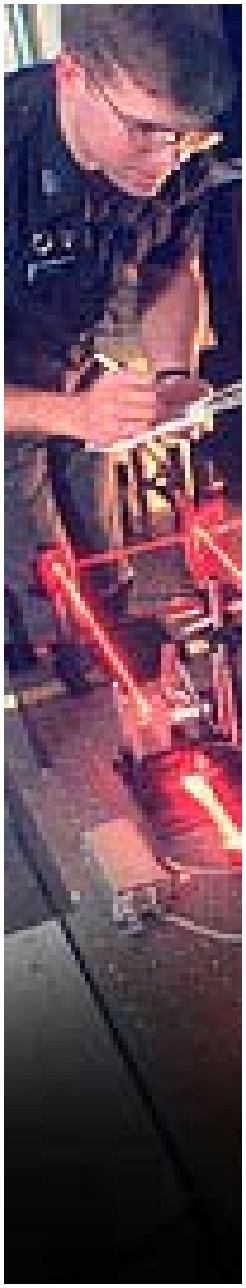


Class Scheduling at United States Military Academy West Point, NY

Fred O'Brien

United States Military Academy

Michael R. Bussieck, Alexander Meeraus

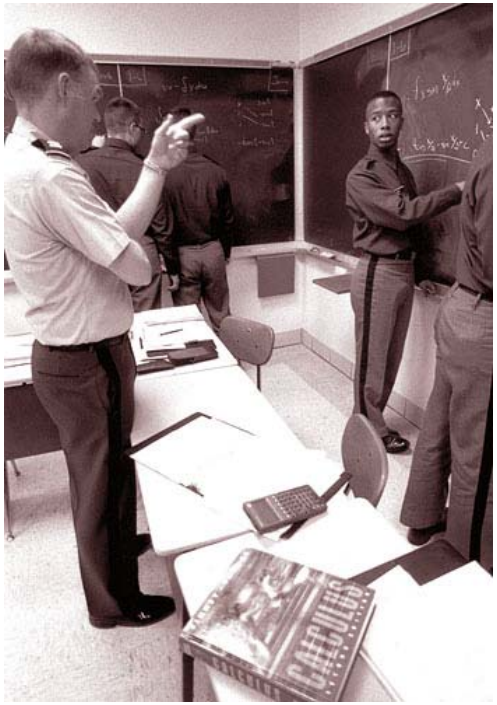
GAMS Development Corporation

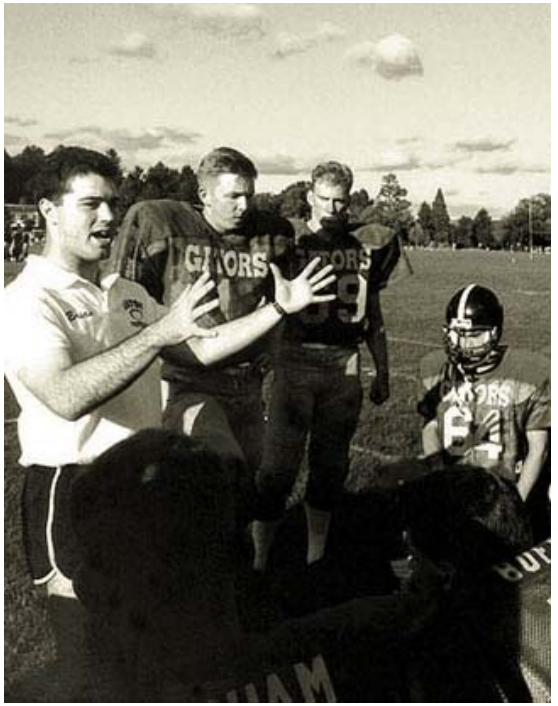
USMA MISSION

To educate, train, and inspire the Corps of Cadets so that each graduate is a commissioned leader of character committed to the values of Duty, Honor, Country; professional growth throughout a career as an officer in the United States Army; and a lifetime of selfless service to the nation.

Program at USMA

" … each student's daily activities are a carefully regimented balance of academic, military, and physical requirements."





USMA is Different

- Technically
  - Day1/day2 schedule
  - Special rules (e.G. < 30% athletes in class)
- Scheduling around the cadets needs
  - No conflicting activities
  - Individual schedule of activities is compliant to vast catalogue of *business rules*

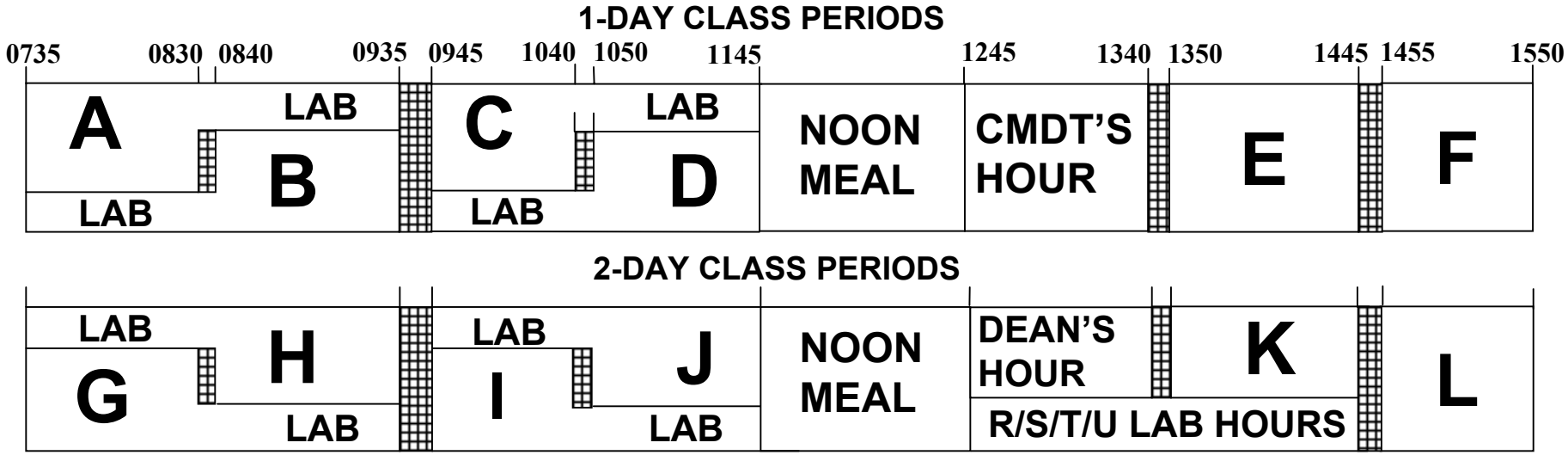
➢ Proper planning

2 Day Schedule

OFFICE OF THE DEAN
UNITED STATES MILITARY ACADEMY

AUGUST 1999
(EDITION OF AUG 98 IS OBSOLETE)

ATTENDANCE PERIODS



1-DAY/2-DAY SCHEDULE: AY 99/00

LEGEND

INDICATES A or B SATURDAY

DATE: 1 A — LESSON NUMBER FOR 40 LESSON COURSES

1-DAY or 2-DAY: 2-121

R/S/T/U FIXED LAB SCHEDULED IN DEANS HOUR /K HOUR

AUGUST 1999

SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
						1
2	9	3 1 K	4 11	5 12	6 1 3	7 14
		REORGANIZATION WEEK				
8	15	10 1st Class Begins 2-1	11 17 1-1	12 1 8 2-2	13 19 1-2	14 20 2-3
15	22	17 23 1-3	18 24 2-R	19 25 1-4	20 26 2-S	21 B 27 1-5 RING WEEKEND
22	29	24 30 2-T 6	25 31 1-6	26 2-5	27 1-5	28 A/C

SEPTEMBER 1999

SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
			1 2-7	2 1-7	3 2-8 U	4 B
5	6 LABOR DAY (No Classes)	7 1-8	8 2-9 R	9 1-9	10 2-10 S	11 A/D HOME FOOTBALL WAKE FOREST
12	13 1-10	14 2-11 T	15 1-11	16 2-12 U	17 1-12	18 A/C AWAY FOOTBALL TULANE
19	20 2-13 R	21 1-13	22 2-14	23 1-14	24 2-15 S	25 A/D HOME FOOTBALL BALL STATE
26	27 1-15	28 2-16 T	29 1-16	30 2-17 U		

OCTOBER 1999

SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
				1 1-17	2 A/D HOME FOOTBALL	
3	4 2-18 R	5 1-18	6 2-19 S	7 1-19 HOME FOOTBALL LOUISVILLE	8 PLEBE PARENT WEEKEND (NO CLASSES)	9 CAROLINA B
10 PLEBE PARENT WEEKEND	11 COLUMBUS DAY (No Classes)	12 2-20 T	13 1-20	14 2-21 U	15 1-21	16 Class Day 2- AWAY FOOTBALL MISSISSIPPI
17	18 1-22	19 2-22 R	20 1-23	21 2-23 S	22 1-24	23 A/C HOMECOMING FOOTBALL NEW MEXICO
24	25 2-24 T	26 1-25	27 2-26 U	28 1-26	29 2-27 R	30 A/D
31						

NOVEMBER 1999

SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
	1 1-27	2 2-28 S	3 1-28	4 2-29	5 1-29	6 B AWAY FOOTBALL AIR FORCE
7	8 2-30 U	9 1-30	10 2-31 R	11 VETERANS DAY (No Classes)	12 1-31	13 A/D AWAY FOOTBALL MEMPHIS
14	15 2-32 S	16 1-32	17 2-33 T	18 1-33	19 2-34 Make ahead WPPWE U	20 A/C HOME FOOTBALL HOUSTON
21 WPPWE 1930	22 1-34	23 2-35	24 1-35 COMPRESSED SCHEDULE	25 THANKSGIVING LEAVE	26	27
28 THANKS-GIVING LEAVE ENDS	29 1-36	30 2-36 R				

DECEMBER 1999

SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
			1 1-37	2 2-35 S	3 1-38	4 B FOOTBALL BEAT NAVY!
5	6 2-37 T	7 1-39	8 2-39 U	9 1-40	10 2-40	11 TERM END EXAMS BEGIN
12	13	14 TERM END EXAMINATIONS	15	16	17	18
19 WINTER LEAVE BEGINS	20	21 WINTER LEAVE	22	23	24	25
26	27	28 WINTER LEAVE	29	30	31	

JANUARY 2000

SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
					1 WINTER LEAVE	
2 WINTER LEAVE ENDS	3	4	5 MILITARY INTERSESSION	6	7	8
9	10	11 MILITARY INTERSESSION	12	13	14	15
16	17 M.L KING'S B'DAY (No Classes)	18 2nd Term Begins 2-	19 1-1	20 2-2	21 1-2	22 B 500TH NIGHT
23	24 2-3	25 1-3	26 2-4 R	27 1-4	28 2-5 S	29 A/C YEARLING WEEKEND
30	31 1-5					

FEBRUARY 2000

SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
		1 2-6 T	2 1-6	3 2- U	4 1-7	5 A/C
6	7 2-8 R	8 1-8	9 2-9 S	10 1-9	11 2-10 T	12 A/D RMC @ RMC
13	14 1-10	15 2-11 U	16 1-11	17 2- R	18 1-12	19 B
20	21 PRESIDENTS DAY (No Classes)	22 2-13	23 1-13	24 2-S	25 1-14	26 A/D B for 1st Class 100TH NIGHT
27	28 2-15 T	29 1-15				

MARCH 2000

SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
			1 2-16 U	2 1-16	3 2- R	4 CLASS DAY 1-17
5	6 2-18	7 1-18	8 2-19 S	9 1-19	10 2-20 T	11 A/C
12	13 1-20	14 2-21 U	15 1-21	16 2- R	17 1- COMPRESSED SCHEDULE	18 SPRING LEAVE BEGINS
19	20	21	22 SPRING LEAVE	23	24	25
26 SPRING LEAVE ENDS	27 1-23	28 2- S	29 1-24	30 2- T	31 1-25	

APRIL 2000

SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
						1 CLASS DAY 2-25
2	3 1-26	4 2-26 U	5 1-27	6 2-27 R	7 1-28	8 A/C
9	10 2-28 S	11 1-29	12 2- T	13 1-30	14 2-30 U	15 A/D FEE
16	17 1-31	18 2-31 R	19 1-32	20 2- S	21 1- Make ahead WPPWE	22 B
23 EASTER WPPWE 1930	24 2- T	25 1-34	26 2-34 U	27 1-35	28 2-35 R	29 A/C SANDHURST
30						

MAY 2000

SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
	1 1-36	2 2-36 S	3 1-37	4 2- T	5 1-38	6 A/C
7	8 2-38 U	9 1-39	10 2-39	11 1-	12 2-40	13 A/D
14	15	16 TERM END EXAMINATIONS	17	18	19	20
21	22 STAP BEGINS	23	24	25	26	27 GRADUATION DAY
28	29 MEMORIAL DAY CLASSES IN SESSION	30	31			

JUNE 2000

SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16 STAP ENDS	17 STAP GRADUATION
18	19	20	21	22	23	24
25	26	27	28	29 RECEPTION "R" DAY	30	

Academic Program

- 8 Term Academic Program (8TAP)
- E.g **MATHEMATICS MAJOR: Statistics/Optimization**

	4		5	6		7	8
1	PH202		ENG SEQ	ENG SEQ		ENG SEQ	ENG SEQ
2	MA206		ENG SEQ	MA363		MA386	MA476*
3	LX2XX		MA376	MA371		MA381*	**MA481***
4	SS20X		MA383	MA387		MA492D*	MA491
5	EV203		SS307	EN302		HI301	HI302
6	MA 391		PL300			LW403	

Enterprise Academy Management System

Management of :

Redbook

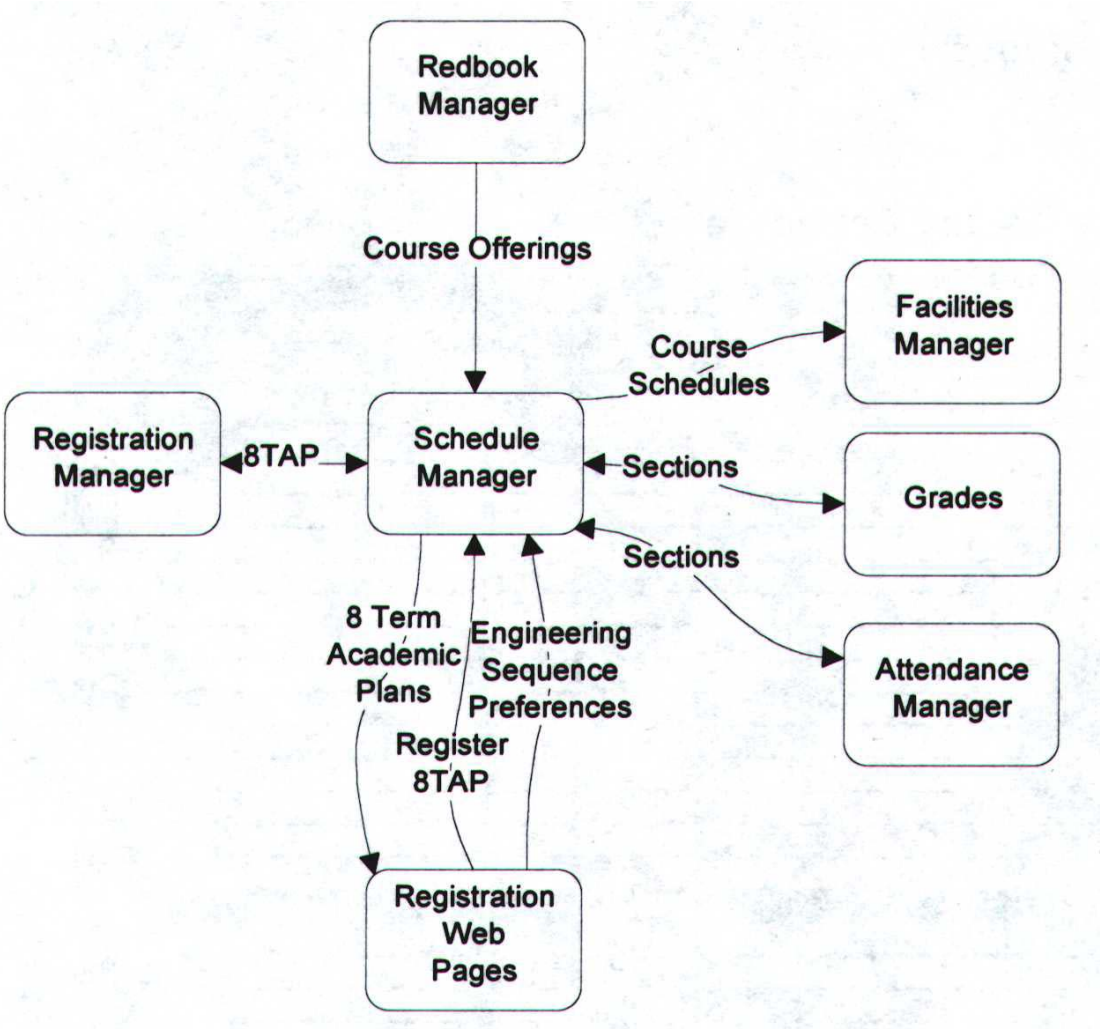
Registration

Schedule

Facility

Attendance

Grades



Academic Scheduling

- Course scheduling
  - For a given set of *course offerings* find *good* schedules for all cadets.
  - Scheduling preps
    - Term balancing (department resources)
    - Initial course offerings
  - Scheduling
  - Manual post scheduling
- Term end exam (TEE) scheduling
  - Find *good* schedules for exam courses and cadets.

Course:
Search
Offerings
Sections
Future Terms:
Course Planner:
Planner
Next Term:
Instruction Periods:
Inst Periods
Instruction Periods Rollup:
Inst Periods
View all courses sponsored by department:
Curric Database
Main

MA104 COURSE OFFERINGS

COURSE	NBR SECT	SECT SIZE	CPBLTY	ENRLD	SEATS
MA104	52	18	936	933	3

MA104 INSTRUCTION PERIODS

COURSE	HOUR	NBR SECT	SECT SIZE	CPBLTY
MA104	AG	13	18	234
MA104	BH	13	18	234
MA104	CI	13	18	234
MA104	DJ	13	18	234

Tight

MA205 COURSE OFFERINGS

COURSE	NBR SECT	SECT SIZE	CPBLTY	ENRLD	SEATS
MA205	5	18	90	70	20

Depts

MA205 INSTRUCTION PERIODS

COURSE	HOUR	NBR SECT	SECT SIZE	CPBLTY
MA205	AG	1	18	18

Scheduling Courses to Hours

- Difficult to handle automatically
- Rotating unpleasant hours year by year

- Helpful in negotiations with departments:

  MA481 CD ⟹ AB

- Drop in conflicts and other improvements

Scheduling Cadet Courses to Hours

- Given course hours & capacity

MA481,AB,36	MA481,CD,18	MA481,EF,18
PE300,C,180	PE300,J,60	MA371,F,18

- Given cadet's course registration

043671XXX,MA481

043671XXX,PE300

- Objective: Find a *good* assignment of cadet's course requests to course hours

043671XXX,MA481,CD

043671XXX,PE300,J

Scheduling System Objectives

- Produced in a timely fashion
- Complies with ***most*** constraints/rules…
  - Individual:
    - Cadet can't be at two places at the same time
    - Course hours are balanced over Day-1, Day-2
    - Free hour
    - Cadet gets scheduled for all courses he/she has registered for
- Capacity:
  - Enrollment of course hour cannot exceed capability
  - Course enrollment of freshmen which are also athletes cannot exceed 60% of the total enrollment

Legacy Scheduling System

- Matching algorithm based on cadet's course registration only
- Reporting programs check schedule against **all** constraints and business rules
- Last years: 80% of cadets rescheduled manually
- Time to generate schedule: 4 weeks (3 Schedulers)

Problems with a MP Model

- There is no solution subject to *all* constraints/rules for real data
- What is the objective for the model?
- *Goal Programming:*
  - Relax constraints/rules by penalizing violations. Select penalties for violations: Calibration of the model.

An Optimization Model

$$\min \sum_{ro}(p1_{ro} * \pi 1_{ro} \quad + \quad p2_{ro} * \pi 2_{ro}) + \sum_{c}(p3_c * \pi 3_c + p4_c * \pi 4_c)$$

$$\sum_{o} x_{c,ro} = 1 \qquad \text{(for all 8TAP entries)}$$

$$\sum_{r} x_{c,ro} \leq 1+\pi 3_c \qquad \text{(for all cadets } c \text{ for all time slots } o\text{)}$$

$$-\sigma - \pi 4_c \leq \sum_{ro \text{ on day-1}} x_{c,ro} - \sum_{ro \text{ on day-2}} x_{c,ro} \leq \sigma + \pi 4_c \qquad \text{(for all cadets } c\text{)}$$

$$x_{c,ro} = 0 \qquad \text{(for all } c, ro \text{ where } c \text{ has activity at } o\text{)}$$

$$\sum_{c} x_{c,ro} \leq cap_{ro} + \pi 1_{ro} \qquad \text{(for all course hours } ro\text{)}$$

$$\sum_{c \text{ freshman\&athlete}} x_{c,ro} - 0.6 \sum_{c} x_{c,ro} \leq \pi 2_{ro} \qquad \text{(for all course hours } ro\text{)}$$

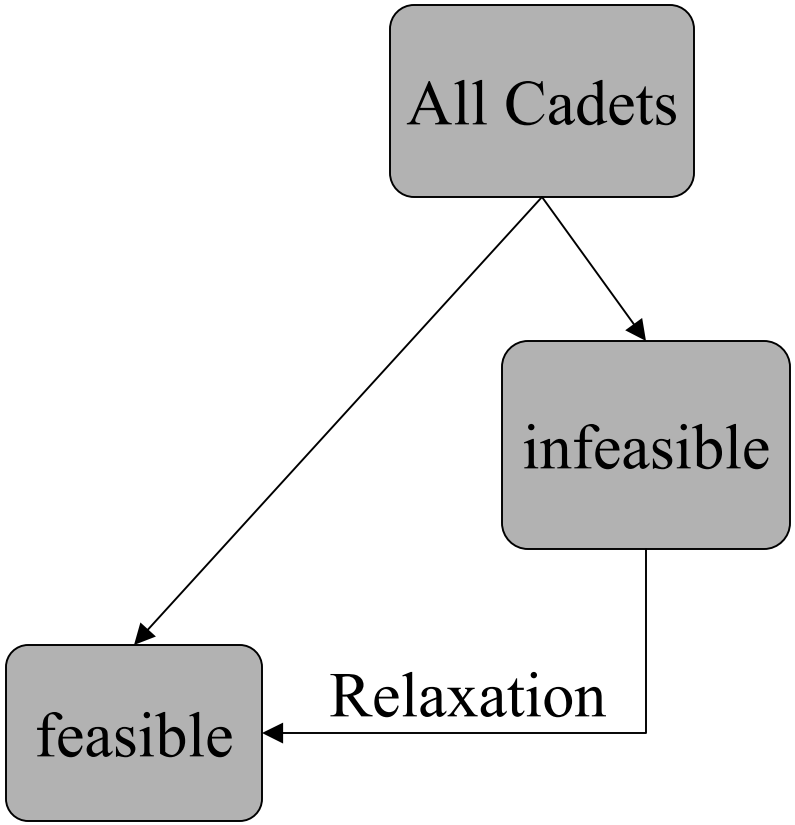
- 60,000 Variables, 500,000 Non-Zeros
- 24 hours CPLEX 6.6 and no integer solution

A 2-Stage Approach

- Prescheduling
  - Filter cadets with no feasible schedule
  - Overcome infeasibility by relaxation/data changes
- Scheduling
  - All individual constraints/rules are hard constraints
  - Find assignment that does not exceed capacity (or penalize overloads)

Prescheduling

- One cadet at a time
  - Check feasibility
  - If infeasible produce several infeasible schedules ranked by severeness of infeasibility
    - Hour Conflict
    - Day – Day Balance
    - Last Hour Free
  - Human Intervenes

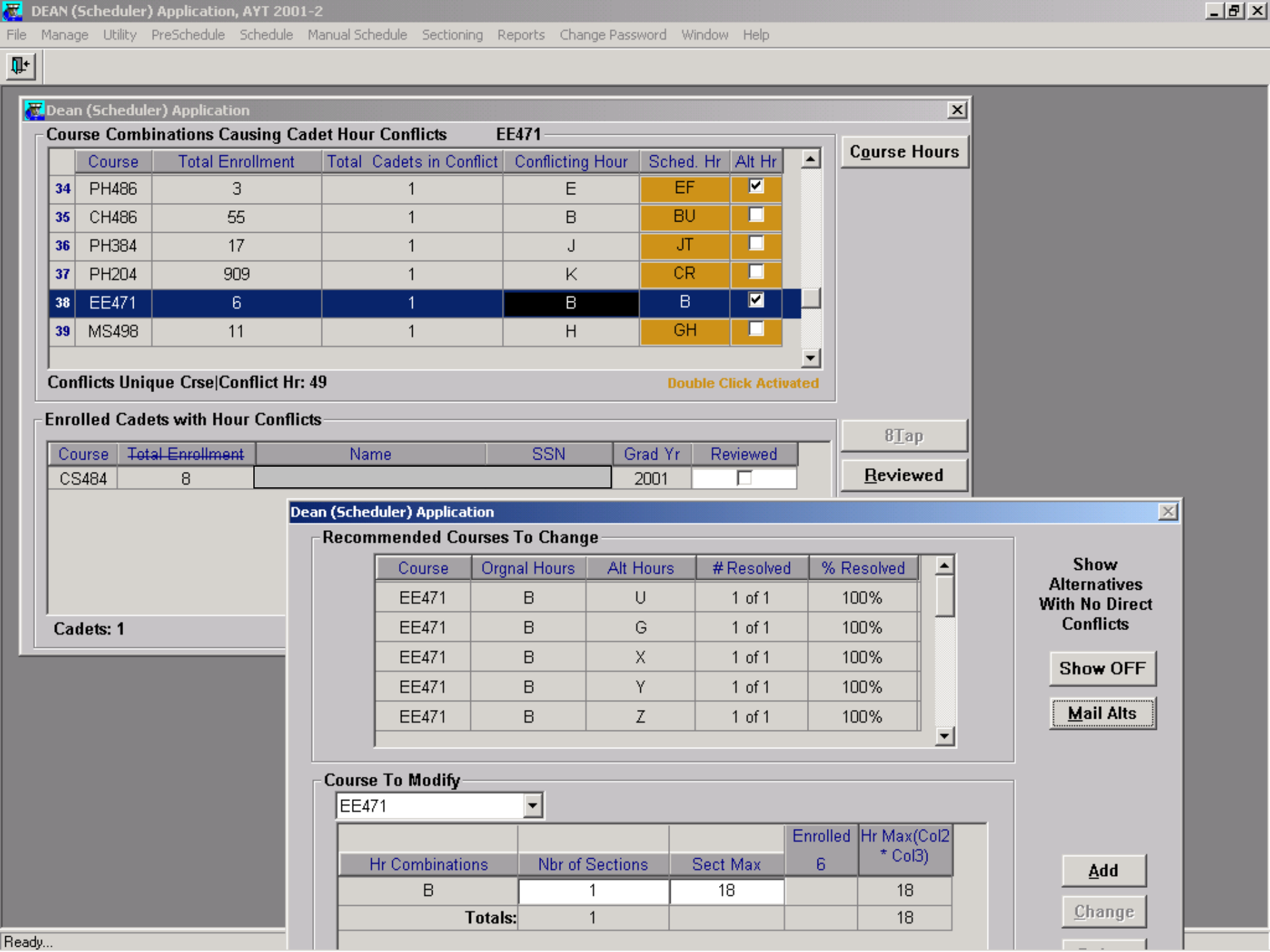


Conflicting Objectives

- Departments want to teach minimum number of sections and good hours.
- Dean wants to keep course enrollment at 18 cadets per section.
- Registrar wants to ensure cadet's day to day balance is satisfied.
- ODIA want to ensure their star running back gets last hour free for football practice

Options

- Change Model Data Inputs
  - Modify hours
  - Modify number of sections per hour
  - Modify cadets 8tap
- Waive Constraint
  - Unbalanced days
  - Last hour free
  - Design Group


DEAN (Scheduler) Application, AYT 2001-2
File Manage Utility PreSchedule Schedule Manual Schedule Sectioning Reports Change Password Window Help
Dean (Scheduler) Application
Course Combinations Causing Cadet Hour Conflicts EE471
Course Hours
Course | Total Enrollment | Total Cadets in Conflict | Conflicting Hour | Sched. Hr | Alt Hr
34 PH486 3 1 E EF
35 CH486 55 1 B BU
36 PH384 17 1 J JT
37 PH204 909 1 K CR
38 EE471 6 1 B B
39 MS498 11 1 H GH
Conflicts Unique Crse|Conflict Hr: 49
Double Click Activated
Enrolled Cadets with Hour Conflicts
Course | Total Enrollment | Name | SSN | Grad Yr | Reviewed
CS484 8 2001
8Tap
Reviewed
Cadets: 1
Dean (Scheduler) Application
Recommended Courses To Change
Course | Orgnal Hours | Alt Hours | # Resolved | % Resolved
EE471 B U 1 of 1 100%
EE471 B G 1 of 1 100%
EE471 B X 1 of 1 100%
EE471 B Y 1 of 1 100%
EE471 B Z 1 of 1 100%
Show Alternatives With No Direct Conflicts
Show OFF
Mail Alts
Course To Modify
EE471
Hr Combinations | Nbr of Sections | Sect Max | Enrolled 6 | Hr Max(Col2 * Col3)
B 1 18 18
Totals: 1 18
Add
Change
Ready...

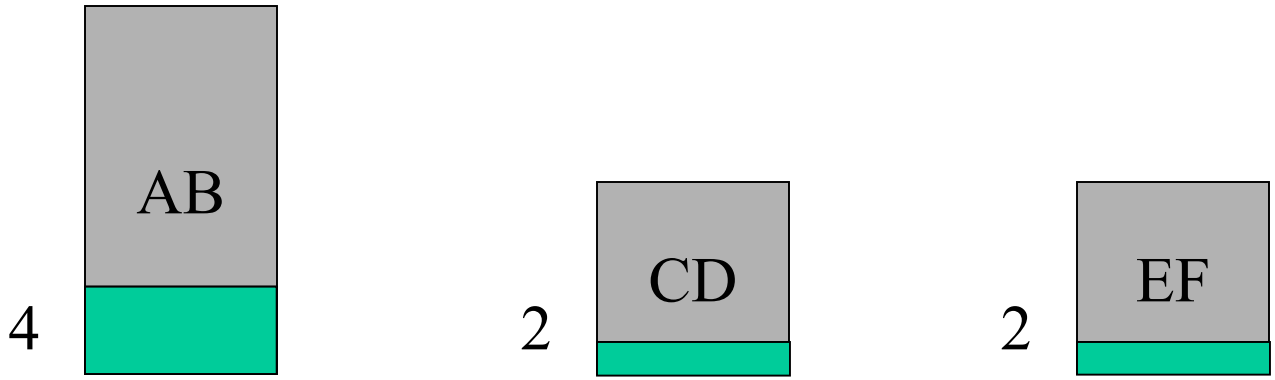
Scheduling

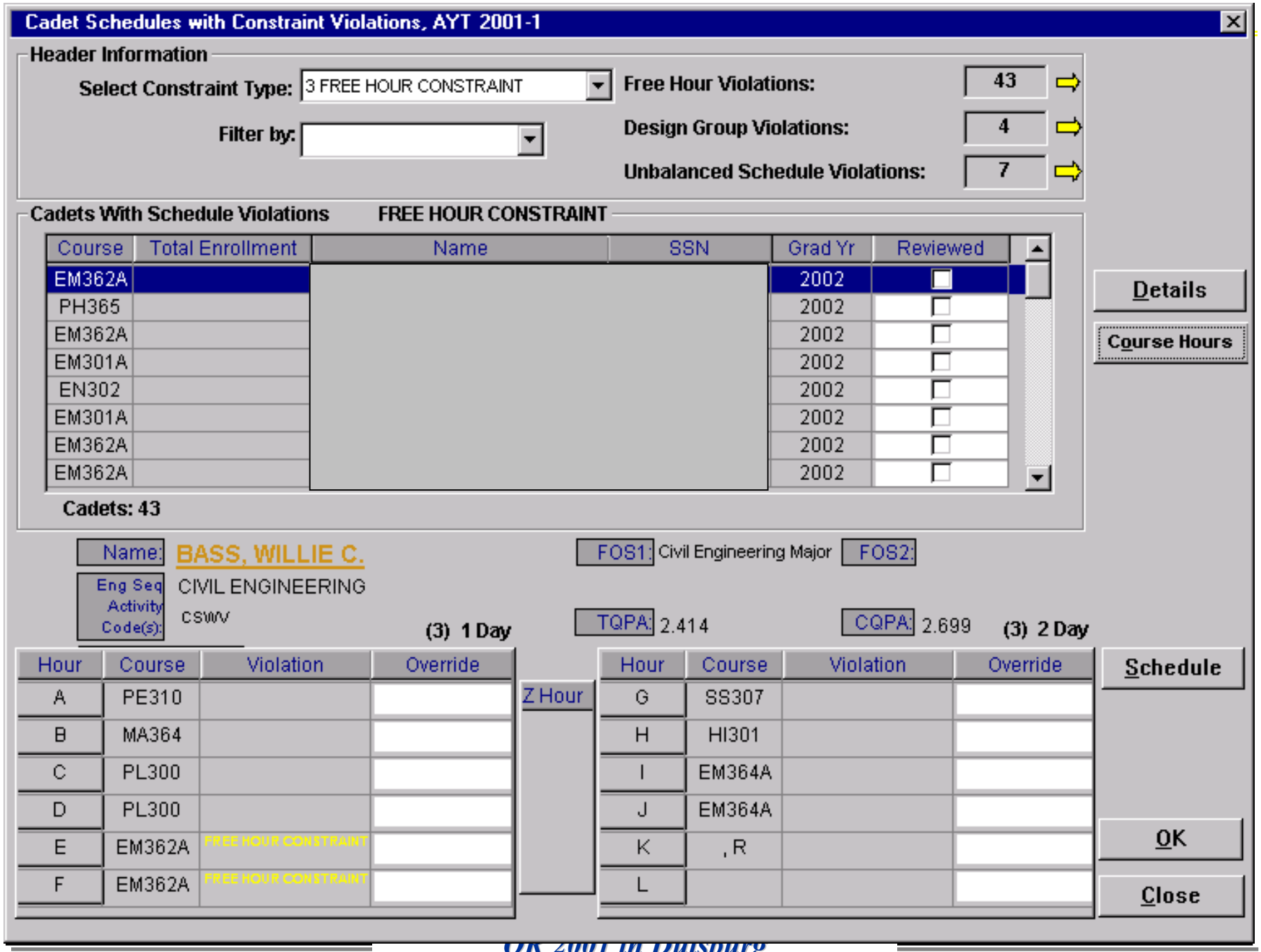
- Now individual constraints allow feasible schedules for all cadets (hard constraints)
- Tight Capacity of Course Hours may still result in an infeasible model:

  → Assign Overload Penalties
- Model with all cadets still *unsolvable*!

Scheduling in Batches

- Take a batch of cadets (10-30) and schedule them independent of the others
- Objective: Meet the capacity profile of the course hours (Penalize Over- and Underload)
- Example:
  - 3 course hours MA481 AB (20), CD,IJ (10)
  - Batch contains 8 cadets with request for MA481




Cadet Schedules with Constraint Violations, AYT 2001-1
Header Information
Select Constraint Type: 3 FREE HOUR CONSTRAINT
Filter by:
Free Hour Violations: 43
Design Group Violations: 4
Unbalanced Schedule Violations: 7
Cadets With Schedule Violations
FREE HOUR CONSTRAINT
Course | Total Enrollment | Name | SSN | Grad Yr | Reviewed
EM362A | 2002
PH365 | 2002
EM362A | 2002
EM301A | 2002
EN302 | 2002
EM301A | 2002
EM362A | 2002
EM362A | 2002
Cadets: 43
Details
Course Hours
Name: BASS, WILLIE C.
FOS1: Civil Engineering Major
FOS2:
Eng Seq Activity Code(s): CSWV
TQPA: 2.414
CQPA: 2.699
(3) 1 Day
(3) 2 Day
Hour | Course | Violation | Override
A | PE310
B | MA364
C | PL300
D | PL300
E | EM362A | FREE HOUR CONSTRAINT
F | EM362A | FREE HOUR CONSTRAINT
Z Hour
Hour | Course | Violation | Override
G | SS307
H | HI301
I | EM364A
J | EM364A
K | , R
L
Schedule
OK
Close

Unbalanced Hours, AYT 2001-2

Filter by Course

Unacceptable Hour Enrollment Variance (+/-) 5

Course(s)	Hours	Enrollment	Max Enrollment	Ideal Enrollment	Varience
CH101	GH	226	253	232.750	-6
CH101	AB	240	253	232.750	8
EM362A	GH	14	24	23.330	-9
EM362A	EF	41	36	35.000	6
EN101	F	254	340	307.140	-53
EN101	E	300	323	291.790	9

Number of Courses: 47

Double Click Activated

Course Hours

Schedule

Enrollment For: CH101 Hour: GH

Name	SSN	Grad Yr	Activity
		2004	CSRI
		2004	CSSR
		2004	
		2004	
		2004	CSFT
		2004	CSIT
		2004	CSBA

Cadet Count: 225

Double Click Activated

Cancel

Results

- AY 2000/2 parallel tested
- AY 2001/1 deployed

	Legacy System	New System
Individual Relaxations free/group/unbal	203/304/116	58/25/4
Capacity Overloads Courses/seats	12/54	9/21
Number of Schedulers	3	1
Time to produce Schedule	4 Weeks	1 Day

Conclusion

- Model is only one component of the system
- Human intervention throughout the process
- "*Solved*" difficult *real world* scheduling problem
- No large MIP formulation but simple heuristic based on solution of hundreds of small MIPs