time periods such as morning sessions. Hence this study intends to model such quality timetable for FASatUSJP by providing those qualities as much as possible. Mainly it will emphasis on the first year timetable as first year students must be motivated to attend lectures since they are new to the system.
- At present the course timetable is prepared by the managerial team of the FAS by using ad-hoc methods. They are doing minor changes to a pre designed structure in each year. But with the increased number of student's registrations andthe introduction of new courses and subject combinations cause many conflicts and the managerial team has to redesign and repeat the process for several times, which is a wasting of time and the other resources such as power, machinery, etc.
- In the meantime lectures are also meet troubles with the assigned lecture halls and other materials. Hence this study intends to minimize such wastages of resources as much as possible by providing a good and feasible model.
- This study intends to solve this combinatorial optimization problem using a possible combination of graph theoretic and integer programming approaches and produce a conflict free solution useful to the faculty management.

The research can be done mainly in two steps as follows.

1. Analyze the current system which includes a comprehensive study of the system, data collection, and identification of problematic areas, as well as, system constraints, restrictions, and objectives.

2. Develop a model to solve the problem based on graph theory and linear programming.

1.4 Significance of the Study

This study is intended to contribute knowledge on timetabling problems and their contribution in the optimization of educational resources. It mainly focused on students' perspective. It has not been considered the views of the academic and the nonacademic staff. The study is therefore very important due to the following reasons:-

1. Enhance the utilization of both human and physical resources in the faculty.

2. No such studies have been done in FAS, hence it will act as a basis for future research.

1.5 Thesis Organization

The first chapter of this dissertation gives an introduction to timetabling problem and why it is a necessity to being automated. It is also describes the timetabling problem in the FAS at USJP, the current situation in the faculty and the problematic areas of the course timetable with the currently available resources. The second chapter is the literature survey of timetabling problem, its background and its evaluation to the present from the past several decades. The third chapter gives the preliminaries of Graph Theory and Integer Linear Programming which are the most fundamental theories used in this study. It gives the methodology which has been used and the way the model is formulated. The fourth chapter gives the results obtained from the study and the discussion of those results. The last chapter contributes the conclusion, limitations of the study and further improvements.

CHAPTER 2

LITERATURE REVIEW

Throughout the decades researches have continuously involved in timetabling problems and many contributions related to automate timetables have appeared in literature. With the introduction of new courses and flexibility to select the courses, have increased the complexity of the timetabling process and its manual solution can require much effort. Continuous changes in the education sector and the improvement in the computer technology have attracted researches in this field. Automated timetabling problems are known to be NP hard, and heuristics methods have often used [15].

The main practical motivation of this research field could be regarded to the impracticability to solve the problem manually as it increases in size. The massive use of computers to solve timetabling problems probably started with Gotlieb's[1] "The construction of class-teacher timetables" in 1963.

The methodologies which have been used for course timetabling problems can be categorized mainly as sequential methods, cluster methods, constraint-based methods, and meta-heuristic methods [4]. In the perspective of different techniques used in timetabling, Graph coloring approach, logic programming, integer programming, tabu search, neural networks and genetic algorithm approaches can be found in literature. Combinations of two or more methods have been exposed very good results in the field.

2.1 Different Approaches to SolveCourse Timetabling Problems

2.1.1 Graph coloring

The oldest and most popular method was graph coloring approach, which is a sequential method where the problem is represented as a graphby representing events (courses) as vertices and the conflictsbetween events are representing as edges between vertices. As an example when some students have to take part in two different events, the conflict is represented as an edge between the vertices representing those events.Then the problem can be formulated as a graph coloring problem which colors the vertices such a way so that no two adjacent vertices are colored by the same color, where each color in the graph corresponds to a time period in the timetable.

Vertex coloring is the most common graph coloring approach, which is to find a way to color the vertices of a graph such that no two adjacent vertices are colored using the same color. The other graph coloring approaches are edge coloring (No vertex is incident to two edges of same color) and face coloring (no two faces sharing a common border have colored with the same color). Most of the times, graph coloring is done by greedy algorithms and some heuristic approaches such as largest degree first, largest saturated degree first, largest weighted degree first are used for vertex ordering. Graph coloring approaches have much practical applications such as map coloring, where countries (areas) in a map are colored in a way that no twoadjacent countries get the same color. This approach can be extended to solve many operational research problems such as timetabling, routing, etc.

A variety of graph coloring approaches can be found in literature. Carter and Laporte[11] have used the graph coloring technique to solve a timetabling problem.

De Werra[2] shows how to reduce a course timetabling problem to graph coloring approach such as edge coloring and vertex coloring as follows:

Associate to each lecture l_i of each course a vertex m_{ij} for each course C_j introduce a clique between vertices m_{ij} (for $i = 1 \ldots q$). Introduce all edges between the clique for C_{j1} and the clique C_{j2} whenever C_{j1} and C_{j2} are conflicting. In case of unavailability, introduce a set of p new vertices, each one corresponding to a period. The new vertices are allconnected each other. This ensures that each one is assigned to a different color. If a course cannot have lectures at a given period, then all the vertices corresponding to the lectures of the course are connected to a vertex corresponding to the given period. Conversely, if a lecture must take place at a given time, then the vertex corresponding to that class is connected to all period vertices but the one representing the given period [16].

A dual-objective course-timetabling system has been designed to construct course schedules forthe Science Division at Rollins College by Rickman and Yellen [7], which models the timetabling problem as a vertex-coloring problem in a weightedgraph.

The weighted graph model allows the system to incorporate both hard and soft constraintsby assigning a 2-component weight to each edge that reflects the undesirability of assigningvarious pairs of timeslots to its endpoints[1].

In almost every method some heuristics have been used to order the events such as largest degree first, largest weighted degree first, saturation degree, etc. The optimality of the timetable depends on the sequencing method which has been used. The graph coloring methods do not consider other constraints as room capacity, teacher availability, consecutiveness, repetitions, etc. Hence this approach can be used as aninitial phase of a timetabling process. In cluster methods the events are split into groups which satisfy hard constraints and then the groups are assigned to time periods to fulfill the soft constraints [4]. Different optimization techniques have been employed to solve the problem of assigning the groups of events into time periods. However in these methods the events are grouped initially and they are fixed which results some inefficient timetables.

2.1.2 Linear programming

Another traditional solution approach that is recently used for timetabling problem is mathematical programming. As mentioned by Daskalaki [13], Lawrie and Akkoyunlu have presented linear and integer programming models for some versions of the problem.Simply a mathematical program can be formulated as follows:

$$\text{Minimize: } f(\underline{x})$$

$$\text{Subject to; } g(\underline{x}) \geq 0$$

Where,$\underline{x}$ is the solution vector and $f(\underline{x})$ is the objective function. The objective function in this case will represent all soft constraints and $g(\underline{x})$contains all hard constraints.

There are several algorithms for solving Linear Programming (LP) problems, but the simplex method developed by George Dantzig is the most widely used [6]. Integer Linear Programming (ILP) is a special type of LP problem, where the variables can only take integer values. As another extension one can use binary integer LP in which the variables can only take the values 0 or 1. The nature of the problem is determined by the objective of the user and the situation where the solutions are going to be used.

For solving integer linear programming problems algorithms such as "branch-and bound", "branch-and-cut", and "‘cutting- plane"’ are used. But most generally branch and bound method is used.

TheBranch and Bound algorithm constructs a sequence of sub problems to search systematically for the optimal solution. This algorithm solves LP relaxations with restricted ranges of possible values of the integer variables. It attempts to generate a sequence of updated bounds on the optimal objective function value.The branching step is taken heuristically, according to one of several rules. Each rule is based on the idea of splitting a problem by restricting one variable to be less than or equal to an integer$j$, or greater than or equal to $j+1$. The performance of the branch-and-bound method depends on the rule for choosing which variable to split (the branching rule).

Daskalaki, Birbas and Housos [13] havepresented a novel 0-1 integer programming formulation of the university timetabling problem which provides constraints for a great number of operational rules and requirements found in most academic institutions. More recently, the teacher assignment problem is formulated as a Mixed Integer Programming problem and is solved as a special case of the fixed charge transportation problem. Using goal programming, in [5] the teacher assignment problem is combined with a form of the timetabling problem and solved through commercial software for goal programming. In a similar manner, IP formulations for the school and the university timetabling problems as optimization problems are also given. A similar strategy for a timetabling problem for universities is solved by grouping sub-problems [4]. A solution approach for the same problem, however with lectures of different length is provided in [17].

Dimopoulou and Miliotis [9]have developed a timetabling system at Athens University of Economics and Business. An Integer Programming method has developed based on MPCODE and XPRESS-MP packages which has been used to assign groups of courses to groups of time slots for the course timetabling problem.

Stephen Chachahas developed and implemented Mathematical programming formulations for optimization of university course Timetabling problem in the case of Makwawa University College of Education. The models have tested using GLPK solver and comparative analysis on the performances of the models have been carried out [14]. It has been proved that it is possible to get optimal solution for the course timetabling problem through a model which involves a mixture of binary and time-indexed variables.

Phillips and Ryanhave [12] present an integer programming method for solving the classroom assignment problem in university course timetabling. They have introduced a novel formulation of the problem which generalizes existing models and maintains tractability even for large instances.

It also addresses how the structure of different classroom assignment problems can affect the relative difficulty of finding and confirming an optimal solution. Their model and methods have been validated through computational results based onthe University of Auckland [12].

An optimum course scheduling timetable for the Department of Statistics at Gazi University has been achieved by using a 0-1 integer programming model, in which both students' and lecturers' dissatisfaction is minimized [10].

2.1.3 Other approaches

Apart from the classical mathematical programming approaches, several new and most efficient techniques for combinatorial problems have also being used for the timetabling problems. Among these, tabu search was used in for the solution of the school and university timetabling problems; constraint logic programming is presented in [7]. Genetic algorithms have been utilized as an effective tool for the solution of timetabling problems [12].

CHAPTER 3

METHODOLOGY

With the increasing number of student registration in FAS, a large number of course units are offered in each semester and each course unit has different number of students. This study intends to formulate a mathematical programming model that will optimize the timetable of FAS so as to reduce timetabling problems. Different person can formulate the problem differently; hence the efficiency of the solution may depend on the way that the problem is formulated. This study uses several phases to solve the timetabling problem.

As the initial step a questionnaire was given to several groups of students, those groups are the second year biology stream students, second year physical science students and first year students. The main objective of giving a questionnaire was to get students'view about the existing timetable and their preferences and suggestions,as the goal of an efficient timetable is to increase their performances. The questionnaire for the first year students was given to them after a week of commencing their academic activities. Those responses can be considered as more reliable, since they are new to the university system and experiencing its facilities as well as difficulties and facing the problems in the scheduling of courses.

Results of the analysis of the questionnaire were used to develop the constraints and the objective function of the integer linear programming problem. Following sections represent the main phases of the timetablingprocess used in this study.

3.1Mathematical Preliminaries

3.1.1 Graph coloring

The oldest and most popular method used for timetabling was graph coloring approach, which is a sequential method where the problem is represented as a graphby representing events (courses) as vertices and the conflictbetween events are representing as edges between vertices. As an example when a student has to take part in two different events, the conflict is represented as an edge between the vertices representing those events.

Definition 1: A graph is a collection of vertices (points) that are connected by edges (lines).

Definition 2: The number of edges incident to a vertex is called the degree of the vertex.

The Figure 3.1 is a graph with five vertices, $\{a, b, c, d, e\}$ and five edges which are $\{ab, bc, cd, da, ae\}$.

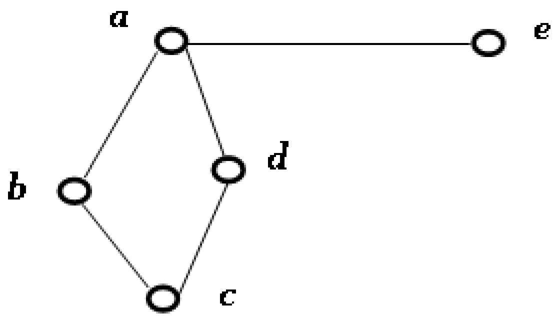


Figure 3.1: A graph

Then the problem can be formulated as a graph coloring problem which colors the vertices such a way so that no two adjacent vertices are colored by the same color, where each color in the graph corresponds to a time period in the timetable. The Figure 3.2 shows a vertex coloring.

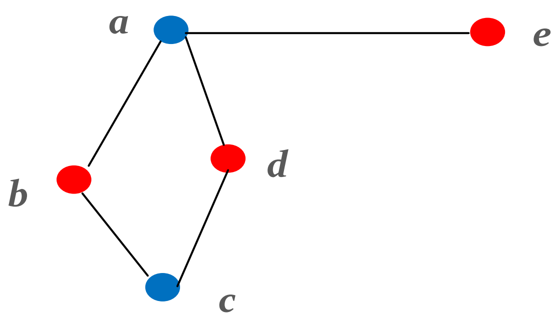


Figure 3.2:Vertex coloring of a graph

Vertex coloring is the most common graph coloring problem, which is to find a way of coloring the vertices of a graph such that no two adjacent vertices are colored using the same color. The other graph coloring approaches are edge coloring (No vertex is incident to two edges of same color) and face coloring (no two faces sharing a common border have colored with the same color). Most of the times, graph coloring is done by greedy algorithms and some heuristic approaches such as largest degree first, largest saturated degree first, largest weighted degree first are used for vertex ordering. Graph coloring approaches have much practical applications such as map coloring, where countries in a map are colored in a way that no twoadjacent countries get the same color. This approach can be extended to solve many operational research problems such as timetabling, routing, etc.

3.1.2 Linear programming

Another traditional solution approach that is recently used for timetabling problem is mathematical programming [6].

Example:

$$\text{maximize} z = 8x_1 + 5x_2$$

$$\text{subject to;}$$

$$x_1 + x_2 \geq 6$$

$$9x_1 + 5x_2 \leq 45$$

$$x_1, x_2 \geq 0,$$

$$x_1, x_2 \text{integers}$$

Solving the above problem by simplex method would result:

$z = 41.25, x_1 = 3.75$and $x_2 = 2.25$, where the variables do not have integer values. However one has to understand that finding an integer solution does not mean to round off the non-integer solutions. It needs to go for the next step to partition the problem by arbitrarily choosing a decision variable.

As an example branching of the variable x_1 ($x_1 \leq 3$ or$x_1 \geq 4$) would create a sub problem. This procedure should be repeated until the required integer solution is reached. With a lower bound for the objective to be 40, the solution would be$z = 40, x_1 = 5$and $x_2 = 0$. Figure 3.3 illustrates the process of solving the above problem and how the branching is done.

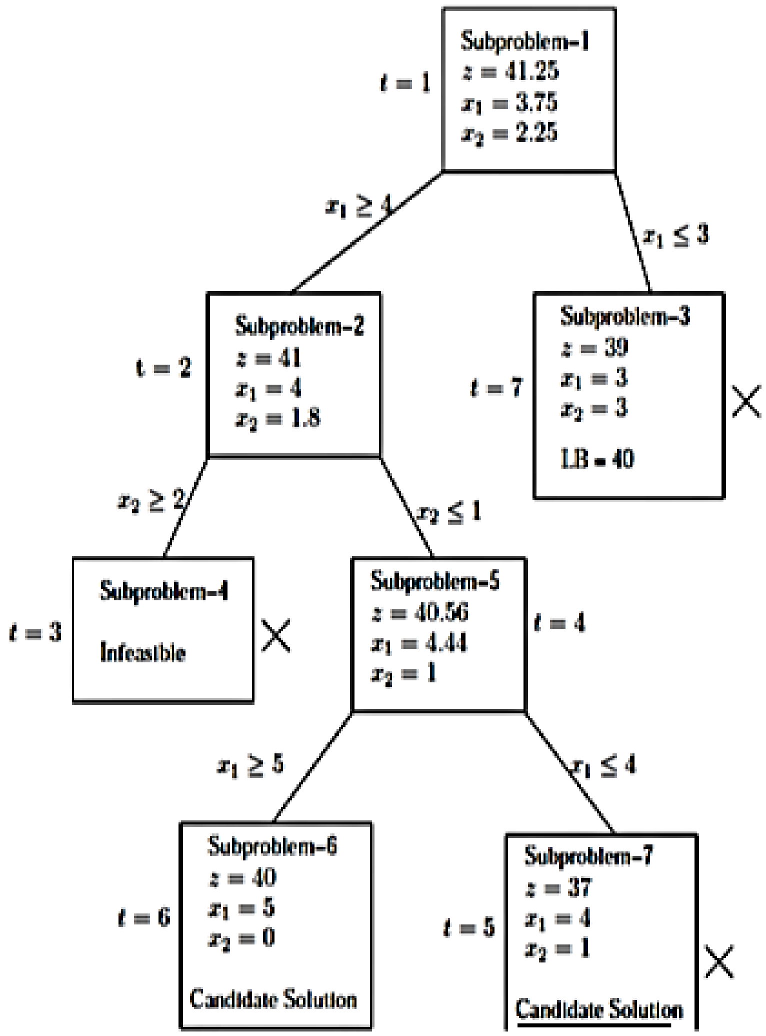


Figure 3.3: Illustration of the Branch and Boundmethod

3.2Solution Procedure

Phase I:

(a) Construct a graph in which vertices represent the subjects and define an edge between two vertices if and only if they appeared in a same subject combination.

(b) Color the graph such that no two vertices sharing a common edge are colored using the same color.

Input: Conflict matrix, $E_{n \times n}$

The component at i^{th} row and j^{th} column is 1 iff there are common students who are following both i^{th} course unit and j^{th}.

Process: Construct an undirected graph G with n vertices using $E_{n \times n}$

Vertex coloring using Maple 12.

The algorithm first tries a greedy coloring of the vertices of the graph (G) starting with a maximum clique in G. If this fails to find a k-coloring (k is the number of colors need to color the graph) it does an exhaustive search using a backtracking algorithm. The problem of testing if a graph is k-colorable is NP-complete. The exhaustive search will take exponential time on some graphs.

Output: Coloring (k)

If G is k colorable then, greedy coloring results k number of course unit groups where each group is a combination of several independent subjects. Two subjects being independent means there are no common students who are following both of them.

Phase II:

(a) Formulation of a binary ILP model by defining the objective function and the set of constraints.

(b) Solve the problem using Branch and Bound method.

Input: - Array of course unit groups, $I_{1 \times k}$.
- Array of time periods, $T_{1 \times 45}$.
- Array of duration of each course unit group, $h_{1 \times k}$.

Process:

- Define the basic variable;

$$x_{ij} = \begin{cases} 1, & if\ i^{th} course\ is\ assigned\ to\ j^{th}\ time\ period \\ 0, & otherwise \end{cases}$$

-Objective:

$minimize z = \sum_{i=1}^{k} \sum_{j=1}^{45} x_{ij}\, p(j)$

- Define $p(j)$; (an increasing function of j).

Constraint 1; $\sum_{i=1}^{k} x_{ij} \leq 1$, for all $j = 1,2, \ldots ,45$

Construct the matrices $A_{1_{k\times 45k}}$ and $b_{1_{k\times 1}}$

Constraint 2; $\sum_{j=1}^{45} x_{ij} = h(i)$, for all $i = 1,2, \ldots , k$

Constructthe matrix $A_{2_{k\times 45k}}$

-Solve ILP; (z, A_1, A_2, b_1, h) using MATLAB 14.

MATLAB 14 uses the Branch and Bound algorithm which constructs a sequence of sub problems to search systematically for the optimal solution. This algorithm solves LP relaxations with restricted ranges of possible values of the integer variables. It attempts to generate a sequence of updated bounds on the optimal objective function value.

Output: Solution to ILP ; $Y_{1\times 45k}$

The solutionarray Y consists of 1s and 0s depending on whether a course has been assigned to a time period or not.

Phase III: Interpret the solution and Backtracking.

(a) Analysis of the solution

(b) If all constrains are not satisfied go to phase I, otherwise interpret the results in a meaningful way.

from 1 to k

from1 to 45

Convert Y to $X_{9\times5}$ such that when ever $X[i,j] = n$ means that the n^{th}course has been assign to i^{th} period at j^{th} day.

- Check for the consecutive time periods

from 1 to k--------------------(course group number)

from 1 to k

from 1 to 5

if $h(i) > 1$ then

if $X[i,j] \ = n$ then

if $X[i,k] = n$, then $X[i,k] = 0$ for all $k \neq j$

$$X[i,j+1] = n$$

- Check for the consecutive periods in $11.00 \ - 12.00$ and $1.00 - 2.00$

from 1 to k

from 1 to 5

If $X[4,j] = n$ and $X[5,j] = n$ then $X[4,j] = \ X[6,j]$

$$X[6,j] = n$$

When constructing the timetable for each academic year, the priority was given to the first year timetable. Since the first year students are new to the system and they must adapt to the environment, more efficient timetable must be issued to them. Next priority was given for the second year students and last priority was given to third year students. When considering the third year, around 120 students which is nearly 20% from the total batch is selected for the special degree programs which reduces the number of students for general lectures. So it is easy to schedule their timetable with the available lecture halls. But the number of course units has been increased, since the students are given the freedom to select much course units from electives.

When determining the constraints and the objective function, for each model the information taken from the analysis of the questionnaire has been considered. Some prominent information from the questionnaire is stated below.

3.3 Information from the Analysis of the Questionnaire

Aquestionnaire was given to different groups of students from different streams, biology and physical streams who are in their first and second years of studies. The questionnaire was given to 150 second year physical science students and 105 biology students while there are 200 students in the first year sample. First year student population is about 300 and there are 275 and 200 students in second year physical and biology streams.

The first section of the questionnaire was based on students' background, second section based on their preferences for lecture halls and the third section based on their preferences on lecturing hours and practical sessions and their preferred dates for morning and evening lectures separately.

The questionnaire and the set of responses have been included in the appendix *A*. A summary of the analysis is given in the following. However for the analysis students preferences for the lecture halls have not been considered.

- Figure 3.4(a), Figure 3.4(b) and Figure 3.4(c) show the distributions of preferences for morning and evening lecturing hours of second year physical, biology and first year students respectively. They clearly reveal that most of the students prefer morning lectures where 86% of physical, 57% of biology and 75% of first year students prefer to have lectures in the morning. Hence the first priority was given to morning hours when modeling the timetable.

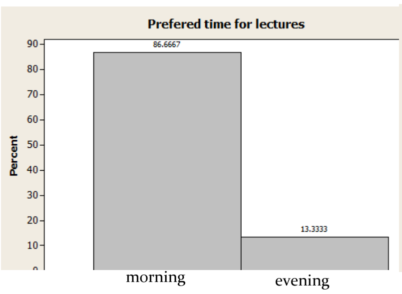


Figure 3.4 (a) preferred time for lectures of 2nd year physical science students

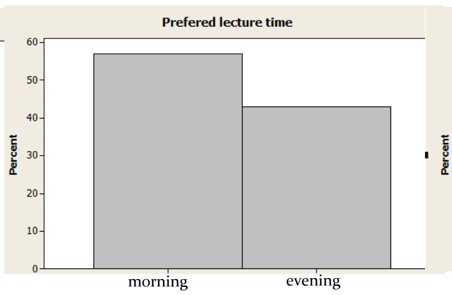


Figure 3.4 (b) preferred time for lectures of 2nd year Biology students

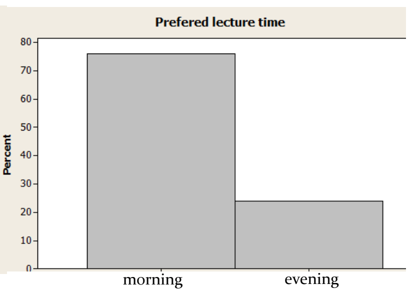
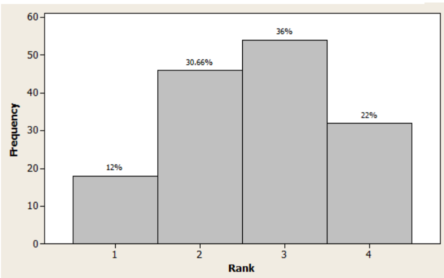
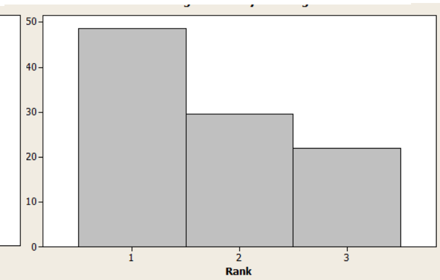


Figure 3.4 (c) preferred time for lectures of first year students

- Next it was asked that which days of the week students prefer to have lectures in the morning and evening separately. The Figure 3.5(a), Figure 3.5(b) and Figure 3.5(c) illustrate their preference to have lectures in Monday morning while Figure 3.6(a), Figure 3.6(b) and Figure 3.6(c) illustrate their preference to have lectures in Tuesday morning.

  It is clear that only 12% of physical science students have given their first preference to Monday morning while 36% of them have given their third priority. Biology and first year students have given the first priority to it, but relatively in small percentages.





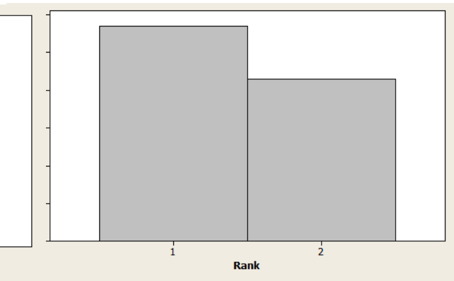
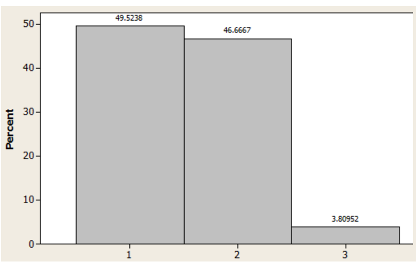


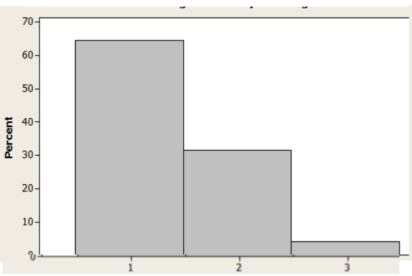
Figure 3.5 (a) Preference to have lectures in Monday morning of 2nd year physical science students

Figure 3.5 (b) Preference to have lectures in Monday morning of 2nd year biology students

Figure 3.5 (a) Preference to have lectures in Monday morning of first year students

For Tuesday morning largest portion of all three groups have given their first preference. 49% of physical science students, 65% of biology students and 55% of first year students prefer to have morning lectures in Tuesday other than Monday.





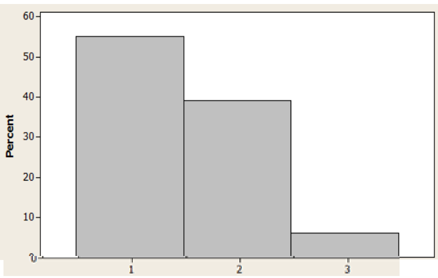


Figure 3.6 (a) Preference to have lectures in Tuesday morning of 2nd year physical science students

Figure 3.6 (b) Preference to have lectures in Tuesday morning of 2nd year physical science students

Figure 3.6 (c) Preference to have lectures in Tuesday morning of 2nd year physical science students

Through the responses it can be seen that irrespective to the time of the lecture most of the students have given their last priority to Thursday and Friday.

For the analysis preference for Monday and Tuesday have been taken. But some students have given their first preference to Wednesday.

Figure 3.7(a), Figure 3.7(b) and Figure 3.7(c) shows the percentage preference of the maximum time gap between two lectures of the three groups. It reveals that from all three groups the highest percentage of them prefer to have a maximum gap of one hour. Least percentage of them like to have an idle time of more than an hour.

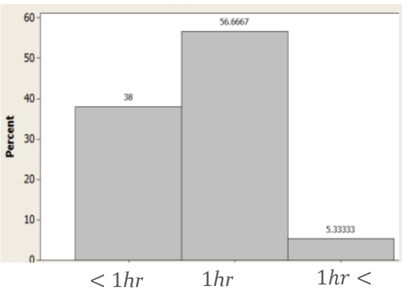


Figure 3.7(a) Preference to havegap between two lectures of 2nd year physical science students

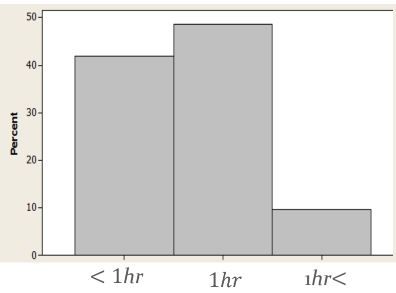


Figure 3.7(b) Preference to havegap between two lectures of 2nd year biology students

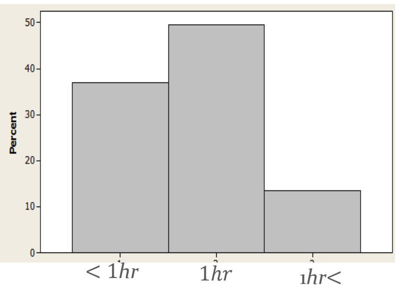


Figure 3.7(c) Preference to havegap between two lectures of first year students

3.4Formulation of the Model

3.4.1 Phase I

At the beginning, a graph coloring (vertex coloring) approach has been used to group the subjects offered in each year separately using the software Maple 12. An undirected graph was constructed such a way that vertices represent the different subjects and an edge between two vertices represents a conflict between them (two subjects are in conflict if they are in the same combination).

A graph with n vertices and$m$ edges can be constructed. Where n is the number of subjects and m is is the number of conflicts between n subjects. Using this result another three graph were constructed in Maple using all the course units for each first, second and third year and then the problem could be further simplified.

3.4.2 Phase II

With the results obtained in phase I, an ILP model was developed which then be solved with the use of MATLAB 14.

3.4.3 ILP model

Terminology

$I = \{set\ of\ course\ unit\ groups\ \} = \{1,2,3, \ldots, k\}$

$J = \{set\ of\ time\ periods\} = \{1,2,3, \ldots, 45\}$

$$H = \{h(i), |\ h(i) is\ the\ duration\ of\ course\ group\ i, i \epsilon\ I\}$$

Basic variable

$$x_{ij} = \begin{cases} 1, & if\ i^{th} course\ is\ assigned\ to\ j^{th}\ period\ of\ the\ week \\ 0, & otherwise \end{cases}$$

Hard Constraints:

Hard constraints are the requirements which must be satisfied by anyfeasible timetable.

$\sum_{j \in J} x_{ij} = H(i) \quad for\ \forall\ i \in I$ ⟶Completeness property

$\sum_{i \in I} x_{ij} \leq 1 \quad for\ \forall\ j \in J$ ⟶Uniqueness property

$x_{ij} - x_{ij+1} = 0\ \ for\ \forall\ i \in I \cap H(i) > 1$ →consecutiveness property

Soft constraints

Soft constraints are the additional properties which are considered to be satisfied by a quality an efficient timetable. This study considered to optimize the assignment of lecture to time periods. Hence it is treated as the soft constraint. Through the analysis of the questionnaire it can be verified that most of the students prefer to have both lectures and practical in the morning. But with the large number of combinations of subjects it is impossible to optimize both. Hence this study intended to focus more on optimize the lecturing hours.

In order to build the model one needs to define the objective function. Hence the objective is taken as to minimize the cost of assigning lectures to time periods. To do so, an objective function $z(t)$ was used as follows.

$$z(t) = p(t)x_{it},$$

where $p(t)$ is the cost of assigning each course group i to time period t.Hence one needs to define $p(t)$ values and for this one $p(t)$ was defined as: $p(t) = \sqrt{t} + 1$.

However this objective function can be changed by the user as desired. It will probably change the result. Hence one can decide the most suitable function for an efficient timetable.

CHAPTER4

ANALYSIS

This chapter provides the graph coloring results with the binary ILP models and the corresponding model timetables, based on those models for each of the three years of studies. And this gives a detailed analysis of each of the timetables which have been constructed and itsimpacts on students and its ability to implement with the available resources.

4.1 Solution Techniques of the Timetabling Problem for the First Year

4.1.1 Graph coloring results

Phase I :

A graph with 15 vertices and 38 edges could be constructed for the first year. Using this result another three graph were constructed in Maple 12 using all the course units for each first, second and third year and then the problem could be further simplified.

The Maple program results five color classes which are given below and the Figure 4.1 gives the resulted coloring.

- STA, PST, ICT, EMF, FSC, ARM
- CHE, ECN, CSC
- MAT, ZOO
- PBT, PHY
- BIO, MAN

Subjects in each color class can be scheduled simultaneously. But if one look at the subject combinations carefully, as an example CSC can be scheduled simultaneously with the subjects in the first color class since CSC do not make conflicts with those subjects in that color class. Similarly ECN can be scheduled with BIO and MAN. Hence one cannot assume that scheduling two subjects in two different color classes is not possible. Therefore further analysis is required.

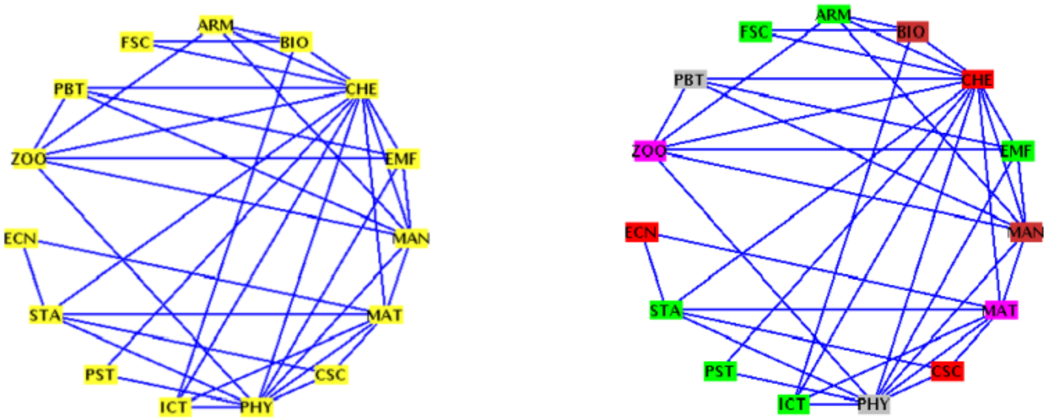


Figure 4.1: Initial graph coloring

For each subject there are several course units. As an example if we consider only the first year first semester courses, totally there are 55 course units. Using the results from the initial coloring, a conflict matrix can be constructed easily for those 55 course units. Using that conflict matrix a new graph with 55 vertices and 617 edges could be constructed. For this graph, graph coloring algorithm results 20 color classes which are listed in the following.

1. CHE 102 1.0 / CSC 105 1.0 / ECN 101 1.0

2. CHE 110 1.0

3. CHE 112 1.0

4. BIO 103 1.0 /MAN 104 1.0 /STA 115 1.0 / PST 104 1.0

5. ARM 101 1.0 /FSC 122 2.0/ EMF 103 1.0 /ICT102 2.0 /PST 102 2.0

6. ARM 102 1.0/ FSC111 1.0 /EMF 106 1.0 /ICT 101 1.0 /PST 101 1.0

7. ARM 103 1.0 /FSC 121 1.0/EMF 113 1.0/ ICT 103 1.0/ PST 103 1.0

8. ARM 104 1.0 /FSC 191 1.0 /EMF 101 1.0 /ICT 104 1.0

9. ARM 106 1.0/EMF 115 1.0/MAT 103 1.0

10. PBT104 1.0 / PHY 131 1.0

11. ZOO 126 1.0

12. ZOO 128 1.0

13. CHE 107 2.0 /CSC 107 2.0/ ECN 102 2.0

14. CHE 108 /110 /CSC 106 1.5

15. BIO 102 2.0/MAN 102 2.0 /STA 114 2.0/ PST 101 2.0

16. BIO 101 1.0 /MAN 101 2.0 /STA 113 2.0/ PST 102 1.0

17. ARM 107 1.0/ PBT 121 2.0/ PHY 103 2.0

18. PBT 122 2.0/PHY 104/105

19. MAT 101 2.0

20. MAT 102 2.0 /ZOO 118/120

In each color class there are several course units (maximum of four course units) which a combination of the three categories mentioned in Table 1.3. Hence there is no difficulty in scheduling all the course units in one color class simultaneously. Some groups contain both two hour and one hour course units. In those cases it is taken that such color class required two consecutive hours of lecturing in order to satisfy the completeness. So with above results there are twelve one hour groups and eight two hour groups. Similar procedure has been followed for the second and third year first semester course units.

Phase II: ILP model for the first year

With the results obtained in phase I, an ILP model was developed which then be solved with the use of MATLAB 14.

$$I_1 = \{set\ of\ course\ unit\ groups\ in\ the\ first\ year\} = \{1,2,3,\dots,20\}$$

$$J = \{set\ of\ time\ periods\} = \{1,2,3,\dots,45\}$$

$$H_1 = \{h(i), |\ h(i) is\ the\ duration\ of\ course\ group\ i\}$$

Basic variable

$$x_{ij} = \begin{cases} 1, & if\ i^{th} course\ is\ assigned\ to\ j^{th}\ period\ of\ the\ week \\ 0, & otherwise \end{cases}$$

Hard Constraints:

Hard constraints are the requirements which must be satisfied by anyfeasible timetable.

$\sum_{j\in J} x_{ij} = H(i) \quad for\ \forall\ i \in I_1$ ⟶Completeness property

$\sum_{i\in I_1} x_{ij} \leq 1 \quad for\ \forall\ j \in J$ ⟶Uniqueness property

$x_{ij} - x_{ij+1} = 0\ \ for\ \forall\ i \in I_1 \cap H(i) > 1$ →consecutiveness property

Soft constraints

This study intended to focus more on optimize the lecturing hours and the objective is taken as to minimize the cost of assigning lectures to time periods (here the cost refers for the undesirability to have lectures at that particular time). Table4.1 shows the costs which have been assigned to eachtime period in each day of the week. These cost values have been assigned based on students' responses. Most of them prefer to have lectures in the morning but they don't prefer to have it on Mondays. Hence relatively small values have been assigned to morning hours except on Mondays.

Time	Monday	Tuesday	Wednesday	Thursday	Friday
8.00-8.55a.m.	35	1	3	5	7
8.55-9.45 a.m.	36	2	4	6	8
10.15-11.00 a.m.	9	11	13	15	17
11.10-12.00noon	10	12	14	16	18
1.00-2.00 p.m.	19	21	23	25	27
2.00-3.00 p.m.	20	22	24	26	28
3.00-4.00 p.m.	29	31	33	100	100
4.00-5.00 p.m.	30	32	34	100	100
5.00-6.00 p.m.	37	38	39	100	100

Table 4.1 Assignment of cost to the time periods for the first year

More specifically higher priority (relativelysmall cost) is given for the first two hours of the day and next priority is for second two hours of the day. Usually the faculty does not hold lectures after 3.00 p.m. on every Thursday, since it has been allocated to students' activities. Hence it has given a large cost 100. For the last two hours on Friday are given the same high value, since most of the students do not prefer that time as usually most of them are leaving the university. Formulation of an ILP model requires a set of constraints and an objective function. When formulating the timetabling problem to an ILP the set of hard constraints are taken to be the set of constraints and the soft constraints are included in the objective function. The following is the ILP which has been modeled.

Since there are 20 different course groups with 45 of one hour time periods, the model would results $900\ (20\ \times 45)$ decision variables and there are 20 linear equations satisfying the first set of constraints and 45 linear inequalities satisfying the second set of constraints. The third constraint refers for the consecutive hours of lectures. It has been evaluated in the program after getting the initial solution from the branch and bound method.

With the solution generated by the model, backtracking was done with some conditional statements, since the solution has assigned some groups to 4$^{\text{th}}$ and 5$^{\text{th}}$ periods of the day which are 11a.m.-12 noon and 1p.m.-2p.m. which are having a break between them. Such groups have been assigned to 5$^{\text{th}}$ and 6$^{\text{th}}$ periods of the day.

4.1.2Modeled timetable for the first year using MATLAB

Table 4.2 is the model timetable for the first year general degree students, generated by the MATLAB program.

By looking at the Table 4.2 some promising results would be obtained. Here in the first year, students do not have lectures after 3.00 p.m. It is desirable since most of the students do not prefer to have lectures in the late evening.

Distribution of the lectures based on the subject combinations will be given in next sections in detail.

Time	Monday	Tuesday	Wednesday	Thursday	Friday
8.00-8.50	CHE 110 1.0	BIO 103 1.0 MAN 104 1.0 STA 115 1.0 PST 104 1.0	CHE 107 2.0 CSC 107 2.0 ECN 102 2.0	ARM 101 1.0 FSC 122 2.0 EMF 103 1.0 ICT102 2.0 PST 102 2.0	CHE 108 /110 CSC 106 1.5
8.55-9.45	ARM 106 1.0 EMF 115 1.0 MAT 103 1.0		CHE 107 2.0 CSC 107 2.0 ECN 102 2.0	ARM 101 1.0 FSC 122 2.0 EMF 103 1.0 ICT102 2.0 PST 102 2.0	CHE 108 /110 CSC 106 1.5
10.15-11.00	MAT 102 2.0 ZOO 118/120	PBT 122 2.0 PHY 104/105	MAT 101 2.0	ARM 107 1.0 PBT 121 2.0 PHY 103 2.0	ARM 102 1.0 FSC111 1.0 EMF 106 1.0 ICT 101 1.0 PST 101 1.0
11.10-12.00	MAT 102 2.0 ZOO 118/120	PBT 122 2.0 PHY 104/105	MAT 101 2.0	ARM 107 1.0 PBT 121 2.0 PHY 103 2.0	CHE 102 1.0 CSC 105 1.0 ECN 101 1.0
1.00-2.00	BIO 101 1.0 MAN 101 2.0 STA 113 2.0 PST 102 1.0	CHE 112 1.0	ARM 104 1.0 FSC 191 1.0 EMF 101 1.0 ICT 104 1.0	BIO 102 2.0 MAN 102 2.0 STA 114 2.0 PST 101 2.0	ZOO 126 1.0
2.00-3.00	BIO 101 1.0 MAN 101 2.0 STA 113 2.0 PST 102 1.0	PBT104 1.0 PHY 131 1.0	ZOO 128 1.0	BIO 102 2.0 MAN 102 2.0 STA 114 2.0 PST 101 2.0	
3.00-4.00					
4.00-5.00					
5.00-5.45					

Table 4.2: Model timetable for the first year

4.2 Solution techniques of the timetabling problem for the second year

4.2.1 Graph coloring results

For the second year first semester, totally there are 62 course units. Using the conflict matrix of second year, another graph with 62 vertices and 1561 edges could be constructed. For this graph, graph coloring algorithm results 23 color classes with 13 one hour groups and 10 two hour groups. The corresponding graph coloring result is listed in the following.

1. MAT 205 1.0/ ZOO 217 1.0

2. ZOO 218 1.0

3. ZOO 219 1.0

4. ZOO 220 1.0

5. ZOO 227 1.0

6. PBT 227 1.0/ PHY 226 1.0

7. ARM 202 1.0 /EMF 204 1.0 /ICT 202 1.0/ FST284 1.0

8. CHE 205 1.0

9. CHE 211 1.0

10. CSC 207 1.0/ CHE 208 1.0

11. BIO 203 1.0 /MAN 203 1.0/ STA 214 1.0/ PST 214 1.0

12. BIO221 1.0 /EMF 201 1.0 /PST 216 1.0/ MAT 201 1.0

13. CHE 204 1.0 /CSC 203 1.0/ ECN 201 2.0

14. CHE 209 2.0 /CSC 201 2.0 /ECN 202 2.0

15. BIO 201 1.0 /MAN 201 2.0 /STA 213 2.0/ PST 206 1.0

16. BIO 202 2.0 /MAN 202 2.0/ STA 215 2.0/ PST 207 1.0

17. PST 217 1.0/ARM 203 2.0/ EMF213 1.0 /ICT 201 2.0/ FST 252 1.0

18. ARM203 2.0 /EMF 220 1.0 /ICT 203 2.0 /FST 256 1.0

19. ARM 207 2.0/ EMF 221 1.0 /MAT 202 2.0 /FST 281 2.0

20. PBT 221 1.0 /PHY 221 2.0 /FST 278/283

21. PBT 231 1.0 /PHY 222 2.0

22. PBT 226 1.0 /PHY 225 2.0 /FST 270 1.0

23. MAT 204 2.0 /ZOO 215 2.0

For the second year, higher priority is given for the second two hours of the day and next priority is for the first two hours of the day. This method have been used in order to reduce the competition for lecture halls. Usual numbering has been used for Thursday and Friday evenings as in the first year.

Time	Monday	Tuesday	Wednesday	Thursday	Friday
8.00-8.55a.m.	19	11	13	15	17
8.55-9.45 a.m.	20	12	14	16	18
10.15-11.00 a.m.	1	3	5	7	9
11.10-12.00noon	2	4	6	8	10
1.00-2.00 p.m.	21	23	25	27	29
2.00-3.00 p.m.	22	24	26	28	30
3.00-4.00 p.m.	31	33	35	100	100
4.00-5.00 p.m.	32	34	36	100	100
5.00-6.00 p.m.	37	38	39	100	100

Table 4.3: Assignment of costs to the time periods for the second

Since there are 23 different course groups with 45 of one hour time periods,the model would results 1035 (23×45) decision variables andthere are 23 linear equations satisfying the first set of constraints and 45 linearinequalities satisfying the second set of constraint. The same procedure wasfollowed to evaluate the third constraint as in the first year.

4.2.2 Model timetable for the second year using MATLAB

Time	Monday	Tuesday	Wednesday	Thursday	Friday
8.00-8.50	ARM 202 1.0 EMF 204 1.0 ICT 202 1.0 FST284 1.0	PBT 226 1.0 PHY 225 2.0 FST 270 1.0	PBT 227 1.0 PHY 226 1.0	ARM 207 2.0 EMF 221 1.0 MAT 202 2.0 FST 281 2.0	CHE 205 1.0
8.55-9.45	BIO 202 2.0 MAN 202 2.0 STA 215 2.0 PST 207 1.0	PBT 226 1.0 PHY 225 2.0 FST 270 1.0	ZOO 227 1.0	ARM 207 2.0 EMF 221 1.0 MAT 202 2.0 FST 281 2.0	MAT 205 1.0 ZOO 217 1.0
10.15-11.00	BIO 202 2.0 MAN 202 2.0 STA 215 2.0 PST 207 1.0	CHE 204/211 CSC 203 1.0 ECN 201 2.0	CHE 209 2.0 CSC 201 2.0 ECN 202 2.0	ZOO 220 1.0	CSC 207 1.0 CHE 208 1.0
11.10-12.00	BIO 203 1.0 EMF 201 1.0 STA 214 1.0 MAT 201 1.0	CHE 204/211 CSC 203 1.0 ECN 201 2.0	CHE 209 2.0 CSC 201 2.0 ECN 202 2.0	ZOO 218 1.0	
1.00-2.00	PBT 231 1.0 PHY 222 2.0	MAT 204 2.0 ZOO 215 2.0	ARM203 2.0 EMF 220 1.0 ICT 203 2.0 FST 256 1.0	PBT 221 1.0 PHY 221 2.0 FST 278/283	PST 217 1.0 ARM 203 2.0 EMF213 1.0 ICT 201 2.0 FST 252 1.0
2.00-3.00	PBT 231 1.0 PHY 222 2.0	MAT 204 2.0 ZOO 215 2.0	ARM203 2.0 EMF 220 1.0 ICT 203 2.0 FST 256 1.0	PBT 221 1.0 PHY 221 2.0 FST 278/283	PST 217 1.0 ARM 203 2.0 EMF213 1.0 ICT 201 2.0 FST 252 1.0
3.00-4.00	BIO221 1.0 MAN 203 1.0 PST 216 1.0 STA 214 1.0		BIO 201 1.0 MAN 201 2.0 STA 213 2.0 PST 206 1.0		
4.00-5.00			BIO 201 1.0 MAN 201 2.0 STA 213 2.0 PST 206 1.0		
5.00-5.45					

Table 4.4: Model timetable for the second year

4.3 Solution techniques of the timetabling problem for the third year

4.3.1 Graph coloring results

For the third year first semester, totally there are 65 course units. Usingthat conflict matrix another graph with 65 vertices and 1855 edgescould be constructed. For this graph, graph coloring algorithm results 24 color classes with 11 one hour groups and 13 two hour groups.

1. MAT 3031 .0 /ZOO 323 1.0

2. MAT 304 1.0 /ZOO 338 1.0

3. ZOO 340 1.0

4. PBT 382 1.0/ PHY 325 1.0

5. PBT 380 1.0 /PHY 381 1.0

6. ARM 307 1.0 /FSC 332 1.0 /EMF 316 1.0 /ICT 327 1.5

7. BIO 304 1.0 /EMF 312 1.0 /STA 324 1.5

8. BIO 303 1.0 /EMF 311 1.0/ STA 323 1.5 /PST 313 1.0

9. BIO 302 1.0 /MAN 326 1.0 /STA 321 1.5/ PST 301 1.0

10. CHE 312 1.0

11. ARM 306 1.0 /FSC 361 1.0 /EMF 315 1.0 /ICT 328 1.5

12. CSC 312 2.0 /ECN 202 2.0 /CHE309 /340

13. CHE 320 1.0 /CSC 313 2.0

14. CHE 302 1.0 /CSC 314 2.0

15. CHE 319 1.0 /CSC 319 2.0

16. BIO 301 2.0 /MAN 327 2.0 /STA 322 1.5 /PST 307 1.0

17. BIO 305 1.0 /EMF 314 1.0 /MAT 301 2.0

18. ARM308 2.0 /FSC 361 1.0 /EMF 317 1.0 / ICT 326 2.0

19. ARM 311 1.0 /FSC 353 1.0 /EMF 319 1.0 /ICT 329 1.5

20. PBT 381 2.0

21. PBT 383 2.0 /PHY 326 1.0

22. PBT 384 2.0 /PHY 321 /322

23. ZOO 320 2.0

24. MAT 302 2.0 /ZOO 322 2.0

For the third year, usual numbering has been used.

Time	Monday	Tuesday	Wednesday	Thursday	Friday
8.00-8.55a.m.	35	1	3	5	7
8.55-9.45 a.m.	36	2	4	6	8
10.15-11.00 a.m.	9	11	13	15	17
11.10-12.00noon	10	12	14	16	18
1.00-2.00 p.m.	19	21	23	25	27
2.00-3.00 p.m.	20	22	24	26	28
3.00-4.00 p.m.	29	31	33	100	100
4.00-5.00 p.m.	30	32	34	100	100
5.00-6.00 p.m.	37	38	39	100	100

Table 4.5: Assignment of costs to the time periods for the third year

For the 24 different course groups with 45 of one hour time periods, themodel results 1080 (24×45) decision variables and there are 24 linearequations satisfying the first set of constraints and 45 linear inequalities satisfyingthe second set of constraints. The same procedure was followed to evaluatethe third constraint as above.Using the above cost values timetable for of the three years has beengenerated. The summary of the result is given in the next chapter.

4.3.2 Modeled timetable for the third year

Time	Monday	Tuesday	Wednesday	Thursday	Friday
8.00-8.50	MAT 304 1.0 ZOO 338 1.0	MAT 302 2.0 ZOO 322 2.0	CHE 320 1.0 CSC 313 2.0	PBT 384 2.0 PHY 321 /322	CHE 312 1.0
8.55-9.45	ZOO 320 2.0	MAT 302 2.0 ZOO 322 2.0	CHE 320 1.0 CSC 313 2.0	PBT 384 2.0 PHY 321 /322	ARM 311 1.0 FSC 353 1.0 EMF 319 1.0 ICT 329 1.5
10.15-11.00	ZOO 320 2.0	CHE 302 1.0 CSC 314 2.0	PBT 381 2.0	CSC 312 2.0 ECN 202 2.0 CHE309 /340	BIO 303 1.0 EMF 311 1.0 STA 323 1.5 PST 313 1.0
11.10-12.00	PBT 382 1.0 PHY 325 1.0	ZOO 340 1.0 CSC 314 2.0	PBT 381 2.0	CSC 312 2.0 ECN 202 2.0 CHE309 /340	MAT 303 1 .0 ZOO 323 1.0
1.00-2.00	PBT 383 2.0 PHY 326 1.0	BIO 304 1.0 EMF 312 1.0 STA 324 1.5	BIO 301 2.0 MAN 327 2.0 STA 322 1.5 PST 307 1.0	BIO 305 1.0 EMF 314 1.0 MAT 301 2.0	CHE 302 1.0 CSC 314 2.0
2.00-3.00	PBT 383 2.0 PHY 326 1.0	ARM308 2.0 FSC 361 1.0 EMF 317 1.0 ICT 326 2.0	BIO 301 2.0 MAN 327 2.0 STA 322 1.5 PST 307 1.0	BIO 305 1.0 EMF 314 1.0 MAT 301 2.0	CHE 302 1.0 CSC 314 2.0
3.00-4.00	CHE 319 1.0 CSC 319 2.0	ARM308 2.0 FSC 361 1.0 EMF 317 1.0 ICT 326 2.0	ARM 307 1.0 FSC 332 1.0 EMF 316 1.0 ICT 327 1.5		
4.00-5.00	CHE 319 1.0 CSC 319 2.0	BIO 302 1.0 MAN 326 1.0 STA 321 1.5 PST 301 1.0	PBT 380 1.0 PHY 381 1.0		
5.00-5.45	ARM 306 1.0 FSC 361 1.0 EMF 315 1.0 ICT 328 1.5				

Table 4.6: Model timetable for the third year

4.4 Analysis

4.4.1 Distribution of lectures based on the combinations

Table 4.7 shows the distribution of lectures based on the 24 subject combinations over the week for all three years.The complete timetable for the general degree courses of three years of studies over the five weekdays is included in the appendix B. The table reveals that each student in the faculty has lectures at least three days per week up to five days.This implies that lectures have not been scattered to one or two days.

For the first year, students do not have lectures after 3.00 p.m. It is desirable since most of the students do not prefer to have lectures in the late evening.For second year students, only in Wednesdays they have lectures until 5.00 p.m. while in Fridays they don't have lectures after 12.00 noon. And for the third year students have lectures after 4.00 p.m. for first three days of the week while in last two days there are lectures until 3.00 p.m. But most of the third year courses are electives and sometimes some of them can be scheduled simultaneously depending on the students' registrations for those electives. In the questionnaire given, most of the students have mentioned that there are large gap between some lectures in a day. Sometimes they have to wait until 3.00 p.m. from 10.00 a.m. which is a long idle time. In this time table it shows that the maximum gap between two lectures in a day is 3 hours for first year and second year while for the third year the maximum idle time is 4 hours. Some days students in some combinations have a single lecture. Student can utilize these types of idle times through practical classes, since any physical science student has MAT practical and any of the biological students has CHE practical and depending on the combination, they can have practical for other two subjects. Hence the time table would be able to optimize the idle time.

For the comparison complete model timetable and the current timetable is given in Appendix C.

Combination (1 st year)	No of days having lectures per week	Maximum no of lectures per day	Minimum no of lectures per day	Maximum gap between two lectures(hrs)	Combination (2 nd year)	No of days having lectures per week	Maximum no of lectures per day	Minimum no of lectures per day	Maximum gap between two lectures(hrs)	Combination (3 rd year)	No of days having lectures per week	Maximum no of lectures per day	Minimum no of lectures per day	Maximum gap between two lectures(hrs)
B01	5	4	2	3	**B01**	5	6	2	0.5	**B01**	5	6	2	4
B02	5	4	2	3	**B02**	5	5	3	2	**B02**	5	6	3	4
B03	5	5	1	2	**B03**	5	5	1	0.5	**B03**	5	6	2	4
B04	5	4	3	2	**B04**	5	4	1	2	**B04**	5	5	3	3
B05	5	5	2	2	**B05**	5	6	1	0.5	**B05**	5	5	2	4
B06	5	4	3	3	**B06**	5	4	1	2	**B06**	5	5	3	2
B07	5	5	2	2	**B07**	5	4	2	3	**B07**	5	6	2	3
B08	4	4	2	3	**B08**	4	5	2	2	**B08**	4	5	2	3
B09	3	5	2	3	**B09**	3	5	2	3	**B09**	3	5	2	3
B10	4	6	1	2	**B10**	4	5	2	2	**B10**	4	6	1	2
B11	5	5	1	3	**B11**	5	5	2	2	**B11**	4	3	1	1
B12	5	4	2	3	**B12**	5	6	2	3	**B12**	5	6	2	2
C01	5	4	3	3	**C01**	5	5	1	1	**C01**	5	4	2	3
C02	5	6	2	3	**C02**	5	4	2	2	**C02**	5	4	2	2
C03	5	4	2	2	**C03**	5	4	3	3	**C03**	5	5	3	2
P01	5	4	2	1	**P01**	5	6	2	2	**P01**	5	6	1	2
P02	5	6	2	3	**P02**	5	4	2	2	**P02**	5	4	2	3
P03	4	5	2	1	**P03**	5	6	1	3	**P03**	5	4	3	2
P04	5	6	2	3	**P04**	5	4	2	3	**P04**	5	4	1	3

P05	4	4	2	1	**P05**	5	6	3	3	**P05**	4	4	3	2
P06	5	5	1	1	**P06**	5	4	2	2	**P06**	5	6	3	4
P07	4	4	2	1	**P07**	4	5	2	2	**P07**	4	6	2	1
P08	5	4	1	0.5	**P08**	5	4	2	2	**P08**	4	5	2	2
P09	5	4	1	0.5	**P09**	5	4	2	2	**P09**	5	4	1	2
Maximum	**5**	**6**	**3**	**3**	**Maximum**	**5**	**6**	**3**	**3**	**Maximum**	**5**	**6**	**3**	**4**
Mode	**5**	**4**	**2**	**3**	**Mode**	**5**	**4**	**2**	**2**	**Mode**	**5**	**6**	**2**	**2**

Table 4.7: Analysis of the timetable based on the combinations

It is generally believe that it is difficult to conduct Mathematics lectures in the afternoons. In the existing time table,students from all three years have at most one Mathematics lecture in the evening.

From the modeled timetable it was able to reduce it to one. That is there exists only one Mathematics lecture for the second year students at 1.00 to 2.00 p.m.

4.4.2 Analysis of the lecture halls requirements

Through the analysis of the complete timetable, number of lecture halls required from each of the three categories for each time period over the week can be obtained.

The graph shown in the Figure 4.2, Figure 4.3 and Figure 4.4 gives the number of lecture halls required to conduct lectures for all three years at each time period from category1(Large), category 2 (Medium) and category 3 (Small) respectively.

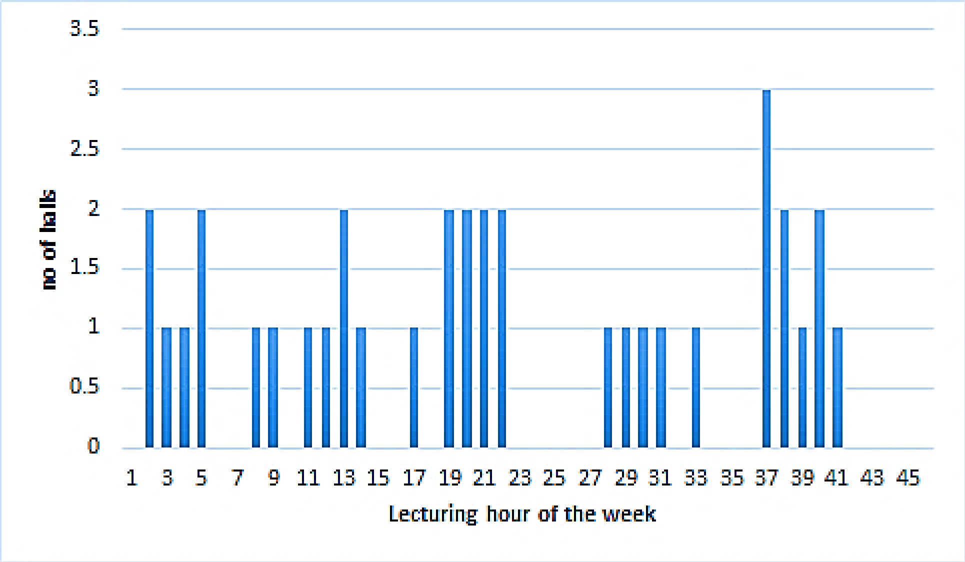


Figure 4.2: Distribution of the requirement of the category 1 lecture halls

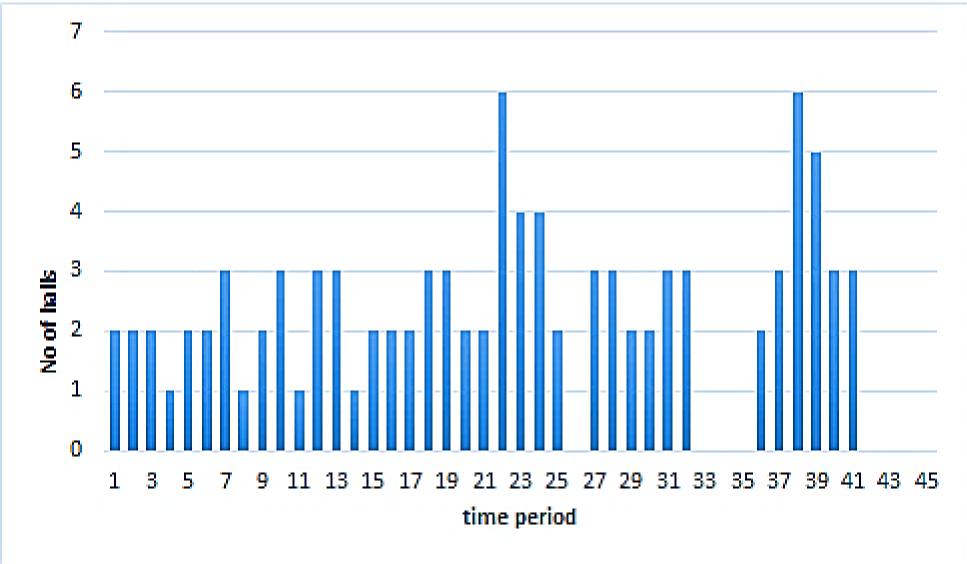


Figure 4.3: Distribution of the requirement of the category 2 lecture halls

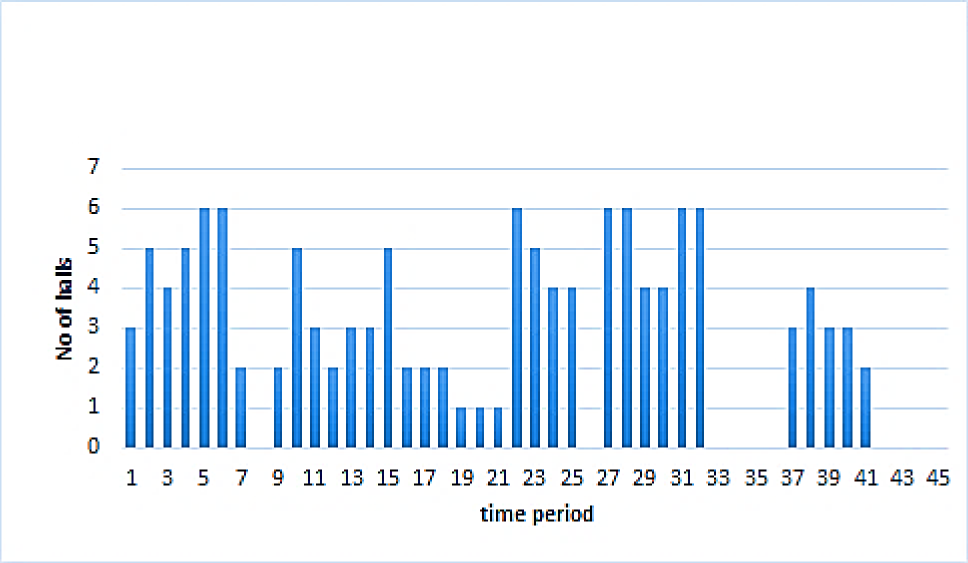


Figure 4.4: Distribution of the requirement of the category 3 lecture halls

The graphs show that the maximum number of halls required from cateory1 is 3 at any time period of the week and the mode of the distribution is 1. It shows that the maximum number of halls required from both category 2 and category 3 is 6 at any time period of the week, and the modes of the two distributions are 3 and 2 respectively. So if the faculty can maintain 3 large lecture halls, 6 medium size lecture halls and 6 small size lecture halls, the resulted automated time table is feasible.

If one looks at the availability of such lecture halls in present as mentioned in chapter 4 it has 3 large lecture halls, 6 medium size halls and 8 small size lecture halls. So the requirement of a feasible timetable is satisfied with the available resources in the faculty.

CHAPTER 5

CONCLUSION

First semester course unit timetable of FAS, USJP has been modeled in this study. For the model formulation, both graph theoretic and ILP approach has been used. For the three years of studies, timetables were modeled separately and finally three of them were joined together to analyze the feasibility. Using graph vertex coloring algorithm course units were grouped such a way that two course units in the same group can be scheduled simultaneously while two course units in two groups cannot. For the first year, graph coloring algorithm results 20 groups and for the second and third years there are 23 and 24 groups respectively.

Using those resulted groups of course units a binary ILP model has been defined for each of the three years. The uniqueness property and the completeness property were defined as the hard constraints which are the essential parts for a feasible timetable while the objective (soft constraint) of optimizing the timetable is given as the objective function of the ILP. Hence the objective is to minimize the cost of assigning courses to time periods. When constructing the timetable it was assumed that teacher will not become a constraint to the solution where allocation of teachers to course units is a responsibility of the department which the subject is offering. Further it was assumed that lecture halls belong to each department is accessible to all departments. With those assumptions, it was able to model a conflict free efficient timetable for the FAS. The model was able to optimize the idle time of the students by reducing the maximum idle time to three hours. Further it was able to implement the result with the currently available lecture halls. Hence this model helps to utilize both physical and human (student) resources in the faculty.

The problem was solved effectively for the first semester which can be extended to the second semester and it can be used for other faculties as well.However, the size of the problem creates complications in achieving an optimum solution. It is therefore necessary to find a way of decreasing machine time, which has not been discussed here.

5.1 Limitations of the Study

This study was conducted with the data collected in 2015. But this data can be changed year by year. Some combinations have been introduced in 2015 which are not offered to third year students. But for the comparison it is assumed that those are offering to all students.

The number of students in each subject depends on the year of the study. Here it has taken to be fixed for all three years for the categorization of subjects and lecture halls. The ordering of course unit groups are taken to be arbitrary, since one cannot give preferences to the subjects. But in departmental level they have their own preferences which are difficult to absorb. If some ordering method can be applied, one would obtain more efficient results.

This study has not considered the distance that the students have to walk when they transferring from one lecture to the other. Here we have assumed that any student is able to access to any of the lecture halls within 10 minutes. But the present some physical science subjects are not conducted in some biology lecture halls and vice versa.

5.2 Further Improvements and Suggestions

This study only searched for a feasible and efficient course unit timetable. Basically it was suggested for the optimization of lecturing hours. The analysis revealed that it can be implemented with the available resources, but it does not allocate each course unit to a lecture hall. As a suggestion it would be assigned using an assignment algorithm such as Hungarian algorithm by further analysis.

Another problem that the faculty management faces is the scheduling the practical sessions. For the subjects, MAT, PHY, CHE, ZOO, PST, ARM, BIO, STA, CSC, ICT and FST, students are having practical. With the limited capacity of laboratories the same practical is repeated several times per week by grouping students. This situation has not been considered in this study, since it requires the data separately from the departments. Hence one can further develop this result by scheduling the practicalsessions.

The timetable which has been modeled only resulted the scheduling of general lectures. But for the fourth year students their special course units have not been scheduled. Mostly the special timetable is decided by the department involved. But if one interests it can be also scheduled by offering a departmental timetable.

One objective of this study is to minimize the wastage of the resources used in the timetabling process, both human and physical resources. An automated system will probably reduce such wastage of human resources, but a detailed cost analysis has not done due to the difficulties in getting information. Having such data a cost analysis can be done and the adequacy of this model would be further verified.

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APPENDIX A-QUESTIONNAIRE

Questionnaire on the faculty time table

This questionnaire is part of a research which intends to gather responses from students at the Faculty of Applied Sciences related to the master time table of the faculty.

By completing this form you will be making an important contribution to redesign the time table in an efficient way.

Background information

1. Your year of Study

   ☐ First ☐ Second ☐ Third ☐ Special

2. Your Stream Of Study

   ☐ Physical ☐ Biological ☐ Other

3. You are coming to the university from:

   ☐ Home ☐ Boarding ☐ Hostel ☐ Other

4. Time taken to travel from your residence to the university

   ☐ Less than a half an hour ☐ Around an hour ☐ More than an hour

Preferences of Lecture Halls

5. Rank the following lecture halls as you prefer for lectures for a group with more than 100 students (1-for highest preference, 2 for the next, etc.)

   ☐ Science Auditorium (S1) ☐ Biology Auditorium (A1)

   ☐ Chemistry Lecture Theatre 1 (C1) ☐ New Faculty Complex

   ☐ Chemistry Lecture Theatre 2 (C2)

   ☐ Physics Lecture Theatre 1 (P1)

6. Your most preferred time to attend the lectures

   ☐ Morning (8-12) ☐ Afternoon (1-3) ☐ After 3 p.m.

7. Rank the days of the week for morning lectures in your preference order.

   ☐ Monday ☐ Thursday
   ☐ Tuesday ☐ Friday
   ☐ Wednesday

8. Rank the days of the week for evening lectures in your preference order.

   ☐ Monday ☐ Thursday
   ☐ Tuesday ☐ Friday
   ☐ Wednesday

9. Your most preferred time for practical classes

   ☐ Morning (8-12) ☐ Afternoon (1-3) ☐ After 3 p.m.

10. Your preference on maximum time gap between two consecutive lectures

    1 30 minutes
    2 60 minutes
    3 More than 60 minutes

11. Do you prefer to have a free day within the week days while having frequent lectures on other days?

    ☐ Yes ☐ No

12. State any other issues that you are facing with the current time table.

Many thanks for your time.

<u>Responses of the second year physical science students:</u>

Note: The numbers represent the rankings of the students for each time periods and days.

Student no	lecture-time	Monday morning	Tuesday morning	Wednesday morning	Thursday morning	Friday morning	gap
1	1	4	1	3	4	5	2
2	2	2	1	3	4	5	2
3	1	1	1	2	4	5	2
4	1	4	1	2	3	5	1
5	1	3	1	3	3	4	1
6	1	1	2	3	3	4	1
7	1	3	1	3	2	4	1
8	2	1	2	2	2	4	3
9	1	1	1	2	3	4	2
10	2	2	1	3	3	4	2
11	1	4	2	3	3	4	1
12	1	4	3	3	3	5	2
13	1	1	2	3	3	4	2
14	1	1	1	3	3	5	1
15	1	2	2	3	3	5	2
16	1	3	1	3	3	5	2
17	1	4	1	2	3	5	2
18	1	3	1	2	3	5	2
19	1	2	2	2	3	5	2
20	1	2	2	2	3	5	2
21	1	2	2	2	3	5	1
22	1	3	2	2	2	5	3
23	1	3	1	2	2	5	1
24	2	3	1	2	4	5	1
25	2	3	1	3	4	5	1
26	1	3	2	3	2	5	1
27	2	3	2	3	3	5	2
28	1	3	2	3	4	5	2
29	1	4	1	3	2	5	2
30	1	1	1	3	3	5	2
31	1	4	1	3	3	5	1
32	2	4	2	3	3	5	2
33	1	4	3	3	4	5	2
34	1	3	1	3	4	5	1
35	1	2	1	2	4	5	1
36	1	3	1	2	4	5	1
37	1	2	2	2	3	5	2

38	1	2	2	2	4	4	1
39	2	2	2	2	3	4	2
40	2	2	2	2	3	5	2
41	1	2	2	2	3	5	2
42	1	4	2	3	3	5	2
43	1	4	3	3	3	5	2
44	1	4	1	3	3	5	2
45	1	4	1	3	3	5	2
46	1	4	1	3	3	5	1
47	2	4	1	3	3	5	1
48	1	4	1	3	3	5	1
49	1	4	1	3	3	5	2
50	1	3	1	3	4	5	1
51	1	1	2	3	4	5	1
52	2	3	1	3	3	5	2
53	1	3	2	3	3	5	2
54	2	3	1	2	3	4	2
55	2	2	1	2	3	4	2
56	2	1	1	2	3	4	2
57	2	1	2	2	3	3	2
58	1	3	3	2	4	4	3
59	1	3	1	2	4	4	2
60	1	1	1	2	3	5	2
61	1	1	2	2	3	5	2
62	1	3	2	2	3	5	2
63	1	3	1	3	3	5	2
64	1	3	1	3	3	5	2
65	1	3	2	3	3	5	1
66	1	3	2	2	3	5	3
67	1	4	1	3	3	5	1
68	1	4	2	3	3	5	1
69	1	3	1	3	3	5	2
70	1	2	1	3	3	5	1
71	1	3	1	2	3	5	2
72	1	4	2	2	3	5	2
73	1	2	2	2	3	5	2
74	1	1	2	2	3	5	1
75	1	1	2	2	4	4	1
76	1	4	1	2	2	4	2
77	1	3	1	2	3	5	3
78	1	1	2	2	3	5	3
79	1	3	1	2	3	5	1
80	1	3	1	2	3	5	1
81	1	2	1	2	4	5	1

82	1	2	1	2	4	5	2
83	1	1	1	2	4	5	1
84	1	4	1	2	4	5	2
85	1	3	1	2	4	5	2
86	1	2	2	2	4	4	3
87	1	2	1	2	4	4	1
88	1	2	1	2	4	4	1
89	1	2	1	2	4	4	1
90	1	2	1	2	3	4	2
91	1	3	2	3	3	4	1
92	1	1	2	3	3	4	2
93	2	2	1	3	3	4	2
94	1	2	2	2	3	4	2
95	1	2	1	3	3	4	2
96	1	2	2	3	2	4	2
97	1	3	2	2	3	4	2
98	2	3	2	2	3	5	2
99	1	3	2	2	3	5	1
100	1	3	1	2	3	5	1
101	1	2	1	2	3	5	1
102	1	2	1	3	3	5	1
103	1	2	1	3	4	5	1
104	1	2	1	2	4	4	2
105	1	2	1	2	4	4	1
106	1	2	2	2	4	5	2
107	1	2	2	2	4	5	1
108	1	2	1	2	3	5	2
109	1	3	2	2	3	5	2
110	1	2	1	2	3	5	2
111	1	3	1	2	3	5	2
112	1	4	1	3	3	5	2
113	1	3	1	2	2	5	2
114	1	4	1	2	3	5	1
115	1	4	1	3	3	5	1
116	1	3	1	3	3	5	1
117	1	3	1	3	3	5	1
118	1	3	1	3	3	5	1
119	1	4	2	3	3	5	1
120	1	1	2	2	3	5	1
121	1	2	2	2	3	5	1
122	2	2	2	2	3	5	2
123	1	3	1	3	3	5	2
124	1	4	1	3	4	5	2
125	1	3	1	3	4	5	1

126	1	4	1	3	2	5	3
127	1	3	1	2	3	5	1
128	1	4	1	2	3	5	2
129	1	4	1	2	3	5	1
130	1	4	1	2	3	5	2
131	1	3	2	2	3	5	2
132	1	2	2	2	3	5	2
133	2	3	2	3	3	5	1
134	1	2	2	3	3	5	2
135	1	3	2	3	4	5	2
136	1	2	1	3	4	5	1
137	1	3	2	2	4	5	2
138	1	2	1	2	2	5	1
139	1	3	1	2	3	5	2
140	1	3	1	1	3	5	1
141	1	3	1	1	3	5	2
142	1	3	2	2	3	5	1
143	1	4	1	2	3	5	2
144	1	2	1	2	3	5	2
145	1	2	2	2	3	5	1
146	1	2	1	2	4	5	1
147	1	3	2	2	2	5	1
148	1	2	2	2	3	5	1
149	2	2	1	1	3	5	1
150	1	3	1	1	3	4	2

Responses of the second year Biological science students:

Student no	lecture-time	Mondaymorning	Tuesdaymorning	Wednesdaymorning	Thursdaymorning	Fridaymorning	gap
2	2	3	1	2	4	5	2
3	1	1	2	3	4	5	1
4	1	1	2	3	5	4	1
5	1	1	2	3	4	5	1
6	1	1	2	3	4	5	2
7	1	1	2	3	4	5	2
8	2	1	2	3	4	5	2
9	1	1	2	3	4	5	1
10	2	1	2	3	5	4	1
11	2	1	2	3	4	5	1
12	2	1	2	3	4	5	3
13	2	1	2	3	4	5	2
14	1	2	1	3	4	5	2
15	1	2	1	3	4	5	1
16	1	2	1	3	4	5	1
17	1	3	1	2	4	5	3
18	1	1	3	2	4	5	3
19	1	3	1	2	4	5	1
20	1	3	1	2	5	4	3
21	1	3	1	2	4	5	1
22	1	3	1	2	4	5	1
23	1	2	1	3	4	5	2
24	2	2	1	3	4	5	2
25	2	1	2	3	4	5	2
26	1	1	2	3	4	5	2
27	2	1	2	3	4	5	2
28	1	3	2	1	4	5	2
29	1	2	3	1	4	5	1
30	1	2	1	3	4	5	3
31	1	1	2	3	4	5	3
32	2	2	1	3	4	5	1
33	1	1	2	3	4	5	1
34	1	3	1	2	4	5	2
35	1	1	3	2	4	5	3
36	1	2	1	3	4	5	1
37	2	1	2	3	4	5	1
38	2	2	1	3	4	5	2

39	2	1	2	3	4	5	2
40	2	3	1	2	4	5	2
41	1	2	1	3	4	5	1
42	1	1	2	3	4	5	2
43	1	2	1	3	4	5	1
44	1	3	1	2	4	5	2
45	1	2	1	3	4	5	1
46	1	1	2	3	4	5	2
47	2	1	2	3	4	5	1
48	1	1	2	3	4	5	3
49	1	2	1	3	4	5	2
50	1	1	2	3	4	5	1
51	1	3	1	2	4	5	2
52	2	2	1	3	4	5	2
53	1	1	2	3	4	5	3
54	2	1	2	3	4	5	1
55	2	1	2	3	4	5	1
56	1	1	2	3	4	5	2
57	1	2	1	3	4	5	1
58	1	1	2	3	4	5	2
59	1	1	2	3	4	5	2
60	1	3	1	2	4	5	3
61	1	2	1	3	4	5	2
62	1	2	1	3	4	5	2
63	1	1	2	3	4	5	2
64	1	1	2	3	4	5	2
65	1	1	2	3	4	5	1
66	1	3	1	2	4	5	1
67	1	3	1	2	4	5	2
68	1	3	1	2	4	5	1
69	1	3	1	2	4	5	2
70	1	2	1	3	4	5	1
71	1	1	2	3	4	5	1
72	1	2	1	3	4	5	2
73	1	1	2	3	4	5	1
74	1	2	1	2	4	5	2
75	1	1	2	3	4	5	1
76	1	3	1	2	4	5	2
77	1	1	2	3	4	5	1
78	1	2	1	3	4	5	1
79	1	2	1	3	4	5	2
80	1	1	3	2	4	5	1
81	1	1	2	3	4	5	2
82	1	3	1	2	4	5	1
83	1	1	2	3	4	5	2

84	1	2	1	3	4	5	1
85	1	1	2	3	4	5	2
86	1	1	2	3	4	5	1
87	2	1	2	3	4	5	2
88	2	1	2	3	4	5	1
89	2	2	1	3	4	5	2
90	1	2	1	3	4	5	1
91	1	1	2	3	4	5	2
92	2	1	2	3	4	5	1
93	2	3	1	2	4	5	2
94	1	1	2	3	4	5	2
95	1	2	1	3	4	5	2
96	1	3	1	2	4	5	2
97	1	3	1	2	4	5	2
98	2	3	1	2	4	5	2
99	2	3	1	2	4	5	2
100	1	2	1	3	4	5	1
101	1	2	1	3	4	5	1
102	1	2	1	3	4	5	1
103	1	1	2	3	4	5	1
104	1	1	2	3	4	5	2
105	1	2	1	3	4	5	2

Responses of the first year students

Student no	lecture-time	Mondaymorning	Tuesdaymorning	Wednesdaymorning	Thursdaymorning	Fridaymorning	Gap
1	1	3	1	2	4	5	2
2	2	3	1	2	4	5	2
3	1	3	1	4	2	5	2
4	1	2	1	3	4	5	3
5	1	2	1	4	3	5	3
6	1	2	1	5	3	4	1
7	2	2	1	3	4	5	2
8	1	1	2	3	4	5	3
9	2	1	2	3	4	5	2
10	2	2	1	3	4	5	2
11	2	1	2	3	4	5	2
12	2	3	1	2	5	4	2
13	2	2	1	3	4	5	2
14	1	2	1	3	4	5	2
15	2	3	1	2	4	5	2
16	2	3	1	2	4	5	2
17	2	2	1	3	4	5	1
18	2	2	1	3	4	5	2
19	1	1	2	3	4	5	3
20	1	3	1	2	4	5	2
21	2	3	1	2	5	4	3
22	1	1	3	2	4	5	3
23	2	3	1	2	4	5	1
24	1	2	1	3	4	5	1
25	1	3	2	1	4	5	1
26	2	3	1	2	4	5	1
27	2	3	1	2	4	5	1
28	2	2	3	1	4	5	1
29	1	2	1	3	4	5	3
30	1	1	2	3	4	5	2
31	1	1	2	3	4	5	1
32	1	1	2	3	4	5	3
33	2	1	2	3	4	5	3
34	1	1	2	3	4	5	3
35	1	2	1	3	4	5	1
36	1	2	1	3	4	5	1
37	2	2	1	3	4	5	2

38	1	2	1	3	4	5	2
39	2	2	1	3	4	5	3
40	1	2	3	1	4	5	2
41	1	4	3	1	2	5	3
42	1	1	2	3	4	5	2
43	1	1	2	3	4	5	3
44	1	2	1	3	4	5	2
45	1	2	1	3	4	5	3
46	2	3	1	2	4	5	2
47	2	1	2	3	4	5	3
48	2	2	3	1	4	5	2
49	1	2	1	3	4	5	1
50	1	3	1	2	4	5	2
51	1	3	1	2	4	5	1
52	2	3	1	2	4	5	1
53	1	3	1	2	4	5	1
54	2	3	1	2	4	5	2
55	1	1	2	3	4	5	1
56	2	1	2	3	4	5	2
57	1	2	1	3	4	5	2
58	2	1	2	3	4	5	2
59	1	1	2	3	4	5	2
60	2	3	2	1	4	5	2
61	1	3	1	2	4	5	3
62	2	1	2	3	4	5	1
63	1	2	1	3	4	5	2
64	2	1	2	3	4	5	2
65	1	2	1	3	4	5	3
66	2	1	2	3	4	5	3
67	1	2	3	1	4	5	2
68	1	2	1	3	4	5	2
69	1	2	1	3	4	5	1
70	1	2	1	3	4	5	1
71	1	2	1	3	4	5	1
72	1	2	1	3	4	5	3
73	1	2	1	3	4	5	2
74	1	2	1	3	4	5	2
75	1	2	1	3	4	5	2
76	2	2	1	3	4	5	2
77	2	2	1	3	4	5	2
78	2	2	1	3	4	5	2
79	2	2	1	3	4	5	1
80	2	2	1	3	4	5	1
81	1	3	1	3	4	5	1
82	2	3	1	3	4	5	3

83	1	1	2	4	3	5	2
84	1	2	1	4	3	5	2
85	1	1	2	3	4	5	2
86	1	2	1	3	4	5	2
87	2	1	2	3	4	5	2
88	1	3	2	1	4	5	2
89	2	3	1	2	4	5	3
90	1	3	1	2	4	5	3
91	2	2	1	3	4	5	2
92	1	2	1	3	4	5	2
93	2	1	2	3	4	5	1
94	1	2	1	3	4	5	2
95	2	2	1	3	4	5	2
96	1	2	1	3	4	5	2
97	2	2	3	1	4	5	1
98	1	2	1	3	4	5	1
99	1	3	1	2	4	5	2
100	1	3	2	1	4	5	1
101	1	3	1	2	4	5	1
102	1	1	2	3	4	5	1
103	1	2	1	3	4	5	1
104	2	1	2	3	4	5	1
105	2	2	1	3	4	5	1
106	1	1	2	3	4	5	2
107	2	2	1	3	4	5	1
108	1	2	1	3	4	5	2
109	2	3	1	2	4	5	3
110	1	3	1	2	4	5	1
111	2	3	1	2	4	5	1
112	1	1	2	4	3	5	2
113	2	1	2	3	4	5	2
114	1	1	2	3	4	5	2
115	2	1	2	3	4	5	1
116	1	2	1	4	3	5	2
117	2	2	1	3	4	5	1
118	1	2	1	3	4	5	2
119	2	3	1	2	4	5	2
120	2	3	2	1	4	5	2
121	2	3	2	1	4	5	2
122	2	3	2	1	4	5	2
123	2	1	2	4	3	5	2
124	1	1	2	3	4	5	2
125	1	2	1	3	4	5	2
126	1	1	2	3	4	5	1
127	2	2	1	3	4	5	1

128	1	1	2	3	4	5	1
129	2	2	1		4	5	1
130	1	2	1	3	4	5	1
131	2	1	2	3	4	5	2
132	1	2	1	3	4	5	2
133	2	3	1	2	4	5	2
134	1	3	2	1	4	5	1
135	2	2	1	3	4	5	2
136	2	1	2	3	4	5	1
137	2	1	2	3	4	5	2
138	1	2	1	3	4	5	1
139	1	2	1	3	4	5	3
140	1	2	1	3	4	5	1
141	1	3	1	2	4	5	1
142	2	1	2	3	4	5	1
143	1	2	1	3	4	5	1
144	2	1	2	3	4	5	1
145	1	2	1	3	4	5	1
146	2	1	2	3	4	5	1
147	1	2	1	3	4	5	1
148	2	1	2	3	4	5	1
149	1	2	1	3	4	5	1
150	2	2	1	3	4	5	1
151	1	2	1	3	4	5	1
152	2	2	1	3	4	5	1
153	1	3	2	1	4	5	2
154	2	3	1	2	4	5	2
155	2	1	2	3	4	5	2
156	1	3	1	2	4	5	2
157	1	2	1	3	4	5	2
158	2	1	2	3	4	5	1
159	2	3	1	2	4	5	1
160	1	1	2	3	4	5	1
161	2	2	1	3	4	5	1
162	1	2	1	3	4	5	1
163	2	2	1	3	4	5	3
164	2	2	1	3	4	5	2
165	2	2	1	3	4	5	1
166	1	2	1	3	4	5	2
167	1	2	1	3	4	5	1
168	1	3	2	1	4	5	2
169	1	3	1	2	4	5	1
170	1	1	2	3	4	5	2
171	1	1	2	3	4	5	1
172	2	3	1	2	4	5	2

173	2	3	1	2	4	5	2
174	1	2	1	3	4	5	2
175	2	2	1	3	4	5	2
176	2	3	2	1	4	5	2
177	2	1	2	3	4	5	2
178	1	1	2	3	4	5	2
179	2	3	1	2	4	5	2
180	2	2	1	3	4	5	2
181	1	2	1	3	4	5	2
182	1	2	1	3	4	5	1
183	1	2	1	3	4	5	1
184	1	2	1	3	4	5	1
185	1	3	1	2	4	5	1
186	1	3	1	3	4	5	1
187	1	3	1	2	4	5	1
188	2	3	1	2	4	5	1
189	1	1	2	3	4	5	3
190	1	2	3	1	4	5	2
191	1	2	1	3	4	5	2
192	2	3	2	1	4	5	2
193	2	2	1	2	4	5	3
194	1	1	2	3	4	5	2
195	1	2	1	3	4	5	2
196	1	3	1	2	4	5	2
197	1	2	1	3	4	5	2
198	1	1	2	3	4	5	2
199	1	2	1	3	4	5	2
200	1	2	1	3	4	5	2

APPENDIX B

Maple 12 coding for graph coloring

Maple results of initial coloring

> restart; with(GraphTheory);

>A := matrix([[CHE, ZOO, PHY, PBT, EMF, ARM, BIO, ICT, MAN, PST, MAT, CSC, STA, ECN, FSC]]);

>G2 := Graph(A, ARM, BIO, ARM, CHE, ARM, MAN, ARM, ZOO, BIO, CHE, BIO, FSC, BIO, ICT, CHE, EMF, CHE, FSC, CHE, ICT, CHE, MAN, CHE, MAT, CHE, PBT, CHE, PHY, CHE, PST, CHE, STA, CHE, ZOO, CSC, MAT, CSC, PHY, CSC, STA, ECN, MAT, ECN, STA, EMF, MAN, EMF, PBT, EMF, PHY, EMF, ZOO, ICT, MAT, ICT, PHY, MAN, MAT, MAN, PBT, MAN, PHY, MAN, ZOO, MAT, PHY, MAT, STA, PBT, ZOO, PHY, PST, PHY, STA, PHY, ZOO);

>IsVertexColorable(G2, 5, 'Co'); true

> Co; [[CHE, CSC, ECN], [ARM, EMF, FSC, ICT, PST, STA], [BIO, MAN], [PBT, PHY],
[MAT, ZOO]]

Maple results of the coloring the first year course units.

Gnew1 := Graph(V1, E1)

Gnew1 := ‘Graph 3: a directed unweighted graph with 55 vertices and 1183 arc(s)‘

>IsVertexColorable(Gnew1, 20, 'Co1');

true

> Co1;

[1, 6, 9], [2, 7, 10], [3, 8], [4], [5], [11, 14, 27, 36, 39], [12, 15, 28, 37, 40], [13, 16, 29,38, 41],[17, 23, 30, 32, 42], [18, 24, 31, 33], [19, 25, 34,

43], [20, 26, 35, 44],[21, 45, 46], [49, 52], [50, 53], [51, 54], [55], [22, 47], [48]]

Maple results of the coloring the Second year course units.

>Gnew2 := Graph(V2, E2);

Gnew2 := ‘Graph 2: a directed unweighted graph with 62 vertices and 1482 arc(s)‘

>IsVertexColorable(Gnew2, 23, ’Co2’);

true;

> Co2; [[1, 6, 9], [2, 7, 10], [3, 8], [4], [5], [11, 15, 22, 30, 33], [12, 16, 23, 31, 34], [13, 17, 24, 32, 35], [14, 25, 36, 46], [18, 26, 27, 37, 56], [19, 28, 38, 57], [20, 29, 39, 58], [21, 40, 42, 59], [41, 43, 60], [47, 50, 61], [48, 51, 62], [49, 52], [53], [54], [55], [44], [45]]

Maple results of the coloring the Third year course units.

>Gnew3 := Graph(V3, E3);

Gnew3 := ‘Graph 2: a directed unweighted graph with 65 vertices and 1719 arc(s)‘

>IsVertexColorable(Gnew3, 24, ’Co3’);

true

[1, 7, 12], [2, 8, 13], [3, 9], [4, 10], [5, 11], [6], [14, 19, 29, 40, 44], [15, 20, 30,41, 45], [16, 31, 42, 46], [17, 32, 43], [18, 33, 52], [21, 25, 34, 36], [22, 26, 35,37], [23, 27, 38, 47], [24, 28, 39, 48], [49, 53], [50, 54], [51, 55], [56, 61], [57,62], [58, 63], [59, 64], [60, 65],[57]]

MATLAB 14 codes to execute the linear programming model and to generate the time table.

```
function Time=SemesterI_TimeTable(Year)
Time=Year;
if Time==1

%import data
[l1]=xlsread('Grouping.xlsx','onehr');
[l2]=xlsread('Grouping.xlsx','twohr');
[T1]=xlsread('Grouping.xlsx','Timeslots');

C1=length(l1); C2=length(l2);
t_courses=length(l1)+length(l2); % total no of courses
n_times=length(T1); %total no of time slots
variables=t_courses*n_times;

% First constraint-matrix A1 for the completness property
l=1;u=n_times;
A1=zeros(t_courses,variables); %initializing
fori=1:t_courses
for q=l:u
A1(i,q)=1;
end
l=u+1;
u=u+n_times;
end



% H is the array representimg the duration for each
course
H=ones(C1+C2,1); %initializing
```

```
fori=C1+1:t_courses
H(i)=2;
end
%Second constraint-matrix A2 represents conflicts free
A2=zeros(n_times,variables);% initializing

fori=1:n_times
for q=1:t_courses
A2(i,n_times*q+i-n_times)=1;
end
end
% B is the array with ones-r.h.s. of the constraints
 B=ones(n_times,1);
% integer linear program
intcon=1:756; % all decision variables are integers

% z is the objective function
 z=zeros(variables,1);
k=1;
fori=1:t_courses
for q=1:n_times
z(k)=sqrt(q)+1;
k=k+1;
end
end
% giving lower and upper bounds for decision
variables(binary)
lb=zeros(variables,1);
ub = ones(variables,1);
% y is the solution of the ILP
y=intlinprog(z,intcon,A2,B,A1,H,lb,ub);

% representing the solution in to matrix
```

```
n=1;X=zeros(C1+C2,n_times);
for p=1:C1+C2
for q=1:42
X(p,q)=y(n);
       n=n+1;
end
end
TT=zeros(1,45);%dummy timetable
%Courses=1:C1+C2;

fori=1:C1+C2
for j=1:n_times
if X(i,j)==1
TT(j) = i;

end
end
end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
    TimeTable1=zeros(9,5);%represent only the group
numbers
  %Table gives values for each timeperiod according to
preferences
Table1=[1,2,3,4,5;6,7,8,9,10;11,12,13,14,15;16,17,18,19,2
0;21,22,23,24,25,;26,27,28,29,30;31,32,33,100,35;36,37,10
0,100,100;41,42,100,100,100];

fori=1:9
for j=1:5
for k=1:45
if Table1(i,j)==k
TimeTable1(i,j)= TT(k);

end
```

```
end
end
end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
  %following loop will assign consecutive time periods
fori=C1+1:t_courses
for p=1:9
for q=1:5
if TimeTable1(p,q)==i
for t=1:9
for s=1:5
if (t~=p && s~=q)
if TimeTable1(t,s)==i
TimeTable1(t,s)=TimeTable1(p+1,q);
TimeTable1(p+1,q)=i;
end;
end
end
end
end
end
end
end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Adjust the two hrs in 11-12
i=4;
for k=C1+1:t_courses
for j=1:5
if (TimeTable1(i,j)==k && TimeTable1(i+1,j)==k)

TimeTable1(i,j)=0;
TimeTable1(i+2,j)=k;
end
end
```

```
end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
GUI Table
[credit,courseunit,compose]=xlsread('Grouping.xlsx','Shee
t2');

NewTable=cell(9,5);
fori=1:9
for j=1:5
for p=1:t_courses

if compose{p,2}==TimeTable1(i,j)
NewTable{i,j}=compose{p,1};

end
end
end
end
f = figure('Position',[0 0 1 1]);
set(f,'unit','normalized');
% Column names and column format
columnname =
{'Monday','Tuesday','Wednesday','Thursday','Friday'};
%columnformat = {'char','char','char','char','char'};
columnformat =
{'numeric','numeric','numeric','numeric','numeric'};


FontSize = 9;
FontWeight='bold';
```

```
rownames = {'8.00-8.50','8.55-9.45','10.15-11.05','11.10-
12.00','1.00-2.00','2.00-3.00','3.00-4.00','4.00-
5.00','5.00-5.45'};
% Define the data
fori=1:9
for j=1:5
d{i,j}=NewTable{i,j};

end
end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% Create the uitable
t = uitable('Data', d,...
            'ColumnName', columnname,...
            'ColumnFormat', columnformat,...
                'ColumnWidth',{300 },...
            'FontSize',FontSize,...
            'FontWeight',FontWeight,...
             'RowName',rownames);
%set(t,'BackgroundColor',[0 0.9 1]);
end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if Time==3

[l1_3]=xlsread('Grouping3.xlsx','onehr');
[l2_3]=xlsread('Grouping3.xlsx','twohr');
[T1_3]=xlsread('Grouping.xlsx','Timeslots');
C1_3=length(l1_3); C2_3=length(l2_3);
t_courses3=length(l1_3)+length(l2_3); % total no of
courses
n_times=length(T1_3); %total no of time slots

l=1;u=n_times;
```

```
A1_3=zeros(t_courses3,t_courses3*n_times); %initializing
fori=1:t_courses3
for q=l:u
   A1_3(i,q)=1;
end
l=u+1;
u=u+n_times;
end
H_3=ones(C1_3+C2_3,1); %initializing

fori=C1_3+1:t_courses3
    H_3(i)=2;
end
A2_3=zeros(n_times,t_courses3*n_times);% initializing

fori=1:n_times
for q=1:t_courses3
    A2_3(i,n_times*q+i-n_times)=1;
end
end

B_3=ones(n_times,1);

% integer linear program
intcon=1:1008; % all decision variables are integers

% z is the objective function
z=zeros(n_times*t_courses3,1);
k=1;
fori=1:t_courses3
for q=1:n_times
z(k)=sqrt(q)+1;
k=k+1;
```

```
end
end
% giving lower and upper bounds for decision
variables(binary)
lb=zeros(n_times*t_courses3,1);
ub = ones(n_times*t_courses3,1);
% y is the solution of the ILP
y=intlinprog(z,intcon,A2_3,B_3,A1_3,H_3,lb,ub);

% representing the solution in to matrix
n=1;X=zeros(C1_3+C2_3,n_times);
for p=1:C1_3+C2_3
for q=1:42
X(p,q)=y(n);
       n=n+1;
end
end

TT=zeros(1,45);
Courses=1:C1_3+C2_3;

fori=1:C1_3+C2_3
for j=1:n_times
if X(i,j)==1
TT(j) = i;

end
end
end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
TimeTable3=zeros(9,5);
Table3=[1,2,3,13,14;4,5,6,15,16;7,8,9,17,18;10,11,12,19,2
0;21,22,23,36,37;24,25,26,38,39;27,28,29,100,100;30,31,32
,100,100;33,34,100,100,100];
```

```
fori=1:9
for j=1:5
for k=1:45
if Table3(i,j)==k
TimeTable3(i,j)= TT(k)
end
end
end
end
fori=C1_3+1:t_courses3
for p=1:9
for q=1:5
if TimeTable3(p,q)==i
for t3=1:9
for s=1:5
if (t3~=p && s~=q)
if TimeTable3(t3,s)==i
TimeTable3(t3,s)=TimeTable3(p+1,q);
TimeTable3(p+1,q)=i;
end;
end
end
end
end
end
end
end
i=4;
for k=C1_3+1:t_courses3
for j=1:5
if (TimeTable3(i,j)==k && TimeTable3(i+1,j)==k)
TimeTable3(i,j)=0;
TimeTable3(i+2,j)=k;
end
```

```
end

end
TimeTable3(3,1)=23;TimeTable3(9,1)=11;TimeTable3(6,3)=16;
TimeTable3(8,2)=9;TimeTable3(5,4)=17;TimeTable3(6,4)=17;
TimeTable3(4,4)=12;TimeTable3(7,2)=18;TimeTable3(9,2)=8;T
imeTable3(4,1)=4;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
[credit3,courseunit3,compose3]=xlsread('Grouping3.xlsx','
groups3');

NewTable3=cell(9,5);
fori=1:9
for j=1:5
for p=1:t_courses3
if compose3{p,3}==TimeTable3(i,j)
NewTable3{i,j}=compose3{p,1};

end
end
end
end

 f3 = figure('Position',[200 400 400 400]);

% Column names and column format
columnname =
{'Monday','Tuesday','Wednesday','Thursday','Friday'};
%columnformat = {'char','char','char','char','char'};
columnformat =
{'numeric','numeric','numeric','numeric','numeric'};
FontSize = 9;
FontWeight='bold';
```

```
rownames = {'8.00-9.00','9.00-10.00','10.00-
11.00','11.00-12.00','1.00-2.00','2.00-3.00','3.00-
4.00','4.00-5.00','5.00-6.00'};
% Define the data

fori=1:9
for j=1:5
d3{i,j}=NewTable3{i,j};

end
end

% Create the uitable
t3 = uitable('Data', d3,...
            'ColumnName', columnname,...
            'ColumnFormat', columnformat,...
            'ColumnWidth',{300 },...
            'FontSize',FontSize,...
             'RowName',rownames);
set(t3,'BackgroundColor',[0 1 0.7]);
end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if Time==2

[l1_2]=xlsread('Grouping2.xlsx','onehr');
[l2_2]=xlsread('Grouping2.xlsx','twohr');
[T1_2]=xlsread('Grouping.xlsx','Timeslots');
C1_2=length(l1_2); C2=length(l2_2);
t_courses2=length(l1_2)+length(l2_2); % total no of
courses
n_times=length(T1_2); %total no of time slots

l=1;u=n_times;
```

```
A1_2=zeros(t_courses2,t_courses2*n_times); %initializing
fori=1:t_courses2
for q=l:u
   A1_2(i,q)=1;
end
l=u+1;
u=u+n_times;
end

H_2=ones(C1_2+C2,1); %initializing

fori=C1_2+1:t_courses2
    H_2(i)=2;
end

A2_2=zeros(n_times,t_courses2*n_times);% initializing

fori=1:n_times
for q=1:t_courses2
    A2_2(i,n_times*q+i-n_times)=1;
end
end
B_2=ones(n_times,1);

% integer linear program

intcon=1:882; % all decision variables are integers

% z is the objective function
z=zeros(n_times*t_courses2,1);
k=1;
fori=1:t_courses2
for q=1:n_times
z(k)=sqrt(q)+1;
```

```
k=k+1;
end
end
% giving lower and upper bounds for decision
variables(binary)
lb=zeros(n_times*t_courses2,1);
ub = ones(n_times*t_courses2,1);
% y is the solution of the ILP
y=intlinprog(z,intcon,A2_2,B_2,A1_2,H_2,lb,ub);

% representing the solution in to matrix
n=1;X=zeros(C1_2+C2,n_times);
for p=1:C1_2+C2
for q=1:42
X(p,q)=y(n);
       n=n+1;
end
end
TT=zeros(1,45);
Courses=1:C1_2+C2;

fori=1:C1_2+C2
for j=1:n_times
if X(i,j)==1
TT(j) = i;

end
end
end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%


 TimeTable2=zeros(9,5);
```

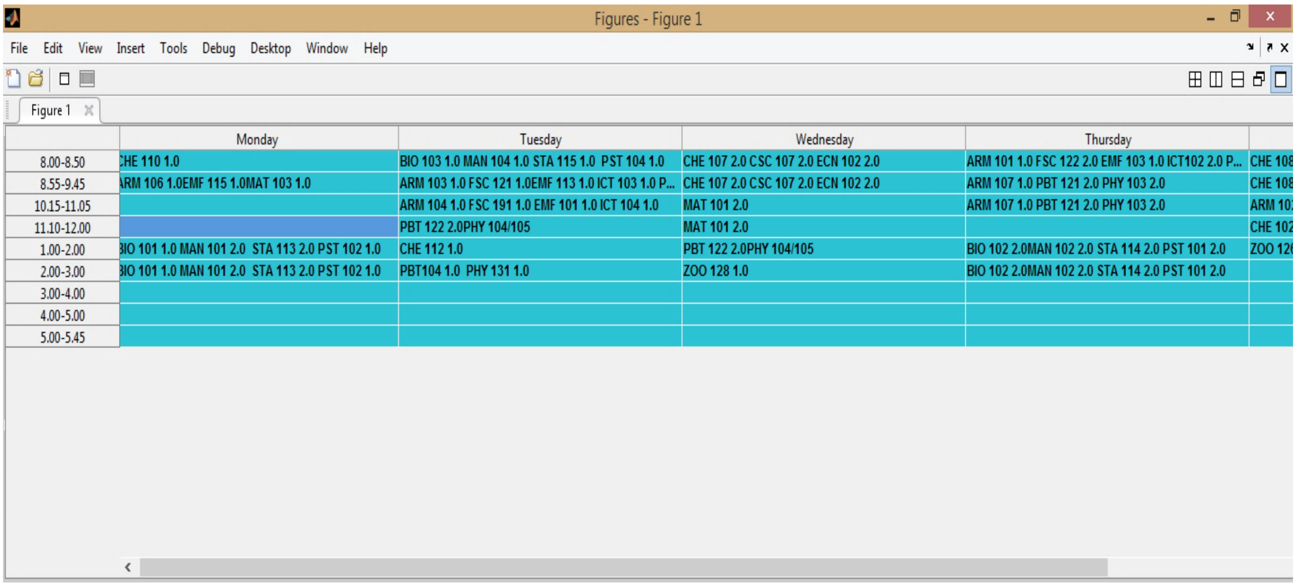
```
Table2=[11,13,15,17,19;12,14,16,18,20;1,3,5,7,9;2,4,6,8,1
0;21,23,25,27,29;22,24,26,28,30;31,32,33,100,34;35,36,37,
100,100;38,39,40,100,100];

fori=1:9
for j=1:5
for k=1:45
if Table2(i,j)==k
TimeTable2(i,j)= TT(k);

end
end
end
end
fori=C1_2+1:t_courses2
for p=1:9
for q=1:5
if TimeTable2(p,q)==i
for t2=1:9
for s=1:5
if (t2~=p && s~=q)
if TimeTable2(t2,s)==i
TimeTable2(t2,s)=TimeTable2(p+1,q);
TimeTable2(p+1,q)=i;
end;
end
end
end
end
end
end
end
```

```
i=4;
for k=C1_2+1:t_courses2
for j=1:5
if (TimeTable2(i,j)==k && TimeTable2(i+1,j)==k)
TimeTable2(i,j)=0;
TimeTable2(i+2,j)=k;
end
end

end
TimeTable2(4,5)=22;TimeTable2(7,5)=3;TimeTable2(4,2)=5;Ti
meTable2(8,3)=15;

[credit2,courseunit2,compose2]=xlsread('Grouping2.xlsx','
groups2');

NewTable2=cell(9,5);
fori=1:9
for j=1:5



for p=1:t_courses2
if compose2{p,2}==TimeTable2(i,j)
NewTable2{i,j}=compose2{p,1};
end
end
end
end
f2 = figure('Position',[200 400 400 400]);

% Column names and column format
```

```
columnname =
{'Monday','Tuesday','Wednesday','Thursday','Friday'};
%columnformat = {'char','char','char','char','char'};
columnformat =
{'numeric','numeric','numeric','numeric','numeric'};
FontSize = 9;
FontWeight='bold';

rownames = {'8.00-8.50','8.55-9.45','10.15-11.05','11.10-
12.00','1.00-2.00','2.00-3.00','3.00-4.00','4.00-
5.00','5.00-5.45'};
% Define the data

fori=1:9
for j=1:5
d2{i,j}=NewTable2{i,j};
end
end





% Create the uitable
t2 = uitable('Data', d2,...
            'ColumnName', columnname,...
            'ColumnFormat', columnformat,...
            'columnWidth',{300},...
            'FontSize',FontSize,...
             'RowName',rownames);
%set(t2,'BackgroundColor',[1 0 0.9]);
end
```

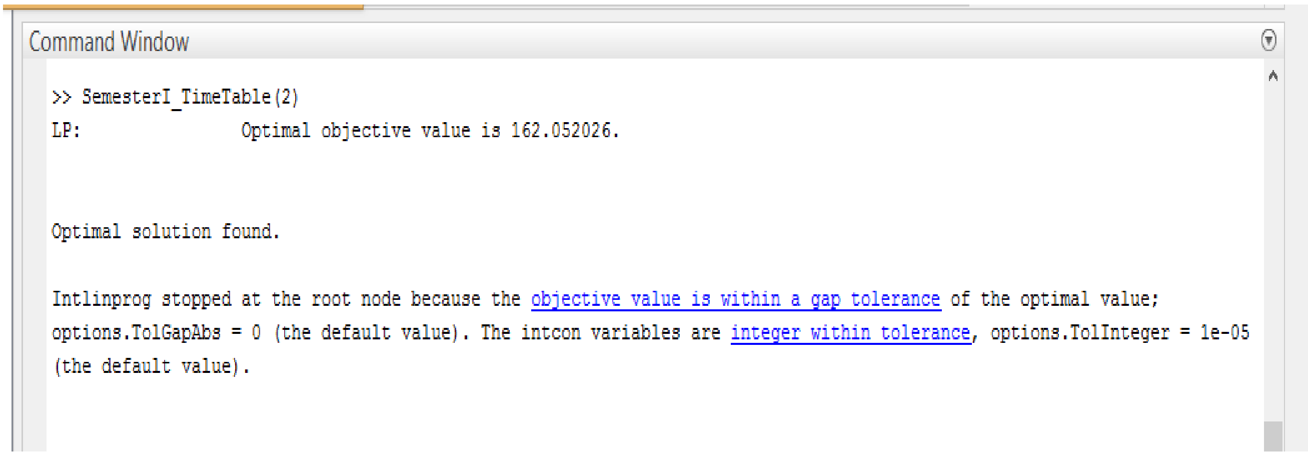
MATLAB Results

```
Command Window

>> SemesterI_TimeTable(1)
LP:                Optimal objective value is 129.220455.


Optimal solution found.

Intlinprog stopped at the root node because the objective value is within a gap tolerance of the optimal value;
options.TolGapAbs = 0 (the default value). The intcon variables are integer within tolerance, options.TolInteger = 1e-05
(the default value).
```

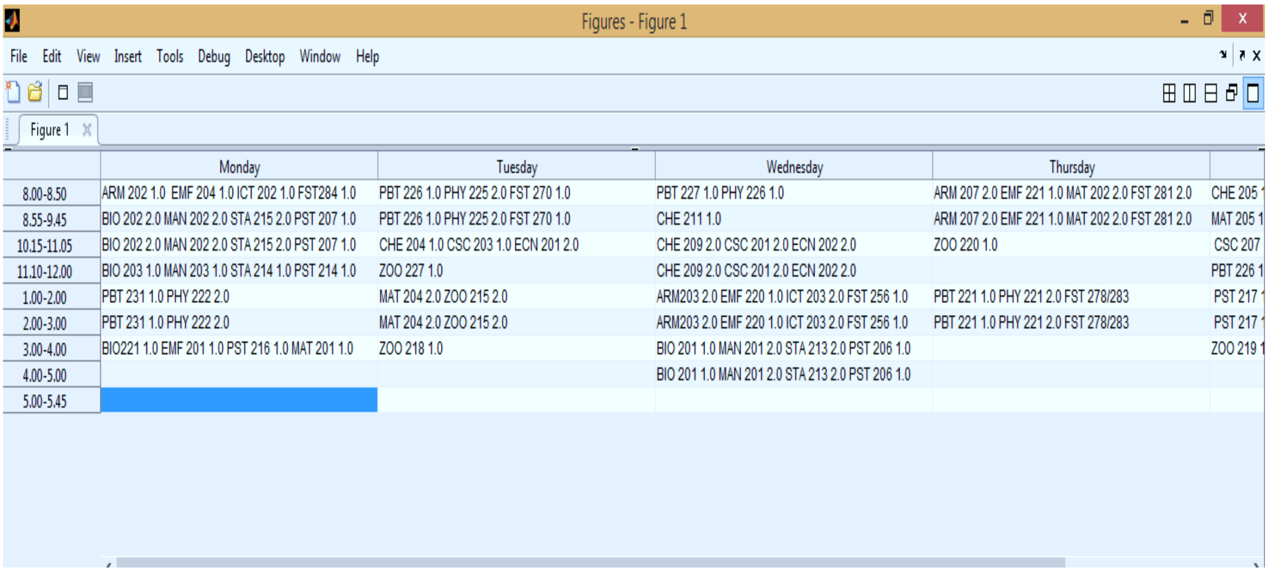


	Monday	Tuesday	Wednesday	Thursday	
8.00-8.50	CHE 110 1.0	BIO 103 1.0 MAN 104 1.0 STA 115 1.0 PST 104 1.0	CHE 107 2.0 CSC 107 2.0 ECN 102 2.0	ARM 101 1.0 FSC 122 2.0 EMF 103 1.0 ICT102 2.0 P...	CHE 108
8.55-9.45	ARM 106 1.0EMF 115 1.0MAT 103 1.0	ARM 103 1.0 FSC 121 1.0EMF 113 1.0 ICT 103 1.0 P...	CHE 107 2.0 CSC 107 2.0 ECN 102 2.0	ARM 107 1.0 PBT 121 2.0 PHY 103 2.0	CHE 108
10.15-11.05		ARM 104 1.0 FSC 191 1.0 EMF 101 1.0 ICT 104 1.0	MAT 101 2.0	ARM 107 1.0 PBT 121 2.0 PHY 103 2.0	ARM 10
11.10-12.00		PBT 122 2.0PHY 104/105	MAT 101 2.0		CHE 102
1.00-2.00	BIO 101 1.0 MAN 101 2.0 STA 113 2.0 PST 102 1.0	CHE 112 1.0	PBT 122 2.0PHY 104/105	BIO 102 2.0MAN 102 2.0 STA 114 2.0 PST 101 2.0	ZOO 12
2.00-3.00	BIO 101 1.0 MAN 101 2.0 STA 113 2.0 PST 102 1.0	PBT104 1.0 PHY 131 1.0	ZOO 128 1.0	BIO 102 2.0MAN 102 2.0 STA 114 2.0 PST 101 2.0	
3.00-4.00					
4.00-5.00					
5.00-5.45					

First Year Timetable



```
>> SemesterI_TimeTable(2)
LP:                Optimal objective value is 162.052026.


Optimal solution found.

Intlinprog stopped at the root node because the objective value is within a gap tolerance of the optimal value;
options.TolGapAbs = 0 (the default value). The intcon variables are integer within tolerance, options.TolInteger = 1e-05
(the default value).
```



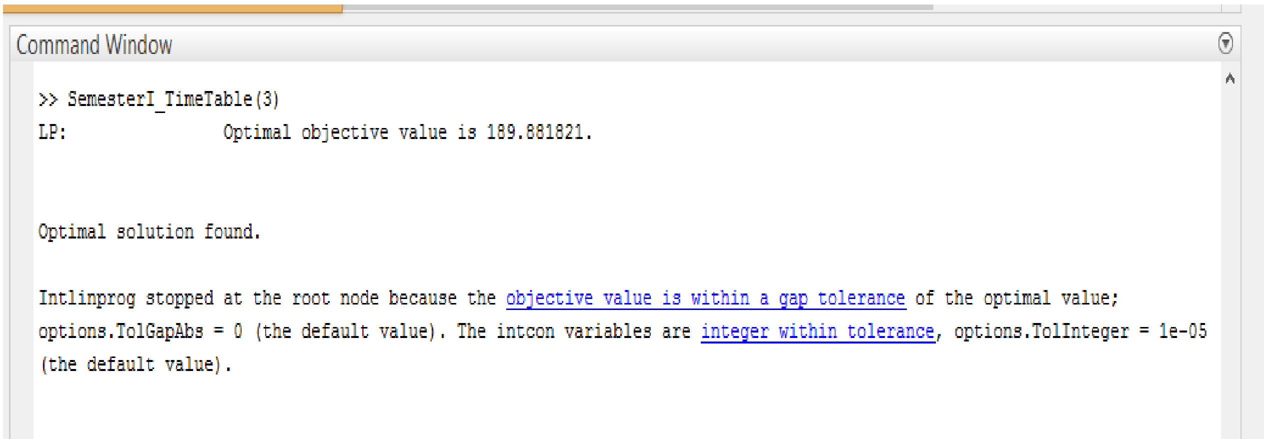
Figures - Figure 1

File Edit View Insert Tools Debug Desktop Window Help

Figure 1

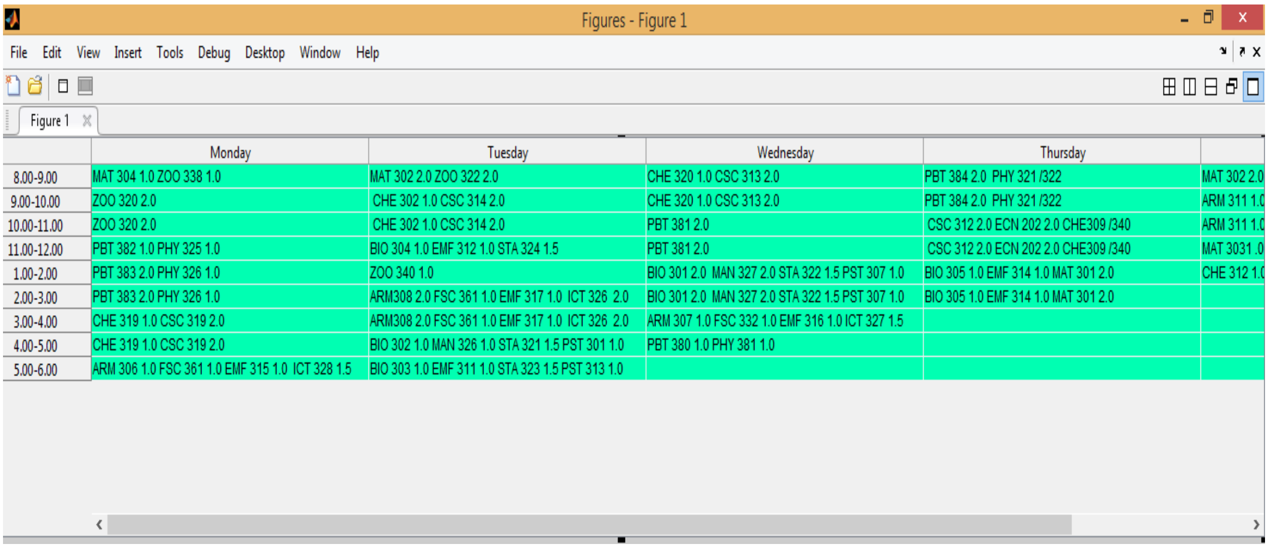
	Monday	Tuesday	Wednesday	Thursday	
8.00-8.50	ARM 202 1.0 EMF 204 1.0 ICT 202 1.0 FST284 1.0	PBT 226 1.0 PHY 225 2.0 FST 270 1.0	PBT 227 1.0 PHY 226 1.0	ARM 207 2.0 EMF 221 1.0 MAT 202 2.0 FST 281 2.0	CHE 205 1
8.55-9.45	BIO 202 2.0 MAN 202 2.0 STA 215 2.0 PST 207 1.0	PBT 226 1.0 PHY 225 2.0 FST 270 1.0	CHE 211 1.0	ARM 207 2.0 EMF 221 1.0 MAT 202 2.0 FST 281 2.0	MAT 205 1
10.15-11.05	BIO 202 2.0 MAN 202 2.0 STA 215 2.0 PST 207 1.0	CHE 204 1.0 CSC 203 1.0 ECN 201 2.0	CHE 209 2.0 CSC 201 2.0 ECN 202 2.0	ZOO 220 1.0	CSC 207
11.10-12.00	BIO 203 1.0 MAN 203 1.0 STA 214 1.0 PST 214 1.0	ZOO 227 1.0	CHE 209 2.0 CSC 201 2.0 ECN 202 2.0		PBT 226 1
1.00-2.00	PBT 231 1.0 PHY 222 2.0	MAT 204 2.0 ZOO 215 2.0	ARM203 2.0 EMF 220 1.0 ICT 203 2.0 FST 256 1.0	PBT 221 1.0 PHY 221 2.0 FST 278/283	PST 217 1
2.00-3.00	PBT 231 1.0 PHY 222 2.0	MAT 204 2.0 ZOO 215 2.0	ARM203 2.0 EMF 220 1.0 ICT 203 2.0 FST 256 1.0	PBT 221 1.0 PHY 221 2.0 FST 278/283	PST 217 1
3.00-4.00	BIO221 1.0 EMF 201 1.0 PST 216 1.0 MAT 201 1.0	ZOO 218 1.0	BIO 201 1.0 MAN 201 2.0 STA 213 2.0 PST 206 1.0		ZOO 219 1
4.00-5.00			BIO 201 1.0 MAN 201 2.0 STA 213 2.0 PST 206 1.0		
5.00-5.45					

Second Year Timetable



Command Window

```
>> SemesterI_TimeTable(3)
LP:                Optimal objective value is 189.881821.


Optimal solution found.

Intlinprog stopped at the root node because the objective value is within a gap tolerance of the optimal value;
options.TolGapAbs = 0 (the default value). The intcon variables are integer within tolerance, options.TolInteger = 1e-05
(the default value).
```



Figures - Figure 1

File Edit View Insert Tools Debug Desktop Window Help

Figure 1

	Monday	Tuesday	Wednesday	Thursday	
8.00-9.00	MAT 304 1.0 ZOO 338 1.0	MAT 302 2.0 ZOO 322 2.0	CHE 320 1.0 CSC 313 2.0	PBT 384 2.0 PHY 321 /322	MAT 302 2.0
9.00-10.00	ZOO 320 2.0	CHE 302 1.0 CSC 314 2.0	CHE 320 1.0 CSC 313 2.0	PBT 384 2.0 PHY 321 /322	ARM 311 1.0
10.00-11.00	ZOO 320 2.0	CHE 302 1.0 CSC 314 2.0	PBT 381 2.0	CSC 312 2.0 ECN 202 2.0 CHE309 /340	ARM 311 1.0
11.00-12.00	PBT 382 1.0 PHY 325 1.0	BIO 304 1.0 EMF 312 1.0 STA 324 1.5	PBT 381 2.0	CSC 312 2.0 ECN 202 2.0 CHE309 /340	MAT 3031 .0
1.00-2.00	PBT 383 2.0 PHY 326 1.0	ZOO 340 1.0	BIO 301 2.0 MAN 327 2.0 STA 322 1.5 PST 307 1.0	BIO 305 1.0 EMF 314 1.0 MAT 301 2.0	CHE 312 1.0
2.00-3.00	PBT 383 2.0 PHY 326 1.0	ARM308 2.0 FSC 361 1.0 EMF 317 1.0 ICT 326 2.0	BIO 301 2.0 MAN 327 2.0 STA 322 1.5 PST 307 1.0	BIO 305 1.0 EMF 314 1.0 MAT 301 2.0	
3.00-4.00	CHE 319 1.0 CSC 319 2.0	ARM308 2.0 FSC 361 1.0 EMF 317 1.0 ICT 326 2.0	ARM 307 1.0 FSC 332 1.0 EMF 316 1.0 ICT 327 1.5		
4.00-5.00	CHE 319 1.0 CSC 319 2.0	BIO 302 1.0 MAN 326 1.0 STA 321 1.5 PST 301 1.0	PBT 380 1.0 PHY 381 1.0		
5.00-6.00	ARM 306 1.0 FSC 361 1.0 EMF 315 1.0 ICT 328 1.5	BIO 303 1.0 EMF 311 1.0 STA 323 1.5 PST 313 1.0			

Third Year Timet

APPENDIX C -FACULTY OF APPLIED SCIENCES - MASTER TIME TABLE 2016

Time	MON			TUE			WED			THU			FRI		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
8.00 - 8.50	CHE	MAT	PHY	CHE	MAN	CHE	MAT	EMF	CHE	CSC	ZOO	CHE	STA	ZOO	MAT
	CSC	PST	PBT	CSC	STA	CSC	PBT	CSC	CSC	EMF	MAT		MAN	MAT	PBT
	ECN	ARM	ICT		BIO		ARM	ECN		ECN	PST		ZOO		FSC
		FSC	PBT					ICT			BIO				
		PBT													
8.55 - 9.45	CSC	MAT	PHY	CHE	STA	ZOO	MAT	CSC	EMF	PHY	ZOO			PBT	MAT
	ECN	PST	PBT	CSC	PST	CSC	EMF	EMF	CSC	FSC	MAT	CHE		MAT	PHY
			ICT			PHY	PST	ICT		ECN	PST				
						BIO	ARM			EMF	BIO				
10.15 - 11.05	STA	MAN	ZOO	PHY	PHY	STA	CSC	CHE		MAT	PBT			STA	STA
	MAN	CSC	MAT	PBT	ECN	MAN	PST	CSC		ZOO	PHY	MAN		MAN	
	FSC		PST	BIO		FSC	ECN	ECN		BIO	FSC	PST		ZOO	
	ICT									PST		ICT		ICT	
	PST														
11.10 - 12.00	STA	MAN	ZOO	PHY	PHY	STA	CSC	CHE		MAT		MAN		EMF	STA
	MAN	CSC	MAT	PBT		MAN	ZOO	CSC		ZOO	PBT	AQS		STA	
	FSC	PST	PST	ARM	ECN					BIO	PHY	PST			
	ICT			BIO		FSC	PST					ICT		ZOO	
	PST						ECN				FSC				
01.00 - 02.00	ARM	FSC	CSC	ZOO	MAT	MAT	STA	PBT	CSC	MAN	CHE	MBL		EMF	MAT
	MAT		EMF	BIO	ZOO	ZOO	PBT		MAN	FSC	ECN	EMF		STA	
			MBL	EMF	BIO	PST	ICT			ICT		STA			
			FSC			BIO				PST		PST			
												FSC			
02.00 - 03.00	ARM	FSC				MAT				MAN		MBL			
	PHY		CSC									EMF		STA	
			EMF	EMF		ZOO			CSC		CHE	STA		MAN	
			MBL		MAT	PST	STA		MAN		ECN	FSC		AQS	
			FSC		ZOO	BIO	PBT	PBT		FSC				STA	MAT
					BIO		ICT			ICT				FSC	
03.00 - 04.00	PHY					PHY				Time Slots for Student Activities					
			STA	EMF	ICT	PBT		EMF						MAN	STA
			ZOO			ICT	PBT		STA					STA	
							STA		MAN						
04.00 - 05.00	ZOO	PHY	STA	IT	MAN	PHY	MAT		PHY					CHE	STA
	BIO	MAN		CHE	ICT	PBT			PBT						EMF
						ICT									
						PBL									
						PBT									
05.00 - 05.45	MAN	MAN	CHE	CHE	MAN		MAT		MAN						
							PST	PST							

FACULTY OF APPLIED SCIENCES –PROPSOED MASTER TIME TABLE 2016

Time	MON			TUE			WED		
	1	2	3	1	2	3	1	2	3
8.00 - 8.50	CHE 110 1.0	ARM 202 1.0	MAT 304 1.0	BIO 103 1.0	PBT 226 1.0	MAT 302 2.0	CHE 107 2.0	PBT 227 1.0	CHE 320 1.0
		EMF 204 1.0	ZOO 338 1.0	MAN 104 1.0	PHY 225 2.0	ZOO 322 2.0	CSC 107 2.0	PHY 226 1.0	CSC 313 2.0
		ICT 202 1.0		STA 115 1.0	FST 270 1.0		ECN 102 2.0		
		FST284 1.0		PST 104 1.0					
8.55 - 9.45	ARM 106 1.0	BIO 202 2.0	ZOO 320 2.0		PBT 226 1.0	MAT 302 2.0	CHE 107 2.0	ZOO 227 1.0	CHE 320 1.0
	EMF 115 1.0	MAN 202 2.0			PHY 225 2.0	ZOO 322 2.0	CSC 107 2.0		CSC 313 2.0
	MAT 103 1.0	STA 215 2.0			FST 270 1.0		ECN 102 2.0		
		PST 207 1.0							
10.15 - 11.05	MAT 102 2.0	BIO 202 2.0	ZOO 320 2.0	PBT 122 2.0	CHE 204/211	CHE 302 1.0	MAT 101 2.0	CHE 209 2.0	PBT 381 2.0
	ZOO 118/120	MAN 202 2.0		PHY 104/105	CSC 203 1.0	CSC 314 2.0		CSC 201 2.0	
		STA 215 2.0			ECN 201 2.0			ECN 202 2.0	
		PST 207 1.0							
11.10 - 12.00	MAT 102 2.0	BIO 203 1.0	PBT 382 1.0	PBT 122 2.0	CHE 204/211	ZOO 340 1.0	MAT 101 2.0	CHE 209 2.0	PBT 381 2.0
	ZOO 118/120	EMF 201 1.0	PHY 325	PHY 104/105	CSC 203 1.0	CSC 314 2.0		CSC 201 2.0	
		STA 214 1.0			ECN 201 2.0			ECN 202 2.0	
		MAT 201 1.0							
01.00 - 02.00	BIO 101 1.0	PBT 231 1.0	PBT 383 2.0	CHE 112 1.0	MAT 204 2.0	BIO 304 1.0	ARM 104 1.0	ARM203 2.0	BIO 301 2.0
	MAN 101 2.0	PHY 222 2.0	PHY 326 1.0		ZOO 215 2.0	EMF 312 1.0	FSC 191 1.0	EMF 220 1.0	MAN 327 2.0
	PST 102 1.0					STA 324 1.5	EMF 101 1.0	ICT 203 2.0	STA 322 1.5
	STA 113 2.0						ICT 104 1.0	FST 256 1.0	PST 307 1.0
02.00 - 03.00	BIO 101 1.0	PBT 231 1.0	PBT 383 2.0	PBT104 1.0	MAT 204 2.0	ARM308 2.0	ZOO 128 1.0	ARM203 2.0	BIO 301 2.0
	MAN 101 2.0	PHY 222 2.0	PHY 326 1.0	PHY 131 1.0	ZOO 215 2.0	FSC 361 1.0		EMF 220 1.0	MAN 327 2.0
	PST 102 1.0					EMF 317 1.0		ICT 203 2.0	STA 322 1.5
	STA 113 2.0					ICT 326 2.0		FST 256 1.0	PST 307 1.0
03.00 - 04.00		BIO221 1.0	CHE 319 1.0			ARM308 2.0		BIO 201 1.0	ARM 307 1.0
		MAN 203 1.0	CSC 319 2.0			FSC 361 1.0		MAN 201 2.0	FSC 332 1.0
		PST 216 1.0				EMF 317 1.0		STA 213 2.0	EMF 316 1.0
		STA 214 1.0				ICT 326 2.0		PST 206 1.0	ICT 327 1.5
04.00 - 05.00			CHE 319 1.0			BIO 302 1.0		BIO 201 1.0	PBT 380 1.0
			CSC 319 2.0			MAN 326 1.0		MAN 201 2.0	PHY 381 1.0
						STA 321 1.5		STA 213 2.0	
						PST 301 1.0		PST 206 1.0	
05.00 - 05.45			ARM 306 1.0						
			FSC 361 1.0						
			EMF 315 1.0						
			ICT 328 1.5						

THU			FRI		
1	2	3	1	2	3
ARM 101 1.0	ARM 207 2.0	PBT 384 2.0	CHE 108 /110	CHE 205 1.0	CHE 312 1.0
FSC 122 2.0	EMF 221 1.0	PHY 321/322	CSC 106 1.5		
EMF 103 1.0	MAT 202 2.0				
ICT102 2.0	FST 281 2.0				
PST 102 2.0					
ARM 101 1.0	ARM 207 2.0	PBT 384 2.0	CHE 108 /110	MAT 205 1.0	ARM 311 1.0
FSC 122 2.0	EMF 221 1.0	PHY 321/322	CSC 106 1.5	ZOO 217 1.0	FSC 353 1.0
EMF 103 1.0	MAT 202 2.0				EMF 319 1.0
ICT102 2.0	FST 281 2.0				ICT 329 1.5
PST 102 2.0					
ARM 107 1.0	ZOO 220 1.0	CSC 312 2.0	ARM 102 1.0	CSC 207 1.0	BIO 303 1.0
PBT 121 2.0		ECN 202 2.0	FSC111 1.0	CHE 208 1.0	EMF 311 1.0
PHY 103 2.0		CHE309/340	EMF 106 1.0		STA 323 1.5
			ICT 101 1.0		PST 313 1.0
			PST 101 1.0		
ARM 107 1.0	ZOO 218 1.0	CSC 312 2.0	CHE 102 1.0		MAT 303 1 .0
PBT 121 2.0		ECN 202 2.0	CSC 105 1.0		ZOO 323 1.0
PHY 103 2.0		CHE309 /340	ECN 101 1.0		
BIO 102 2.0	PBT 221 1.0	BIO 305 1.0	ZOO 126 1.0	PST 217 1.0	CHE 302 1.0
MAN 102 2.0	PHY 221 2.0	EMF 314 1.0		ARM 203 2.0	CSC 314 2.0
STA 114 2.0	FST 278/283	MAT 3012.0		EMF213 1.0	
PST 101 2.0				ICT 201 2.0	
				FST 252 1.0	
BIO 102 2.0	PBT 221 1.0	BIO 305 1.0		PST 217 1.0	CHE 302 1.0
MAN 102 2.0	PHY 221 2.0	EMF 314 1.0		ARM 2032.0	CSC 314 2.0
STA 114 2.0	FST 278/283	MAT 301 2.0		EMF213 1.0	
PST 101 2.0				ICT 201 2.0	
				FST 252 1.0	

Time Slots for Student Activities