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## Course planning at Lufthansa technical training: Constructing more profitable schedules

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April 5, 1997

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**Contents**

1. Introduction.....	1
2. The Problem Setting .....	2
3. The Prototype.....	5
4. The Decision Support System.....	9
5. Summary and Conclusions .....	12
Acknowledgements .....	13
Appendix.....	13
References.....	15

**Abstract:** Lufthansa Technical Training GmbH (LTT) performs training courses for Lufthansa AG as well as for several other international airlines. Courses of about 670 different types are offered of which several hundred take place each year. The course scheduling problem faced by LTT is to develop a yearly schedule which maximizes the profit margin incurred while meeting a variety of complex precedence, temporal, and resource-related constraints. A "good" operational schedule should also meet a number of additional subordinate objectives. In the past, scheduling was solely done manually. We describe the problem and survey the process of developing a prototype course scheduling module. The operational planning situation of 1996 served as our major test instance; it turned out that the best so-found schedule is substantially better than the solution manually constructed by LTT, measured in terms of profit margin incurred as well as computation time required. Details on the subsequently developed fully-fledged decision support system are also provided.

**Keywords:** COURSE SCHEDULING; AVIATION; TRAINING; HEURISTICS

## 1. Introduction

Lufthansa AG, the German national flag carrier, currently has about 40,000 employees and is one of the largest employers in the country. Almost every fourth of them is engaged in the technical area that is responsible for the checks, maintenance, and overhauls necessary to maintain a high standard of safety. The training of its technical staff is entrusted to Lufthansa Technical Training GmbH (LTT). While the Lufthansa AG remains the single largest customer of LTT, an increasing number of other airlines are enlisting its services. LTT provides a full range of technical training for the aviation industry, qualifying airline staff to perform duties in areas such as aircraft maintenance, overhaul, and inspection. About 670 different theoretical and practical course types are offered, lasting from a few days up to one year and ranging from aircraft maintenance over overhauls up to inspector courses. To satisfy all (or at least most) customer requests, several hundred courses of different types are held each year. LTT maintains offices in Frankfurt, Hamburg, and Berlin.

The manual construction of an operational course schedule for the LTT is an extraordinarily tedious and time-consuming task that each year monopolizes two employees for several weeks and results in a plan taking several square meters of paper. The long time this process takes makes it not only burdensome and costly in terms of staff expenses; it also implies that finding one operational schedule - however good it may be - is usually all one can hope for. In other words, due to limited temporal and monetary budgets, it is virtually impossible to apply different planning strategies and compare the resulting schedules. Yet, since alternative plans will mostly differ in terms of course numbers planned, instructor and training facility utilizations, and operating profits, it was hypothesized that the ability to come up with several alternatives would allow to select schedules faring better than the manually constructed ones.

In this contribution, we describe a feasibility study, carried out in cooperation with LTT, in which a proof prototype of a course scheduling module was developed and implemented. As the prototype demonstrated that notable increases in profit margin could be achieved from

using an algorithmic approach, LTT management took the decision to develop a fully-fledged decision support system. We also survey the most important features of this system.

## 2. The Problem Setting

The course scheduling problem (CSP) as faced by LTT is characterized by the subsequent assumptions:

- *Planning horizon and periods:* Planning is done on an annual basis. The planning horizon comprises all working days of the considered calendar year, taking into account weekends and holidays. Each working day is divided into a day and a night shift; night shifts are necessary because some aircraft are available for practical training only at night. Since instructors may teach in several courses within the same shift, planning has to be done on the level of periods, each having a duration of one lesson.
- *Course types:* Each course type comprises a fixed number of lessons covering different subjects. The number of lessons to be held per day is limited for each course type.
- *Courses:* Several courses of the same type may take place. All courses actually scheduled must be completely held within the planning horizon.
- *Topics:* Lessons on the same subject are combined to topics. Each topic can only be held by certain instructors (with specific qualifications) and in certain facilities (with specific equipment).
- *Blocks and block groups:* Topics are aggregated to blocks. Certain related blocks which must be held consecutively, i.e. without interruption by other blocks, are combined to block groups. For educational and legal reasons, precedences exist between some blocks (e.g. theoretical instruction *before* practical training *before* tests). For each course type, a *standard sequence* of blocks exists which meets all precedence requirements and has been found to perform well under practical considerations. To achieve compact schedules, courses must be scheduled to successive working days; so, training always commences in the earliest possible lesson of the respective shift with the other lessons following suit. Some blocks (e.g. tests, practical lessons held in night shifts) may even start only in the first period of a shift.
- *Labor regulations:* All lessons of a day must take place either in a day or in a night shift; this rule applies to instructors and participants alike. Resting periods have to be included between consecutive working periods.

- *Participant availability:* Course demand information is compiled from customer requests, in terms of number of intended participants per course type. However, for each customer there is a quota on the number of participants which may be trained at the same time; this quota serves to avoid critical shortages in the customer's workforce.
- *Participant limits:* Certain limits on the number of participants of each course type also apply from the side of LTT. Minimum numbers arise from economic considerations while maximum numbers are dictated partly by educational experience and partly by seating capacities of rooms.
- *Start periods:* Customers often wish to confine the beginning of a course to a certain period, such as a specific month or the second quarter of the year.
- *Instructors and tutors:* LTT employs a number of staff instructors. The majority of instructors is specialized on a certain aircraft type, mastering most subjects concerning that specific type. Others have specialized on a particular subject matter, covering that subject for various aircraft types. Consequently, each instructor is able to cover only a subset of subjects such that instructors are categorized into groups of identical qualification. In addition to the staff instructors, qualified technical staff of the Lufthansa Technik AG or former LTT instructors may be used as so-called tutors for certain topics (usually practical ones). Even though during each such topic at least one instructor must be present, tutors allow to temporarily augment instructor capacities (this is done e.g. for practical topics where course participants are usually taught in smaller groups, thus requiring more instructors).
- *Instructor and tutor availability:* No instructor or tutor can be assigned to more than one course per lesson. Instructors and tutors are available for a number of periods per day. However, they may not be available in certain periods which are already fixed at the time of planning (e.g. for approved vacation days). In addition, a number of periods may be reserved for absence not yet fixed at the time of planning (e.g. for remaining vacation days, special projects or other tasks). Finally, lesson preparation times for the instructors have to be worked into a schedule, as well as travel times for periods in which instructors shuttle between different training sites (both do not apply for tutors).
- *Training facilities' availability:* Facilities can be distinguished into those required for theoretical training (e.g. classrooms, rooms fitted with computer-based training equipment) and those for practical training (e.g. workshops, aircraft, simulators). Most of these resources are scarce and have to be considered in the planning process. Capacities are varying over time since some facilities are temporarily rented to other institutions.

- *Deadlines and due dates:* Aircraft fleets are subject to steady change. In order to renew their fleets, airlines introduce new aircraft types into service while old ones are discontinued. Since it neither makes sense to offer courses for discarded aircraft types nor to train staff on new types too early, scheduling of certain course types may be subject to deadlines or due dates.

Experience shows that, owing to the above restrictions, some courses requested by customers may be impossible to be scheduled such that demand will be satisfied only partially.

A variety of objectives determine the quality of a course schedule. They result from economic considerations, customer demand, management directives, quality requirements, and staff interests. Among them are the following ones (listed in order of decreasing priority):

- *Profit:* Each scheduled course earns a fee per attending participant and day which is offset by various costs. Instructor cost arises when instructors are used in other than their home locations (travel cost); it is composed of a fixed part reflecting transportation cost and opportunity cost (related to the decrease of working capacity by travel time), and a variable part representing accommodation and expenses. Tutor cost is due as tutors are paid per lesson taught. Labour cost of staff and administrative cost are assumed to be fixed over the planning horizon; thus, they are not considered here. The total profit margin of the schedule, i.e. total sales revenue less all above costs, is to be maximized.
- *Service level:* Usually not the whole customer demand can be satisfied. Hence, the service level as measured by the percentage of the total demand actually met should be maximized.
- *Course priority:* Due to contractual commitments to customers, the introduction of new aircraft types, or urgently needed training of specific course types, some courses have a higher priority than others and thus get preferential treatment.
- *Instructor preparation:* Teaching times and preparation times should be evenly distributed in such a way that preparation takes place directly before teaching.
- *Standard sequence:* Courses should be performed in the standard block sequence.
- *Travel times:* Travel times between different offices reduce the total capacity of an instructor and thus should be minimized.
- *Workload distribution:* The total workload should be evenly distributed among the staff.
- *Instructor redundancy:* When all instructors of a specific qualification group are scheduled to the same period (but different courses), an unforeseen absence (e.g. due to illness) of only one of them implies that a complete course has to be cancelled on short



notice. Hence, a schedule should maintain a reserve of at least one instructor of each qualification group for each lesson in order to safeguard against absence-induced cancellations.

- *Effective course duration:* The effective duration of a course depends upon its starting day: A four-day course started on a Wednesday has to include the weekend, thus taking six days, while the same course started on a Tuesday would take only four days. Since airline staff usually works in shifts around the week, each weekend or holiday over which a course lasts results in increased expenses and reduced staff capacities on the customers side. Accordingly, the effective course duration should be kept as short as possible.
- *Instructor continuity:* In each course, as few instructors as possible should be involved to avoid unduly changes for instructors and participants.

This problem can be characterized as a multi-criteria decision making one. However, due to economic considerations, maximization of profit margin is of paramount importance such that only this objective was considered explicitly in the algorithms developed. The objective of course priority maximization can be achieved by appropriately weighting the course fees. Several other subordinate objectives, viz. travel time reduction, standard sequence adherence, and effective course duration minimization were incorporated implicitly (cf. Haase et al. 1997).

### 3. The Prototype

LTT management commissioned us to carry out a feasibility study, in cooperation with LTT staff, in which a proof prototype of a course scheduling module was developed and implemented. The motivation behind this step was to assess the potential for improvements in the planning process that could be reaped from using an algorithmic approach.

As is known from other large-scale practice projects, the acquisition and aggregation of operational planning data proved to be a massively time-consuming and costly task. A considerable portion of the data, e.g. fixed and variable travel cost, had to be gathered for the first time. The majority of data already existing was available only in written form and had to be brought into a computer-readable form. Yet another part, e.g. information on the resource requirements of different course types, though existing in principle, had to be completely restructured since the parameters used within our algorithms are much more detailed than the information existing so far. A complete description of the operational instance of 1996 used, to which we refer as LTT96, would be beyond the scope of this contribution. Therefore, we restrict the presentation to some characteristics summarized in Table 1.

Periods	Course Types	Courses	Instructors	Instructor Groups	Rooms	Room Groups	Customers
3,000	79	164	82	122	3	3	6

*Table 1: LTT96 Operational Instance - General Characteristics*

The number of periods  $T$  arises from 250 working days, each comprising a day and a night shift of six lessons each. Customers demand only complete courses; the number of training days requested totals 3,318. Courses have on average a number of 55 start days; the majority of courses is required to be held within a certain month. The average number of vacation days per instructor is about 36 days while the average size of an instructor group is 3.4. The maximum number of courses of the same type is nine. Some statistics on the distribution of number of blocks and duration over the courses are shown in Tables 2 and 3.

Number of blocks	1-4	5-8	9-12	13-16	17-20	Average
Count of courses	56	11	53	32	12	9.19

*Table 2: LTT Operational Instance - Numbers of Blocks*

Duration (days)	1-10	11-20	21-30	31-40	41-50	51-57	Average
Count of courses	64	23	39	24	12	2	20.23

*Table 3: LTT Operational Instance - Durations*

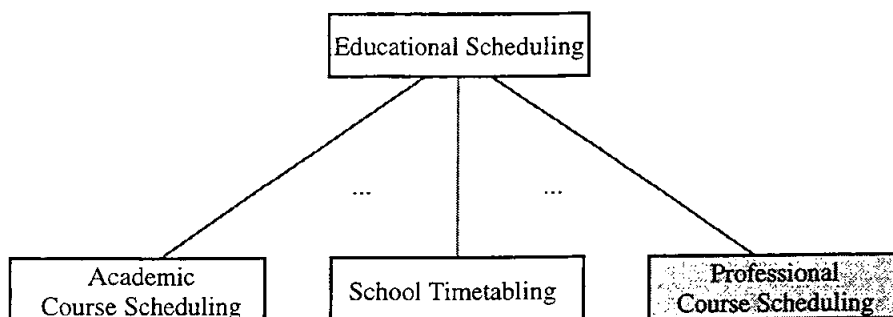
The first step when attacking complex planning problems usually consists of formulating a mathematical model of the objectives and requirements involved. Two such models for the CSP have been proposed, one using concepts from the project scheduling varsity (Haase et al. 1997), the other using a knapsack formulation approach (Haase, Latteier 1996). Building upon the insight gained during the modelling process, several standard avenues for solving problems were dismissed early on. Considering the size of operational instances, the complexity of the problem forbade the development of exact methods. Also, no off-the-shelf software available on the marketplace could be used to tackle the problem. The next question offering itself was, Can solution approaches from similar problem settings be transferred to the problem at hand?

Within the last 15 years, a variety of articles has been published on problems located within the area of course scheduling. Virtually all articles gravitate around two problem fields,

namely school timetabling (de Gans 1981; Abramson 1991; Cangalovic, Schreuder 1991, 1992; Hertz 1992; Alvarez-Valdes et al. 1994; Costa 1994) and academic course scheduling (Tripathy 1984; Aubin, Ferland 1989; Kang, White 1992; Sampson et al. 1995). One might conjecture that the CSP and the above problem settings are rather closely related. However, it turned out that the majority of problems covered in the open literature differ in several fundamental aspects from the CSP:

- Most timetabling or academic course scheduling problems are adapted to non-profit organizations such as schools, colleges, or universities. None of these organizations is seeking to maximize the profit margin arising from a schedule.
- Both timetabling and academic course scheduling intend to find repetitive schedules covering a relatively small timespan, usually one week. In contrast, a solution of the CSP represents a non-repetitive schedule for a much longer planning horizon, such as a year.
- For many of the problems discussed even the associated feasibility problem is (strongly) NP-complete, owing to the combination of scarce resources and a fixed planning horizon within which all courses (lessons, lectures) have to be scheduled. In contrast, because some requested courses may be rejected, there exists a trivial solution for each instance of the CSP, viz. to schedule no course at all.

An exception to these findings is provided by the work of Eglese, Rand (1987) who address the scheduling of conference seminars. The problem they consider is to find an assignment of periods and participants to seminars which covers all participants and meets a number of constraints essentially representing scarce room resources. However, since all seminars have a uniform duration of one period each seminar is scheduled as a whole. Each seminar can only be held by one speaker rather than by a group of alternative speakers. Finally, no precedence or temporal constraints are part of the problem. Hence, also their approach is not applicable to the CSP. Other than that, only very little research has been documented on related scheduling problems.



*Figure 1: Professional Course Scheduling Is One Discipline of Educational Scheduling*

So, we consider the CSP to belong to a separate problem field apart from the numerous other fields in educational scheduling (Figure 1). We refer to this field as professional course scheduling. A more detailed presentation of the differences between the above fields can be found in the Appendix.

Hence, we decided to develop a tailored construction scheme using several weighted priority rules; appropriate weights were determined dynamically by a local search procedure. Details of the algorithms as well as comprehensive computational results are reported elsewhere (Haase et al. 1997). Therefore, we restrict ourselves to demonstrating the suitability of our approach by comparing our best solution for LTT96 to the manually constructed solution; Table 4 summarizes some characteristic measures of the two schedules. The gap between both objective function values amounts to about DM 275,000, translating to an increase in profit margin of about 26%, which might have been reaped from implementing the algorithmic schedule. We should point out, however, that these figures must be interpreted with caution because, while the fees incurred from different courses were exactly known, the cost figures used in our analysis are only approximate values.

	LTT	Algorithm
Total profit margin	1,061,747	1,336,919
Fixed travel cost	108,800	16,000
Variable travel cost	238,733	32,361
Tutor cost	23,520	47,520
Avg. number of days assigned (staff HAM/BER)	44.13	11.2
Avg. number of lessons assigned (staff HAM/BER)	224.2	54.77
Avg. number of days assigned (all staff)	71.24	69.03
Avg. number of lessons assigned (all staff)	367.66	330.11

*Table 4: Comparison with Manually Constructed Schedule*

It is interesting to note that, since both solutions succeeded in scheduling all requested courses, the increased profit margin can only be accorded to differing travel and tutor costs. As can be seen from lines three and four, the travel cost incurred by the manual schedule is substantially higher whereas the algorithmic schedule uses about twice as much tutors. This is supported by the findings in lines six and seven. Since about 93% of all courses are performed in Frankfurt, the extent to which staff from the other two LTT offices in Hamburg (HAM) and Berlin (BER) are utilized is a meaningful indicator of the travel cost entailed. It turns out that the manual schedule makes about four times as much use of such instructors as the

algorithmic one. The last two lines provide some insight into the workload distribution of the staff. On average, the number of days accorded to instructors is about the same for both schedules but the LTT-schedule assigns more than 10% more lessons to them than our schedule. Again, this is due to the higher extent to which our schedule makes use of tutors. Note, finally, that - using an implementation in Borland C on a 486DX, 100 MHz personal computer - computation times required were in the range of several hours, which seems acceptable considering the fact that we are dealing with a problem of long-term planning, with a planning horizon of one year.

#### **4. The Decision Support System**

After the validity of our approach had been proven by means of the above prototypic system, additional requirements on the way to building a comprehensive decision support system were formulated. First of all, the entire planning information had to be organized into a data structure and transferred into a database system; this was perceived to be necessary because a substantial part of the data required for operational planning is subject to constant changes or modifications, dealing with which should be facilitated and kept redundancy-free as far as possible. For example, explicitly storing all instructors able to teach a particular topic together with the topic would entail considerable effort if one instructor obtains an additional qualification. Therefore, each topic is characterized in terms of instructor qualifications and training facilities required whereas the instructor data comprise the subject qualifications. Thus, to determine the group of instructors qualified to cover a particular topic it now suffices to run a simple query on the database.

Another major requirement was the capability to represent schedules in a graphical manner. This capability is essential since the merely numerical output usually produced by scientific code is hardly viable to be used in the day-to-day operations of a company. In contrast, a user-friendly interface as provided by contemporary software allows for easy interaction with the system, improving the acceptance among the users. Other requirements include topics such as data integrity conservation, access control for security reasons, and simultaneous multi-user accessibility. Eventually, the decision was made to utilize a client-server architecture; it employs a centralized Oracle database under the UNIX operating system and Windows 95-based front-ends developed under Borland Delphi.

As is common with such systems, a large part of the functionality involved is pretty much straightforward, such as features allowing to store, retrieve, manipulate, or delete single courses or complete plans. Other features, such as online help screens, etc., are standard for contemporary software. We therefore concentrate on describing the way in which information is represented in different views. In particular, three main views are available.

	05.01.97	06.01.97	07.01.97	08.01.97	09.01.97	10.01.97	11.01.97	12.01.97
	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Instructor 1								
Instructor 2								
Instructor 3								
Instructor 4								
Instructor 5								
Instructor 6								
Project 1								
Project 2								
Project 3								
Project 4								

Project 2 is not scheduled

Survey Statistics

Figure 2: Overall Plan View

First, the overall view (Figure 2) which allows to display an arbitrary number of course plans and instructors. Basically, this view is the one of the manually constructed plan-on-paper. Each column corresponds to one calendar day of the planning horizon. Regarding the columns, the window is split in two parts, each row represents a requested course in the lower part and an instructor in the upper part. Each course is displayed in a specific colour, as is any day of an instructor in which he is exclusively assigned to that course. Vacation days, weekends, holidays, or days where an instructor is teaching in more than one course are marked in other ways. To avoid cluttering the screen, several filters allow to restrict the view to specific courses or instructors. Even so, most courses are too long to be displayed completely on the screen; hence placing the mouse cursor on a course provides additional information, such as whether that course has been feasibly scheduled and if so, its start and finish dates.

	02.12.96	03.12.96	04.12.96	05.12.96	06.12.96	07.12.96	08.12.96	09.12.96	10.12.96	11.12.96
	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed
1	Elec	FW	FW							
2	Elec	FW	FW							
3	Elec	FW								
4	Elec	FW								
5	FW	FW								
6	FW	FW								
7										
8										
9										
10										
11										
12										

Figure 3: Detailed View of a Course Plan

Second, a view that details the information available for a specific course (Figure 3). Again, each column stands for one calendar day, each row for one lesson. Since training days are divided into a day and a night shift of six hours each, the top six rows correspond to daytime, the bottom six rows to nighttime training. Entries indicate the particular block to which the individual lesson belongs; here, different colours correspond to different blocks. In that way, the course view is very similar to an ordinary school timetable. Still, here also the sequence of blocks becomes apparent (in Figure 3 Elec, FW, TW, Struc, Prac, Struc, and then the final Test), an information that is usually of little interest in school timetabling. Again, weekends and holidays are marked differently.

	03.01.97	04.01.97	05.01.97	06.01.97	07.01.97	08.01.97	09.01.97	10.01.97	11.01.97	12.01.97
	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun
1				Elec	FW	FW	VACATION	VACATION		
2				Elec	FW	FW	VACATION	VACATION		
3				Elec	FW		VACATION	VACATION		
4				Elec	FW		VACATION	VACATION		
5				FW	FW		VACATION	VACATION		
6							VACATION	VACATION		
7							VACATION	VACATION		
8							VACATION	VACATION		
9							VACATION	VACATION		
10							VACATION	VACATION		

Figure 4: Detailed View of an Instructor Plan

Third, a similar view presents a detailed timetable for a particular instructor (Figure 4), using the same format as the course plan view. In addition, also vacation days of the instructor are

marked and, when the mouse cursor is placed on a particular block, the corresponding course and topic are displayed.

Another feature to be included later on will allow to produce aggregations of either the planning data or the results of the planning process, providing valuable information e.g. on staff workload, instructor assignments, training facility utilization. In the past, informations like these had to be compiled manually, a tedious and costly task that could not be done on a regular basis. Some exemplary evaluations are listed in Table 5. Other evaluations can easily be envisioned.

---

list all requested courses, group by type
list all scheduled courses, group by type
list all instructors assigned to a specific course, group by topic
list the workload of each instructor, group by day/night
list the workload of each tutor, group by course
list the travel cost of each office, group by course

---

*Table 5: Some Exemplary Evaluations*

Finally, an additional interface to another system, which is used by the marketing department to develop and manage information on the design of different course types, will allow to more easily take marketing aspects into consideration when constructing schedules.

## **5. Summary and Conclusions**

The management of LTT had been well aware that gains could possibly be achieved by changing their scheduling process. It was, however, unknown what kind of changes would be best in the unique environment of professional course scheduling, where a variety of objectives and constraints need to be taken into consideration. Following some preliminary economic analysis, LTT management asked us to build a proof prototype of the most innovative component of a course scheduling decision support system, viz. a course scheduling module. In doing so, LTT accepted to make a significant investment in time and staff expenses to perform both initial acquisition and ongoing update of the required planning data.

Using the operational data of 1996, the prototype demonstrated that notable increases in profit margin could be achieved from using algorithmically constructed schedules. LTT found these results to be highly satisfactory. Therefore, the company made the decision to expand the prototype into a fully-fledged decision support system that will be integrated into their regular



operations. Benefits expected from such a system include a further increase of profit margin and reduction of travel cost and times, faster generation of operational schedules, usage of resources to capacity, ability to react more flexible to short-term changes, and provision of detailed statistical information for planners, staff, and customers.

The experiences gained throughout this project demonstrate that efficient planning can provide significant contributions to cost reductions and profit margin increases.

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### **Appendix**

In order to illustrate the inherent differences between the problem fields depicted in Figure 1, we juxtapose some fundamental characteristics. Note that the symbols used here may have other meanings than in the above sections. Objectives or requirements, i.e. restrictions, bracketed in [] are not necessarily found in all cases. "Complete scheduling (C)" means that all courses (classes) must be scheduled. "No clashes (T, C, R)" signifies that no teacher (course, room) may be assigned to more than one period at a time. "Availabilities" states that the mentioned objects must simply be available to allow scheduling whereas "Capacities (C)" means that for the courses specific capacity limits have to be considered. "Preferences (R, P)" means that some teachers may prefer certain rooms or periods over others. The remaining requirements should be self-explanatory.

Objects of Planning	Objectives	Requirements
Teachers (T)	Feasibility	Complete scheduling (C)
Courses (C)	Preference maximization	No clashes (C, R)
Rooms (R)		Availabilities (R)
Periods (P)		Preferences (R, P)
		[Availabilities (T)]
		[Capacities (C)]

*Table 6: Characteristics of Academic Course Scheduling*

Objects of Planning	Objective	Requirements
Teachers (T)	Feasibility	Complete scheduling (C)
Classes (C)		No clashes (T, C, R)
Subjects (S)		Availabilities (R)
Rooms (R)		Compactness (P)
Periods (P)		[Availabilities (T, C)]
		[Even distribution (P)]

*Table 7: Characteristics of School Timetabling*

Objects of Planning	Objectives	Requirements
Teachers (T)	Profit	No clashes (T, C, R)
Courses (C)	Service level	Availabilities (T, C, R)
Subjects (S)	Standard sequence (C)	Precedence relations (S)
Rooms (R)	Even distribution (T)	Temporal restrictions (C, S)
Periods (P)	Redundancy (T)	[Capacities (C)]
	Compactness (K)	[...]
	Teacher alternation	

*Table 8: Characteristics of Professional Course Scheduling*

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