Teaching Policy Design, Using a Case Study of Unintended Consequences when the EU Regulates Hospital Doctors' Hours

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Abstract

The purpose of this paper is to encourage readers to help us assess and improve the major project in a graduate level system dynamics course in policy modeling. This year, we modified the project in hopes that it would contribute more to the learning objectives in the course. We have seen both positive and negative effects of the change; the jury is still out. To provide a context for reader reaction, we describe the project in some detail. It is based on a case study of the unintended consequences suffered by UK hospital doctors due to the European Working Time Directive. Thus, despite the pedagogical slant of this paper, it may also interest health policy analysts. We emphasize the process of managing the project and the tasks required of students, and solicit comments and suggestions about certain key features. Three of the authors were students in the course, and some of their work is used to illustrate how students carried out the project.

The primary purpose of this paper is to improve a graduate-level system dynamics policy design course at the University of Bergen in Norway (UiB) by motivating helpful comments and suggestions regarding our pedagogical strategy.[1] In addition, we hope to foster a broader discussion of methods for teaching policy design skills—skills that enable students to go beyond policy parameter testing, explore the operational requirements of their simulation-based policy proposals, and build more useful models.

Excessive reliance on policy parameter analysis is not limited to student modelers. Wheat's (2010) content analysis of three decades of articles published in the *System Dynamics Review* found that policy analysis was limited to parameter sensitivity testing in nearly 75 percent of models of public issues, despite admonitions to the contrary from experienced system dynamicists over the years (cf., Richardson and Pugh 1989, Ford 1999, Sterman 2000, and Morecroft 2007). Improvement in policy modeling practice is not likely to occur without improvement in policy modeling instruction.

Our pedagogical strategy includes a project that requires students to transform *explanatory* models of dynamic problems into *policy* models that enable assessment of options for alleviating problematic behavior through system intervention. More than forty years ago, Forrester (1969, p. 113) distinguished problem explanation from policy design in the modeling process: "First … generate a model that creates the problem. [Next] … restructure the system so that the internal processes lead in a different direction." More recently, he reiterated that distinction: "A model should demonstrate how the symptoms are being generated. . . .Only by clearly understanding what is causing the problem can one begin to see where [policy] attention should be focused." (Forrester 2009) The goal of explanatory modeling is to reveal the historical systemic reasons for a pattern of behavior widely viewed as a serious issue (e.g., rising traffic congestion or declining employment). The policy design task is to explore and evaluate ways to

[1] Three of the authors were students in this year's course, and the other author was the instructor.

alleviate the problem; i.e., to improve the dynamic performance of the model system in ways that suggest feasible, cost-effective policies in the real world system that the model represents. This paper discusses a policy modeling project designed to help students improve their policy modeling skills, and we hope to receive reader feedback that helps us improve the effectiveness of the project in the coming years.

Background

During the first semester of the international system dynamics (SD) master's degree program at UiB, students take three modeling courses sequentially. The third course is devoted to skills for building *explanatory* models of dynamic problems that emerge from complex social and economic systems. The course objective is to enable students to start with a real-world dynamic problem and use stock-and-flow structures to represent real-world operational relationships in ways that provide a plausible systemic explanation of the dynamic problem and enable reasonably accurate simulated replication of the problematic behavior pattern. The students have an intense six-week project to practice and enhance their explanatory modeling skills. There is relatively little time for them to develop skills in formal policy design; i.e., changing the *structure* of an explanatory model to alleviate its problematic *behavior*. Thus, during the fall semester, students' own policy analysis consists primarily of identifying leverage points in their models and testing the sensitivity of their models to changes in parameters that represent conditions that could be modified by real-world policy makers.

In 2010, we developed a new course—*Policy Design and Implementation*—to extend students' policy modeling skills. Running six weeks (with 36 lecture hours and 18 lab hours) at the beginning of the second semester, it is the fourth sequential course for SD students at UiB. The course embraces a key purpose of system dynamics modeling—improving the behavior of social systems by designing feasible, cost-effective, and transparent public policies with minimal adverse unintended consequences. The objective of the course is to enable our students to build operational policy models and communicate effectively with policy makers and staff about policy options. Course content is delivered via lectures about key concepts and methods of policy analysis, design, and evaluation; reading assignments from both the SD and public policy and management literature; and exposition of methods for designing policy models and also simulators that provide an interactive learning experience for model users.

The major task for students in the course is a policy modeling project that requires each student to (a) restructure an explanatory model of a dynamic problem with a feasible policy that alleviates problematic behavior cost-effectively, (b) develop an interactive simulator to help policy makers and staff improve their mental models of the dynamic problem and their assessment of the cost-effectiveness and feasibility of particular policy options, and (c) write a short report that identifies policy implementation obstacles and suggests strategies for dealing with those challenges.

Until this year, the basic task in the policy modeling project assignment was unchanged. Students had to select from the SD literature a peer-reviewed article and model that contained little or no policy design (either the model's purpose was merely explanatory or its analysis was limited to policy parameter testing). Next, if necessary, they translated the original model into *iThink*, confirmed that their version replicated the behavior described in the article, and analyzed the model. Finally, the students designed a policy to improve the reference behavior in the explanatory model and developed an interactive simulator as a learning tool. The drawback in the past has been the excessive amount of time required for students to identify an acceptable model in the literature, gain access to the equations, translate the model from one software language to another, and analyze the model—all of which was preparatory to the real purpose of the project: to build a policy model.

Now the assignment has been streamlined to encourage quicker engagement in the main task *by giving each student the same explanatory model of a problem when the course begins*. While also based on a peer-reviewed paper and model of a specific real-world problem, the model given to the students is a simplified version that is analyzed with them during a lecture. Then students are challenged to design policies to alleviate the problematic behavior in the "given" model. To add some realism to the research task, each student has to choose a particular country as the context for his or her particular policy model. Thus, country-specific data collection is required for calibrating each student's "given" model, and country-specific social, economic, and political conditions shape the feasibility and cost-effectiveness of policy options.

At the beginning of the 2013 *Policy Design and Implementation* course, students received the instructions and project evaluation criteria listed in Table 1. The scope of this paper is limited to the pedagogical issues associated with points 1, 2, and 3 in the table; namely, the issues regarding the provision of the same explanatory model to each student, and the requirement that each student calibrate the explanatory model and design a remedial policy in a different country context. Other instructional issues regarding feasibility analysis, development of evaluation skills (e.g., cost-benefit analysis), and designing simulators that provide an effective learning experience will be deferred for now.

1. You will receive a working explanatory model of a problem in one country.
2. You will choose another country where it is reasonable to assume a similar dynamic problem might exist. If preliminary research supports that assumption, calibrate the given model to your chosen country.
3. You will build a policy model by adding new structure to the explanatory model.
4. You will build a policy simulator that demonstrates why a policy is needed, explains how your policy would work in your chosen country, and calculates the cost-effectiveness of your policy in your chosen country.
5. You will write a policy implementation report that explains the policy constraints in your model and highlights other obstacles (not in your model) that could make implementation difficult in "your" country and necessitate additional planning.
6. The following criteria will be used to evaluate your work: (a) model equations with the right units for the right reasons, (b) evidence that your policy proposal is feasible and that you have adequately considered implementation obstacles, and (c) the professionalism and effectiveness of your simulator, including your use of the iThink story-telling feature.

Table 1. Project Instructions and Evaluation Criteria

The rest of the paper is organized in three sections. First, we discuss the explanatory model the students took as a "given" in this year's project; it is a modified version of an award-winning model built by a medical doctor studying system dynamics under the supervision of Professor John Morecroft at London Business School. Next is a comparison of individual approaches to the assignment by three students who calibrated the project explanatory model to particular countries and designed policies they expect to be cost-effective and feasible in each country's context. The final section offers our collective assessment of the project and its contribution to the learning objectives in the course and underscores our request for reader feedback.

The Explanatory Model

The 2013 project required each student to design a model-based policy to address the unintended consequences of the European Working Time Directive (EWTD) as it applied to hospital doctors. November 2013 will mark the twentieth anniversary of European Council Directive 93/104/EC "concerning certain aspects of the organization of working time."[2] Although amended in 2000 and 2003, the essence of today's EWTD can still be found in Article 6 of Section II in the original 1993 directive: "Member States shall take measures necessary to ensure that, in keeping with the need to protect the safety and health of workers … the average working time for each seven-day period, including overtime, does not exceed 48 hours." Hospital "doctors in training" were excluded from the regulatory scope of the directive until an amendment in 2000; even then, Member States were permitted a transitional implementation period until 2004 or later (2009 in the United Kingdom), depending on the documented degree of difficulty in balancing EWTD requirements with responsibilities for delivery of health care services. During the transitional period, the working time limits were to be gradually implemented with weekly averages of 58, 56, and 52 hours spread over the transition period, on the way to a 48-hour workweek.

EWTD regulations probably had the most "bite" in countries such as the United Kingdom (UK) where doctors' hours have historically exceeded the 48-hour target by wide margins. According to Morecroft (2007, p. 315), junior doctors in the UK—those in training to become specialists—were working about 72 hours weekly prior to the application of EWTD regulations to doctors. Such a wide gap between traditional practice and the regulatory requirement may be one reason that British system dynamicists have been active in modeling the impact of the EWTD on doctors in UK hospitals (cf., Ratnarajah 2004, Winch and Derrick 2006, and Morecroft 2007).

The explanatory model given to the students ("Project model") for the policy modeling project was adapted from the Ratnarajah model ("Original model") described in a case study in Morecroft (2007). Both models support the claim by UK doctors that EWTD regulations, although aimed at improving doctors' working conditions in hospitals, unintentionally lowered doctors' morale, reduced incentives for junior doctors to work in hospitals, and led to an increase in the recruitment of foreign doctors to close the junior doctor deficit.

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[2] Documentation for EWTD details mentioned in this section is accessible via internet links to relevant pages of the 1993, 2000, and 2003 archives of the *Official Journal of the European Communities*. See the References.

Understanding the Project model will be easier if we present it in stages, starting with what might be called the naive perspective that changes in doctors' work hours will have no effect on doctors' morale. See Figure 1.

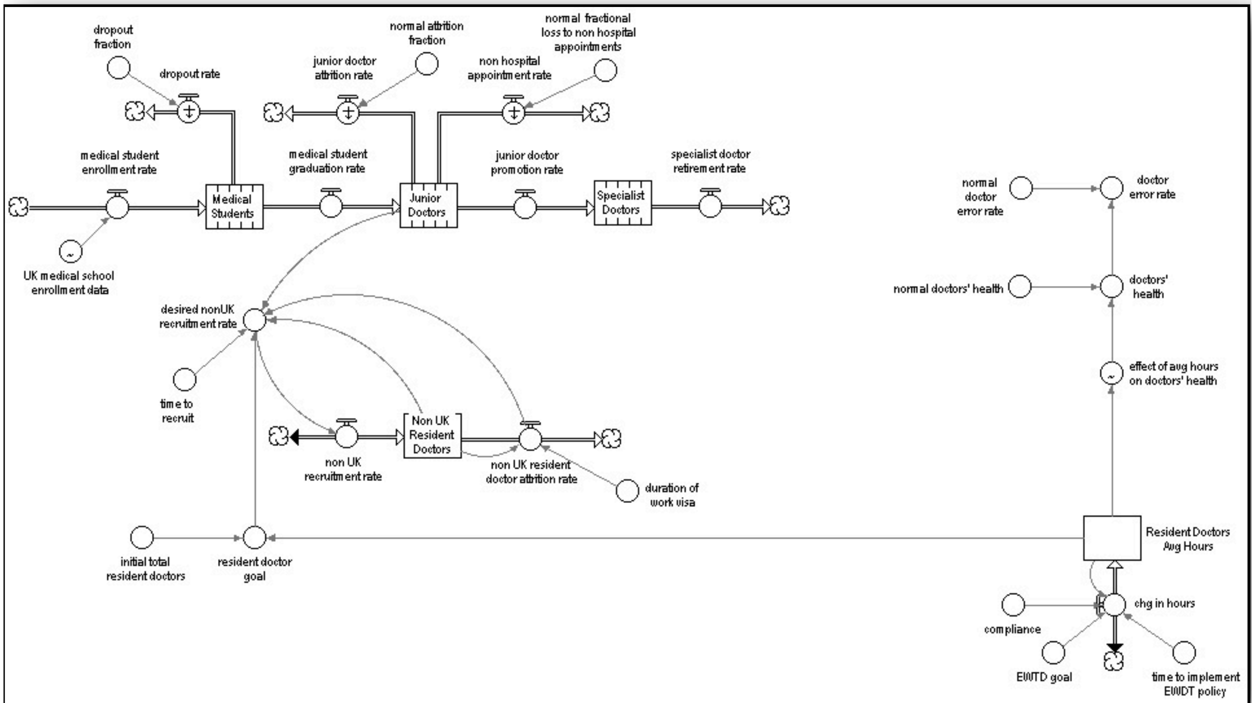


Figure 1. Doctors' Morale is not included in the Naive Model

On the right side of the naive model diagram in Figure 1, perfect compliance with EWDT policy assures that resident doctors' working time converges toward the 48-hour-week on schedule. As the average work week decreases, there is a positive effect on doctors' health, including a reduction in fatigue. Healthier, more alert doctors make fewer mistakes when working with patients, causing the doctor error rate to fall. In this model, the EWDT produces healthier doctors and healthier patients. However, the model is not so naive that it ignores the doctor supply implications of the EWDT policy. On the left side of the Figure 1 diagram, the resident doctor goal rises as the average workweek falls—more doctors are needed if doctors work shorter hours. The potential doctor shortage problem is solved by recruiting more non-UK doctors. The experience chain involving medical students, junior doctors, and specialist doctors is unaffected by the EWTD policy in the naive model.

If pressed, the naive perspective would likely concede that the EWTD policy has some effect on doctors' morale. Indeed, it is not hard to imagine the naive model morphing into an optimistic model, where improvments in the health of both doctors' and patients lead to an improvement in doctors' morale. See Figure 2.

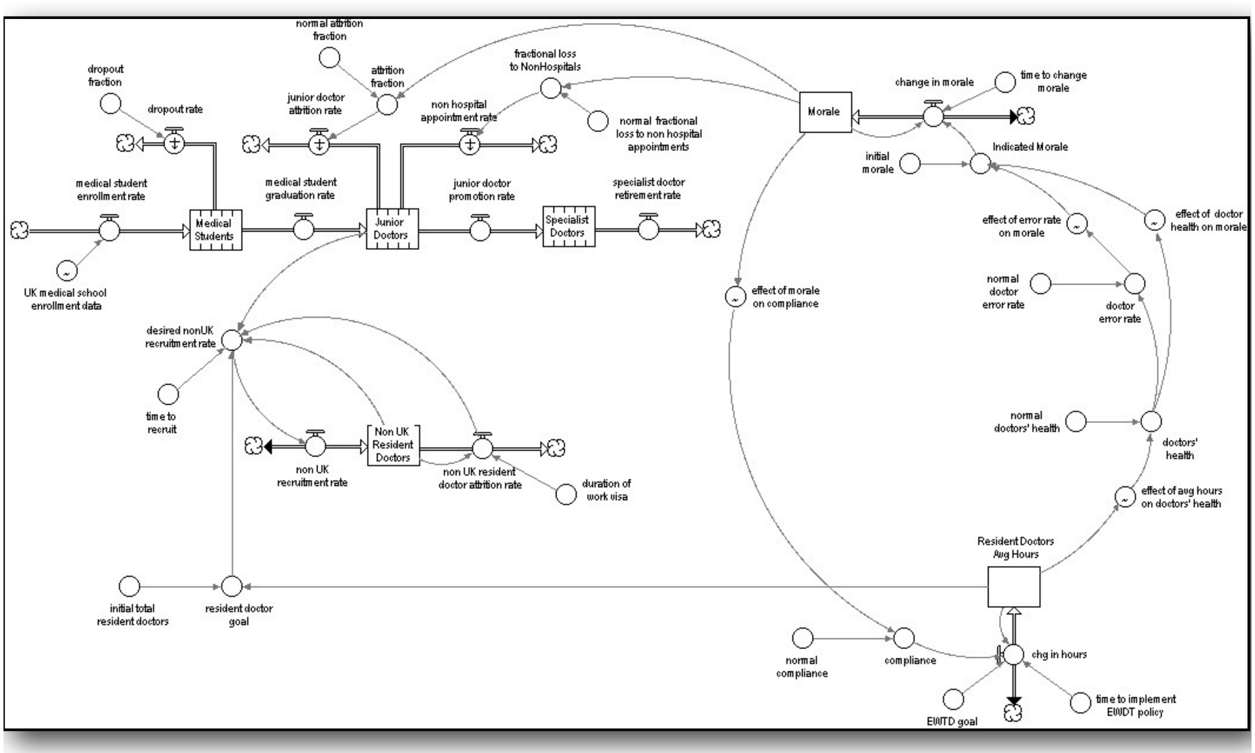


Figure 2. Optimistic Model that Expects EWTD Policy to Boost Doctors' Morale

Moreover, improvements in morale that are associated with EWTD policy would be likely to improve compliance with that policy. On the right side of the optimistic model diagram in Figure 2, two reinforcing loops are visible. More compliance with EWTD policy reduces average working hours, which improves the health of doctors and patients, which improves doctors' morale, and gives another boost to compliance. In addition, doctors' morale influences junior doctor outflow rates: higher morale reduces attrition from the medical profession and also reduces the loss to non-hospital careers such as general practice.

Adding more pessimistic feedback loops yields the final Project model in Figure 3. There is now a link from Resident Doctors Avg Hours to a new variable called "handovers" which represents the number of times each week that a patient's records are "handed over" from one doctor to another at the end of a shift change. The decrease in the workweek creates more shift changes during the week and more handovers. More handovers increase the risk of poor communication between doctors and increase the doctor error rate, with a subsequent negative impact on doctors' morale.

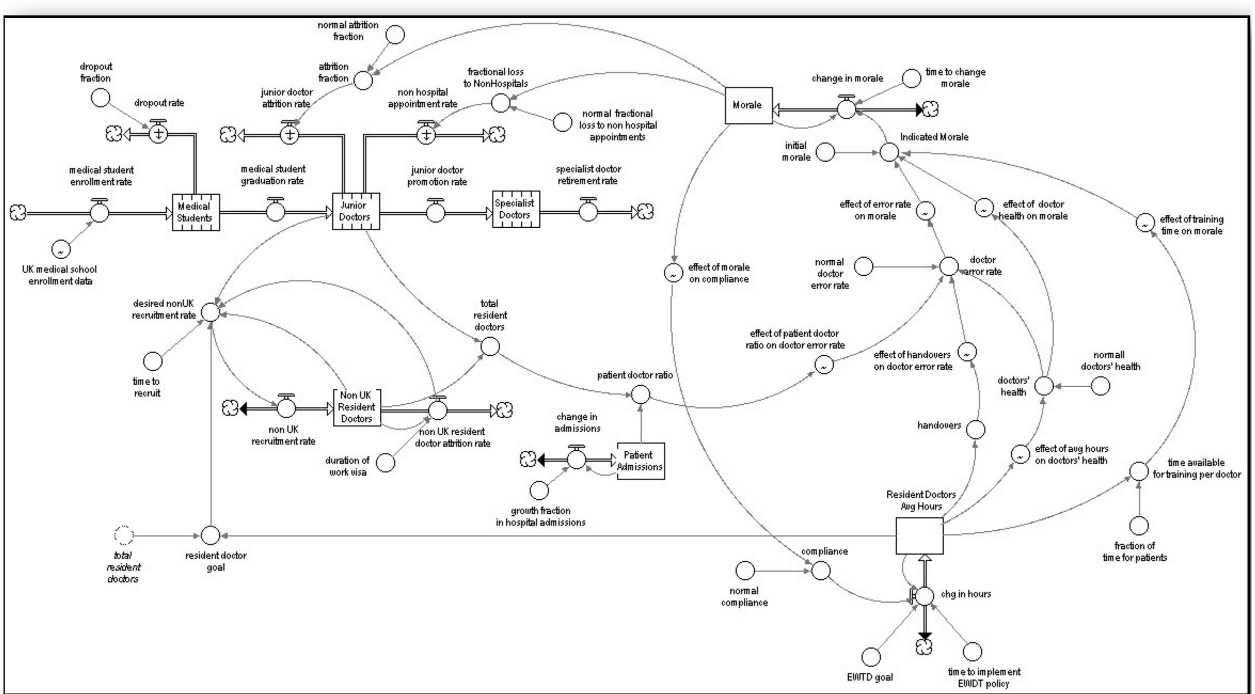
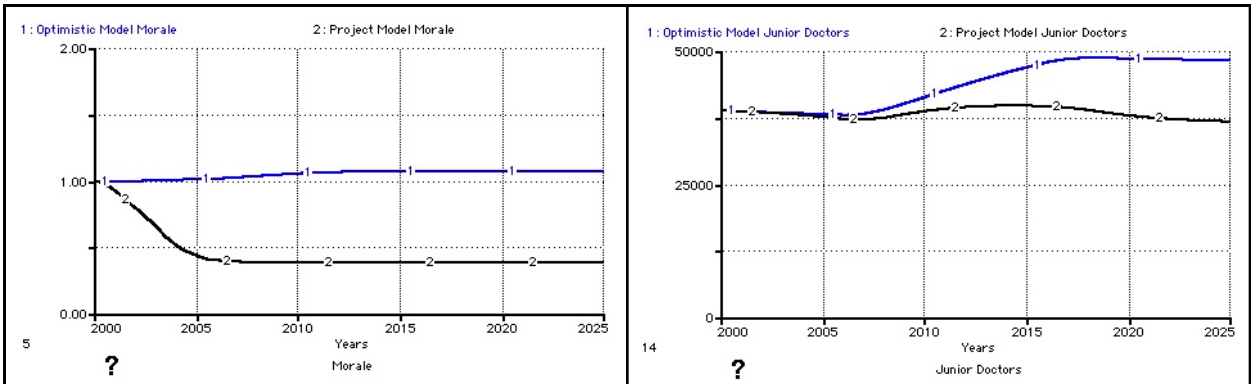


Figure 3. Project Model Generates the EWTD Unintended Adverse Consequences
source: adapted from Ratnarajah's Original Model in Morecroft (2007)

Another new link on the far right of the Project model in Figure 3 is for the reduction in doctor training time that results from a reduced workweek. Reduced training time, according to Morecroft's (2007) account of Ratnarajah's (2004) research, is perhaps the most critical unintended effect of EWTD policy. When junior doctors lose training time, they suffer a setback in their progress towards specialist doctor status, with a corresponding delay in attainment of professional status and a high salary. The result is a blow to doctors' morale.

Another new feature on display in the Project model in Figure 3 is a feedback effect from the doctor stocks to doctors' morale, via the patient-doctor ratio and the doctor error rate. As the patient-doctor ratio increases (due to a doctor goal that does not keep pace with patient admissions), the error rate increases and morale decreases.

Figure 4 compares the behavior of the optimistic model with the Project model. The optimistic model gives the impression that morale will actually increase and the number of junior doctors will be 25 percent higher in 2025 compared to 2000. The Project model generates a decline in morale, and the number of junior doctors—after a bubble due to rising medical school graduates—resumes a downward trend, falling below its initial level by 5 percent in 2025.



a. Morale Increases in Optimistic Model (1)
Decreases in Project Model (2)

b. Junior Doctors Increase in Optimistic Model (1)
Decrease in Project Model after Bubble (2)

Figure 4. Behavior Differences between Optimistic Model and Project Model

Keep in mind that the Project model was adapted from the Original Ratnarajah model. Both the Project model and the Original model, when simulated, show doctors' morale falling due to the EWTD regulations, with adverse feedback effects on the supply of UK doctors. In both models, stocks of junior and specialist doctors are lower and the stock of non-UK doctors is higher than would be the case in the absence of the EWTD regulations. The simpler Project model was deemed an adequate proxy for the Original model However, it is important to recognize that the Project model is not merely a *simplified* version of the Original model. Additional modifications were made for reasons other than simplification and, in our view, produced a more tractable and realistic model. The structural differences cause the Project model to exhibit a more moderate response to the EWTD regulations, as can be seen in Appendix A where the two models are compared. The point, however, is that the two models provide similar insights and policy implications.

Student Policy Models

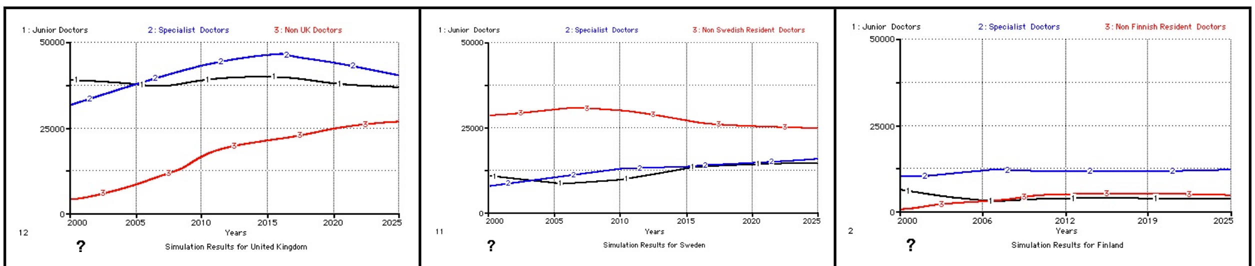
Three of the authors were students in the *Policy Design and Implementation* course in 2013, and they developed policy models to address the impact of the EWTD in the UK (Lewis 2013), Sweden (Li 2013), and Finland (Tadesse 2013). They calibrated their explanatory models differently, and they adopted different strategies to offset various "doctor deficit" effects of the EWTD in their particular countries. In this section, we briefly summarize their work.

Initializing the Explanatory Models. Ratnarajah's original EWTD model (Morecroft 2007) was developed to analyze the medical workforce dynamics in the United Kingdom (UK). Thus, when Lewis studied the UK situation, he used the explanatory model calibrated with parameter assumptions "given" at the beginning of the policy design course. Li and Tadesse, on the other hand, calibrated their explanatory models to fit the situations in Sweden and Finland, respectively. Table 2 summarizes major differences in the parameter estimates used in the three explanatory models. The country models also differed with respect to the exogenous growth in medical students. During the 2000-2010 period, the UK medical school enrollment rate averaged about 6000 students/year while growing rapidly at a 3.3% annual rate. The growth rate in the other two countries was 1.8% per year, with average yearly enrollments of about 1500 and 600 students in Sweden and Finland, respectively.

parameter values	UK	Sweden	Finland
initial foreign resident doctors (persons)	4,000	28,670	482
initial patient admissions (persons/year)	6,000,000	951,440	785,975
initial junior doctors (persons)	39,000	10,684	6086
initial medical students (persons)	25,000	4090	2605
initial specialist doctors (persons)	31,790	7721	9450
medical student dropout fraction (1/year)	0.18	0.08	0.016
duration of junior doctor training to become a specialist (years)	10	10	7
growth fraction in hospital patient admissions (1/year)	0.05	0.05	-0.05
initial resident doctors' average working hours (hours/week)	72	40	48.5
workweek goal (hours/week)	48	40	43
reference junior doctor attrition fraction (1/year)	0.012	0.003	0.0175
reference fractional loss to non-hospital appointments (1/year)	0.025	0.01	0.02

Table 2. Major Differences in Parameter Values in the Students' Explanatory Models

Behavior Patterns. Although the students used the same explanatory model, the calibration differences resulted in three distinct sets of behavior patterns. Figure 5 compares the behavior of the doctors stocks in the three explanatory models, simulated over a 25-year period.



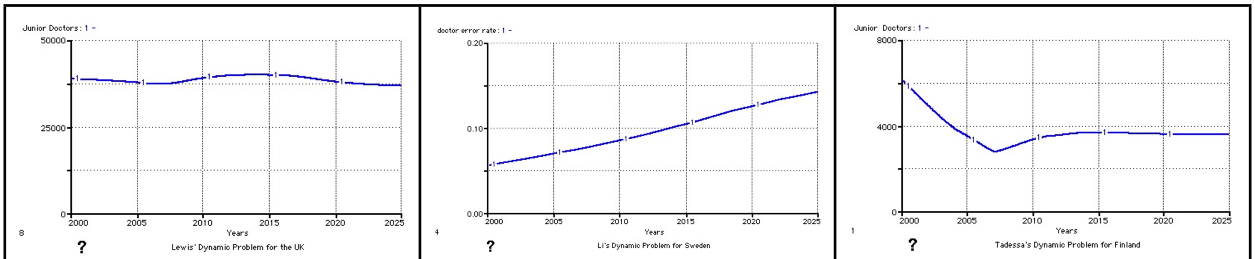
(a) Doctor Stock Patterns: UK

(b) Doctor Stock Patterns: Sweden

(c) Doctor Stock Patterns: Finland

Figure 5. Simulated Doctor Stock Patterns in Students' Explanatory Models, 2000-2025
junior doctors (black 1), specialists (blue 2), foreign doctors (red 3)

Dynamic Problems. The panels in Figure 5 make clear that doctor trends differ from country to country. What is perceived as a looming doctor deficit in the UK may not be an issue in Sweden or Finland, where the patterns suggest more stability. For the UK, Lewis focused on the declining stock of junior doctors, as did Tadesse who was concerned that the non-Finnish resident doctors would outnumber the Finnish doctors. For Sweden, Li was more concerned about the doctor error rate, which he associated with a rising patient-doctor ratio. Figure 6 displays the relevant patterns that motivated the three students.



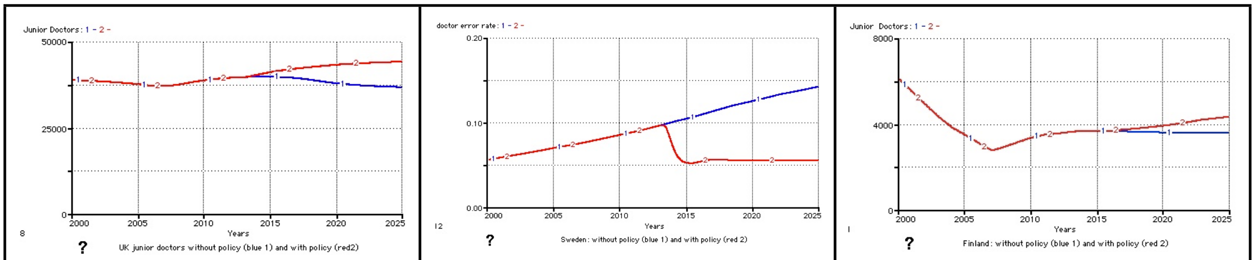
a. Junior Doctor projections: UK | b. Error Rate projections: Sweden | c. Junior Doctor projections: Finland

Figure 6. Dynamic Problems Specified by the Students, projected over 2000-2025

Goals and General Strategies. Each student followed the general approach to policy modeling taught in the course and described in Wheat (2013). Each began by establishing a goal for a stock, based on his perception of the issues in the hypothetical country and the capacity to manage that stock. Then each student adopted a strategy for managing the target stock through one of its existing flows or by creating a new flow. Lewis targeted the UK stock of junior doctors; he aimed to reduce the attrition rate by restoring lost training time and boosting morale. Li established a dynamic goal for the non-Swedish resident doctor stock based on a desired patient-ratio goal necessary to lower and stabilize the doctor error rate. Tadesse set a specific goal for junior doctors, and focused his strategy on raising medical school enrollment rates and, indirectly, increasing the graduate flow into the junior doctor stock.

Policy Results for UK. Lewis' goal was to raise the junior doctor stock to 45,000 over a fifteen-year period, with a strategy to increase training time, increase morale, and reduce the junior doctor attrition rate. He reasoned that restoring the post-EWTD training time (11 hours/ week) to its pre-EWTD level (16 hours/week) would do the trick. Of course, for UK to remain in compliance with the EWTD, the number of *patient* hours for UK junior doctors would have to decline by the same amount. Lewis' model recruits 4600 additonal non-UK resident doctors to make up for the patient-hour decline. As Lewis' policy model begins to stabilize in 2025, there are about 44,400 junior doctors, 46,000 specialist doctors, and 24,000 non-UK resident doctors (a change of 20 percent, 15 percent, and -11 percent, respectively, when compared to stock levels without the policy). The eventual reduction in the junior doctor attrition rate not only raised the junior doctor stock immediately; it also gradually increased the specialist doctor stock as more junior doctors remained in the experience chain. Moreover, the policy reduced the need for non-UK resident doctors, even with the "extra" recruitment needed to cover patient time lost due to the training time increase. See panel (a) in Figure 7 for the results, and see Appendix C for a diagram and equations for the policy structure that Lewis added to the explanatory model.

Policy Results for Sweden. Li's goal was to reduce the doctor error to its level in 2000 over a three-year period, with a strategy based on recruiting enough non-Swedish doctors to restore the patient-doctor ratio to its level in 2000. He recognized the fundamental problem in the goal formulation in the explanatory model; i.e., that the number of patients had no influence on the desired number of doctors. Panel (b) in Figure 7 indicates the new policy structure had its desired effect within the model, but perhaps more quickly than is feasible. See Appendix D for a diagram and equations for the policy structure that Li added to the explanatory model.



a. UK: Junior Doctors Increase | b. Sweden: Error Rate Decreases | c. Finland: Junior Doctors Increase

Figure 7. Students' Policy Models' Impact on Dynamic Problems Specified in Figure 6

Policy Results for Finland. Tadesse's goal for Finland would increase the number of junior doctors to 4600 over a period of about eighteen years. Although a close inspection of panel (c) in Figure 7 indicates the goal is not reached by 2025, a longer simulation run confirms that the policy works more or less as expected; there is mild oscillation around the goal that begins in 2030 and dampens over several decades. The binding constraint is the physical capacity; a higher goal would not be feasible with current medical school classroom capacity in Finland. See Appendix E for a diagram and equations for the policy structure that Tadesse added to the explanatory model.

Of course, the students' policy models simulated many indicators in addition to the patterns of junior doctor and error rates. Table 3 summarizes the effects on trends of greatest concern.

indicator	**Lewis' strategy for UK:** *increase training for junior doctors*	**Li's strategy for Sweden:** *reduce & stabilize patient-doctor ratio*	**Tadesse's strategy for Finland:** *increase & stabilize medical school enrollments*
junior doctors	rose & stabilized at goal	rose slightly & stabilized	rose & eventually oscillated mildly around the goal
specialist doctors	rose & stabilized at implicit goal	rose slightly & stabilized	rose & eventually oscillated mildly around the goal
foreign doctors	declined & stabilized at implicit goal	rising continuously at same pace as patients	declined & eventually oscillated mildly around the goal
patient-doctor ratio	continues to rise	declined & stabilized at goal	continues to decline but only because patient trend is down
doctor error rate	continues to rise	declined & stabilized at goal	continues to decline but only because patient-doctor trend is down
doctors' morale	rose substantially and stabilized	rose & stabilized	rose slightly & stabilized
EWTD compliance	rose & stabilized	rose & stabilized	rose slightly & stabilized
monetary costs	least costly of 3 policies	most costly, by far	costly
unintended adverse consequences	none identified	none identified	none identified

Table 3. Impact of Students' Policies on Key Indicators

Each student's policy would be costly, especially Li's plan to reduce and stabilize the patient-doctor ratio. However, it appears that each student's policy would improve EWTD compliance while making the costs of compliance explicit instead of hiding those costs "off budget" in the form of externalities that EWTD had imposed on hospital doctors.

In addition to adding stock-and-flow structure representing aspects of their policies' implementation process, students prepared short reports discussing feasibility issues that are not modeled but warrant additional planning. Rudimentary analyses of policy cost-effectiveness were also conducted. Finally, each student's model was integrated with a simulator designed to be a "learning experience" for users of the model. As mentioned earlier, discussion of these features of the project are beyond the scope of this paper. We prefer to focus the readers' attention and assessment on the defining feature of the policy modeling assignment itself,

Discussion

We have reasons to be be pleased with this year's project, but it still falls short of our expectations. Our vision for the course is not yet realized. Here, we sketch our preliminary assessment, largely with the hope that the issues we mention will trigger ideas, comments, and suggestions from others.

Strong points. As in the past, this year's students were dealing with real-world issues, which always provides higher interest and motivation. By working with a single case study (Morecroft 2007), there was an opportunity to dig deeply into the details of the issue. This year's topic is timely and controversial; thus, the students had no difficulty finding sufficient reading material to round out their understanding of the issues. Moreover, it was the twist of "unintended consequences" that motivated the need for a new policy, and that is probably a good lesson for students who sometimes think of policy conflict as a zero-sum game involving good guys and bad guys. EWTD was not a bad policy idea, but it undermined its own implementation by failing to anticipate second- and third-order effects of its regulations. Interestingly, our three students' policies suggest that improved EWTD compliance could result from addressing the issues generated by EWTD enforcement.

The new format of the project—"giving" all the students the same explanatory model that was already in *iThink*, was already well documented, and could be analyzed during a lecture—did free up more time for thinking hard about policy options, doing research on the feasibility of various options, and then designing the policy structure to be grafted onto the explanatory model. There was also more time for students to devote to the question of what constitutes an effective simulator, and several students succeeded in producing a professional-looking interface and opportunites for users to have a true learning experience.

Weak points. Less progress was made on implementation modeling. That could be due to time constraints that still remain, but it also may be due to the lack of many good examples in the literature. Nevertheless, for several students, the implementation report that accompanied the model revealed a heightened sensitivity to feasibility considerations. We plan to put more emphasis on implementation modeling in next year's course (but we need to find a way to do that that does undermine the progress we're seeing in formulation of policy structure and with simulator design).

The "given" explanatory model still required considerable time to calibrate; thus, there was no immediate start on policy modeling.

A real concern that we have is about adverse unintended consequences of the "given" explanatory model approach. We gave each student the same explanatory model developed for one country's dynamic problem, and required him or her to calibrate that model with another country's data in search of a dynamic problem that needs a policy model. Are we inadvertantly undermining some of our efforts in the previous course, where we emphasize that an explanatory model should reflect the operational processes actually found in the context of a particular problem? What are the risks that students will think too quickly that they have an "archetype" model and that one size fits all?

In addtion to reader respons on the issues we have raised about our particular approach, we would also welcome fresh ideas. So, we conclude with a specific question to readers who have some experience in teaching or learning model-based policy design: What kinds of tasks have you found useful for practicing and developing specific policy modeling skills?

We hope this paper contributes to a broader conversation within the SD community about effective ways of teaching and learning policy design skills.

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Wheat, ID. (2013). Model-based Policy Design that Takes Implementation Seriously, in *Policy Informatics Handbook*, K. Desouza and E. Johnston (eds.), Cambridge: MIT Press (forthcoming).

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Appendix A: Comparison of the Project Model and Original Model

As presented in Morecroft (2007), Ratnarajah's original model was organized into sectors, using *iThink*'s "ghosts" (aka "shadows" in *Vensim*) to hide many of the links and thereby simplify the presentation of the stock-and-flow diagram. While that enables a useful sub-model approach to explaining the model in the textbook, hiding the links makes it difficult to see how the full model fits together. In particular, important feedback loops (or the absence of expected feedback) might be overlooked. Simplifying the original model, therefore, actually required complicating it first: eliminating most ghosts and restoring the missing links. Fortunately, that was not difficult because a working version of the model was contained on the companion CD in the Morecroft textbook. Figure A1 shows the re-linked version of the full Original model.

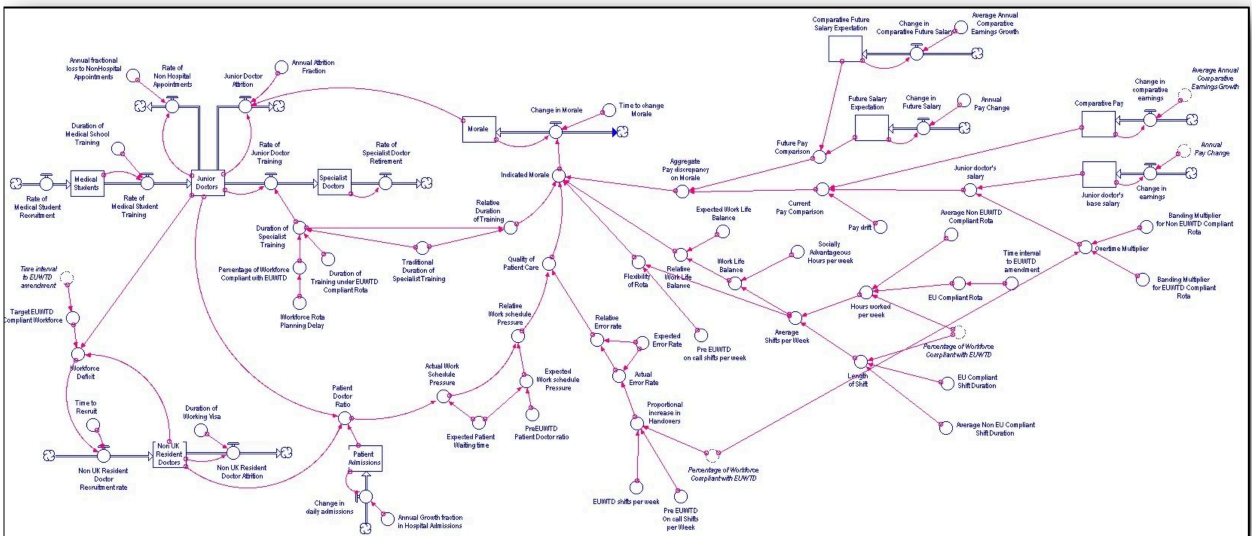


Figure A1. Re-linked Version of Ratnarajah's Full Original Model in Morecroft (2007)

The Project model, displayed below in Figure A2, retains most of what appears in the left-hand side of the Original model but with a few different formulations. The Project model uses historical medical school enrollment data to drive the enrollment rate, in contrast with the Original model that assumes a constant enrollment rate. The Project version also includes a medical school dropout rate and an average dropout fraction estimated from the data; there are no dropouts in the Original model.

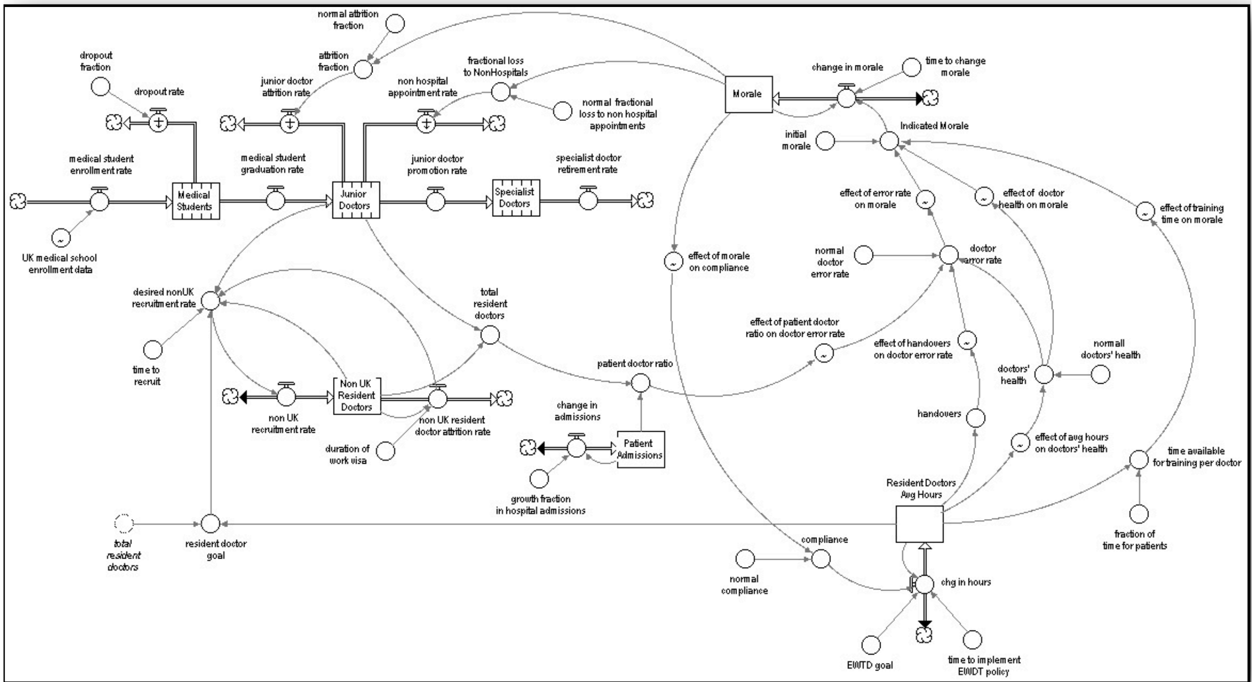


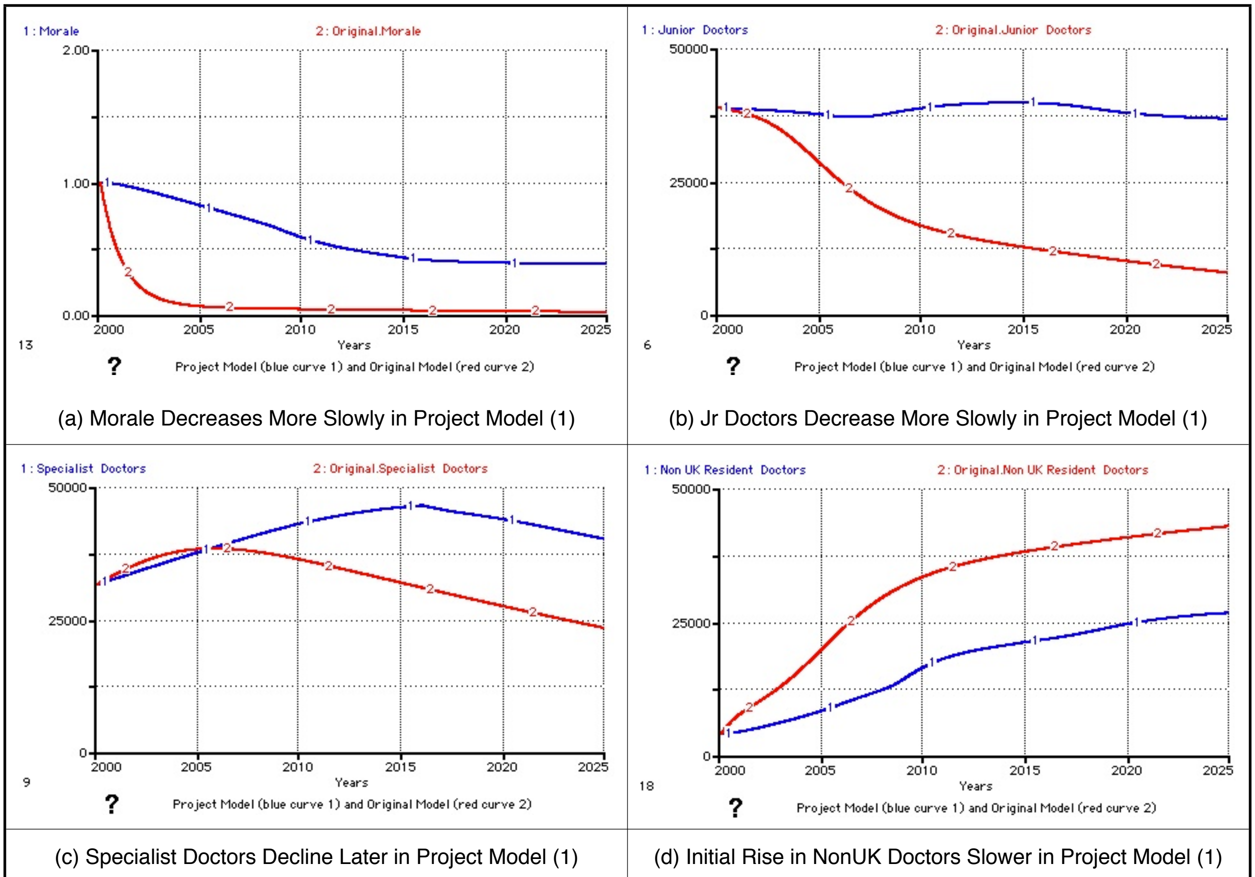
Figure A2. This Project Model is a Modified Version of Ratnarajah's Original Model (same as Figure 3)

The Project model retains the experience chain of medical students, junior doctors, and specialist doctors (but uses conveyor stocks instead of reservoirs); also relies on non-UK doctors to rectify junior doctor shortages (but uses a different formulation of the doctor goal); and uses the same exogenous growth rate for patients. Both models contain the feedback loop that causes a drop in doctors' morale to increase the junior doctor attrition rate from the medical profession, but the Project version includes a similar morale effect on doctors' preference for working outside of hospitals (e.g., as general practioners).

The right-hand side of the Original model consists of numerous effects on doctors' morale, but the Project model consolidates those effects into a smaller number, and uses mostly nonlinear graphical functions to replace Ratnarajah's linear relationships. Yet, we retained his well-researched point estimates as the reference (or "normal) parameter values in the graphical functions. The other main difference is that the Project model assumes that doctors' morale has a feedback effect on compliance with the EWTD regulations. In both models, compliance with EWTD regulations reduces doctors' hours and unintentionally reduces doctors' morale. However, the strength of that effect is moderated in the Project model by assuming that falling morale reduces compliance. This counteracting feedback loop is operating in the Project model but not in the Original model.

As expected, the difference in structure of the two models results in different behavior. A big difference can be seen in the doctors' morale pattern in Figure A3, panel (a). In the Original model, doctors' morale plummets quickly after the EWTD regulations are extended to doctors in

2000 and stabilizes just above zero in about five years. In the Project model, doctors' morale declines by "only" sixty percent before stabilizing. In panel (b) the Project model indicates an overall 5 percent decline in the number of junior doctors over a twenty-five year period, moderated largely by a bubble increase in the middle years that reflected a rising medical school graduate rates. The Original model, which assumed no change in the number of medical school graduates, suggests a steady 85 percent drop in junior doctors over the same period. We leave it to the reader to opine which patterns are more realistic.



(a) Morale Decreases More Slowly in Project Model (1)

(b) Jr Doctors Decrease More Slowly in Project Model (1)

(c) Specialist Doctors Decline Later in Project Model (1)

(d) Initial Rise in NonUK Doctors Slower in Project Model (1)

Figure A3. Project Model displays a more Moderate Response to EWTD

Despite the difference in structure and the more moderate response of the Project model, it is important not to lose sight of the essential agreement between the two models: both show doctors' morale falling due to the EWTD regulations. The result—in both models—is that junior and specialist doctor stocks are lower and the stock of non-UK doctors is higher than they would be in the absence of the EWTD regulations.

Ultimately, the trend in the number of doctors is meaningless without comparing it with the trend in patients. Figure A4 drives home the essential message that comes from both the Original and the Project Model—the patient/doctor ratio is expected to rise rapidly. However, this problematic pattern is not solely due to falling morale and departing doctors. It reflects the way that doctor goal is formulated in both the Original and Project models. The doctor goal only increases in proportion to the decrease in the workweek. The number of patients does not influence the desired number of doctors.

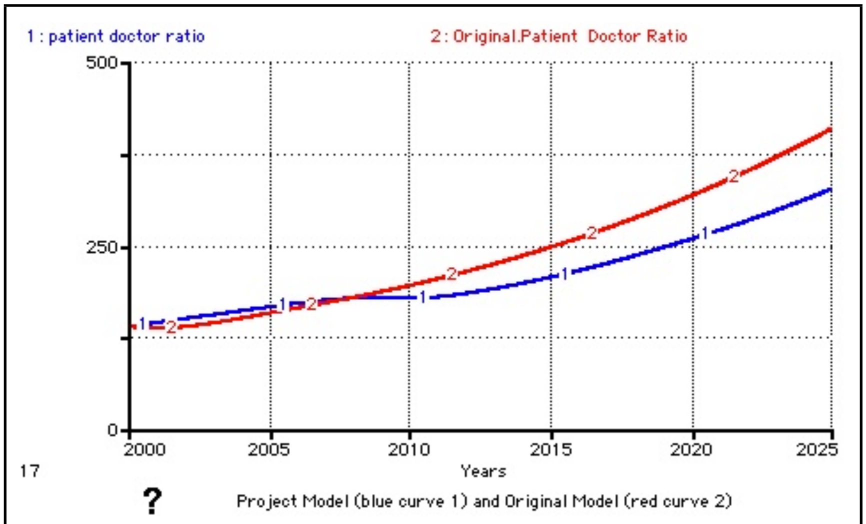


Figure A4. Patient-Doctor Ratio Rising Rapidly in Both Models

New policies are needed to counteract the unintended consequences of the EWTD regulations. That was the task assigned to the students in the *Policy Design and Implementation* course at the University of Bergen during the spring semester 2013..

The equations for the Project model are listed in Appendix B. The equations for the Original model are available on the companion CD in the Morecroft (2007) textbook.

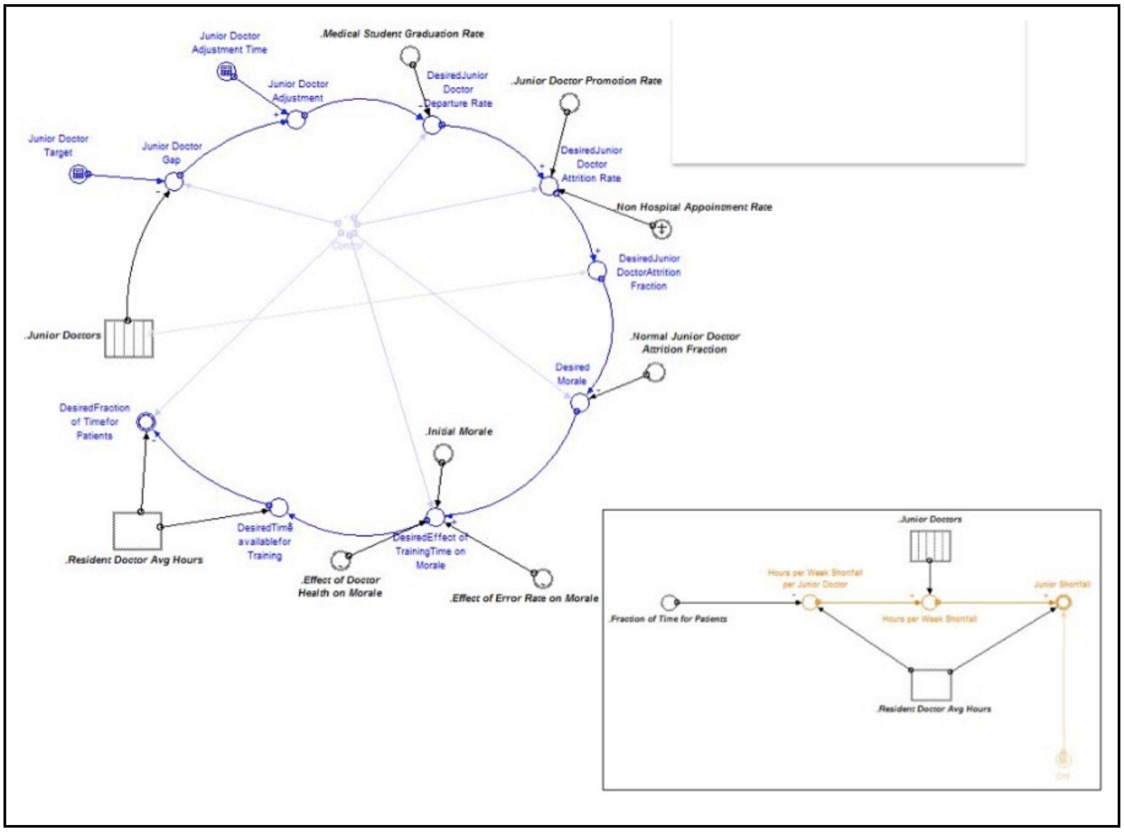
Appendix B: Explanatory Project Model Equations

Morale(t) = Morale(t - dt) + (change_in_morale) * dt
INIT Morale = initial_morale
INFLOWS:
change_in_morale = (Indicated_Morale-Morale)/Time_to_change_Morale
Non_UK_Resident__Doctors(t) = Non_UK_Resident__Doctors(t - dt) + (non_UK_recruitment_rate - non_UK_resident__doctor_attrition_rate) * dt
INIT Non_UK_Resident__Doctors = 4000
INFLOWS:
non_UK_recruitment_rate = desired_nonUK_recruitment_rate
OUTFLOWS:
non_UK_resident__doctor_attrition_rate = Non_UK_Resident__Doctors/duration_of__work_visa
Patient__Admissions(t) = Patient__Admissions(t - dt) + (change_in_daily_admissions) * dt
INIT Patient__Admissions = 6000000
INFLOWS:
change_in_admissions = Patient__admissions*growth_fraction_in_hospital_admissions
Resident_Doctors_Avg_Hours(t) = Resident_Doctors_Avg_Hours(t - dt) + (chg_in_hours) * dt
INIT Resident_Doctors_Avg_Hours = 72
INFLOWS:
chg_in_hours = EWTD_policy_impact*(compliance*(EWTD_goal-Resident_Doctors_Avg_Hours)/time_to_implement_EWDT_policy)
Junior__Doctors(t) = Junior__Doctors(t - dt) + (medical_student_graduation_rate - junior_doctor_promotion_rate - non_hospital_appointment_rate - junior_doctor_attrition_rate) * dt
INIT Junior__Doctors = 39000
TRANSIT TIME = Duration_of__Specialist__Training
INFLOWS:
medical_student_graduation_rate = CONVEYOR OUTFLOW
OUTFLOWS:
junior_doctor_promotion_rate = CONVEYOR OUTFLOW
non_hospital_appointment_rate = LEAKAGE OUTFLOW
LEAKAGE FRACTION = fractional_loss_to_NonHospitals
LEAK ZONE = 0% to 100%
junior_doctor_attrition_rate = LEAKAGE OUTFLOW
LEAKAGE FRACTION = attrition_fraction
LEAK ZONE = 0% to 100%
Medical_Students(t) = Medical_Students(t - dt) + (medical_student_enrollment_rate - medical_student_graduation_rate - dropout_rate) * dt
INIT Medical_Students = 25000
TRANSIT TIME = Duration_of_Medical_School_Training
INFLOWS:
medical_student_enrollment_rate = UK_medical_school_enrollment_data
OUTFLOWS:
medical_student_graduation_rate = CONVEYOR OUTFLOW
dropout_rate = LEAKAGE OUTFLOW
LEAKAGE FRACTION = dropout_fraction
LEAK ZONE = 0% to 100%
Specialist__Doctors(t) = Specialist__Doctors(t - dt) + (junior_doctor_promotion_rate - specialist_doctor_retirement_rate) * dt
INIT Specialist__Doctors = 31790
TRANSIT TIME = time_until_retirement
INFLOWS:
junior_doctor_promotion_rate = CONVEYOR OUTFLOW
OUTFLOWS:
specialist_doctor_retirement_rate = CONVEYOR OUTFLOW
attrition_fraction = min(1,Normal_Attrition__Fraction/Morale)
compliance = normal_compliance*effect_of_morale_on_compliance
desired_nonUK_recruitment_rate = (resident_doctor_goal-(Junior__Doctors+Non_UK_Resident__Doctors))/
Time_to__Recruit+smth1(non_UK_resident__doctor_attrition_rate,.25)

doctors'_health = normall__doctors'_health*effect_of_avg_hours_on_doctors'_health
doctor_error_rate =
effect_of_patient_doctor_ratio_on_doctor_error_rate*effect_of_handovers_on_doctor_error_rate*normal_doctor_error_rate/doctors'_health
dropout_fraction = 0.18
duration_of_medical_school_training = 5
Duration_of__Specialist__Training = 10
duration_of__work_visa = 4
effect_of_avg_hours_on_doctors'_health = GRAPH(Resident_Doctors_Avg_Hours/
init(Resident_Doctors_Avg_Hours))
(0.00, 1.15), (0.5, 1.10), (1.00, 1.00), (1.50, 0.75), (2.00, 0.4)
effect_of_error_rate_on_morale = GRAPH(doctor_error_rate/init(doctor_error_rate))
(0.00, 1.50), (0.5, 1.19), (1.00, 1.00), (1.50, 0.806), (2.00, 0.705)
effect_of_handovers_on_doctor_error_rate = GRAPH(handovers/init(handovers))
(1.00, 1.00), (1.25, 1.10), (1.50, 1.25), (1.75, 1.40), (2.00, 1.50)
effect_of_morale_on_compliance = GRAPH(Morale/init(Morale))
(0.00, 0.00), (0.5, 0.1), (1.00, 0.4), (1.50, 0.8), (2.00, 1.00)
effect_of_patient_doctor_ratio_on_doctor_error_rate = GRAPH(patient_doctor_ratio/init(patient_doctor_ratio))
(0.00, 0.00), (0.5, 0.5), (1.00, 1.00), (1.50, 1.75), (2.00, 2.50)
effect_of_training_time_on_morale = GRAPH(time_available_for_training_per_doctor/
init(time_available_for_training_per_doctor))
(0.00, 0.1), (0.5, 0.25), (1.00, 1.00), (1.50, 1.20), (2.00, 1.25)
effect_of__doctor_health_on_morale = GRAPH(doctors'_health/init(doctors'_health))
(0.5, 0.2), (0.75, 0.6), (1.00, 1.00), (1.25, 1.20), (1.50, 1.25)
EWDT_policy_switch = 1
EWTD_goal = 48
EWTD_policy_impact = if(time>EWTD_policy_start_date)and(EWDT_policy_switch=1)then(1)else(0)
EWTD_policy_start_date = 2000
EWTD_schedule = GRAPH(TIME)
(2000, 72.0), (2002, 64.7), (2005, 57.0), (2008, 51.2), (2010, 48.0)
fractional_loss_to_NonHospitals = min(1,normal__fractional__loss_to_non_hospital__appointments/Morale)
fraction_of_time_for_patients = 56/72
growth_fraction_in_hospital_admissions = 0.05
handovers = init(Resident_Doctors_Avg_Hours)/Resident_Doctors_Avg_Hours
Indicated_Morale =
initial_morale*effect_of_doctor_health_on_morale*effect_of_error_rate_on_morale*effect_of_training_time_on_morale
initial_morale = 1
normall__doctors'_health = 48/72
normal_attrition__fraction = 0.012
normal_compliance = 1
normal_doctor_error_rate = 0.0375
normal__fractional__loss_to_non_hospital__appointments = 0.025
patient_doctor_ratio = Patient__Admissions/total_resident_doctors
resident_doctor_goal = (init(Resident_Doctors_Avg_Hours)/
Resident_Doctors_Avg_Hours)*init(total_resident_doctors)
Target_EUWTD_Compliant_Workforce = SMTH1(56600,5,46700)
time_available_for_training_per_doctor = Resident_Doctors_Avg_Hours*(1-fraction_of_time_for_patients)
time_to_change_morale = 1
time_to_implement_EWDT_policy = max(.5,2009-time)
time_to__recruit = 0.5
time_until_retirement = 16
total_resident_doctors = Junior__Doctors+Non_UK_Resident__Doctors
UK_medical_school_enrollment_data = GRAPH(TIME)
(1996, 4480), (1997, 4577), (1998, 4683), (1999, 4871), (2000, 5238), (2001, 5675), (2002, 6287), (2003, 6953), (2004, 7262), (2005, 7106), (2006, 7176), (2007, 7017), (2008, 7144), (2009, 7000), (2010, 7000)
UK_medical_school_graduates_data = GRAPH(TIME)
(1987, 4638), (1988, 4434), (1989, 4255), (1990, 3637), (1991, 3527), (1992, 3644), (1993, 3635), (1994, 3715), (1995, 3803), (1996, 3885), (1997, 3997), (1998, 4251), (1999, 4155), (2000, 4432), (2001, 4269), (2002, 4450), (2003, 4641), (2004, 4805), (2005, 5176), (2006, 5576), (2007, 6208), (2008, 5569), (2009, 5684), (2010, 5757)

Appendix C: Policy Model for UK (Lewis 2013)

Excerpted from Lewis' full model:

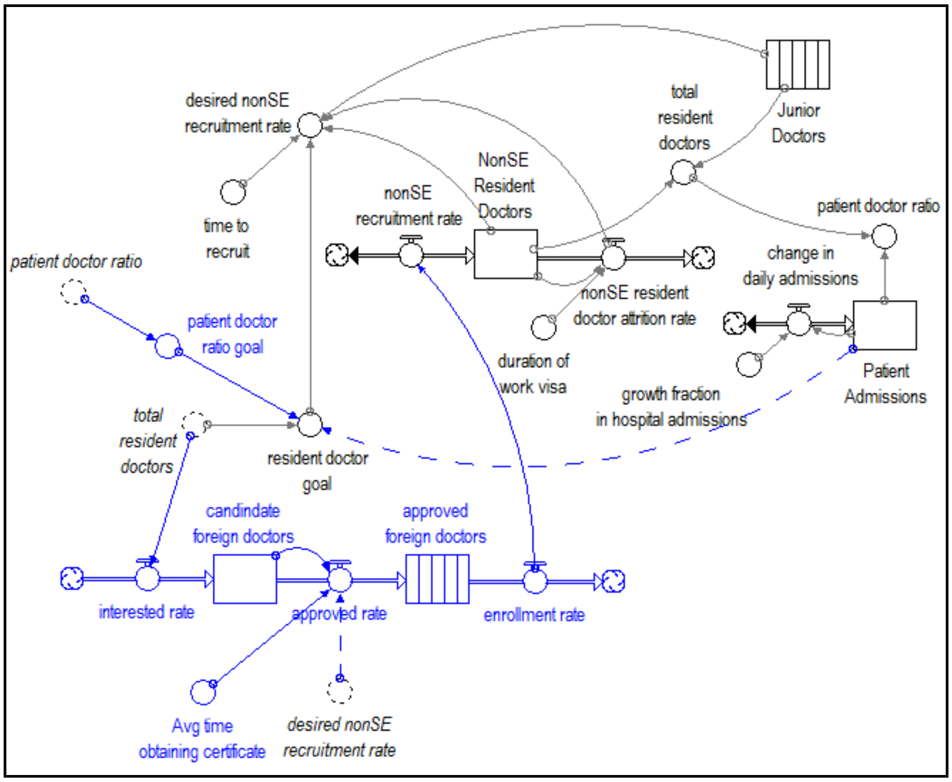


Equations for Excerpted Portion of Model: [cost structure not shown in diagram or equations]

Control = IF(TIME>=Policy_Start_Date)AND(SWITCH=1)THEN(1)ELSE(0)
Desired_Effect_of_Training_Time_on_Morale = Control*(Desired_Morale/(.initial_morale*.Effect_of_Doctor_Health_on_Morale*.effect_of_error_rate_on_morale))
Desired_Fraction_of_Time_for_Patients = Control*(1-(Desired_Time_available_for_training/.Resident_Doctor_Avg_Hours))
Desired_Junior_Doctor_Attrition_Fraction = Desired_Junior_Doctor_Attrition_Rate/.Junior_Doctors
Desired_Junior_Doctor_Attrition_Rate = Control*Max(0,(Desired_Junior_Doctor_Departure_Rate-SMTH1(.junior_doctor_promotion_rate,0.5)-SMTH1(.non_hospital_appointment_rate,0.5)))
Desired_Junior_Doctor_Departure_Rate = Control*MAX(0,SMTH1(.medical_student_graduation_rate,0.5)-Junior_Doctor_Adjustment)
Desired_Morale = Control*min(1,.Normal_Junior_Doctor_Attrition_Fraction/Desired_Junior_Doctor_Attrition_Fraction)
Desired_Time_available_for_Training =
    Desired_effect_of_training_time_on_morale*INIT(.Resident_Doctor_Avg_Hours)*16/72
Junior_Doctor_Adjustment = Junior_Doctor_Gap/Junior_Doctor_Adjustment_Time
Junior_Doctor_Adjustment_Time = 5
Junior_Doctor_Gap = Control*(Junior_Doctor_Target-.Junior_Doctors)
Junior_Doctor_Target = 45000
Policy_Start_Date = 2013
Hours_per_Week_Shortfall = Hours_per_week_Shortfall_per_Junior_Doctor*.Junior_Doctors
Hours_per_Week_Shortfall_per_Junior_Doctor =
    (INIT(.fraction_of_time_for_patients)-.fraction_of_time_for_patients)*.Resident_Doctor_Avg_Hours
Junior_Shortfall = IF(Off=0)then(Hours_per_week_shortfall/.Resident_Doctor_Avg_Hours)ELSE(0)

Appendix D: Policy Model for Sweden (Li 2013)

Excerpted from Li's full model:



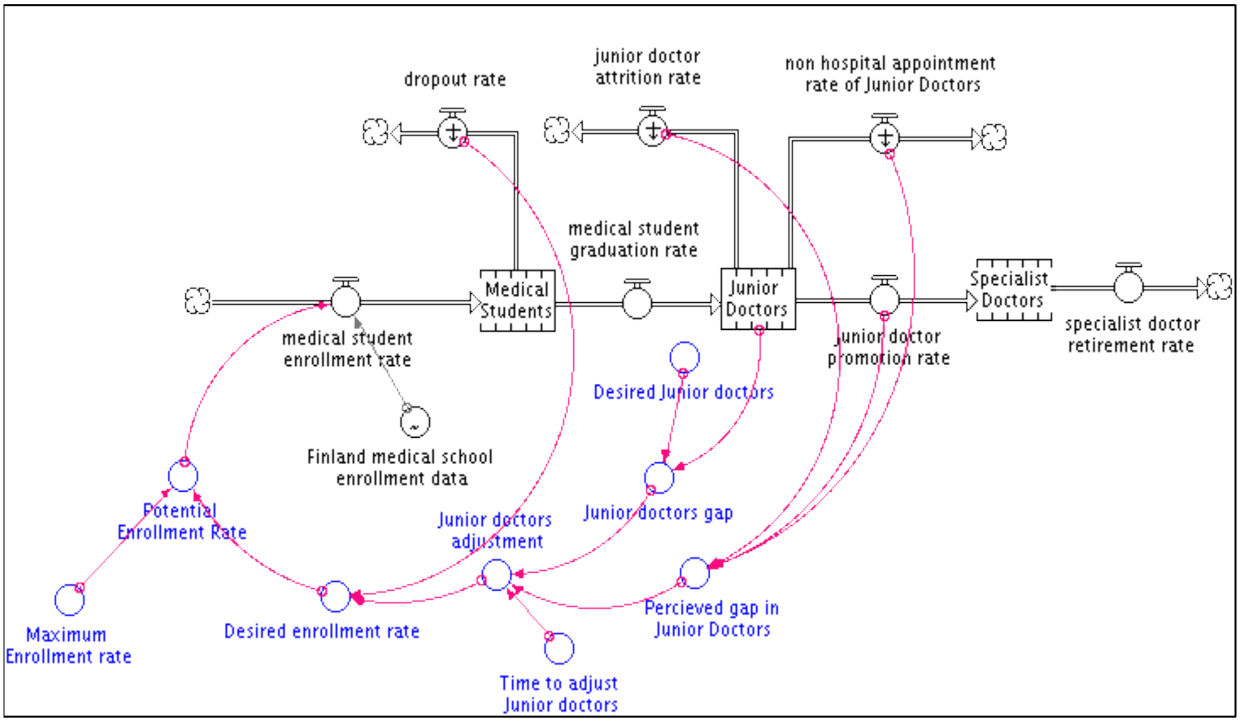
Equations for Excerpted Portion of Model:

candidate__foreign_doctors(t) = candidate__foreign_doctors(t - dt) + (interested_rate - approved_rate) * dt
INIT candidate__foreign_doctors = 2000
INFLOWS:
interested_rate = total_resident_doctors*0.3
OUTFLOWS:
approved_rate = MIN(SMTH1(desired_nonSE_recruitment_rate,Avg_time_obtaining_certificate),
(candindate__foreign_doctors/Avg_time_obtaining_certificate))
approved__foreign_doctors(t) = approved__foreign_doctors(t - dt) + (approved_rate - enrollment_rate) * dt
INIT approved__foreign_doctors = 2000
TRANSIT TIME = appointing_interval
INFLOWS:
approved_rate = MIN(SMTH1(desired_nonSE_recruitment_rate,Avg_time_obtaining_certificate),
(candindate__foreign_doctors/Avg_time_obtaining_certificate))
OUTFLOWS:
enrollment_rate = CONVEYOR OUTFLOW
nonSE_recruitment_rate = (1-policy_switch)*desired_nonSE_recruitment_rate+policy_switch*enrollment_rate
Avg_time_obtaining_certificate = 0.65
desired_nonSE_recruitment_rate = (resident_doctor_goal-(Junior__Doctors+NonSE_Resident__Doctors))/
Time_to__Recruit+smth1(nonSE_resident__doctor_attrition_rate,.25)
patient_doctor_ratio_goal = INIT(patient_doctor_ratio)
resident_doctor_goal = (init(Resident_Doctors_Avg_Hours)/Resident_Doctors_Avg_Hours)*((1-
policy_switch)*init(total_resident_doctors)+policy_switch*Patient__Admissions/patient_doctor_ratio_goal)
time_to__recruit = 0.9

[cost structure not shown in diagram or equations]

Appendix E: Policy Model for Finland (Tadesse 2013)

Equations for Excerpted Portion of Model:



Equations for Excerpted Portion of Model:

Automatic = 0

Automatic__Policy_Switch = If(User_Control=1)then(1)else(0)

Desired_enrollment_rate = smth1(Junior_doctors__adjustment, 1)+smth1(dropout_rate,1)

Desired_Junior_doctors = 4600

Do_nothing = 1

Finland_medical_school_enrollment_data = GRAPH(TIME)

(1990, 525), (1991, 524), (1992, 503), (1993, 379), (1994, 354), (1995, 365), (1996, 367), (1997, 366), (1998, 434), (1999, 558), (2000, 515), (2001, 576), (2002, 610), (2003, 639), (2004, 624), (2005, 627), (2006, 638), (2007, 621), (2008, 616), (2009, 621), (2010, 611)

Junior_doctors_gap = Desired_Junior_doctors-Junior__Doctors

Junior_doctors__adjustment = Percieved_gap_in__Junior_Doctors+Junior_doctors_gap/
Time_to_adjust__Junior_doctors

Maximum__Enrollment_rate = 780

Percieved_gap_in__Junior_Doctors = SMTH1(junior_doctor_attrition_rate,1) +
smth1(non_hospital_appointment__rate_of_Junior_Doctors, 1) +
smth1(junior_doctor_promotion_rate,1)

Policy_start_time = 2010

Potential__Enrollment_Rate = min(Maximum__Enrollment_rate, Desired_enrollment_rate)

SemiAutomatic = 0

Time_to_adjust__Junior_doctors = 6

[cost structure not shown in diagram or equations]