

# ORIE 5980 M.Eng. Project

*Evening Prelims Scheduling*

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# Study of Current Scheduling Process

## AY1415 Survey results (from Cornell Registrar's Office)

- Did the scheduled evening prelims take place as planned?
- Was the schedule of those evening prelims well timed?

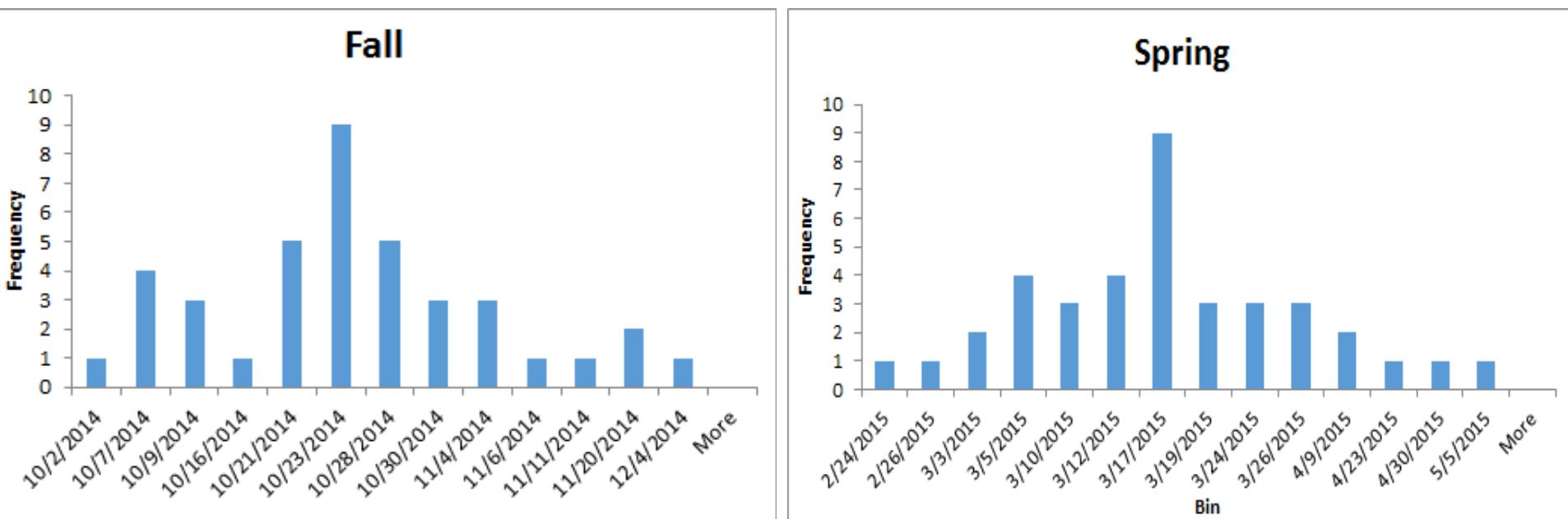
## Take away:

- Combined with course enrollment data, we found that a larger number of conflicts still exists, though most professors seem to be OK with current schedule.
- Current schedule was not very satisfying enough to accommodate course progress and important date like holiday and drop date.
- The prelim dates are not well spaced, some too early to semester beginning, some too close to semester end, and some too close to each other.

# Study of Current Scheduling Process

## 2014-2015 prelim schedule

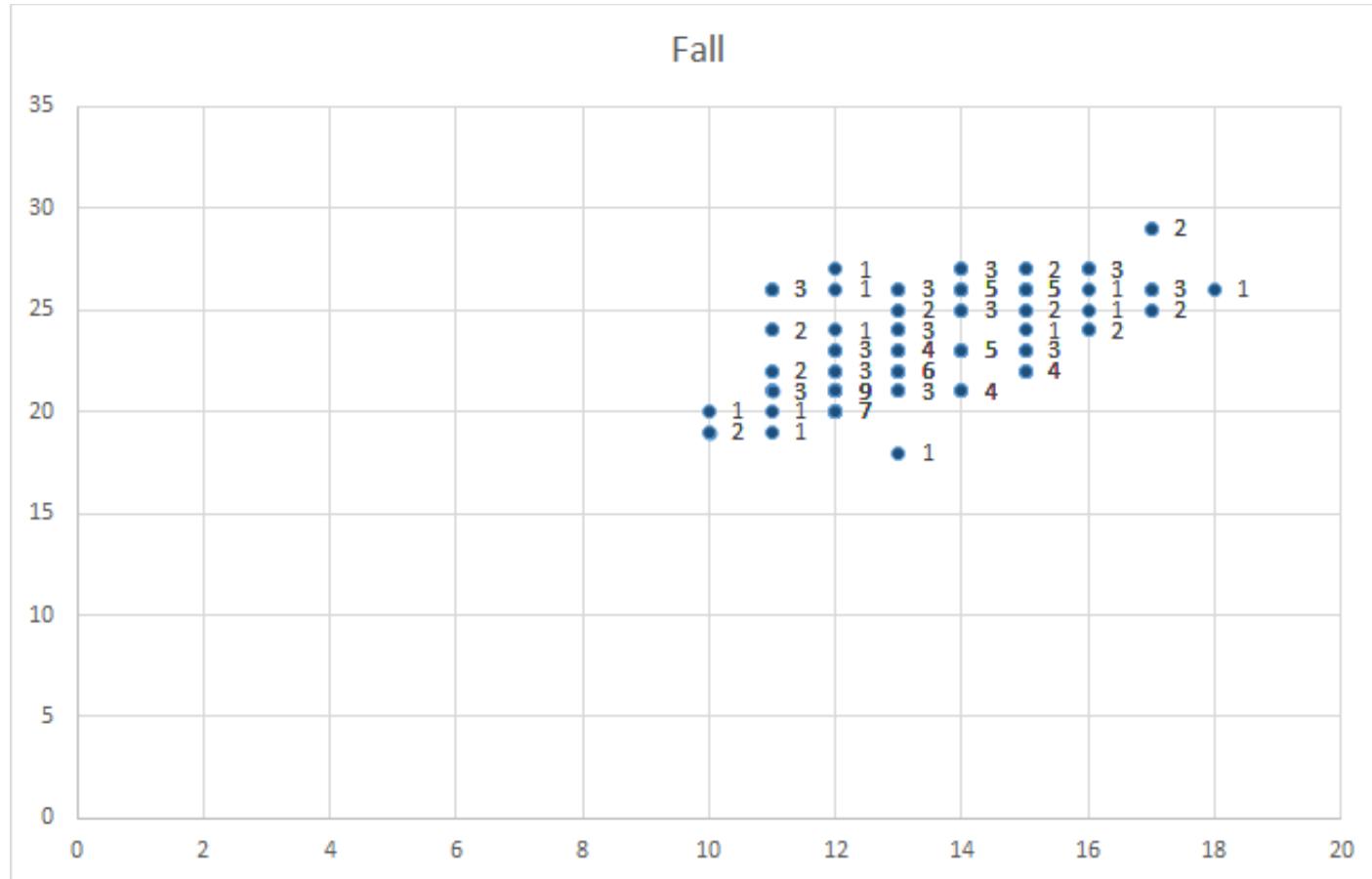
- One-Prelim Courses



# Study of Current Scheduling Process

## 2014-2015 prelim schedule

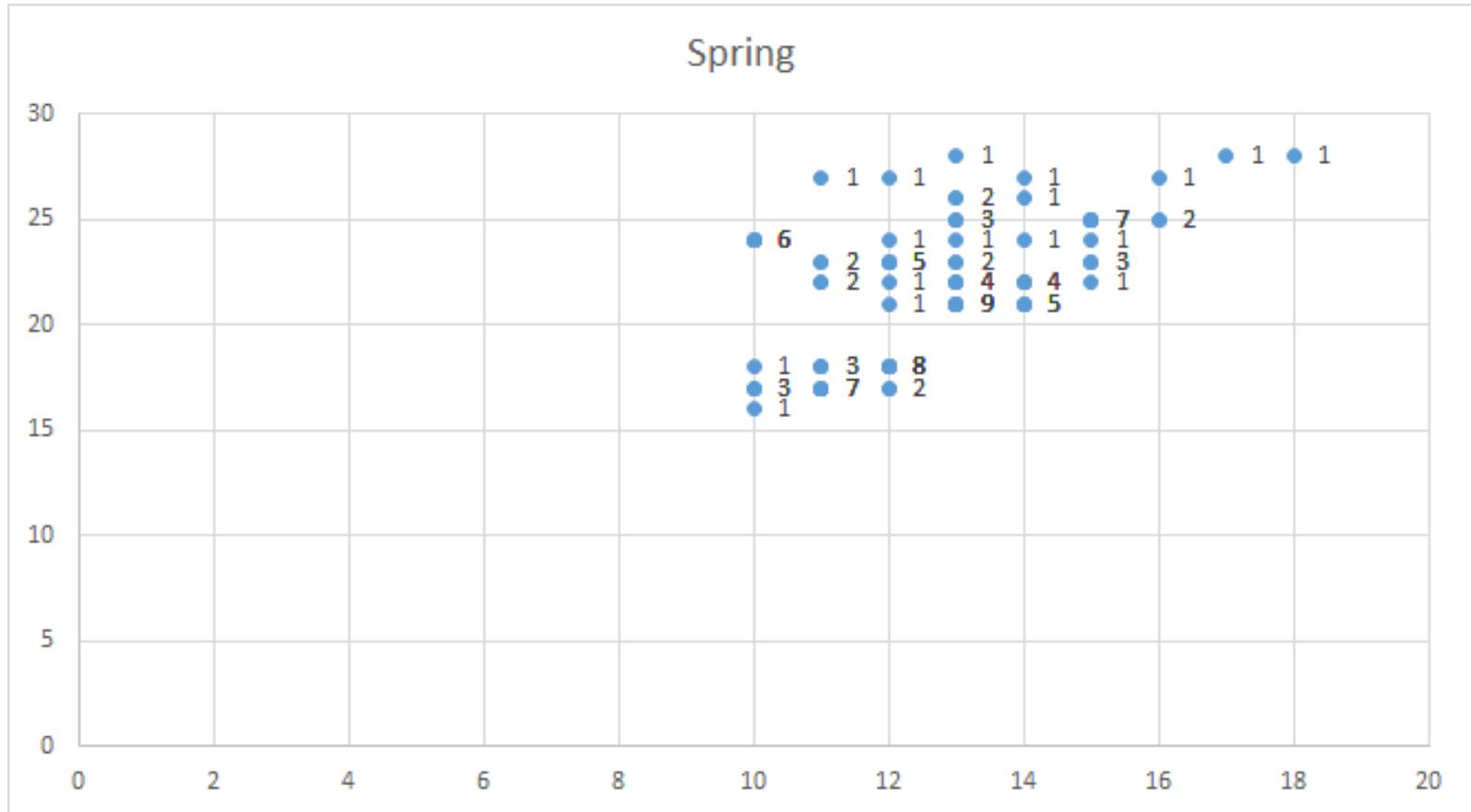
- Two-Prelim Courses



# Study of Current Scheduling Process

## 2014-2015 prelim schedule

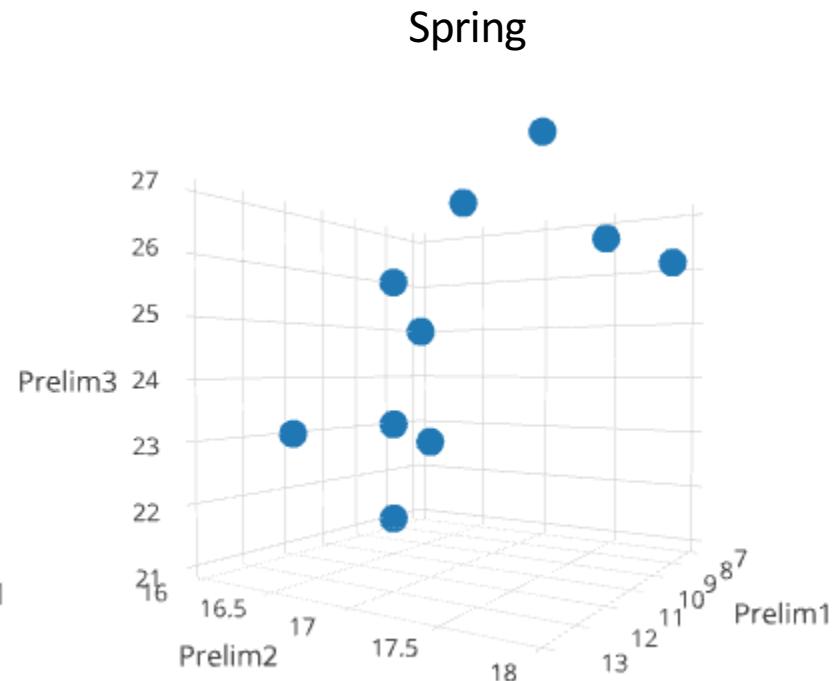
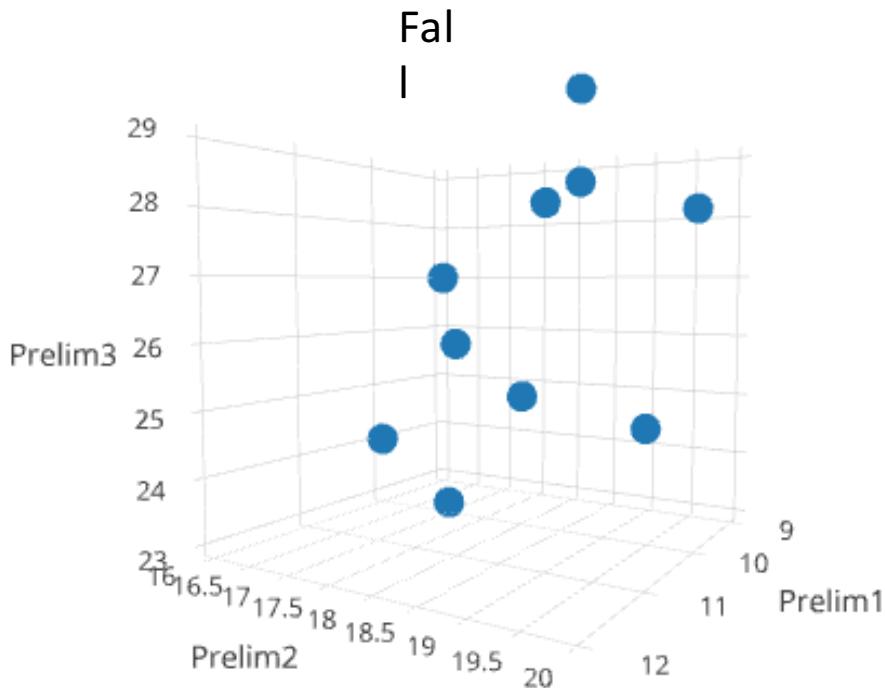
- Two-Prelim Courses



# Study of Current Scheduling Process

## 2014-2015 prelim schedule

- Three-Prelim Courses



Study of current schedule gave us insight on cause of conflicts and potential for improvements.

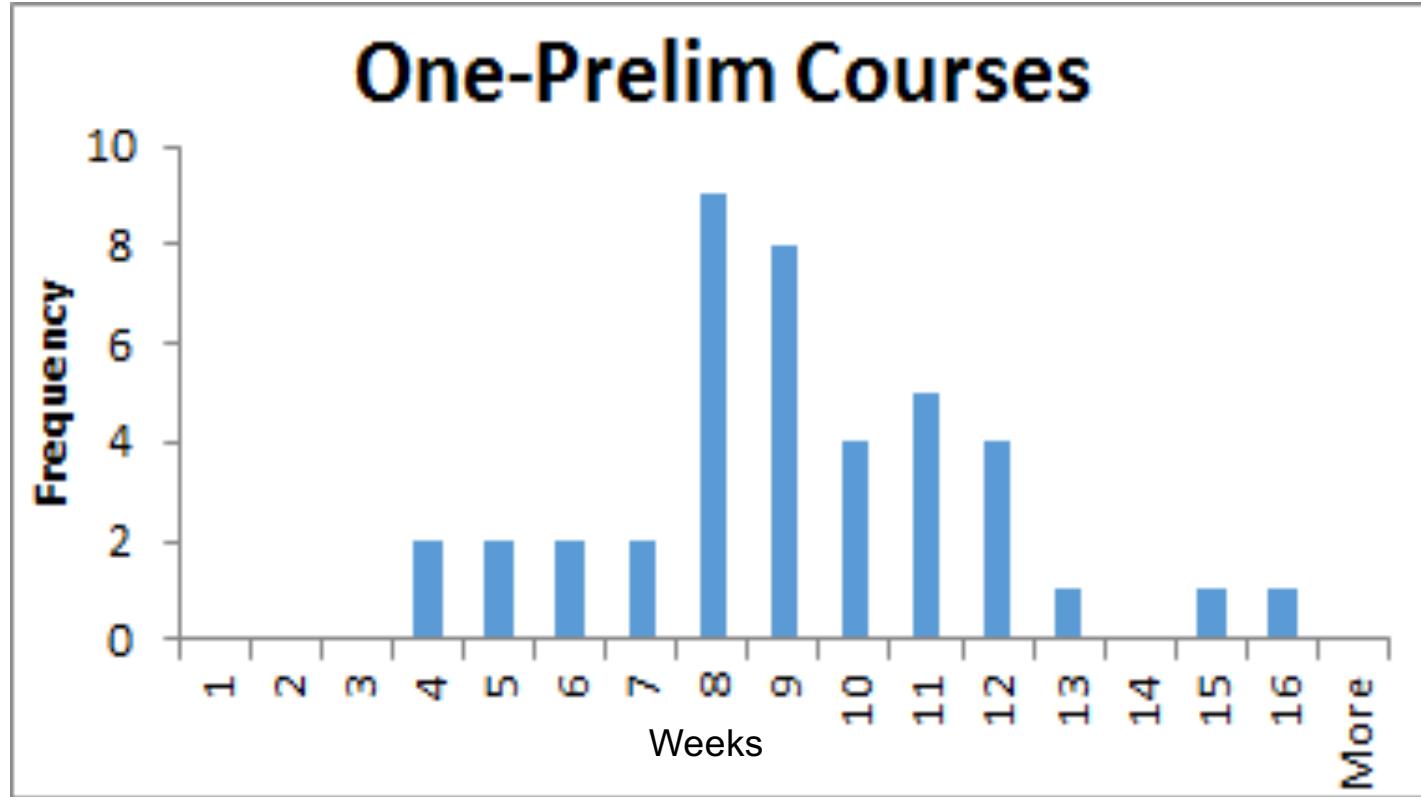
# Study of Current Scheduling Process

## Goals for the Second Survey:

- A bigger sample space.
- More detailed questions about professors' concern.
- Learn about professors' preferred prelim schedule, based on course progress and enrollment conflicts.
- To solve the spacing problem, we asked how important professors think it is for their prelims to be equally spaced across the semester.

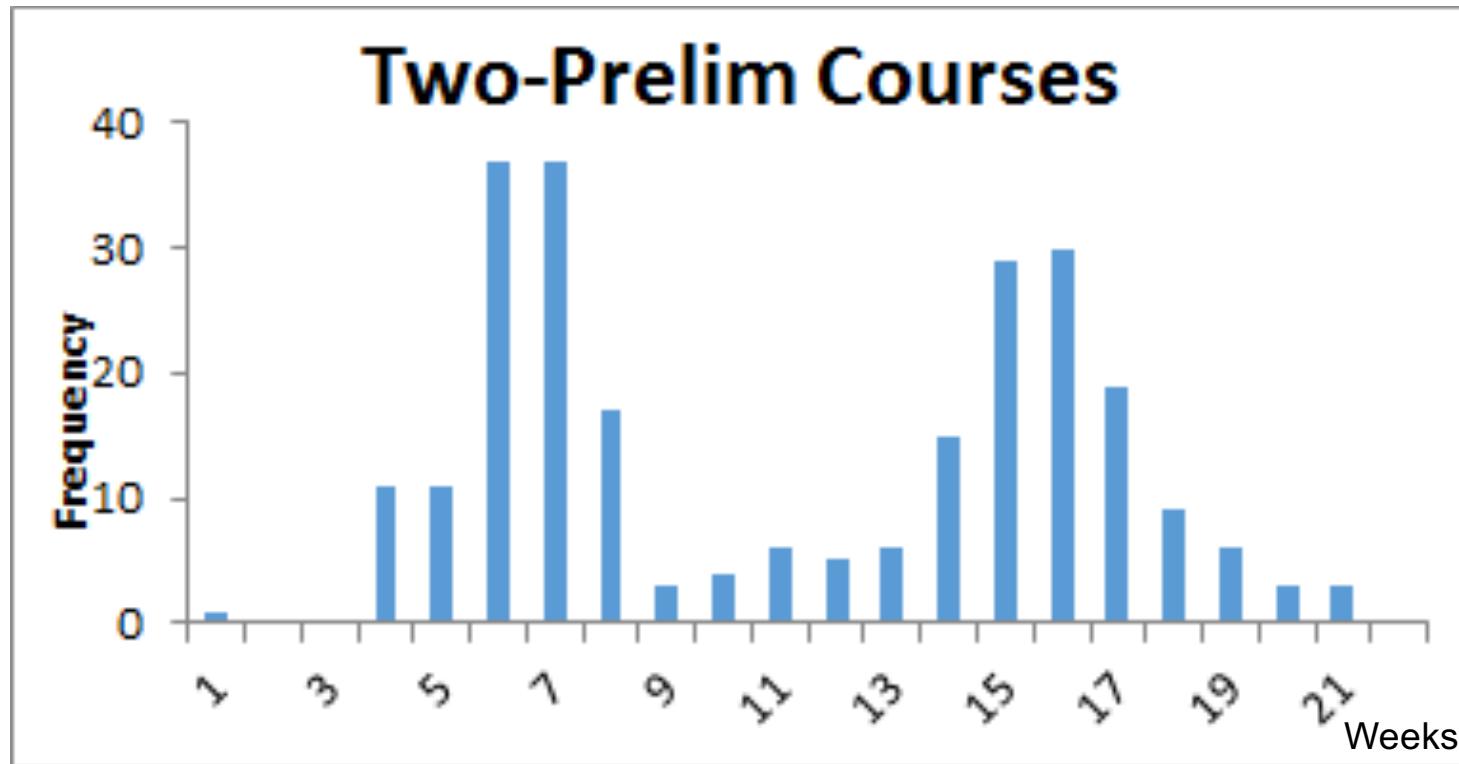
# Step Further: Our own Survey & Result

Professors' ideal prelim schedule



# Step Further: Our own Survey & Result

Professors' ideal prelim schedule



# Step Further: Our own Survey & Result

## Pattern Generation:

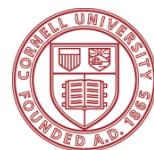
ID	Number of Prelims	Set of Possible Pattern
71	1	8 9
77	2	(6, 14) (6, 15) (6 16) (6 17) (7 14) (7 15) (7 16) (7 17)
8	2	(9, 18) (9, 19)
103	1	10 11
123	2	(8, 16) (8, 17)
32	2	(9, 16) (9, 17)
17	2	(4, 10) (4, 11) (5 10) (5 11)
85	2	(4, 10) (4, 11) (5 10) (5 11)
19	2	(6, 16) (6, 17) (6 18) (6 19) (7 16) (7 17) (7 18) (7 19)
83	2	(6, 14) (6, 15) (7 14) (7 15)
69	2	(4, 16) (4, 17) (5 16) (5 17)
64	2	(4, 16) (4, 17) (5 16) (5 17)
37	2	(6, 16) (6, 17) (7 16) (7 17)
79	2	(6, 14) (6, 15) (7 14) (7 15)
109	1	9
26	2	(6, 14) (6, 15) (7 14) (7 15)
101	1	8
54	1	9
107	2	(6, 16) (6, 17) (7 16) (7 17)
105	1	12 13
87	2	(6, 14) (6, 15) (7 14) (7 15)
41	2	(6, 14) (6 15) (7 14) (7 15)
124	2	(8, 16) (8 17)
81	2	(8, 16) (8 17)
111	1	8

Based on the feedback, we generated prelim patterns, which were directly used as input in our final IP model.

# Step Further: Our own Survey & Result

Professors' None-quantitative preference (Sample):

- The first prelim should be before the drop deadline.
- No prelims immediately before or after long vacations like spring and fall break.
- Last prelims shouldn't be too close to the final.
- Two highly correlated large courses shouldn't have prelims in same evening due to the amount of conflicts
- Interval between two prelims should be long enough to fit course progress
- Prelims schedule should adjust according to students' special need like recruitment season and religious holidays.
- .....



# Course Data Analysis

## Course Indexing

Generate a unique index for each distinct course.

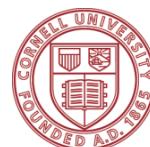
- W - Co-meet: an undergraduate level course and a graduate course that have class and prelim together
- C - Cross-list: courses offered by different department that meet together and shares the same course id
- B - both

## Assumption

- Half-term courses: treat them as full-semester courses

## Enrollment information

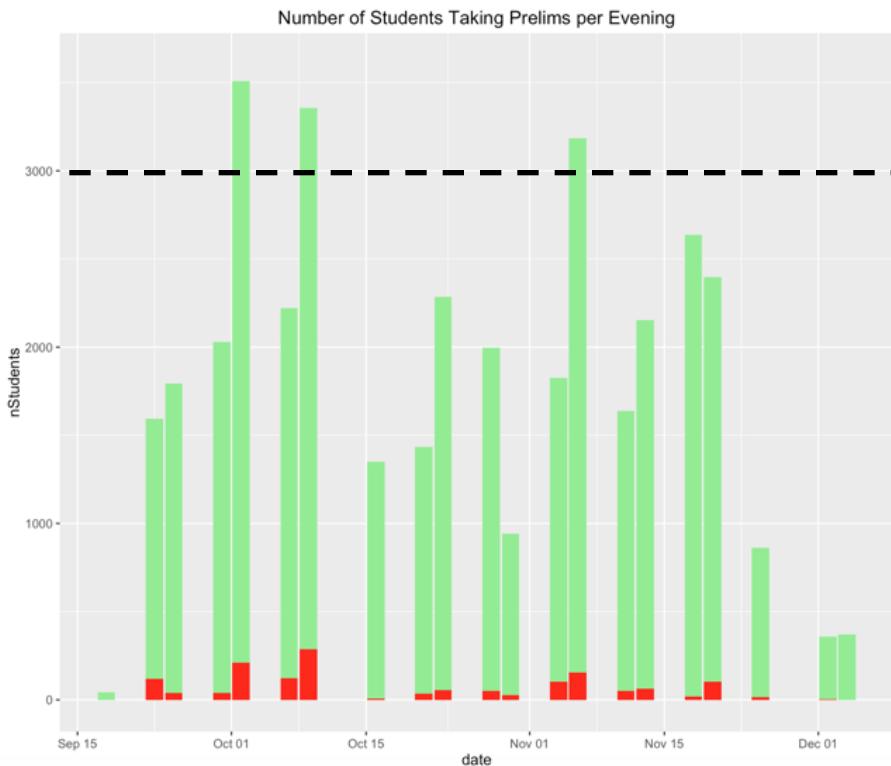
- Assign an unique id to each student and each course
- Obtain the matrix recording the number of overlaps for any pair of courses.



# Course Data Analysis

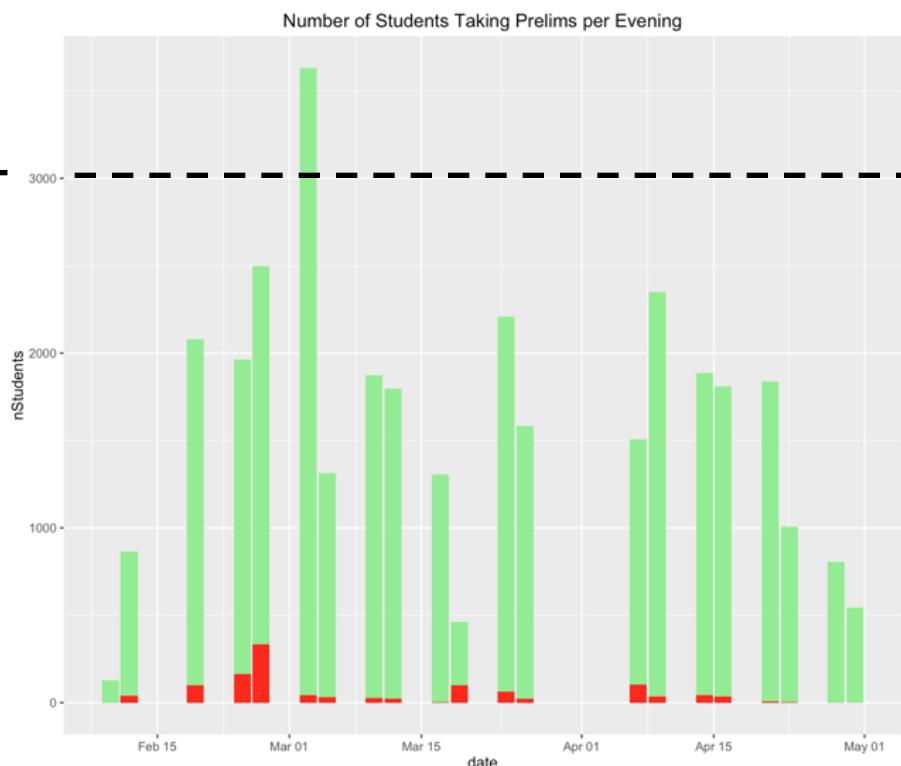
## Evaluating Current Schedule

2014 Fall Semester



1,478 Conflicts

2015 Spring Semester

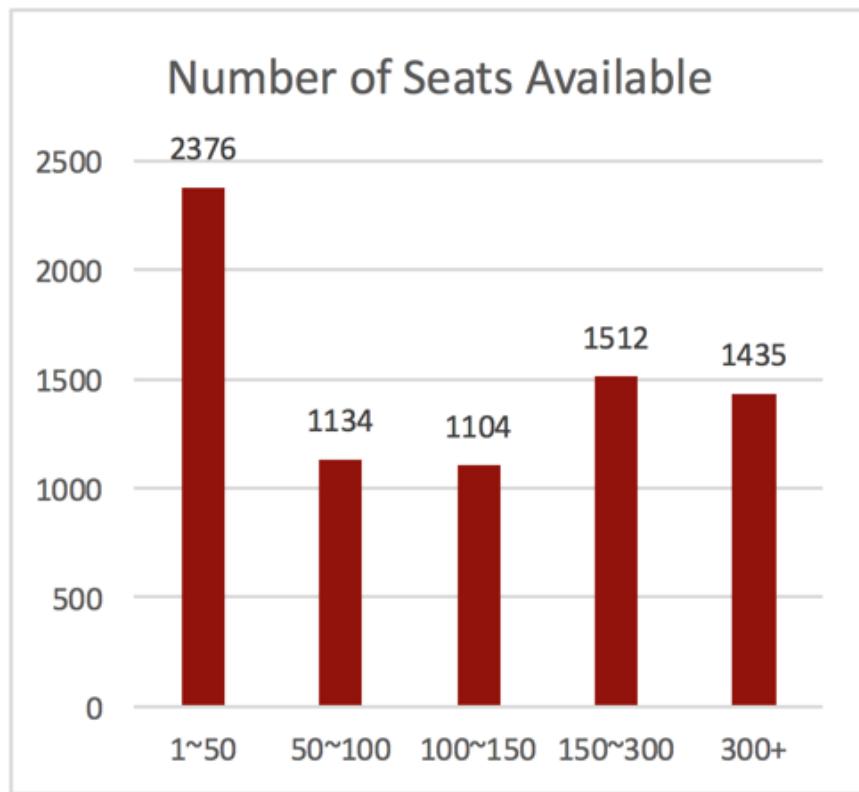


1,203 Conflicts

# Course Data Analysis

## Capacity Analysis

The capacity is limited for every time slot.



Cumulative Sum of Seats				
$\geq 0$	$\geq 50$	$\geq 100$	$\geq 150$	$\geq 300$
7561	5185	4051	2947	1435

- Current Capacity Constraint is 3,000 every night
- There's a potential to relax this limit to 5,000

# Linear Programming Formulation

- Decision Variables

$x_{ijk}$ ,  $y_{iji'j'k}$

$i$ : index of the course

$j$ : index of the prelim (within a course)

$k$ : index of evenings in the semester

$x_{ijk} = \begin{cases} 1 & \text{if the } j\text{th prelim of course } i \text{ happens on evening } k \\ 0 & \text{otherwise} \end{cases}$

$y_{iji'j'k} = \begin{cases} 1 & \text{if the } j\text{th prelim of course } i \text{ and } j'\text{th prelim of course } i' \text{ happen on eveing } k \\ 0 & \text{otherwise} \end{cases}$

- Parameters

$O_{ii'} : \text{the number of students enrolled in both course } i \text{ and course } i'$

$E_i : \text{enrollment size of course } i$

$P_i : \text{number of prelims for course } i$

# Linear Programming Formulation

- Objective Function

$$\sum_i \sum_j \sum_k O_{ii'} * y_{iji'j'k}$$

- Constraints

$$(1) \quad \sum_j \sum_k x_{ijk} = P_i \quad \forall i$$

$$(2) \quad x_{ijk} + x_{i'j'k} - y_{iji'j'k} \leq 1 \quad \forall i, j, i', j', k$$

$$(3) \quad \sum_k x_{ijk} = 1 \quad \forall i, j$$

$$(4) \quad \sum_j x_{ijk} \leq 1 \quad \forall i, k$$

$$(5) \quad \sum_i \sum_j E_i * x_{ijk} \leq Capacity \quad \forall k$$

$$(6) \quad x_{ijk} + \sum_{a=1}^k x_{i(j+1)a} \leq 1 \quad \forall i, j, k$$

$$(7) \quad x_{ijk} + \sum_{m=1}^6 x_{i(j+1)(k+m)} \leq 1 \quad \forall j \in \{1, \dots, j-1\} \quad \forall k \in \{1, \dots, k-6\}$$



# Linear Model

## Model Limitations

- The problem was very large, and the run time was very long
  - 2 million variables
  - 6 million constraints
- So many variables and constraints made it difficult to guarantee all constraints were being enforced correctly
- Are we optimizing the right problem?
  - Is 100 conflicts much better than 300 if the schedule is dramatically different than before?
- Lack of flexibility
  - It is hard to adjust the constraints and objective to satisfy diverse requests from professors. Complexity grows very quickly

# New Integer Programming Model

## Model formulation

- Decision Variables

$x_{ik}, y_{ii'e}$

$i$ : index of the course

$k$ : legal configuration of prelims

$e$ : index of evening spots

$x_{ik} = \begin{cases} 1 & \text{if course } i \text{ has the } k \text{ legal configuration of prelims} \\ 0 & \text{otherwise} \end{cases}$

$y_{ii'e} = \begin{cases} 1 & \text{if the course } i \text{ selects } k \ni e, \text{ and } i' \text{ selects } k' \ni e \\ 0 & \text{otherwise} \end{cases}$

- Parameters

For each  $i \in S$ ,  $S_i = \{s_j : s_j = \{e_j^1\}\}$  where  $j = 1, \dots, K_i$

For each  $i \in P$ ,  $P_i = \{p_j : p_j = \{e_j^1, e_j^2\}\}$  where  $j = 1, \dots, K_i$

For each  $i \in T$ ,  $T_i = \{t_j : t_j = \{e_j^1, e_j^2, e_j^3\}\}$  where  $j = 1, \dots, K_i$

$O_{ii'} : \text{the number of students enrolled in both course } i \text{ and course } i'$

$E_i : \text{enrollment size of course } i$

$K_i : \text{the number of configurations of course } i$

# New Integer Programming Model

## Model formulation

- Objective Function

$$\sum_e \sum_i \sum_{i'} O_{ii'} * y_{ii'e}$$

- Constraints

$$(1) \quad \sum_i \sum_{k:e \in k} E_i * x_{ik} \leq Capacity \quad \forall i \text{ in } S \cup P \cup T, e \text{ in evenings}$$

$$(2) \quad x_{ik} + x_{i'k} - y_{ii'k} \leq 1 \quad \forall i, i' \text{ in } S \cup P \cup T, k = 1 \dots Ki$$

$$(3) \quad \sum_{k=1}^{Ki} x_{ik} = 1 \quad \forall i \text{ in } S \cup P \cup T$$

# New Integer Programming Model

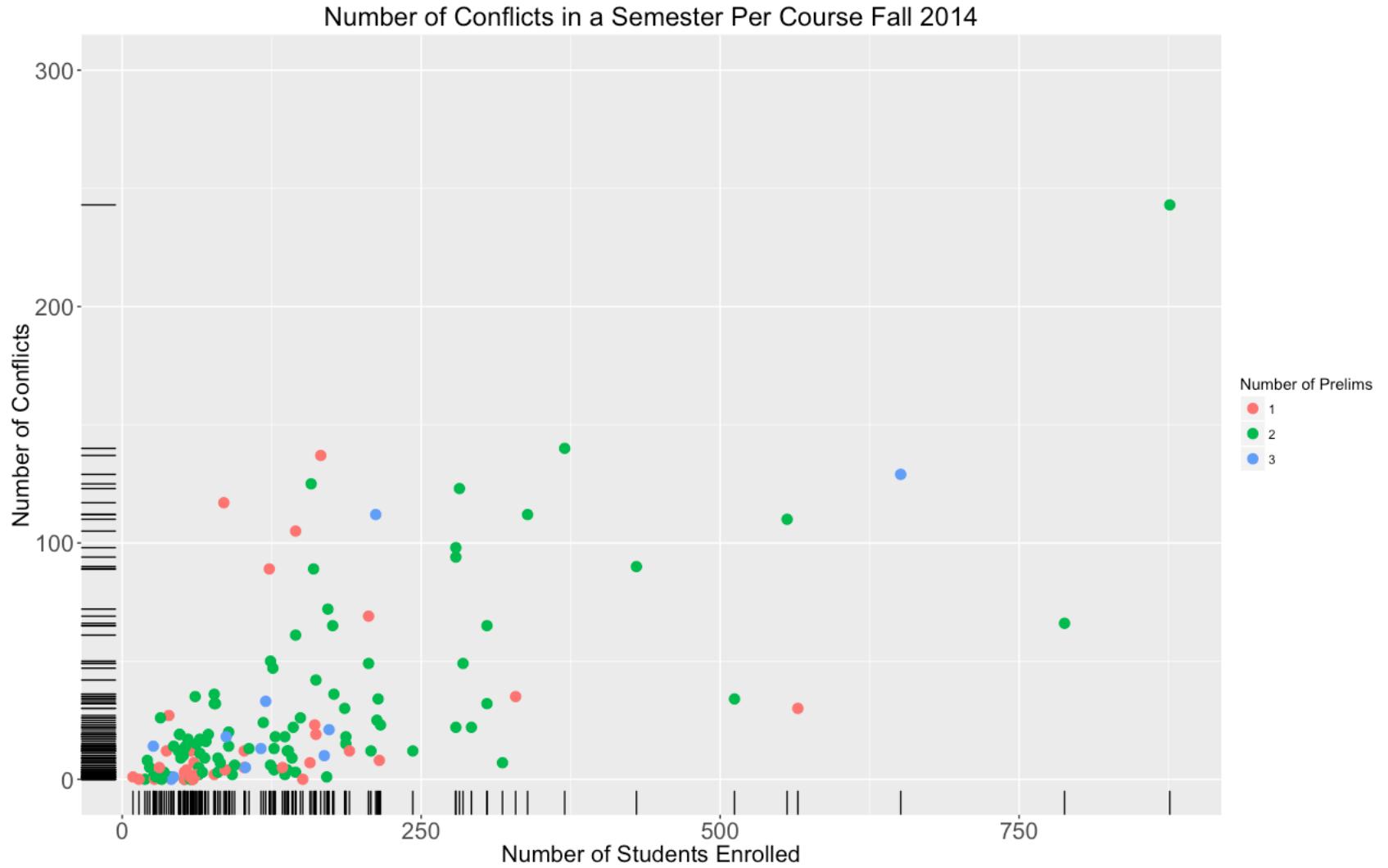
## Original Schedule Adjusted Plus/Minus 1 Evening

- Suppose course has prelims scheduled on  $e_1$  and  $e_2$
- Now consider the following possible configurations

	<u>Prelim 1</u>	<u>Prelim 2</u>
○	$e_1 - 1$	$e_2 - 1$
○	$e_1$	$e_2$
○	$e_1 + 1$	$e_2 + 1$

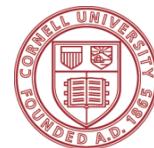
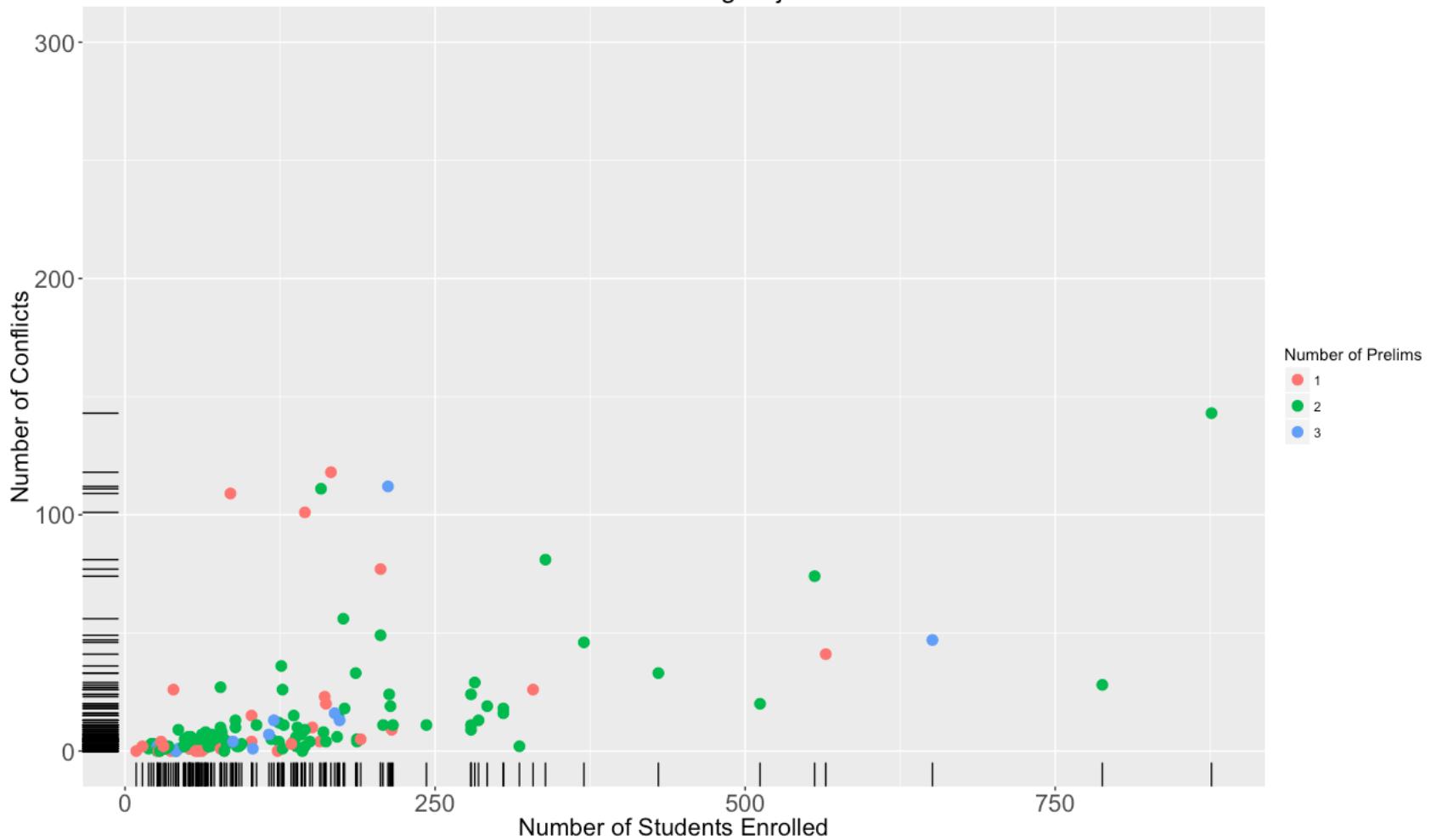
- Minor change from original schedule, same spacing kept

# New Integer Programming Model



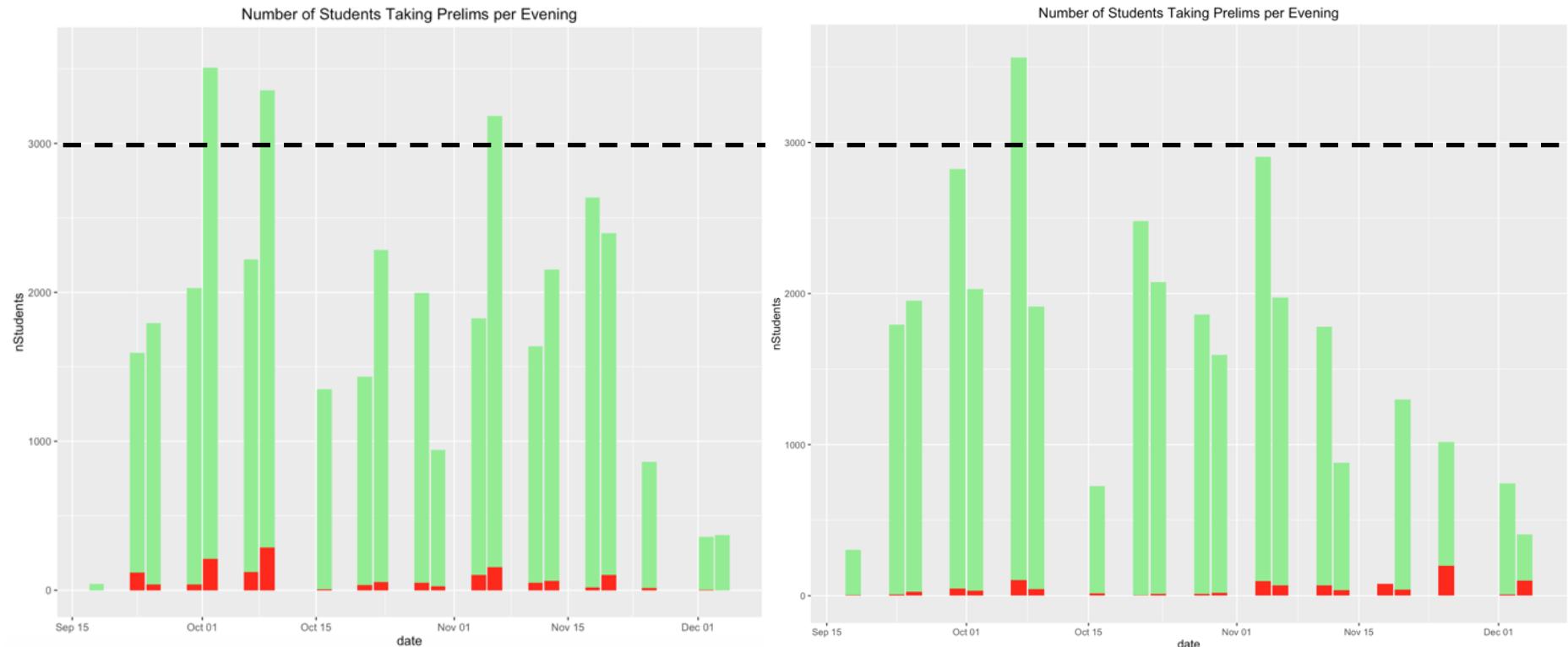
# New Integer Programming Model

Number of Conflicts in a Semester Per Course Fall 2014  
Plus/Minus 1 Evening Adjustment



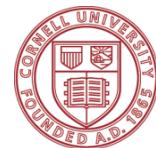
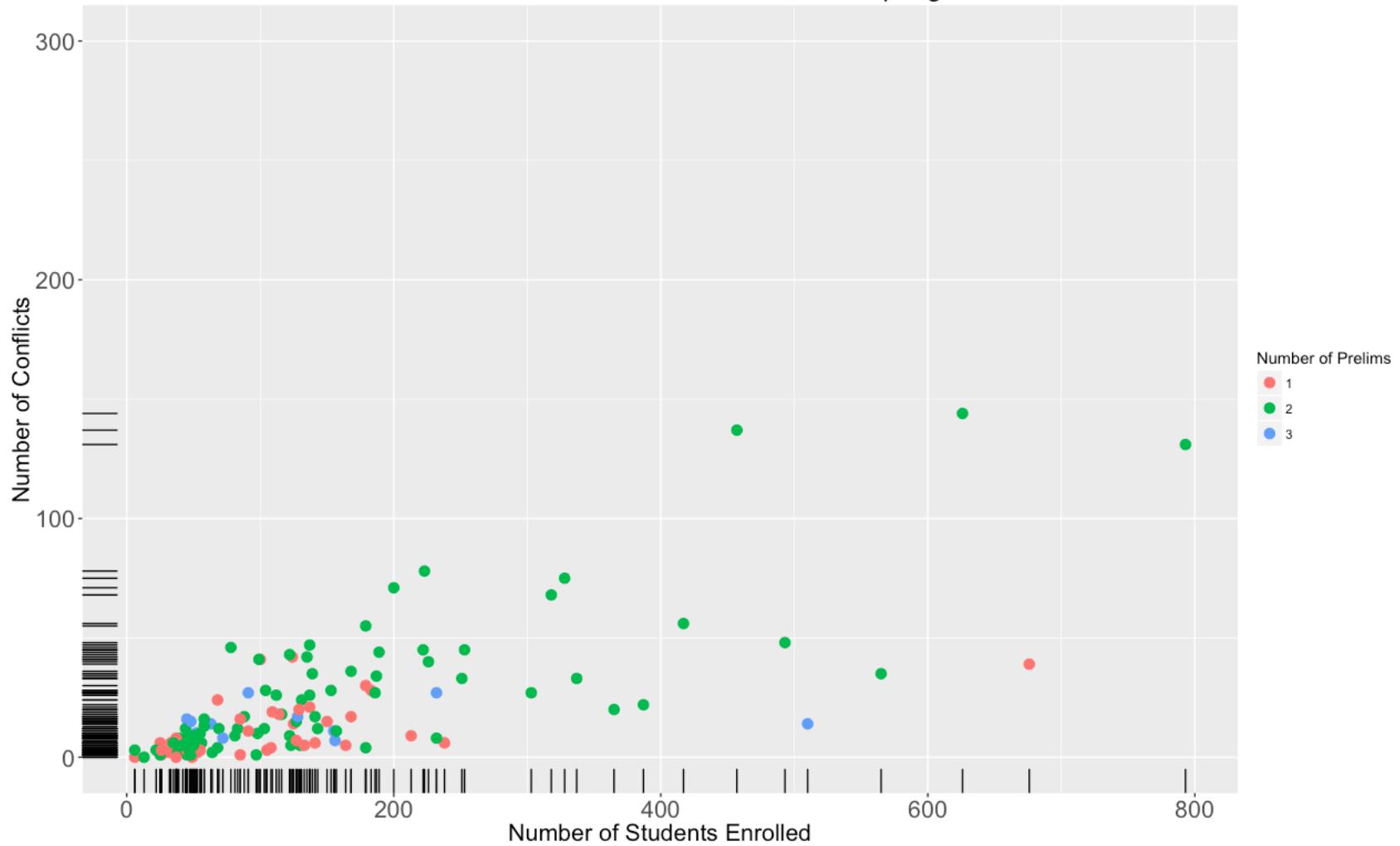
# New Integer Programming Model

2014 Fall Semester with Plus/Minus One Evening



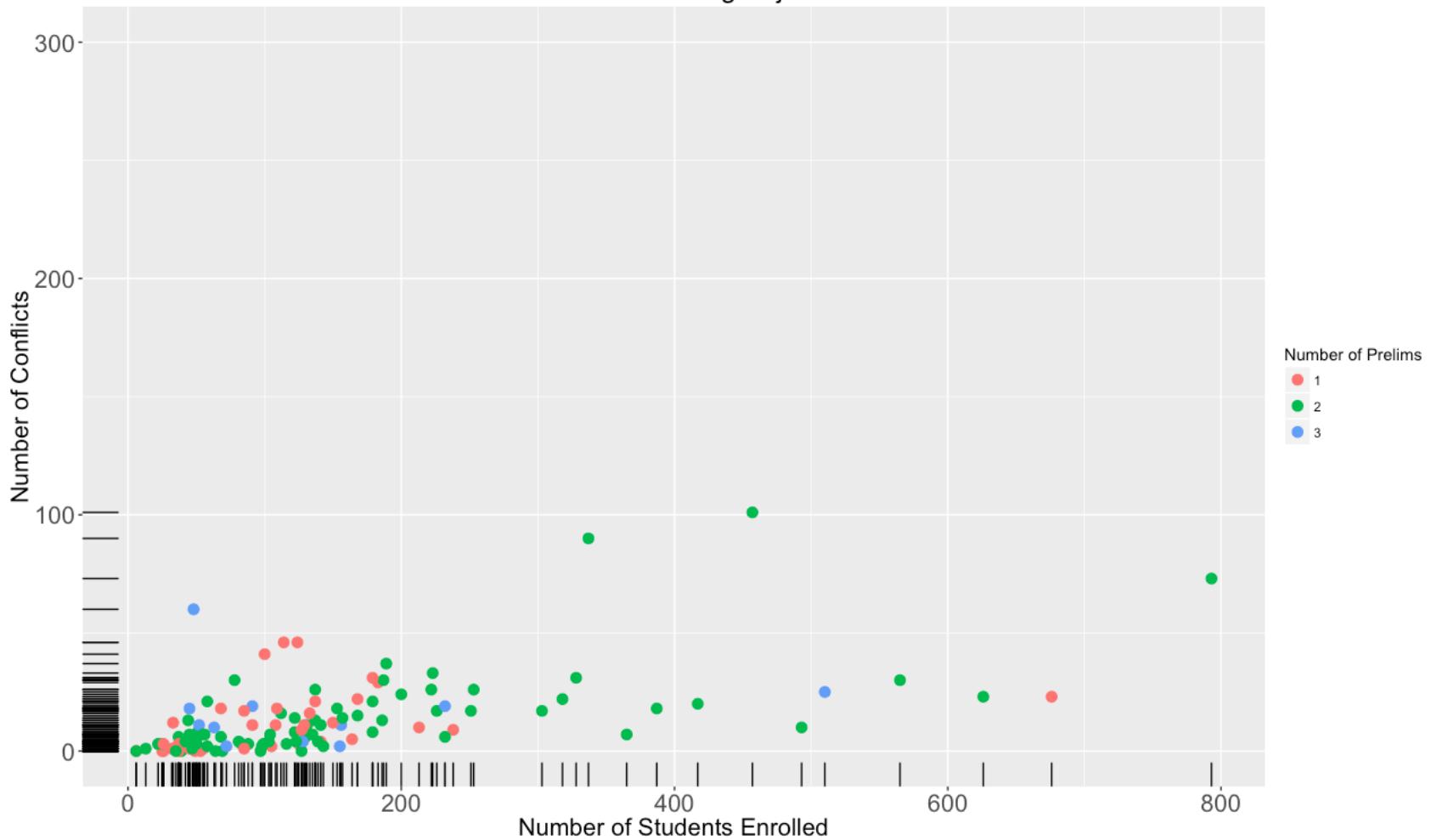
# New Integer Programming Model

Number of Conflicts in a Semester Per Course Spring 2015



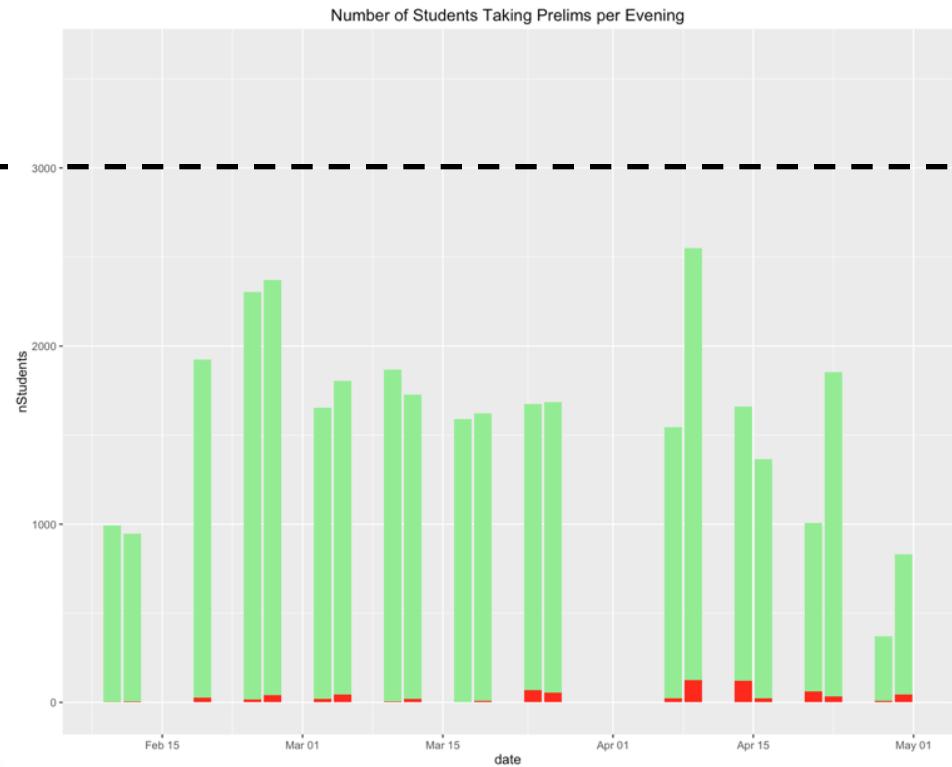
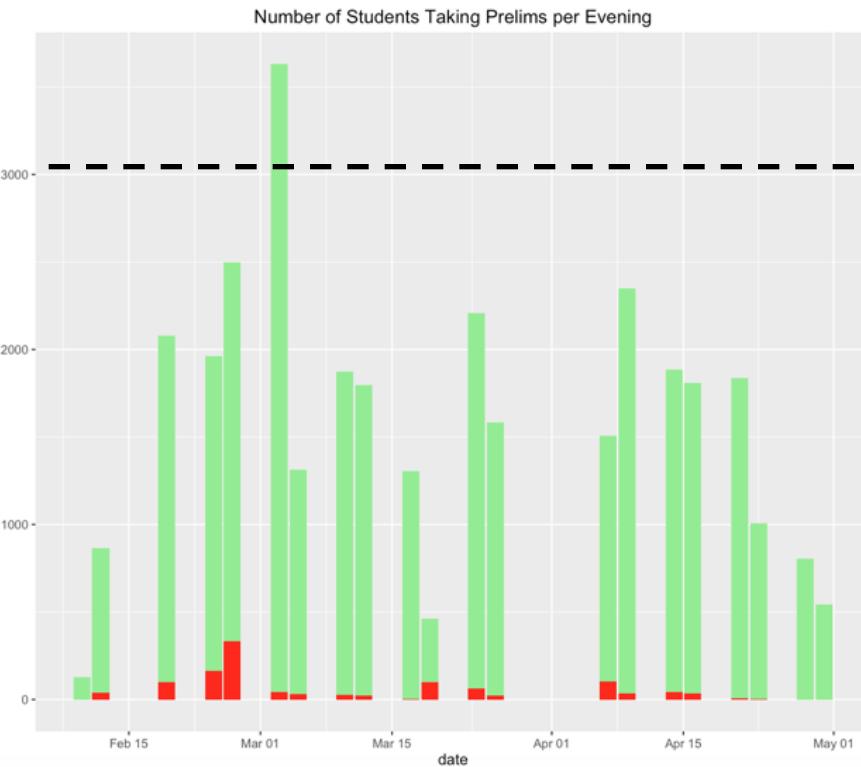
# New Integer Programming Model

Number of Conflicts in a Semester Per Course Spring 2015  
Plus/Minus 1 Evening Adjustment



# New Integer Programming Model

2015 Spring Semester with Plus/Minus One Evening



# New Integer Programming Model

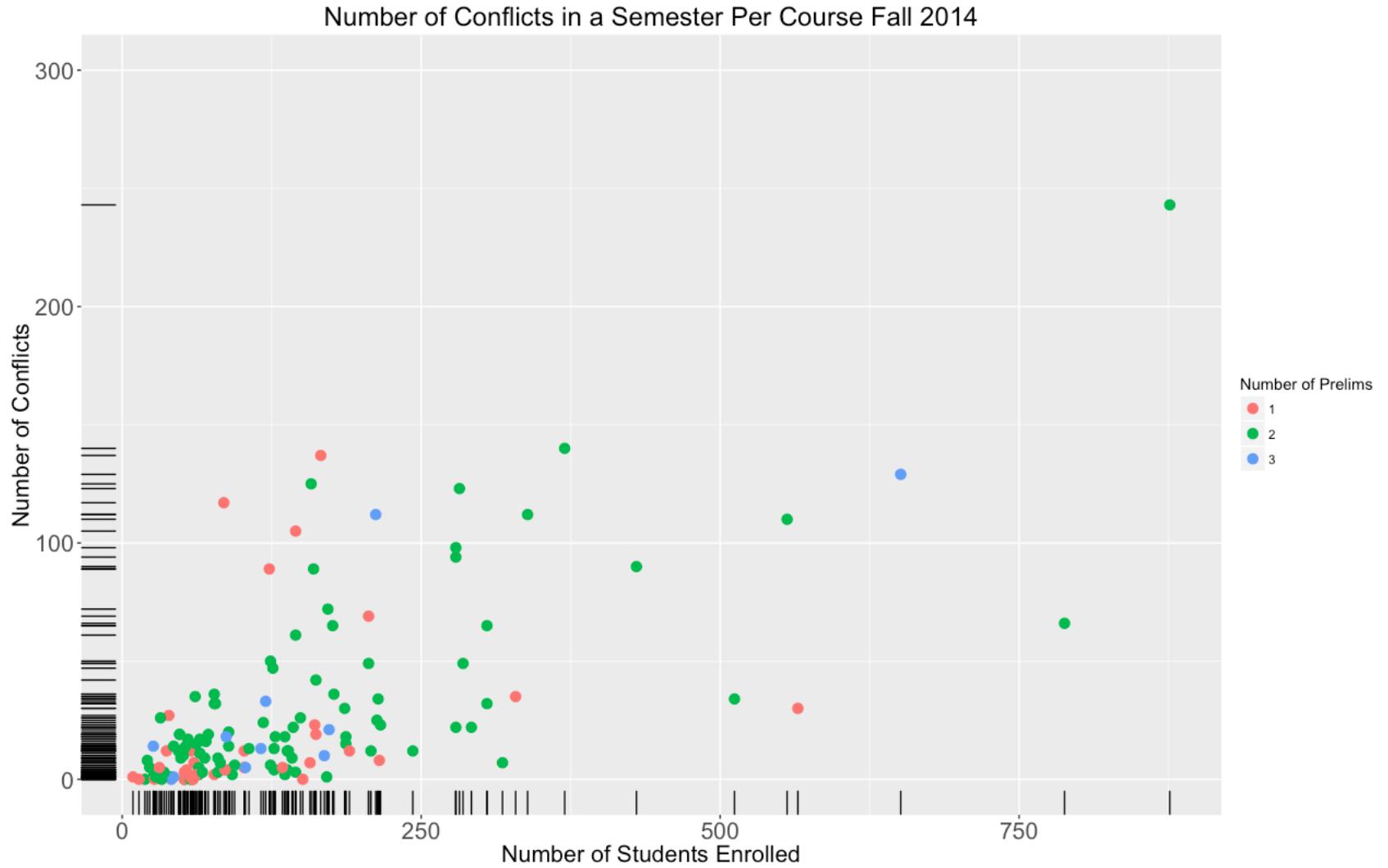
## Original Schedule Plus/Minus 1 Evening Relaxed

- Suppose course has prelims scheduled on  $e_1$  and  $e_2$
- Now consider the following possible configurations

<u>Prelim 1</u>	<u>Prelim 2</u>
$e_1 - 1$	$e_2 - 1$
$e_1 - 1$	$e_2$
$e_1$	$e_2 - 1$
$e_1$	$e_2$
$e_1$	$e_2 + 1$
$e_1 + 1$	$e_2$
$e_1 + 1$	$e_2 + 1$

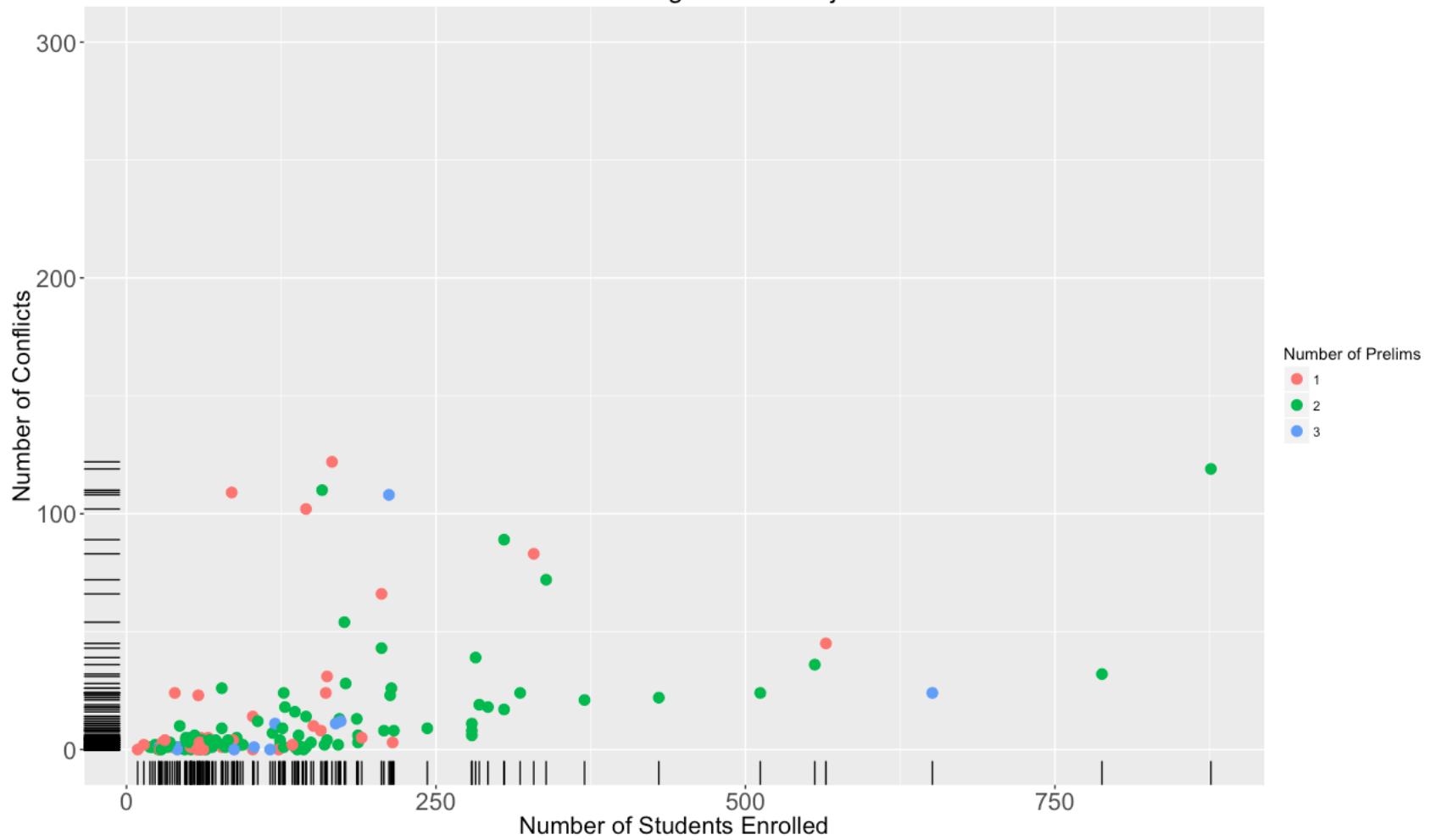
- Slightly bigger change from original schedule

# New Integer Programming Model



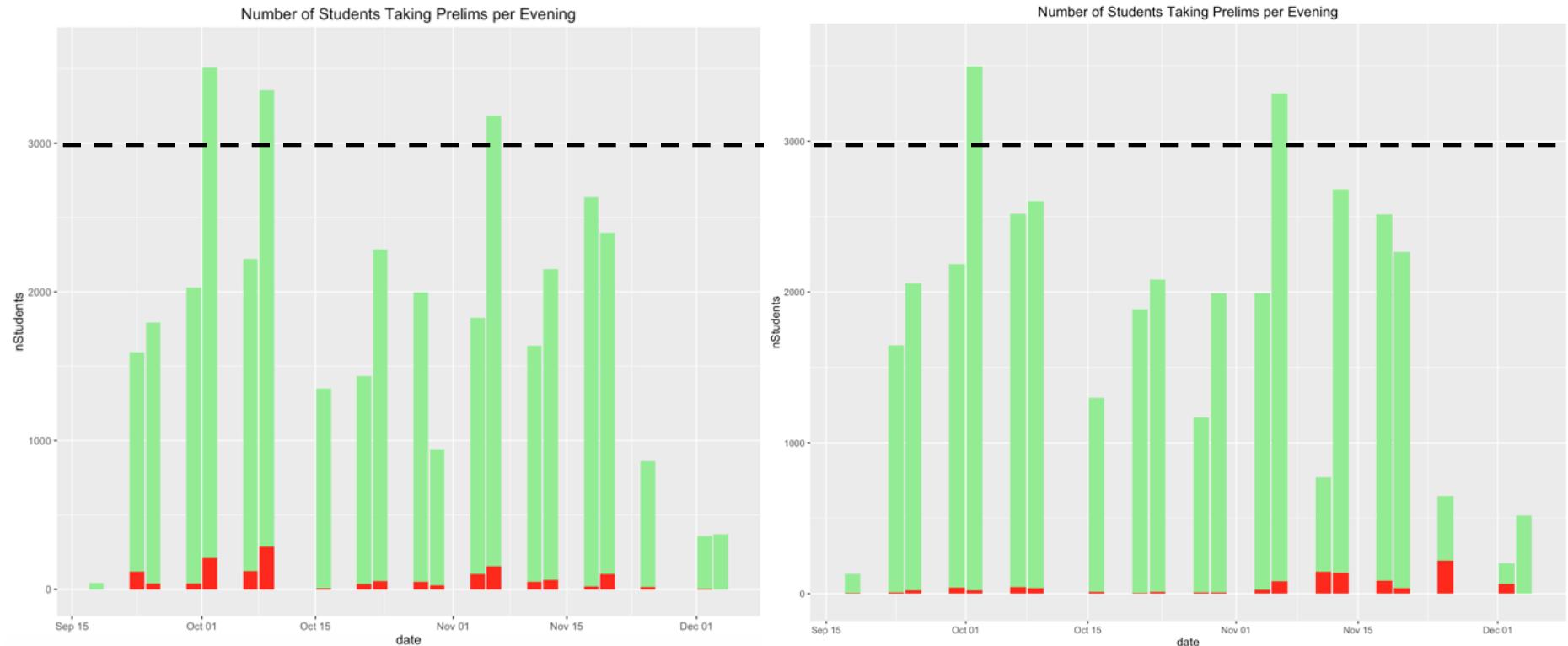
# New Integer Programming Model

Number of Conflicts in a Semester Per Course Fall 2014  
Plus/Minus 1 Evening Relaxed Adjustment



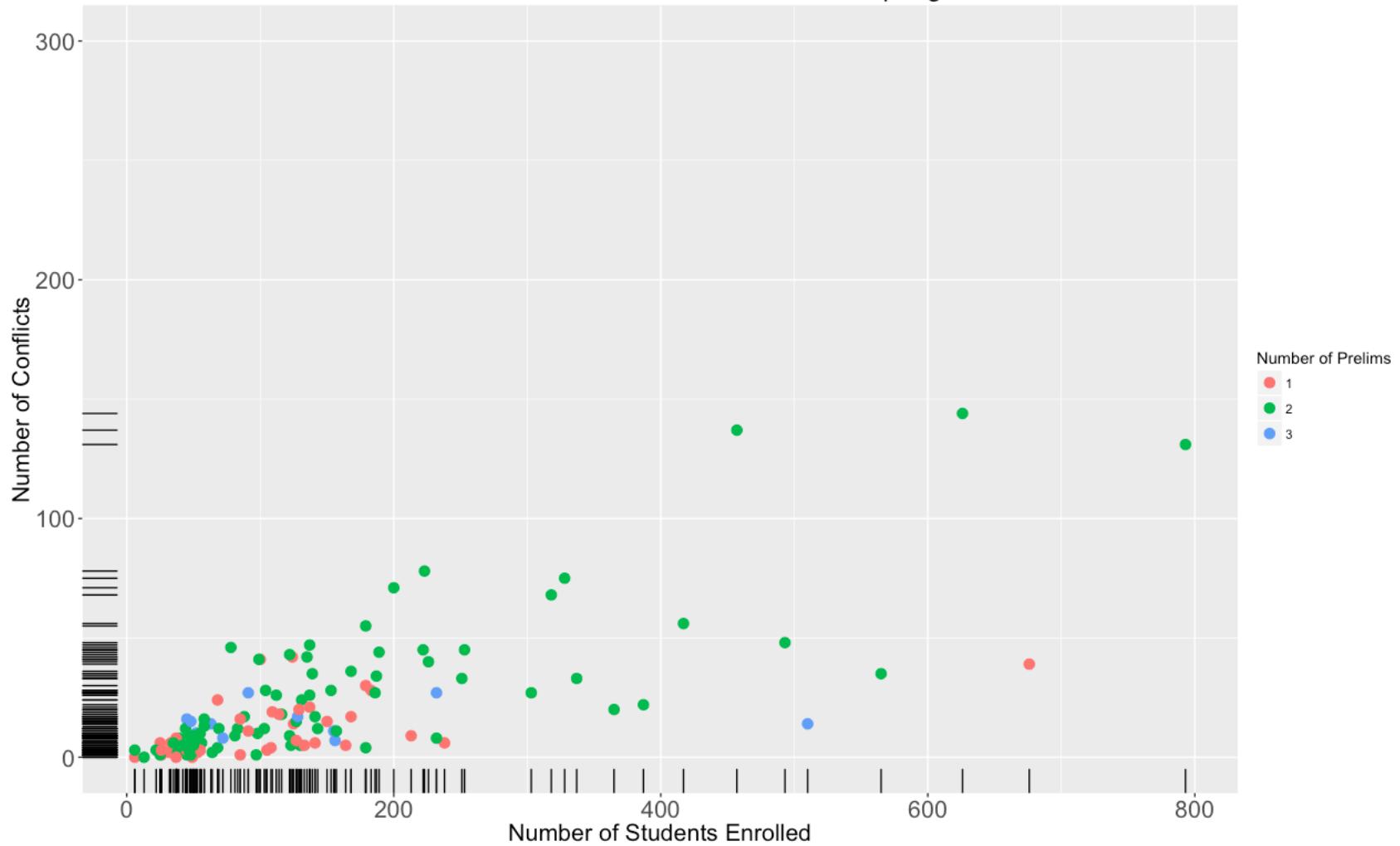
# New Integer Programming Model

2014 Fall Semester with Plus/Minus One Evening (Relaxed)

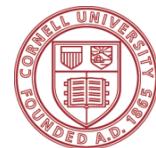
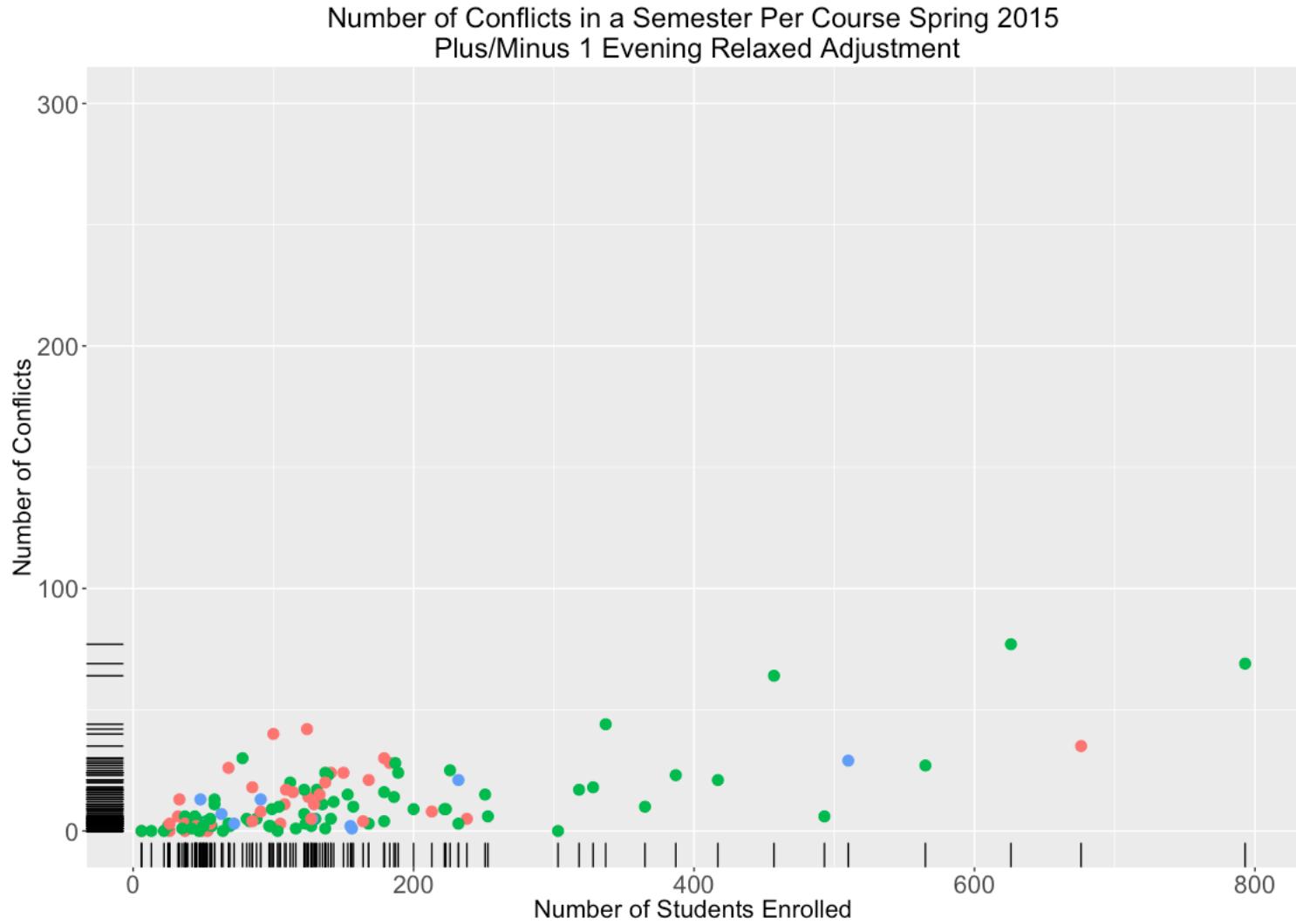


# New Integer Programming Model

Number of Conflicts in a Semester Per Course Spring 2015

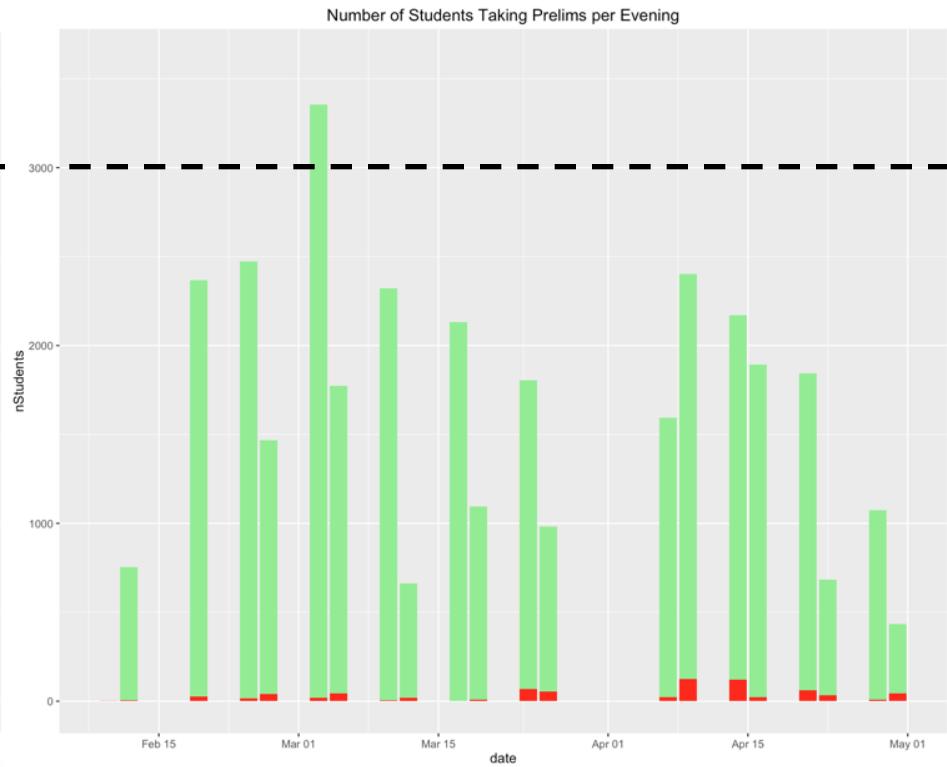
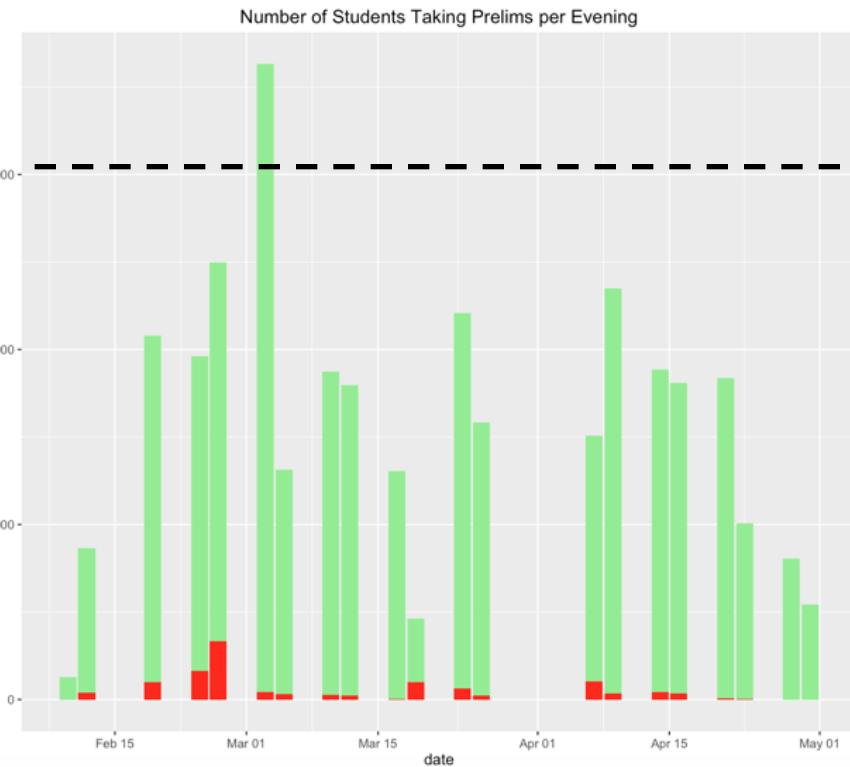


# New Integer Programming Model



# New Integer Programming Model

2015 Spring Semester with Plus/Minus One Evening (Relaxed)



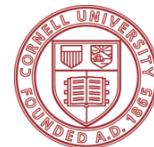
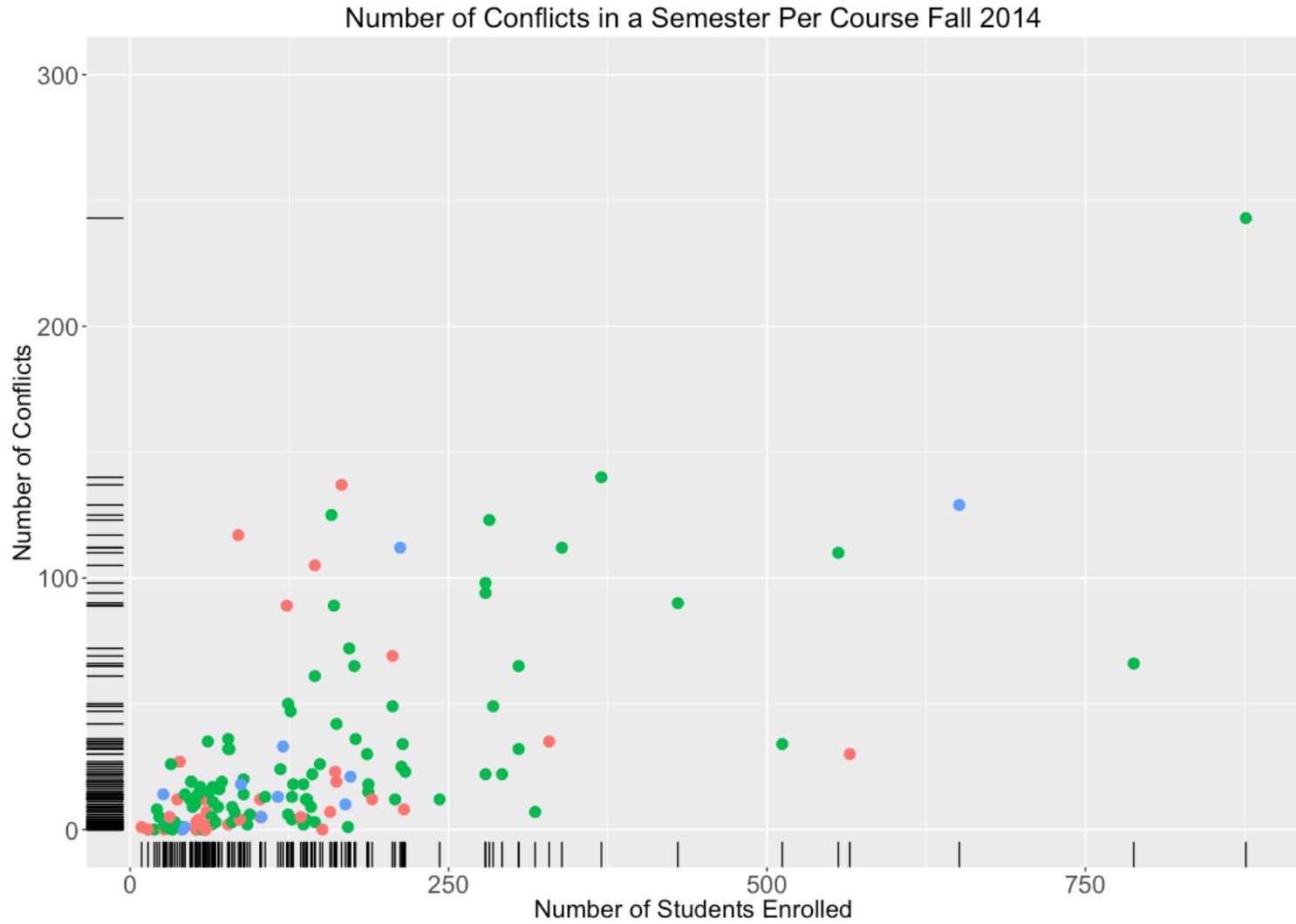


# New Integer Programming Model

## Using Survey Responses as Model Inputs

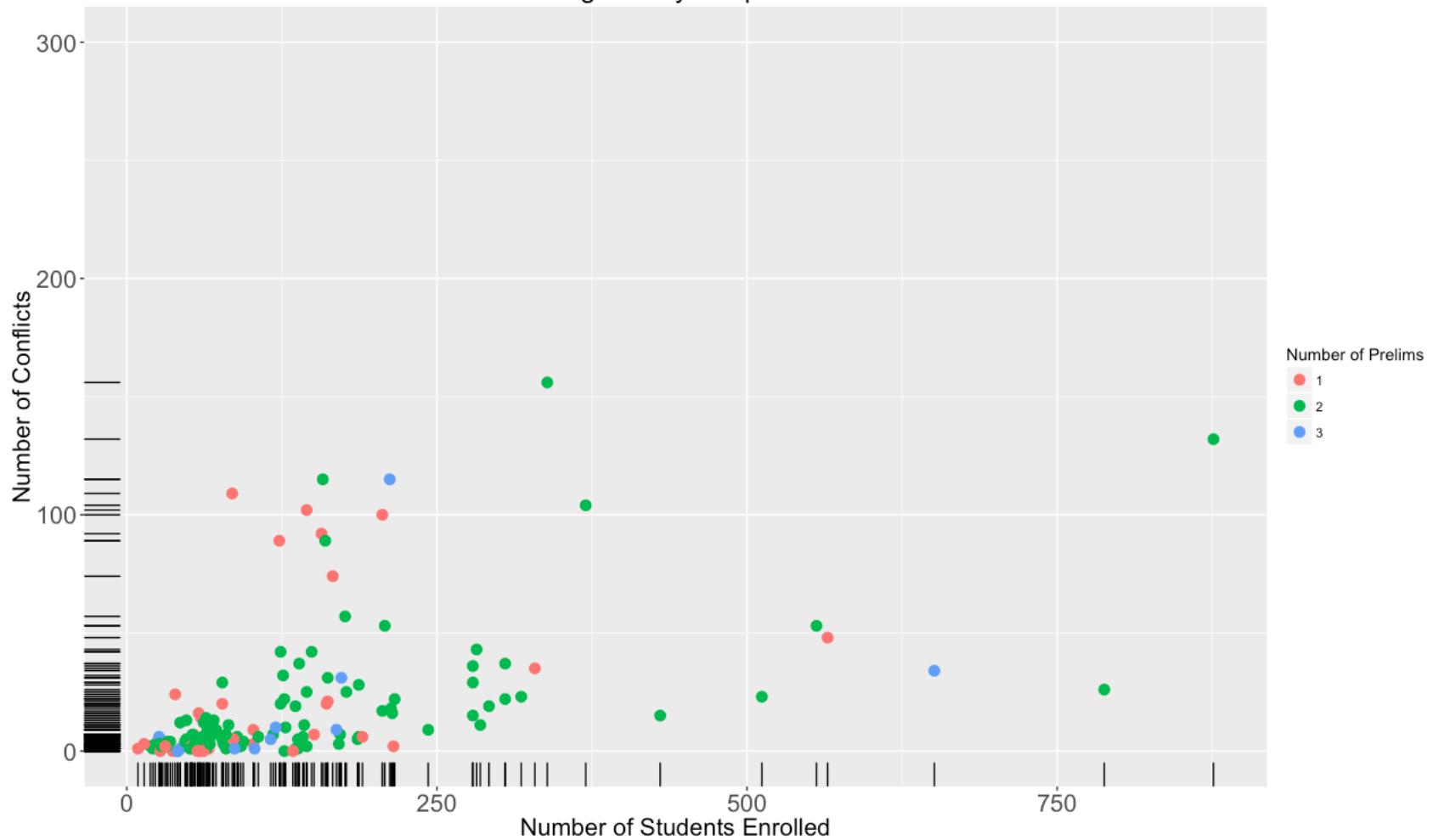
- ~50 responses could be used as patterns for each semester
- Faculty response guaranteed on of patterns given was chosen
- For courses with no faculty response, the set of configurations was the original assignment plus or minus 1 evening
- Faculty who responded all had similar preferences

# New Integer Programming Model



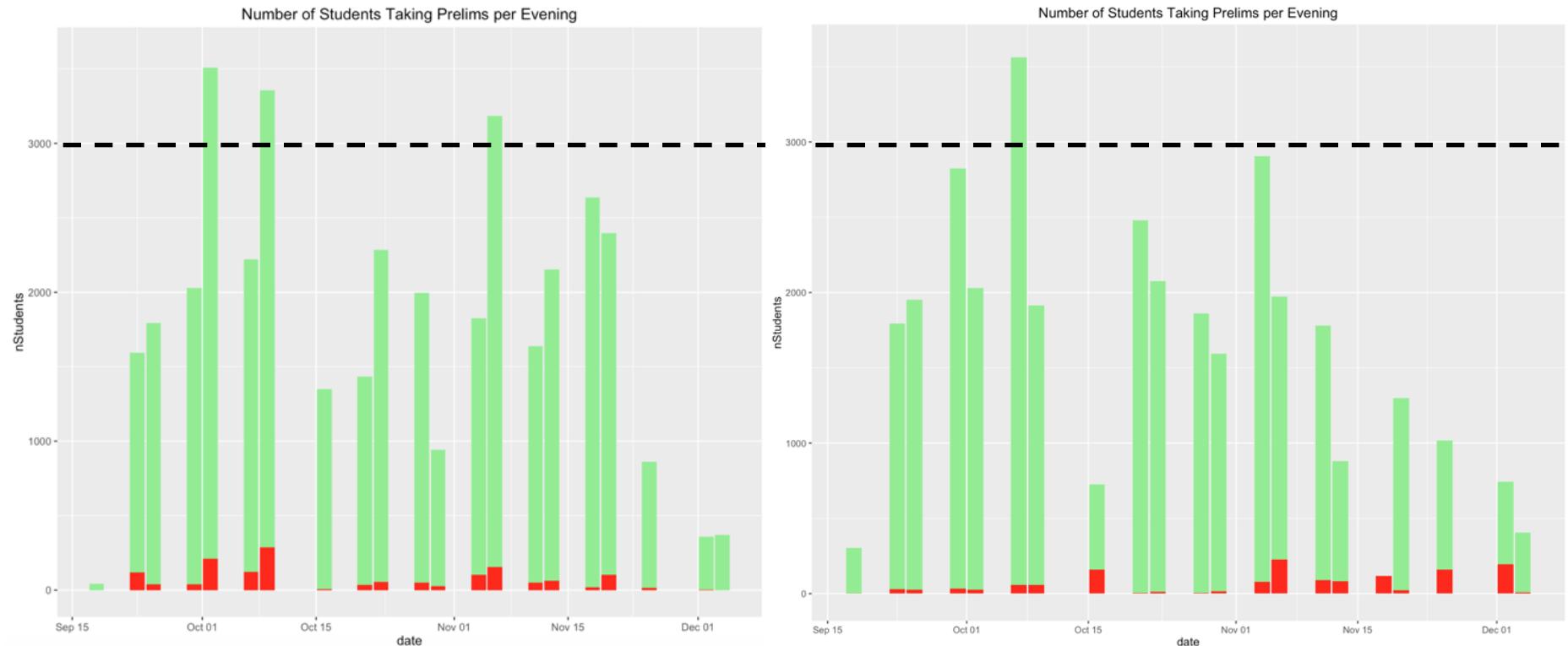
# New Integer Programming Model

Number of Conflicts in a Semester Per Course Fall 2014  
Using Survey Responses



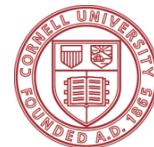
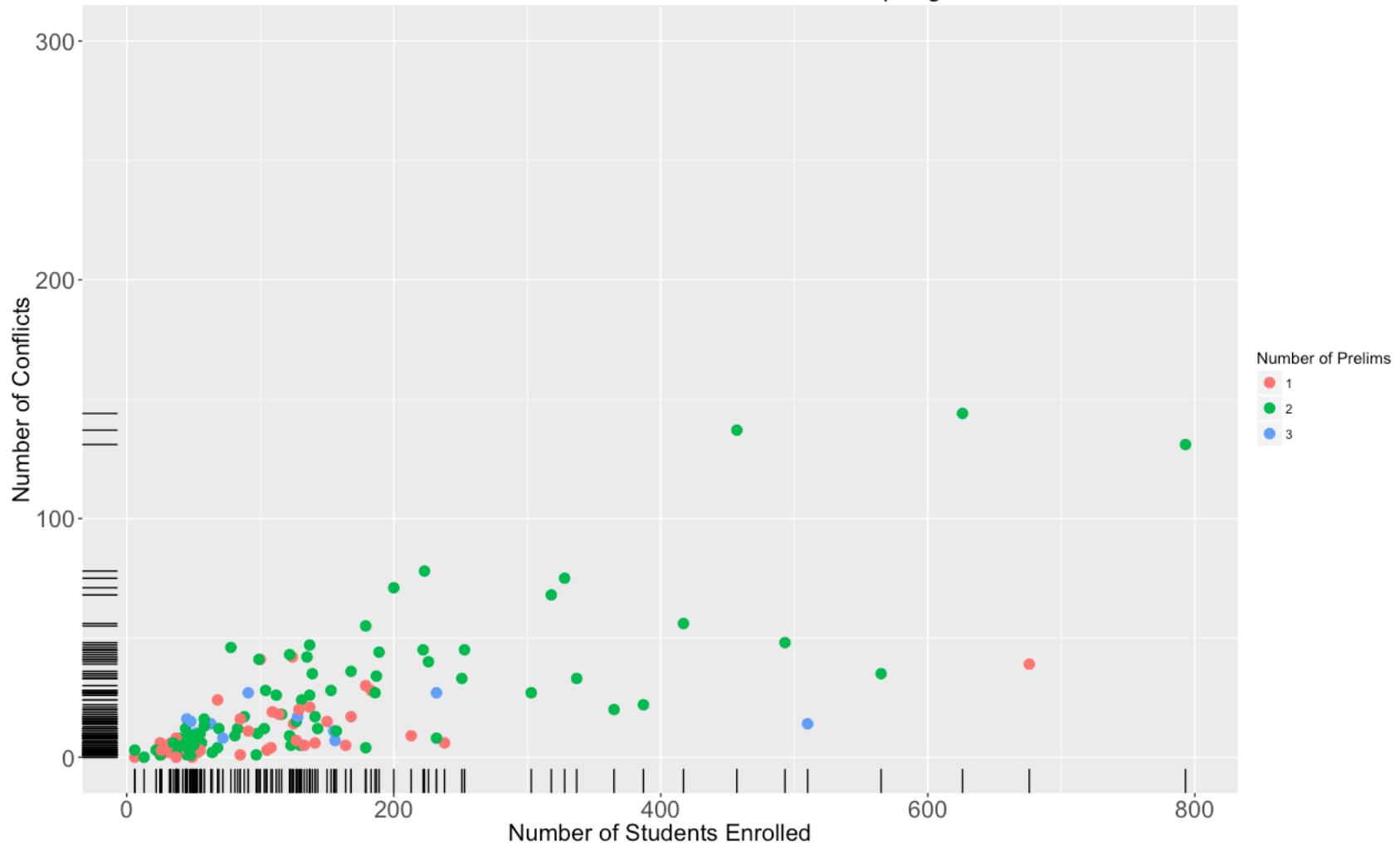
# New Integer Programming Model

2014 Fall Semester with Survey Response or Plus/Minus One Evening



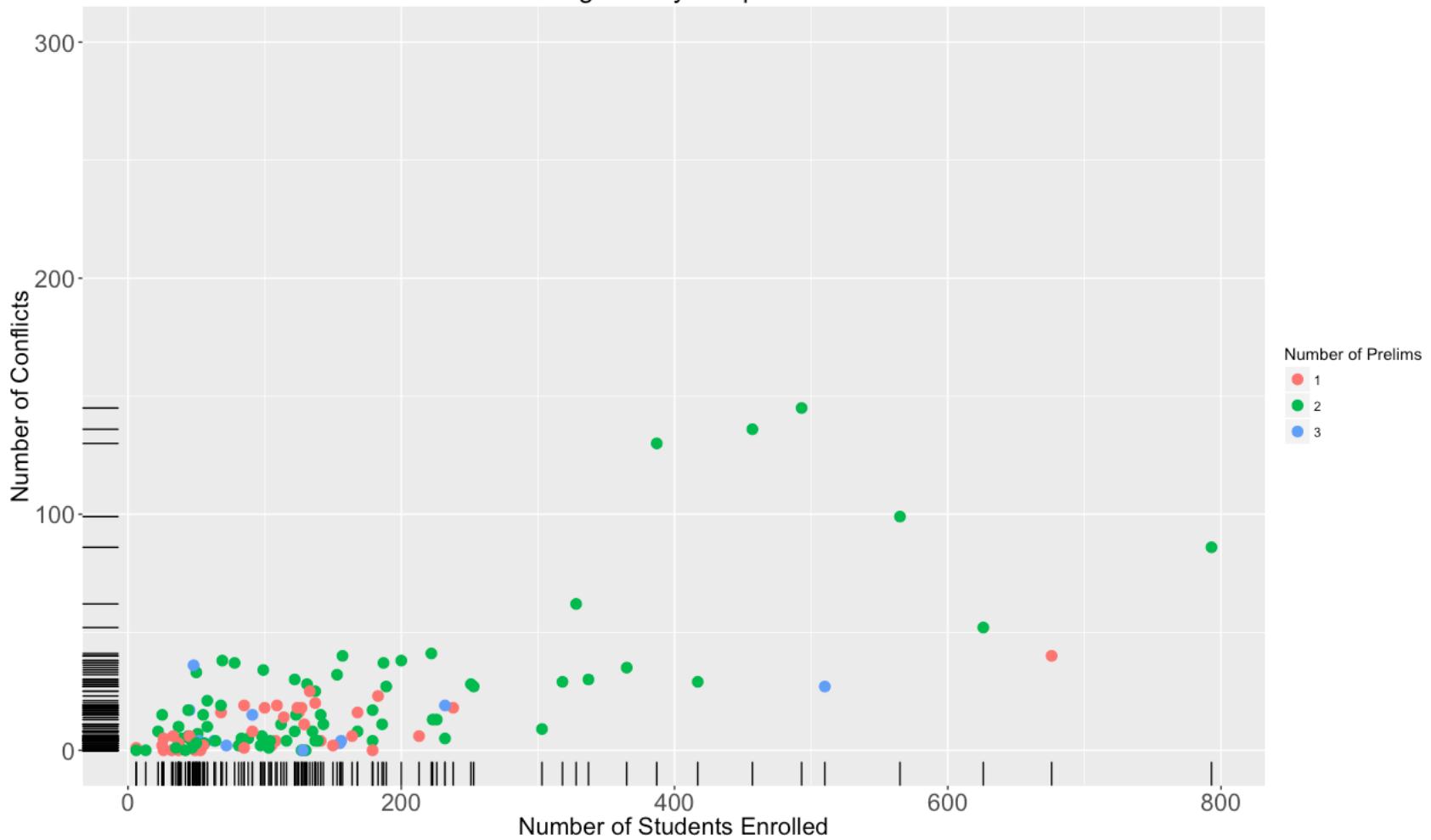
# New Integer Programming Model

Number of Conflicts in a Semester Per Course Spring 2015



# New Integer Programming Model

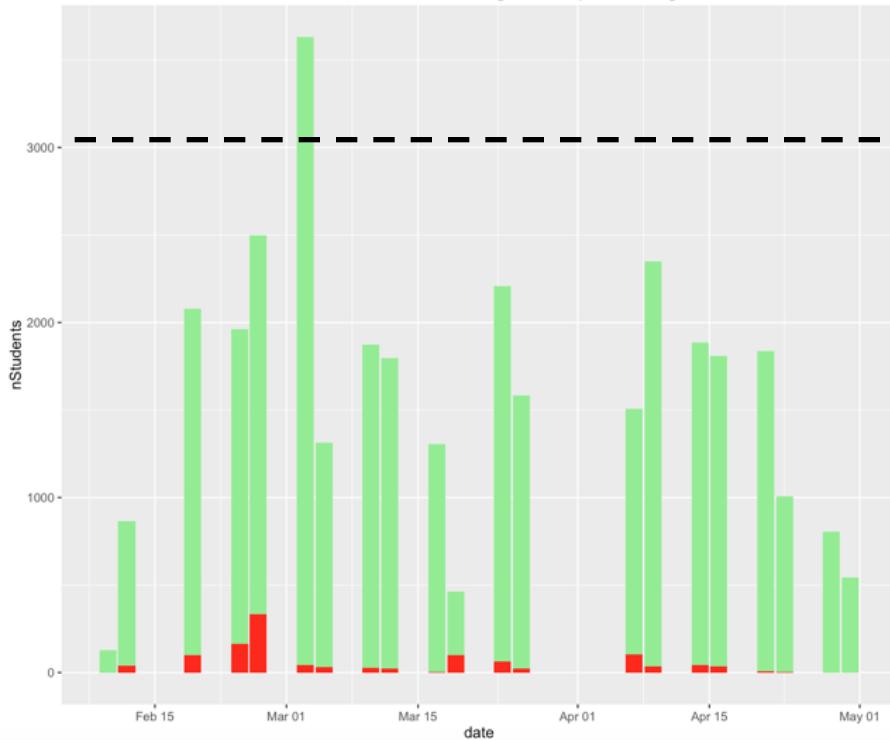
Number of Conflicts in a Semester Per Course Spring 2015  
Using Survey Responses



# New Integer Programming Model

2015 Spring Semester with Survey Response or Plus/Minus One Evening

Number of Students Taking Prelims per Evening



Number of Students Taking Prelims per Evening



# New Integer Programming Model

## Total Number of Conflicts in a Semester

	Original	$\pm 1$	$\pm 1$ Relaxed	Survey
Fall 2014	1478	500	367	715
Spring 2015	1203	476	397	882

## Number of Conflicts per Course

	Original		$\pm 1$		$\pm 1$ Relaxed		Survey	
	Mean	Median	Mean	Median	Mean	Median	Mean	Median
Fall	28	13	15	5	14	4	20	7
Spring	21	12	13	8	11	6	17	8



# New Integer Programming Model

## Limitations

- We have been working with end of the semester enrollments
  - To what extent does pre-enrollment change things?
- We have been working with just two semesters of data
  - How has the number of conflicts changed over the years?
  - How much does the schedule for a course change in a year?
- Need to promote diversity in preferences
  - Survey results suggest most faculty prefer same slots



# New Integer Programming Model

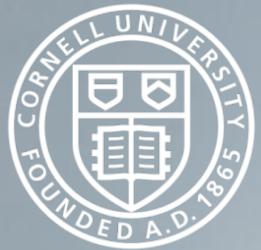
## Future Development

Integrate the data collection, data processing, optimizing and result comparing parts; design an interface for this tool.

## Implementation

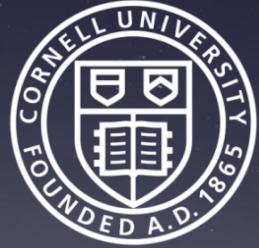
Incentivize professors provide their desired time slots:

- Fast responses will guarantee priority when there's conflicts.
- If the professor is willing to provide a more flexible schedule, his/her course could be assigned schedule first.



# Q&A





# Thank You very much

