



Norwegian University of
Science and Technology

Serious game of student`s workload planning

Mariya Chirchenkova

Applied Computer Science

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Supervisor: Rune Hjelsvold, IDI

Co-supervisor: Mariusz Nowostawski, IDI

Norwegian University of Science and Technology
Department of Computer Science

Preface

This paper is Master's thesis in IMT at NTNU, that was carried out during autumn semester of 2017. The idea of the project came up after doing Advanced project work on related topic. Prototype of the game that was created in scope of that project had several limitations and there were big field for improvement and development. So the model of the game and interface were improved. Strategies that students use were discovered and discussed. Policies that students can use in their managing workload are proposed.

For those who have background in System dynamics principles it will be easier to understand the work. Despite this assumed background of the readers of this report has no limitations, because all steps of work are described precisely and flow of the report is understandable. Main terms are explained and main milestones are pointed out.

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Acknowledgment

My studying at NTNU was interesting and exiting. Nevertheless during my studies there were a lot of challenges on my way. But this challenges made me stronger in all senses. Here I want to thank people that helped me overcome this challenges.

Firstly, I would like to say big THANK YOU to my supervisors. Both of them helped me to make my work better. Both Rune Hjelsvold and Mariusz Nowostawski provided guidance that I needed for Master's thesis. They inspired me when was struggling, gave me feedbacks and shared their big scientific experience with me.

Also I want to thank all professors and teachers that contributed to my education at NTNU. It was amazing path through research, applied knowledge and real experience.

And of course I want to say "thank you" to my family that supported me and believed in me all the time. They gave me motivation and trust.

M.C.

Abstract

This research focuses on the problem of students workload planning. According to some researchers, students poor performance can be a result of poor course design, as well as a result of poor workload planning.

Thesis begins with introduction to the topic thorough review of solutions proposed by another researches for the workload planning. As a method to solve this issue, we have developed serious game, allowing player to test different strategies and learn from own practice what behavioral patterns lead to good performance, which to bed performance. Initial research was carried in general domain of workload planning. For conceptualization purposes we defined all data relative to student workload planning.

Serious game that was created is System Dynamics based game. Key assumptions of game were: game runs through one study semester, with known rate of new assignments published. In the beginning of each week student has to make a plan, how many hours he will work in a week. Decision is based on time til the end of semester, assignment backlog and other factors. Goal of the game is to complete all tasks within deadline and at descent grade.

As a first step of development, a Casual loop diagram, summarizing problem entities and their relations was presented. Then thesis presents process of developing level and rate diagram, where authors accounted factors like subjective perception, decrease in energy and influence of dissatisfaction with grades. The model was validated using System Dynamics methods and through data collection.

To provide better utility, Online simulation was developed. Simulation is hosted on Forio server and can be accessed via direct URL. In order to ensure learning effect, players can simulate pre-defined strategies and compare outcomes.

In final part I present insights derived from exploration of model structure and behaviour. Those insights contain either patterns of behavior preventing positive result or patterns of behaviour promoting positive result. Hence students can learn, what behavioural patterns they should follow to achieve good result. In case they already selected strategy with expected poor performance- which behavioral patterns they should avoid, to improve their workload skills.

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1 Introduction

1.1 Topic covered by the project

People in different spheres of life tend to overwork during certain period of time. The most common reason for it is desire to meet certain deadlines. Students on bachelor level obliged to deliver various assignments are good example of this trend. Once they understand that they are unable to complete given assignment within the deadline, they try to work extra hours to catch up with the schedule. However such overwork turns out to be not beneficial in long term perspective. Even though many understand disadvantages of overworking, they are still unable to create proper plan, allowing to meet deadlines while having a smooth work progress. The masters project aims to provide some insights for target audience regarding workload planning.

1.2 Problem Formulation

The inspiration for this work came from understanding that most research about Managing student workload was done from the prospective of course design, changing teachers behavior, motivating students more to use time efficiently. There were no research about student perspective of workload and how they can change their behavior to make their work more productive. Forcing students to behave on one or another manner is not working. The most effective way help them work productively is to provide internal understanding of the process and prove validity of results with visual representation.

1.3 Justification, Motivation and Benefits

The thesis is written to provide value to students suffering from incorrect workload planning. One of the inspiration factors for this work was research [1] showing how bad workload planning can decrease students grades. After analysis of problem domain, we provide casual loop diagram for readers to understand key entities of workload planning process. Than we proceed with Rate and flow diagram, that will allow student to test different learning strategies.

Model development was carried out in several iterations, on each the model was validated and tested. Those measures ensured that model corresponds to real world scenarios. In fact, Stock and Flow model that will help to manage student workload can be used not just for student management techniques but also for

many other fields that need project management. If variable names are changed, the model can be treated as universal for many different areas. For example, it can be used in project management in IT or other industry.

In educational industry primary target for the game are students, however other sides of educational process (teachers, course responsible, etc.) might also benefit from it. Students and employees who get insights of proper workload planning can achieve more during shorter time, hence increase their value for organization. Another personal benefit, if follow suggestions on how to plan time, will be avoidance of stress, depression, lack of sleep and wasting time.

1.4 Feasibility study

To begin with, Master Thesis provided valuable experience for me as I summarized and enhanced my knowledge obtained during master studies at NTNU. This project required knowledge of topics from intersection of multiple study areas: Serious Games, Psychology, System Dynamics, Front-end development. Hence it was a great stimulus for revision and summarization of master level courses.

Not least, project have enriched my research and scientific writing skills. I already had experience in developing games based on System Dynamics principles from course Advanced project work. Despite that, I had several difficulties with developing system dynamic model and implementing prototype. After solving those, I improved my skills and knowledge about system dynamics principles even more.

1.5 Research questions

1. How can we apply System Dynamics modeling to develop serious game for workload planning?
2. How can System Dynamic model can be used by students to understand underlying factors that influence time management behaviour?
3. What is the learning outcome from policy analysis? What beneficial and non beneficial strategies can be proposed for students?

1.6 Choice of methods

The practical, e.g. modelling part is implemented with help of System Dynamics. Author had for quite some time interest to gain expertise in this field of study. However real experience was gained during Advanced Project Work course during master studies at NTNU. The attractiveness of System Dynamics for author can be justified by mentioning, that system dynamics is a great conceptualization tool, for problems being viewed on the macro level. Macro level, means that we define finite number of entities and we do not make any difference between members of those entities.

That is in contrast to other imitation modeling techniques, for example in agent based modeling we assume that every single member of entity is different and hence we observe interaction even between members of the same group. Another limitation of system dynamics is an assumption, that time is discrete, however, for our problem formulation it is not a limitation, as we are reviewing the case of student making mid-term plan for his workload.

1.7 Ethical and legal considerations

The scope of my master thesis had no activity that can be considered as illegal. The activities carried out, while writing thesis, did not resulted in any damage or disruption of work of any parties. Nor did I not contradicted any information security policies, as I did not dealt with sensitive information.

Through my work I carried out survey, implying data collection. However it was performed according to ethical rules. Before participation in experiment each person signed informed consent containing all necessary information about study scope and purpose. Collected data was used just to make data analysis and was not distributed in such way that participants may perish. Participation was entirely voluntarily and people were able to terminate their participation at any moment of time without explanation of reasons.

Questionnaire was designed with respect to research ethics, e.g. it does not ask any provocative questions, neither participants can feel embarrassed while doing the experiment. For the purpose of analyzes of experiment results I have not collected any data identifying participant. In my project I used Vensim PLE and Forio Epicenter software tools. Both are free for unlimited period for non-commercial use.

1.8 Contributions

First contribution of Master Thesis is developed serious game for educational purposes. The game aims to help students to manage (better plan) their workload. In order to do this, I created system dynamics model which is the base for the game. After analysis of the problem domain, I defined key entities and relations between factors that influence behavior of the system. As a result, I get Casual loop diagram-summarizing my findings about the system structure. Next, I built Stock and Flow model. This model can be simulated, so that player defines his learning strategy and observes outcome. In order to increase convenience of usage, I developed a web interface and published it online through the Forio Framework.

Second contribution is a set of insights (success factors), described in Chapter 4, related to the workload planning. By utilizing those, student can either choose beneficial learning strategy in beginning of semester, or switch to beneficial strategy

during semester. Beneficial strategy means being able to finish semester with good grades and with smooth and gradual learning process. Accounting the fact that people tend to believe in what they understand, all of insights are explained in detail, including references to model structure and behavioral analysis.

1.9 Outline

Thesis is organized in following way: Chapter 2 describes state-of-the-art of workload problem. Research done in this field and relevant problems are discussed. Chapter 3 provides methodology of my research. Chapter 4 introduces reader into system dynamics model development process and in the end provides web-published model of workload planning. Chapter 5 analyses behavior of model under different learning strategies and gives evidence for utilization of factors leading to beneficial learning strategies. Chapter 6 discusses achievements of the thesis. The conclusion, Chapter 7, contains condensed findings of this thesis, gives conclusion of this work and direction for future work. The bibliography consists of all references I cited in the thesis.

2 Background and related literature

2.1 Problem of workload management

Managing workload is necessary technique for many different areas. A lot of assignments and tasks in higher education institutions are project related demanding self management of their workload. In order to understand it correctly we have to provide definition of the workload. According to [2] "Interpretation of workload essentially equates it to the number of hours worked." For the domain of students life this essentially is a sum of hours spent in class and time outside class spent learning. "Students' workload has been recognized as a major factor in the teaching and learning environment"[3].

Even though students seem to be solely responsible for planning their workload, in reality workload is partly framed by teachers and administration, by planning assignments (release date, complexity level, deadline)[4]. To create a curriculum that will have acceptable workload from student perspective and meanwhile motivate them to achieve good learning outcomes and work hard, many factors should be taken into account. For example:

- Mature course curriculum with proper level of detail. The teacher has to maintain both high level understanding of course scope and enough deep knowledge of course topics.
- Comprehensive mix of theory and practice. Both parts should keep students interested and curious. Students are expected to actively interact with teacher and fellow students, while participating in discussions or doing assignments[5].

Recommendations above concentrate on proper curriculum design and teachers effort. However, workload problem should be viewed from student side also. In paper [6] authors summarized several interesting facts, how students plan and analyze their workload.

Firstly, not all students blame teachers for poor workload planning. They acknowledge that unmanageable quantitative workload is often a result of their procrastination or late start. Many students confirmed that they rarely start doing assignment once it is released, even though they have time available. Students tend to be more deadline oriented, by beginning work as late as possible.

Secondly, proper time allocation turned out to be not the only success factor. Stimulus like stress, motivation and interest were found to play important role.

Depending on circumstances they can speed up or slow down assignment completion [7].

Thirdly, behavior of the lecturer in the class was found to play important role, too. Students gave negative review to teachers reading from the slides, while appreciated those bringing interaction and gamification to the study process [8].

2.2 Time management

"Time management can be defined as the ability of a person to accomplish the desired goals either in the short-term or long-term with the effective allocation of time." [9]

In this work research was done from the student side of workload problem. One of the factors influencing workload planning is time management. Paper [10] looks through the time management strategies that are used for research productivity. Opinion that is widely spread is that "productivity is directly proportional to the time spent completing a deliverable". However, Chase et al. describes another factors influencing productivity [10]. According to this paper we can divide time management strategies into 3 main categories:

- time assessment behaviors
- planning behaviors
- monitoring behaviors

According to their findings, time is one of the most valuable constituent element of studying productivity in academic sphere, however best result can be achieved if combined with other factors. Authors of [11] confirm this: 'Effective studying often requires quite a lot of time and in fairly good-sized chunks.'

Planning behaviors

The strategy of effective scheduling was recognized to have an influence on overall performance. Students have to maintain balanced life strategy which includes both work and rest, allocating enough time for sleep and physical training.

Solely balanced life strategy is not enough. Students have to plan their scope of work realistically. For instance, they need to divide main task into smaller parts and create a time blocks for it. Authors of [12] even say "Careful planning is central to enhancing productivity". The similar opinion state authors of [13], saying that proper time organization pushes student towards success, while poor time organization might challenge student's survival in college.

Often students tend to manage their time poorly even though they have good knowledge of time management practices. Reason is that they follow the idea of not wasting time for planning, rather start working immediately. Disadvantages of this idea are highlighted by authors of [14]:

'It takes time and trouble to get yourself organized for learning. But, in the long run, muddling along takes even more - and the results won't be as satisfying.'

Those students, who do devote time to planning also make mistakes. After studying actual time distribution during the work day, author of [9] comes to conclusion: "The two ways that students mismanage time are by wasting it and by trying to do too much."

Monitoring behaviors

Another valuable factor is periodical analyses of progress and results of time management strategy in use. To facilitate this process, it is advised to use project management software. More specifically, authors of [15] advise to make periodical analysis of Time Spent:

1. Was the goal reached within defined deadline? If no, what factors prevented it? Those factors should be eliminated, when possible.
2. Periodically student have to make evaluation of time management skills and time spent procrastinating. Actual status should be measured and than compared to previous measures, to see if there is any progress.

Project management software can facilitate process by creating timetables for upcoming week. Based on input software will write time blocks and do preliminary analyses of historical performance.

In process of learning time-management techniques students can explore and identify their own time-management skills while learning new. They are gaining experience how complicated can be estimation of time of some part of the work. And we can proof or not statement about if using time-management skills can make studying process more effective.

Improper time management behavior is usually defined as one of the reason for bad academic marks [16]. Such behavior include putting everything until deadline or not correct distribution of time. The situation when student feel frustration about time and feeling they are not able to finish tasks normally on time is very common. Authors claim that time management strategies and ability to use them is way how to manage study successfully. Moreover receiving bad grades can be caused by lack of time management techniques.

So time management is possibility to finish tasks with required quality within required period of time. Results prove value of time management related to academic grades. Because of this, great effort should be put in order to make better students planning abilities [17].

Accounting arguments presented above, it would be beneficial for students to get to know more about time management and its advantages. Providing solely theoretical study might result in a moderate effect, while allowing hands on expe-

rience, for example serious game to test time management strategies should boost students planning skills.

2.3 Types of System Dynamics models

To reflect necessity of allowing students to have practical experience with time management decisions, I opted to develop a serious game based on System Dynamics (arguments for this were presented in section 1.6). To facilitate readers understanding of method used, I provide short introduction to System Dynamics below.

There are 2 types of system dynamics diagrams: causal loop (qualitative) and Level and rate (quantitative). Qualitative models are very good for conceptual understanding. Consider the simple model on Figure 1. It describes generic situation of subject performing some action influencing system in order to achieve desired outcome. However based on the extent to which system status changes, there is system reaction, which either tries to mitigate or reinforce system change.

On Figure 1 There are 3 variables connected by feedback arrows. When arrow-head points at variable, it means that this variable is dependent on the variable, where arrow originates. For example feedback arrow going from action to outcome shows that value of outcome is changed whenever value of action is changed. If set of arrows form a loop, it is called feedback loop. On Figure 1 we have two feedback loops. Based on the nature of process going in the feedback loop, we assign it a name. As in our example: intended consequence and unintended consequence.

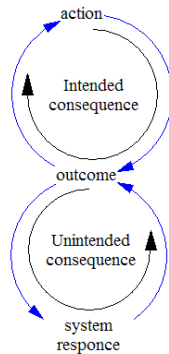


Figure 1: Causal loop diagram

Causal loop diagrams provide good understanding of insights, however, they have several limitations. To begin with, they can not be perfect by definition, the reason for this is that model is always a simplified version of real world objects. Modelers work on improving causal diagrams, to make it more precise and conse-

quently show results that are closer to reality. For example, adding more details to some causal loops can provide higher level of reliability.

Causal diagram cannot derive numerical result. For this purpose modelers develop so-called stock and flow diagrams, that again provide simplification of reality, but with some quantitative characteristics[18]. Models of this kind combine power of system architects, who identified model components, together with computational power of PCs, capable of running this model over certain time horizon with preset initial values.

Refer to the simple model on Figure 2. In rate and level models there are 3 types of variables: level, rate and auxiliary variables. Variable Assignment Backlog is a level variable and Assignment completion is a rate variable. Level variables have memory, e.g. can accumulate material and can be changed only through rate variables. Auxiliary variables are those standing for more structural formulation of relations between levels and rates.

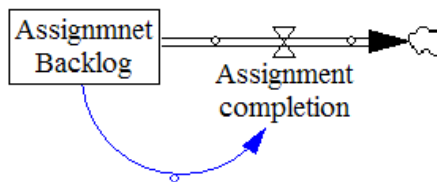


Figure 2: Rate and Level diagram

Behind each variable there is an equation, defining numerical relation between dependant variables. Whole system than can be represented as a system of equations. Once input parameters are provided, numerical result can be derived at the output. In other words, model can be simulated.

If model was built correctly, runs (e.g. simulations) will enable deeper and more rigorous understanding of real world system in focus. The essence of model will be presented in Chapter 4.

2.4 System Dynamics applied to serious games

Paper [19] considers complex approach of system dynamics principles for serious game creation. They highlight, that System dynamics game provides descent level of entertainment, while maintaining educational focus. "Most of the SD based games are decision making games in which players take on the role of a decision maker"[19]. In order to create effective serious game it has to meet several requirements. First is goal achievement and second is enjoyment from playing [7]:

1. **Achieving goals of the game.** Players have to change their way of thinking after playing game. They have to learn something new from the game and make relevant conclusions for themselves. Clarifying goals that should be achieved is important task of game creator. If players cannot stop play game because they just like the process of gaming and don't make any inferences game is not achieving target.
2. **Providing enjoyment.** Humor, social interaction and other factors that have influence on amount of enjoyment from the game should be taken into account in the process of creation serious game.

Consider one of the methods of developing serious game on Figure 3. After the problem of interest is defined, first step is to carry out case study. "A case study is an intensive analysis of an individual unit (as a person or community) stressing developmental factors in relation to environment" [20]. This definition implies that by default no interaction is expected during reviewing the problem.

However in order to decrease cognitive load, while studying the case, we need to visualize information, i.e. bring in interaction (simulation). Simulation is "the imitative representation of the functioning of one system or process by means of the functioning of another" according to [21].

However displaying results in a nice manner is not enough. To boost learning effect, it is necessary to ensure that reader is involved and willing to explore. Suitable method is gamification. Even though simulations pretend to reflect real-world scenarios, they can contain several game features that will actually add extra value to the system and not present in real world.

This approach is presented on Figure 3. Intersections of domains show what result can developers get. Authors [22] claim that this is conceptual representation and in practice, boundaries can be different. In this thesis I developed game from intersection of all 3 domains: serious game implemented by system dynamics simulation based on data available from case study (In further sections I will refer to this as game)

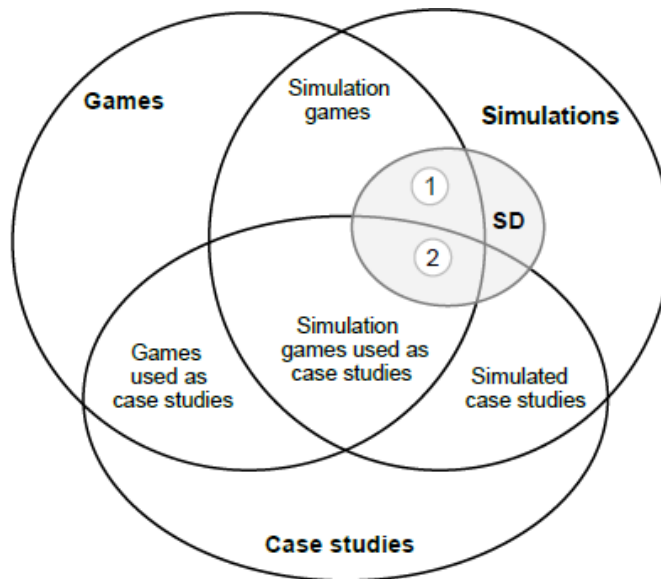


Figure 3: Games, (SD) simulations and case studies

2.5 Approaches to conveying insights/learning

In this chapter I will investigate, how to develop a game with high utility. To ensure desired learning effect, developer of the game should take into consideration factors below:

- defined what insights players are supposed to understand
- account player's knowledge of system dynamics and any related system thinking skills
- what activities will lead to desired insights and what will contrary distract from them

The game should display only proper parts of conceptual framework, reference behavior and causal loop diagram, while hiding the others.

Game developers and designers have to take into account the fact about prior experience of System Dynamics and make proper choices about parts of the game that will be accessible by the user. It is bad decision in some cases to display underlying system to the game players. Developer of the game should account player's knowledge, before deciding to display complete level and rate diagram. Sometimes logic is not clear for inexperienced player and overwhelming them with technical information increases their cognitive load and distracts from desired learning effect.

On the other hand, sometimes level and rate diagrams are not too comprehensive. In those cases developer might decide that desired learning effect should be achieved through elaboration of existing system, e.g. adding new structure. Than only observation of behaviour is insufficient and players should be presented complete model, either gradually, or at once. Moreover, they might be given more input controls to influence model behaviour.

Two approaches presented above are extreme cases, allowing only two possibilities. However, there is a lot more in between. Not only the content of the game, but also the sequence of activities matters. Members of SD community have a lot of discussions on this matter, started as early as sufficient instruments for game development came to market. The goal of developers in favour of presenting complete rate and level diagrams is to simplify learning process, i.e. decrease cognitive load. Contrary developers in favour of hiding rate and level diagrams work on ways to achieve sufficient cognitive effort to replicate the essential features of modelling.

Learning by exploring Rate and Flow model

Basic game flow, when player gets possibility to discover complete diagram is similar to the discovery learning literature:

- Create hypotheses
- Develop an experiment to test them
- Observe experiment outcomes and compare them against hypotheses
- Analyse the reason for difference between outcome and hypotheses; adjust hypotheses

This process is supposed to go in a cycle, as shown on Figure 4. Players are expected to do multiple rounds, as after each round they will have to adjust their hypotheses, in other words change their understanding of the system. Primary sources for such analysis will be: actual outcome of experiment, investigation of rate and flow model, any textual description of model behaviour provided.

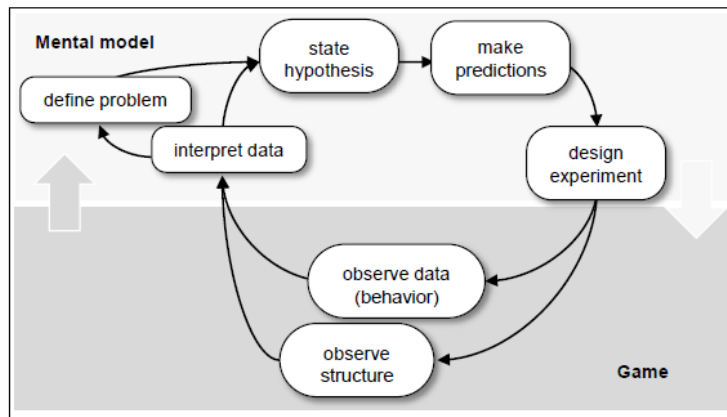


Figure 4: The process of discovering insights with a SD-based game [19]

Game developer will give hints to frame the learning process: firstly to make player understand the model structure and behaviour and then make player design experiment, after analysis of which they will get desired learning outcomes.

Learning by playing predefined strategies

Games developed according to this principle typically begin with textual introduction followed by choice of decisions and observation of results. In the end players can analyze their results and compare them to the reference behaviour. This process is displayed on Figure 5.

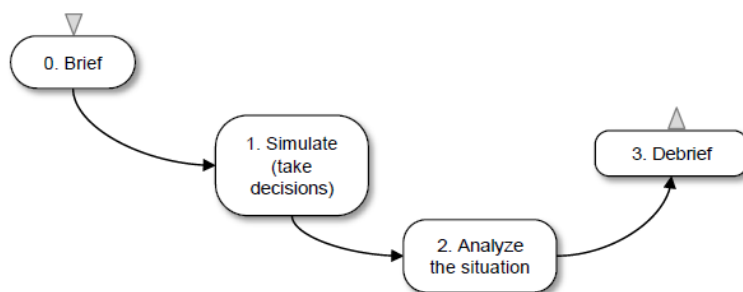


Figure 5: Simple one round simulator-based games

However disadvantage is that games of that kind do not allow to test custom insights. This means what ever ideas player gets during interaction with the game will remain as hypotheses, unless they are included in basic strategy. To remove this disadvantage, games have to be constructed as a cyclic process, where after

each cycle player adjusts assumptions about the model behaviour. Resulting game flow is shown on Figure 6.

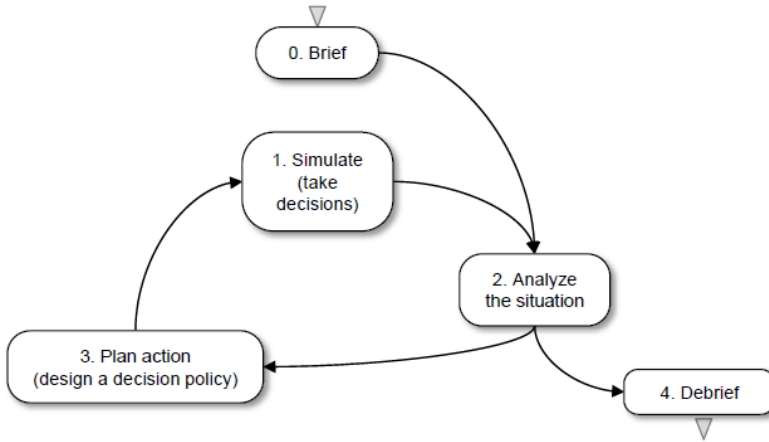


Figure 6: Analysis-driven process for simulator-based games

Consider how player starts the interaction with simulation on Figure 6. Right from the start player gets into theoretical explanations and analysis of reference behaviour. According to authors of [19] this can bore player and destruct them from proper learning goals. Possible way to avoid that is to allow player firstly take one trial round of playing and only after provide explanations and deeper analysis. Of course simple rules how to interact with a game will be explained beforehand on the Briefing stage. Game flow is shown on Figure 7.

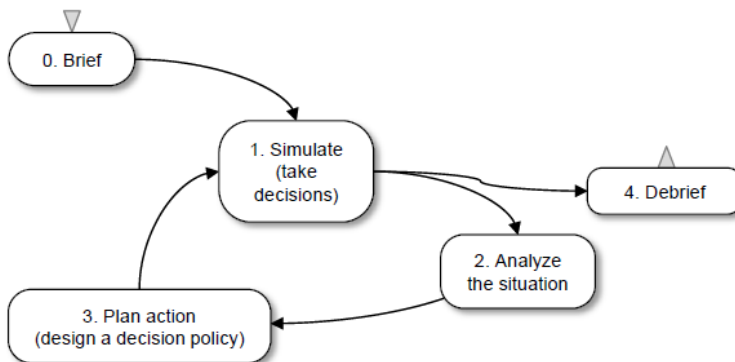


Figure 7: Trial-driven process

2.6 System dynamics based games

In this section I will provide review of existing System dynamics based games, so that reader will get understanding of possibilities and profile of this type of serious games.

2.6.1 New Product Development online simulation

Authors of [23] developed a simulation for a classical problem: how to finish project on time and within budget. Project is split into two sequential sub-projects, each quantified as a number of tasks to be done. As there might be delays, after the end of second sub-project there is a “slack”- time that can be used for project work if needed. Primary goal for player is to finish project on time and within budget, secondary goal-to use as little of slack time as possible.

Comprehensive description of model is provided in paper [24]. Tasks are completed by employees with initial rate 1 tasks/person/week. Completion rate is based on productivity of employees, viewed as a direct cause of team experience, and error rate.

Having a Slack allows project manager to manipulate the deadlines for the sub-projects. In fact employee's workload depends on the sub-project deadline, rather than on backlog of tasks or project time-line. If the project is expected to be finished on time, but sub-project deadline is not possible to meet, certain negative factors arise:

- Effect of errors. Employees start to complete tasks with errors. Errors are discovered by QA team members. This introduces more time delay and utilization of more workforce.
- Overwork. If staff starts to overwork, task completion rate decreases. Moreover exhaustion increases, which is a cause of employees leaving the company.

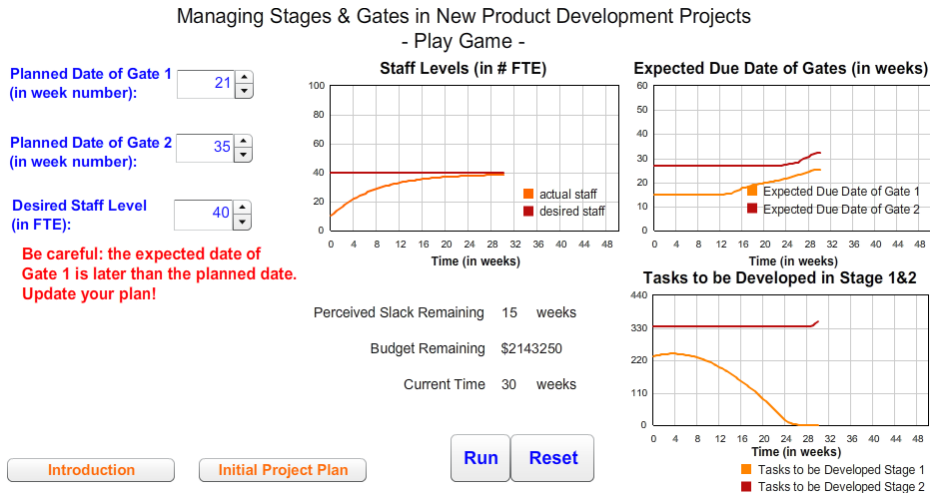


Figure 8: New Product Development online simulation

If manager decides, that it is not possible to finish project on time- they can hire more employees within allocated budget. Accounting real world scenario, new employees get hired not simultaneously, rather gradually through certain period. Once employee is enrolled- they possess low level of experience. This, however, increases while tasks are completed.

Simulation delivers a high educational value, due to utilization of concepts described above. Interface of simulation is presented on Figure 8. Dashboard has simple design with integrated control Panel. While playing the game, reader gets warnings, if he is approaching limits of resources.

2.6.2 Battle Burnout online simulation

Simulation model developed by [25] shows to the reader problem of overworking. Overworking, according to model assumption, means taking extra assignments, without getting deadline extension. As a measure of negative influence model uses entities like "Level of stress" and "Productivity". Reference behavior of the model is quite evident: once Workload increases, Level of stress increases and Productivity decreases. However, authors of model went further into exploring the problem and introduced factor of vacation.

From prototype approbation authors realized, that even with constant workload, after several month productivity decreases. Therefore to achieve initial level of productivity one needs to take a vacation. During vacation stress is decreased with constant speed, at the same time productivity increases. Extent to which those values change is based on duration of vacation. Another valuable assumption au-

thors utilize is that after vacation employee is a subject to short-term increase in stress. Possible psychological reason behind can be that employee can not immediately start working at full productivity after vacation.

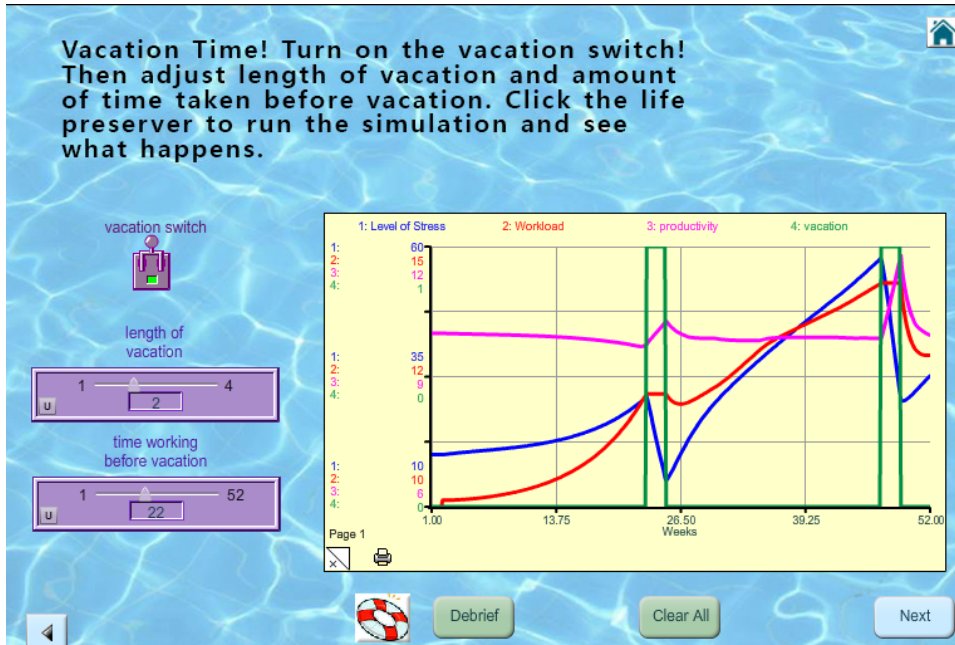


Figure 9: Battle Burnout online simulation

Simulation is designed in a user-friendly way. In order to avoid long theoretical explanations, developers opted to give introduction by asking user to play simple demo games, before interacting with main game.

Disadvantage of developed web simulation is that authors do not give possibility to explore system dynamics model (casual loop or stock and flow version). Some readers might have got better insights for understanding behavioral patterns, if they see the model.

Another disadvantage is that authors offer no policy analysis, after reader tested various strategies. Even though model gives conceptual idea of importance of taking regular vacations, some readers might have benefited from deriving more particular behavioral patterns, e.g.: what is the optimal length of vacation and what is the maximum duration of work without vacation. Partial policy analysis is not possible due to not clarifying all initial assumptions: how is workload measured and what is the rate of incoming tasks, what is the equation for productivity, is it

possible to complete tasks with different quality level, etc. Dashboard of internet simulation is presented on Figure 9.

2.7 System dynamics applied to project management

In this section I explore known principles of project management, that can be applied to student workload game.

Project management is one of the fields where system dynamics methods are useful and applicable. System dynamics has high value for this area because of improved model structures, value to the users and amount of applications [26]. One of the biggest advantages of application of system dynamics in this scope is possibility to simulate and built close to real project dynamics and connect to the experience of projects managers.

Tasks for developers usually begin in the scope-"To Do" and with flow of work that is done by developers on the project tasks are moving to the accomplishment of the project. Project managers aim is to finish on time, withing required budget and according to standards. Building monitoring feedback loops possibility in system dynamics displays perfectly how managers realizing their goal of dropping distance between project quality and targets.

One of the most important features of system dynamics models for project management that we can use in managing student workload is deadline [7]. Process of monitoring to meet a deadline is widely used in project management systems. There are 3 possible solutions to the problem of missing deadline. First is adding extra workforce- hiring more professionals to the project. Second is work overtime-adding extra working hours. And third is work faster. In case of student workload hiring more people is not applicable rule but two others are possible to use.

Knock-on effects are another issue in system dynamics models for project management. "Hopelessness" mental issues can escalate the consequences- tiredness and overwork possibly create state of "hopelessness". This fact can cause enlargement of number of errors and decrease in productivity. In scope of academic research and industry applications system dynamic was found useful tool for project management field. Another finding was that combining system dynamics with other more traditional methods can provide effective use of it. Strategic and tactical sides of system dynamic science will be able to add weight to traditional project management tools [27].

In order to answer the question if we need or not computer modelling in project management area we can make analysis of advantages and disadvantages of formal models compared to mental models. Mental models are versatile. The data that they can proceed can be in different forms. They can be easily adjusted to new requirement and modified. On the other hand people usually don't put enough

effort to make a deep analysis or investigate their own mental models. Some of the disadvantages of the mental models can be solved by computer models. So computer models have next advantages compared to mental models:

- They are constructed in clear and detailed manner
- Capable of accounting vast number of factors
- Input conditions and simulation process happen in controlled environment, to ensure single version of output

The important factor which influences quality of system dynamics models is validity of the simulation model. The possibility of the model to restore previous system behaviour is one requirement that need to be passed by the model. This requirement is called historical fit. There are some extra tests that are suggested by system dynamics researchers. These checking measures based mostly on stability of the system on behalf of policy requirements, stability of the model behaviour and compliance of the model to the real system. The validation phase is going as side to side testing of assumptions of the model.

Earlier, formal modelling tools were too complicated and understanding of them required special knowledge. Project managers didn't participated in the process of development of the models, but they were main users of the system on later stages. It was always a question of balance between too simple and too complicated models. When system was build in too complex way they compared it with black box system where details were hidden. And opposite situation happened when model was simplified. Model didn't display and didn't take into account important relationships of real system. To resolve this problem, experts should involve more project managers into process of creation a model and make this process interactive. Such modeling behaviour is called "Management Flight Simulators". They widely popular among professionals of all levels as effective tool for educational purposes.

2.8 Casual loop diagram

There is already a causal loop diagram for problem of student workload presented in [28]. Hence in this chapter we explain structure of causal loop diagram, which afterwards will be the basis for construction of rate and flow diagram.

In [28] authors presented complex causal loop diagram, which has both, focus on student performance, and on correct planning of course curriculum. As goal of the master thesis is to develop serious game for students, I opted to simplify feedback loops focusing on course planning by teachers, while make more granulate design of feedback processes in student workload planning.

On Figure 10 I present the casual loop model. It corresponds to original model,

however, I introduced several changes discussed later in this section. Consider the process of student completing assignments: there is some Backlog of assignments, which is increased by new assignments made available and decreased by assignments being completed by the student. Arrow from Work completion to Assignment Backlog has negative polarity meaning that whenever Work completion increases, Assignment Backlog decreases and vice versa. Contrary arrow between Assignment rate and Assignment Backlog has positive polarity, meaning that whenever Assignment rate increases, Assignment Backlog also increases and vice versa. Based on the size of Backlog student experiences pressure (denoted by arrow with positive polarity) and hence allocates more time to work on assignments. If more time is allocated, more work completion happens. Arrow with positive polarity between Workweek and Work completion describes this.

Now we have a closed feedback loop. It has balancing nature, meaning the more intervention we put on the system, the stronger will be system's resilience to change state. This feedback loop describes process of assignment completion. However if student gets too much tasks in the Backlog, he will decrease the backlog by allocating more time, probably working during night hours. To highlight this behaviour we call the loop "Midnight Oil".

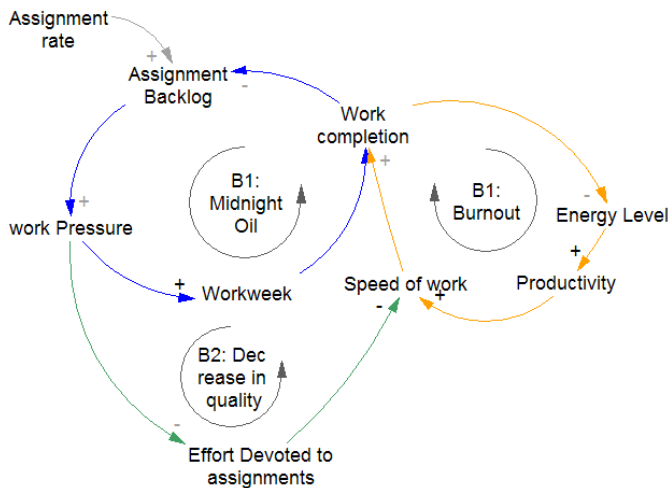


Figure 10: Casual loop diagram of student Workload

Consider another balancing feedback loop "Decrease in quality". As a measure to decrease workload, student might decide to put less effort in completion of assignments, in other words deliver assignments of worse quality due to time constraints. This process is direct cause of work Pressure and if quality decreases, overall Speed

of work increases (denoted by arrow with negative polarity). This loop I formulated in a different way compared to [28]. Reason is that according to Bowyer [29] students make decision to submit work of lower quality under the pressure of too many tasks in backlog.

Last feedback loop displayed is Balancing loop presenting effect of student becoming too tired to work productively. This is described by arrow with negative polarity from Work completion to Energy Level. The lower is the productivity, the slower student will work, and in the end, less tasks will be completed. Compared to original model, cause for decrease in Energy Level is Work completion, not the Workweek. Reason for this change is that according to Bowyer [29] students fail to objectively estimate their accumulated tiredness, hence they overestimate number of tasks that can be completed during a week. In other words, model has to rely on actual workweek, embedded in Work completion, rather than on planned workweek.

Now, we presented basic model enough for conceptual understanding. Note that model consists of 3 balancing loop, which means that any increase in scope of action made to change system state will receive immediate system counter action. Hence for best result, work completion should be carried out in smooth manner.

3 Methodology

In this chapter I define all the task completed during work on the Thesis. For each task I specify methodology used and accomplished result. My Master Thesis comprises both theoretical and practical parts.

3.1 State of the art analysis

During theoretical part, described in Chapter 2, I gathered all relevant data in scientific publications to build a Workload model. More specifically, I searched for quantitative data describing student's studying process and formal models describing similar problems. Formal models provided me conceptual understanding, so that I was able to argue for Casual loop diagram, while quantitative data comes in hand when developing level and rate diagram.

3.2 Development of casual loop diagram

Serious game that was created is System Dynamics based game. I argue for choice of System Dynamics in Section 1.6

There are 2 types of system dynamics diagrams: Casual loop (qualitative) and Rate and Level (quantitative). For our model casual diagram was developed (see section 3.1). Having it in place allows to conceptualize the problem. In other words I, as a developer, am able to understand what are core entities and what should be left outside system boundary. However, the causal diagram has several limitations. Casual diagrams cannot be perfect by definition, the reason for this is that result of modeling is always simpler version than real world objects. On the other hand, adding more details to some loops provided higher level of reliability.

3.3 Level and rate diagram

Casual diagram doesn't differentiate levels and rates. The next logical step was to build Level and Rate Diagram.

"Quantitative system dynamics brings together the best combination of both people and their creative thinking ability and computers and their data manipulation ability. Computer simulation modeling adds significant value to qualitative mapping by enabling deeper and more rigorous analysis." [30]

This quote nicely explains the main advantage of applying quantitative modeling-getting possibility to observe particular result (e.g. values of model variables) at any time of simulation. In section 3.2 I developed level and rate diagram based on

casual loop diagram and quantitative data available. As it requires more detail, I referred again to Chapter 2 to justify some inter-dependencies.

Once model is developed, a lot of effort should be put into validation (process of verifying that model behavior does not contradict any basic physical laws). Example of model not passing validation is having negative stock of assignment backlog. Model validation was done in Section 4.1.

3.4 Online model

Vensim is a great tool for building desktop models [31]. However it is not convenient to share desktop models for industrial or academical purposes. Hence we need a tool allowing running system dynamics models online. I used Forio Epicenter [32], to create GUI, e.g. display outputs and controls of the model. Ready online model I hosted on Forio Epicenter server, so that it can be accessed via URL[28].

3.5 Questionnaire

Another important step is model testing, where modeler ensures that model provides correct output, when put in a real world conditions. I opted for allowing fellow students to interact with the model and to gather their comments via questionnaire. It helped me to adjust model parameters, where not enough qualitative data from previous research work was available.

As a result I get mature system dynamics game, able to deliver reliable result, while remaining on proper abstraction level.

Another goal of having questionnaire was to ensure that model indeed provides educational effect on the players. By asking specific questions, we attracted attention of players to the main learning insights.

3.6 Model analysis

However, not all learning insights can be understood from playing with simulation. Similar to difference between black-box and white-box testing, analyzing the full rate and flow model brings more information, compared to interaction with simulation. In Section 4.4 I derived learning outcomes of the model. Questions in focus were:

- What patterns of behavior lead to good student performance
- If semester is already progressing with poor performance, what can be done to improve performance

4 The model

4.1 Stock and flow model

In this section I will step by step build the stock and flow model according to assumptions presented in Chapter 2.

4.1.1 Benefits qualitative models in SD

Benefit of stock and flow model compared to casual loop diagram is that model can be simulated, e.g. for defined input model provides respective output. By output I mean model state- values for all of the model variables after end of simulation. The simulation happens as discrete process with predefined time step. By specifying initial and final time, developers of model define, how many time steps model will go through before it produces the output.

Analysis of final model state might be too comprehensive (and distracting), so developers tend to show output for limited number of variables. If it is interesting to know final value of variable than it is shown as a single numerical value, else in some cases, it is interesting to know all values of variable at different time steps, to understand the dynamics. Outputs of later once than are displayed as graph.

While casual loop diagrams provide conceptual understanding of problem in focus, stock and flow models allow readers to interact with the system. Once problem is understood, and reader is familiar with core entities, they can make various assumptions, how to achieve better result. Those assumptions are translated into values of model variables and provided as an input to stock and flow model. For each assumption model provides output, which can be analyzed and compared with reference simulation. If reason for result is not clear, reader can analyze change of core model parameters at various time steps.

In this thesis to perform system dynamics modeling I used Vensim PLE software, which is free for educational purposes. Free version allows to build system dynamics models, to simulate them and to prepare them for integration with GUI.

4.1.2 Domain of assignments

In order for the reader to be able to follow development process, as if they build the model themselves, I will introduce the model as a set of blocks (domains). This approach is different from the way we built casual loop diagram: there we introduced variables consequently by following the loop flow. Reason for another approach is that on stock and flow diagram there are a lot of auxiliary connections between

variables- impossible to follow the order. When utilizing domain introduction approach, each set represents logical part of the problem in focus. Once all domains are described, I will connect them and present complete model.

The core of the model is the life cycle of assignment. According to model definition there is some backlog of task for the student. As student completes task it is counted as an accomplished task. Hence there should be variables Assignment Backlog and Assignments completed in the model. Those two variables are connected by process of completion-hence we need another variable Work completion.

Another essential assumption is that student does not get all of the assignments immediately after start of semester. Rather there is some study plan, scheduling when each assignment is published. Gradual introduction of assignments through semester helps students to better manage time. To reflect this process I created variable Assignment rate. I represent this assumption on Figure 11.

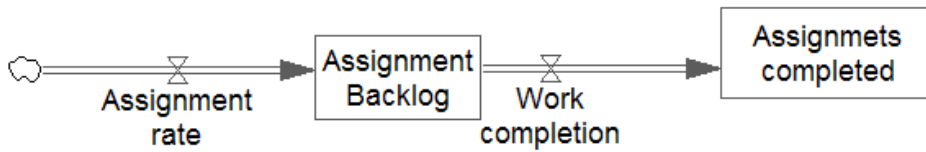


Figure 11: Domain of assignments

In Vensim there are different types of variables. Variables Assignment Backlog and Assignments completed are shown inside rectangle, while Work completion is shown under an arrow. Variables shown in rectangle- are level variables. This means those variables have possibility to accumulate units. Level variables can not be changed immediately, rather they can be changed gradually by their inflows and outflows- rate variables. Example from the real life: water in the bath is level, while speed of water outflow through pipe is a rate.

In domain of assignments Assignment Backlog and Assignment Completed are levels, accumulating assignments, while work completion and Assignment rate are rates changing respective levels. Note a cloud on the left side of diagram. To follow the real world scenario, there should be a level, representing all assignments to be published during semester. However in our model we do not plan to analyze assignments, not yet published - hence we denote this variable by cloud to show that it is located outside system boundary. More types of variables I will introduce on later stages of model development.

4.1.3 Domain of grades

As assignments are delivered, they are graded. In other words, each assignment receives a grade (using 0..100 scale). Grading process is denoted by variable *Grades received* on Figure 12. In order to understand how successful the student was during semester, we introduce the variable *avg grades*. According to the name it should equal sum of all grades divided by completed assignments. To calculate sum of all grades we introduce level variable *Grades* which will be increased by every new grade received (denoted by inflow rate *Grades received*).

Students might not pass all assignments, so in average grade should be decreased by non-delivered assignments. To reflect this, I introduce variable *avg grades including F*.

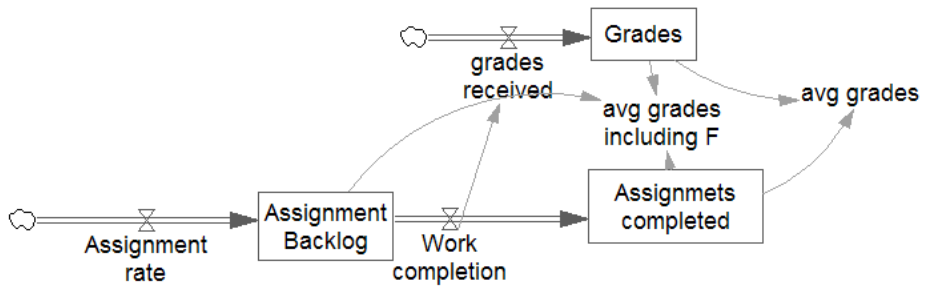


Figure 12: Domain of grades

4.1.4 Formulating equations for variables

The model developed so far on Figure 12 has variables which are rates, levels and auxiliary type variables (for example *avg grades*). Each variable picture on model is a function (equation) with multiple input parameters and single output. Input parameters are values of those variables, which are connected with variable in focus by arrow, with arrowhead in direction of variable. Then value of output will be input for next variable connected by arrow with current. The list of all model's equations will be presented in Appendix B, while in main text I will illustrate only some of those, to give idea of basic concept utilized.

Level equations

As described in [33] the level variable can be changed only by rate variables. Once I connect level and rate variables, Vensim assigns basic equation to the rate, according to next rule: current value of level differs from value of level at next time step by net rate. Net rate is the sum of all inflow rates, subtracted all outflow rates.

For example in my model Vensim automatically generated following equation:

$$\text{Assignment Backlog} = \int (-\text{Assignment rate} + \text{Work completion}) dt$$

However one more thing that needs to be specified is the value of level at the start of simulation. Assignments are usually published after some theoretical material was presented during lectures. Hence, if we do not account resits for previous semester, student will begin semester with empty Assignment Backlog:

$$\text{INITIAL}(\text{Assignment Backlog}) = 0$$

Rate equations

4.1.5 Domain of work pressure

When thinking how much time to invest into studying upcoming week, student would usually consider how many task he has in the backlog, how long it is till the end of semester and how many new assignments he will get. Of course, speed of *work completion* is also important, as when one considers time available, they assume that they will continue to work in the same tempo as currently.

Above mentioned factors can be accounted in variable *Not enough time*. Based on the extent of how big is ratio between remaining work and available time, student will experience *work Pressure*.

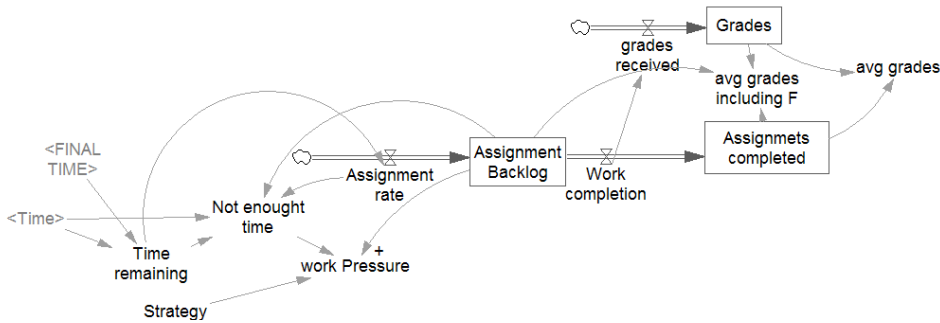


Figure 13: Domain of work pressure

There is also a human factor, needed to be taken into account. According to [34] failing to account delay in human perception leads to big inaccuracy in system dynamics models. For the problem in focus, this means that even though there might not be enough time to complete tasks, some of the students might be reluctant to acknowledge the problem. They will typically have some time delay in perception and/or trend to underestimate the amount of work to be done. To account subjec-

tive perception and to allow students with different learning techniques to interact with model, we introduce variable *Strategy*.

4.1.6 Domain of time allocation

As a result of pressure student experiences (variable *Work Pressure*), they will make a plan of how much time to allocate to studying during next time step (i.e. next week). However, there is an upper margin of time available for allocation: student has to sleep, eat, etc. Approach suggested in system dynamics is to introduce a constant variable and then to formulate equation as constant multiplied by coefficient (from 0..1). Following this approach, we define *Max Workweek* and formulate *Planned Workweek* as:

$$\text{Planned Workweek} = \text{Max Workweek} * \text{work Pressure}$$

Now consider the nature of *Work completion* : work is being done over certain period of time with some *Speed of work* (e.g. number of tasks done per hour). Essentially *Work completion* will equal multiplication of mentioned parameters. This formulation might seem to be confusing as *Work completion* is a rate, meaning it is some value divided by time unit Week and *Speed of work* is also a parameter divided by another time unit (Hour). However measuring Planned Workweek in Hours per Week makes this formulation essential.

One common pitfall in System Dynamics is decreasing a level to negative value. In real life *Assignment Backlog* will always be non-negative. Hence I have to formulate outflow rate equation in a way that level does not get negative. Idea from software development would be to implement *IF THEN ELSE* statement. However in author of [18] argues against this, saying that it brings unnecessary discontinuous processes in the model. What is rather suggested is to use *MIN*, *MAX* functions.

Variable *Max completion* is the maximum possible value of outflow allowed at current time step, so that level stays non-negative. Than Work completion can be defined as:

$$\begin{aligned} \text{Work Completion} &= \\ &= \text{MIN}(\text{Speed of Work} * \text{Planned Workweek}, \text{Max Completion}) \end{aligned}$$

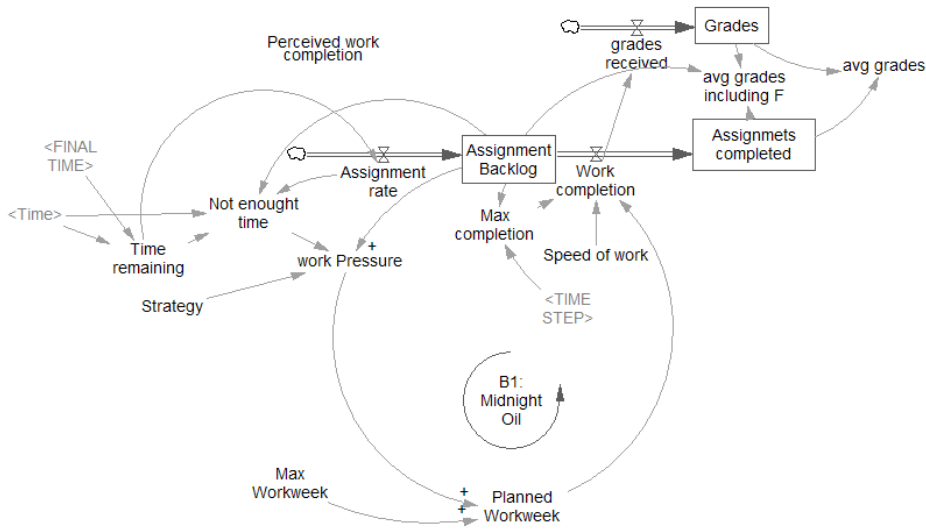


Figure 14: Domain of time allocation

Resulting model is provided on Figure 14.

4.1.7 Domain of applied Effort

When the *Work Pressure* increases, not only student tend to allocate more time to studying, but they are also likely to put less effort in completion of assignments. While running against deadlines, students tend to deliver assignments of poor quality aiming for moderate mark, while still trying to deliver high quality assignment and eventually not delivering it due to time constraints [8].

Refer to the Figure 15. Students have ambitions and hence have in mind some level of *Desired Grades* . If *Work Pressure* increases student will likely aim for lower grade, hence put less *Effort devoted to the assignment*.

Now, consider nature of *Speed of Work*: number of assignments completed per hour. Essentially the less effort one devotes, the more assignments they are able to complete. However as shown in preceding chapters student is not likely to stay always at maximum productivity level. Various factors can influence (decrease) *Productivity* and subsequently decreasing *Speed of Work*.

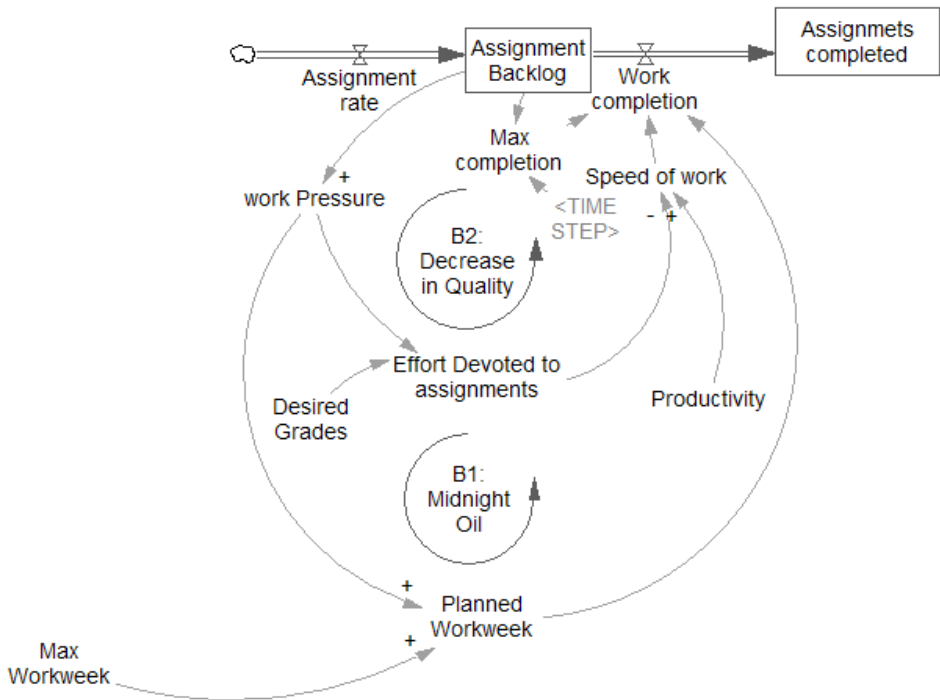


Figure 15: Domain of applied Effort

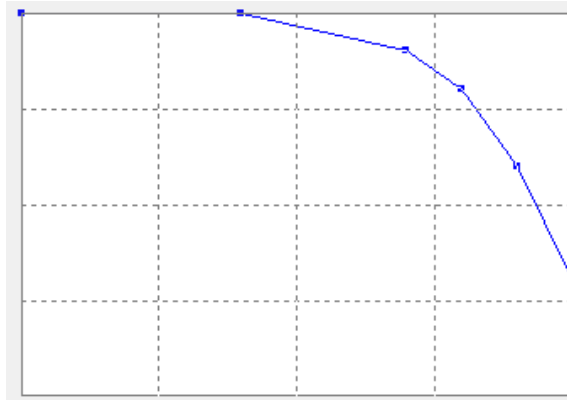


Figure 17: Energy level

As shown above, level of energy depends on how tired the person is. Hence there should be some correlation between time spent working (denoted by variable *Actual workweek*) and decrease in energy level. First assumption is that energy decrease does not happen immediately after overworking, rather it happens with some delay [36]. To reflect this we introduce variable *Energy erosion*. Decrease of *Productivity* will be direct cause of *Energy erosion*.

Second Challenge is that *Energy erosion* is a dimensionless variable, while *Actual workweek* is measured in Hours/Week. In this scenario it is not possible to have a direct relation between variables: mathematical equation will be inconsistent. Similar situations can be solved by utilization of so-called look-up functions. Those functions that are defined not by equation, but rather by set of input,output pairs. In the beginning, I indicate known pairs of input, output values and then function is extrapolated for the all possible values of inputs. To ensure correct operation, look up functions have to satisfy certain requirements:

- **Normalized** . All possible values of input and output should be in interval [0..1]
- **Dimensionless** input and output

To satisfy requirement of having dimensionless input, I formulate *Energy erosion* as a quotient:

$$\text{Energy erosion} = \text{DELAY FIXED}(\text{Actual workweek}/\text{Max Workweek}, 1, 0.4)$$

By utilizing quotient of *Actual workweek/Max Workweek*, I also ensure that input is normalized.

Dimensionless and normalized output will be provided by default, however *Productivity* should represent non-normalized value. To manage this, I formulate *Pro-*

ductivity:

$$\text{Productivity} = \text{Energy lever} * \text{Max Productivity}$$

Next step is to actually formulate the known pairs of input, output. Consider the essence of Productivity: it stays high while student works usual number of hours, but that drops when student starts to overwork. In other words, until workweek duration is not greater than 0.4 (equal to 40 Hours of work/week), productivity should be maximal. As shown on Figure 17 we can define two pairs already: (0,1) and (0.4,1). Considering minimum productivity, it can decrease down to 0,3 of maximum productivity according to [37]. Hence we can define another pair of values: (1,0.3)

In the interval of input values 0,4..1 we expect to have variable output, that will be constantly decreasing. General assumption is that in the beginning decrease in output will be small related to decrease in input, which gives us hint to U-shape of function. According to the model formulation, assignments published are challenging, requiring concentration and application of theoretical material learned. In other words, student can not do them automatically, without putting enough effort. This reasoning gives evidence that S shape function, where on the high values of input output varies only slightly, is not applicable to our situation.

Based on data collection, carried out as a part of this project, I found 3 more pairs, that help me to define U-shape decrease in productivity: (0.7,0.9), (0.8, 0.8), (0.9, 0.6), (1, 0.3).

to create GUI, e.g. display outputs and controls of the model [31].

Forio comprises functionality to develop GUI and subsequently publish model online on the Forio hosting. Another helpful feature of Forio Epicenter: contrary to Vensim PLE it allows to run model for each timestep, with possibility to change decisions, based on outputs of previous step. This way interaction with model happens as a game, where student should repeat cycle of Do-Check-Act. Forio Epicenter have build in interfaces to transfer data between Vensim and GUI. Initial setup can be made through interface builder, while more granulate adjustments are made through RestAPI and Flow.js

Short guide to publishing model in Forio

Forio is quite fresh online service on the market and upgrades are pushed constantly. However, due to limited audience of users and rapid development of imitation modeling field, it does not posses comprehensive documentation. Once model is developed and simulated in Vensim, it can be published in Forio Epicenter. To do so, one needs to follow steps below:

1. All variables that are to be used as input parameters have to be assigned *GAME()* function.
2. Save Vensim model with *.vmf* file extension
3. Create a new project in Forio and upload desktop model.
4. Select type of GUI: *Run comparison*- every time model is simulated without breaks till final time. This implies that most educational value is derived from comparison of outputs corresponding to different inputs. *Step by step simulation* - students can change their decisions (input parameters) on every time step, however different runs can not be compared
5. Build GUI using interface builder. Drag and drop components form left-hand side vertical menu. When developing Input controls- only variables with *GAME()* function are accessible. In order to display output use Bar chart for variables not requiring analysis of dynamics and Line chart to see how variable changed during simulation.
6. Program additional functionality by editing files on Interface tab

Forio version of Workload planning model

To prepare model for export from Vensim to Forio [38], I set input parameters as *GAME()* functions and converted model to *.vmf* file. Once model is uploaded, I started with development of GUI. Best practice for developing GUI is to have 4 tabs [39]:

- **Introduction**, giving instruction for player
- **Dashboard** displaying key parameters of current simulation. As discussed in

previous chapter, we need to know dynamics of Assignment Backlog, Actual Workweek and final value of average grade. Hence on Dashboard we display 2 graphs.

- **Decisions** or Control panel, is the tab comprising controls for all input parameters
- **Run Manager** Allows to manage which result of previous simulations to compare with current on the dashboard.


On Figure 19 I present Introduction tab of online simulation. It was created to give basic info about simulation to the player. Main purpose is to state assumptions and targeted learning outcome for the player. Front-end of this application is developed in flat design, without redundant elements in order to make user focus on functionality. To adhere best practice, web page has responsive design (Bootstrap technology)- hence it can be viewed on tablets and smart phones. Component responsible for display of graphs is also mobile-friendly.

Student Workload

🏠 Introduction
📊 Dashboard
⚙️ Decisions
📅 Run Manager

Welcome to Student Workload planner!

Background history



According to some researches, influence of incorrect workload planning on students performance can be as big as poor course curriculum or incorrect teaching methods

Figure 19: Introduction to Workload planning model

The dashboard (displayed on Figure 20) provides key outputs of the model. In order to make it work properly I have to set up data binding between interface and model. The easiest way is to use data binding in Interface Builder- each input/output can be programmed through properties feature to be binded with respective model variable. However, if developer is to create a custom output/input component, they have to rely on Flow.js framework. For the moment, most of the interactions with the model can be performed using Epicenter APIs.

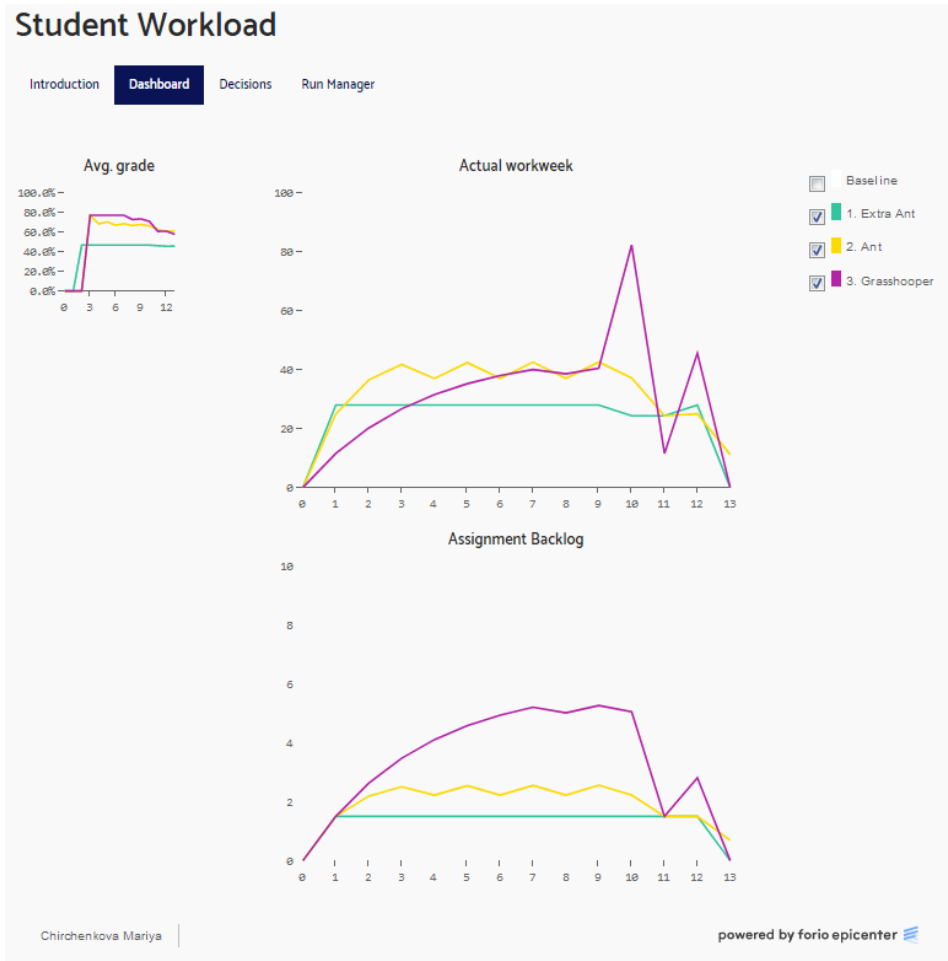


Figure 20: Forio version of Workload planning model

Forio Epicenter has a built in Vensim engine, so when user runs the model, no translation happens. Consider possible actions user might want to do, while

interacting with model:

- **Create a new run.** Every time user wants to start a simulation, they create a new run. In situations when developer wants possibility to run few simulations step by step simultaneously, they have to utilize Run API (RESTful)
- **Process input.** Model variables of type "CONSTANT" or "LOOKUP" can be assigned a value only at the beginning of simulation. Auxiliary variables set to Game() function can be changed after any time step. In our model Desired Grade and strategy are set to Game() function. Variables are accessed through Run API (RESTful)
- **Advance model.** Once new run is created, player starts to simulate the model. This is done through calling functions step(), reset(), start game() from Epicenter APIs
- **Update outputs.** The essential way to display necessary parameters is to have model variables storing values for those parameters. For example, if we are interested to display total number of Assignments per semester, we do not write a computation function in Javascript, rather we introduce a dedicated level variable in Vensim model. As model variables are binded with outputs through Flow.js, outputs will be updated automatically after each time step. However for cases when it is not possible to introduce Vensim variable, Forio stores variables as a set of pairs: (value, time step)

While developing front-end I utilized all of the functions above.

Refer to the way student should run the simulation. Three strategies are already simulated, so student can either simulate his own strategy or compare behavior of key variables in standard strategies. Reader can easily verify that output of Forio model is identical to output of rate and flow model discussed in Chapter 3.1. Note check box area in right upper corner- strategies not needed for comparison can be hidden from graphs. If player has basic understanding of system dynamics principles, casual loop diagram can be shown to provide deeper learning insights.

Model is hosted on Forio Epicenter server (free offer for educational purposes) and can be accessed via URL [\[28\]](#).

5 Model analysis and Results

5.1 Model analysis

Even though output of the developed model seem to correspond to the aggregated analysis of questionnaire, it would be beneficial to run several formal tests, in order to get more confidence into the model. One of the reasons is that we are not able to test model against all set of possible outputs to verify correct behavior.

There exist quite a number of formal system dynamics tests. For my model I selected set of Extreme conditions tests. The idea of this family of tests is to provide extreme (not very probable in real life) inputs and verify that model still behaves in appropriate way. Based on model structure extreme values can be maximum or minimum values from function definition. In some cases it is also feasible to take as an input values causing another variables to achieve maximum or minimum values. When models are comprehensive, it is hard to look for entry points for extreme conditions test, so better to follow guidelines described in [18]:

5.1.1 Extreme inputs for look up variables

Referring to our rate and level model on Figure 19 , we see that Energy Level is the only look up variable. First step is to verify that input values always belong to the definition domain. Input value originates from Energy erosion, which is quotient of *Actual workweek* divided by *Max workweek*. *Actual workweek* is formulated in a way that it always has values between 0 and *Max workweek*. Hence look up function in variable *Energy Level* receives correct input. The output is defined to be in range [0,3..1], which can not cause incorrect behavior of subsequent variables like *Productivity* or *Speed of Work*.

5.1.2 No production without resources

This group of tests refers to the fact that rate changing the level variable should equal to 0 if resources needed for that rate are empty.

- Test 1: If student does not have time in a week, there will be no work on assignments
- Test 2: If student wants to complete tasks with 0 effort, grades should equal 0.
- Test 3: If student is sick, not able to work on assignments, no assignment should be completed.

Test	Input condition	Correct result	Received result
1	“Max workweek”=0	“Work completion”=0	“Work completion”=0
2	“Desired grades”=0	“Grades”=0	“Grades”=0
3	“Max productivity”=0	“Work completion”=0	“Work completion”=0
4	“Assignment rate”=0 ; “Not enough time”>20; “Assignment Backlog”=0	“Assignment Backlog”>=0	“Assignment Backlog”>=0

Table 1: Extreme condition testing

5.1.3 Formulation of outflows

Rates taking material out from level should be formulated in a way that level does not become negative. In our model only outflow rate is “*Work completion*”. For the validity of experiment we need to make the inflow rate equal to 0 and current value of the level also equal to 0.

Results of the tests can be observed in Table 1. As it is seen from comparison of columns 2 and 3, all of the tests were passed successfully.

5.2 Strategies

There is existing casual diagram to model the issue of managing student workload. According to [18] There are 2 basic strategies which student can behave:

1. "Ant strategy never put off until tomorrow what you can do today or
2. grasshopper strategy- never do today what can be put off until tomorrow" [18].

Student that chose first strategy always try to work hard when he just received assignments and not putting off until last minute and deadline. This helps him to avoid stress before exams and distribute work over the semester.

In contrast, grasshopper student attending parties, doing other activities than studies at the beginning of semester and at last minute he overwhelmed by too much work, stressed and his productivity becoming lower [18].

In order to provide better learning effect, I decided to make above mentioned strategies more precise and include additional 4 strategies. New strategies were defined based on template of student time management behaviours discussed in [40]. In order to simulate strategies, I had to translate them into model variables. For each of strategy I specified two input parameters of the model "Not enough

time" and "Strategy":

- "Not enough time" is parameter that shows at what moment during semester student does objective assessment whether he will have time to complete all tasks. According to [41] a lot of students make this assessment once in a semester. Parameter is measured in weeks and equals number of weeks till the end.
- "Strategy" is equal to number of tasks in backlog when person starts to panic- in other words- utilize Max Workweek.

To demonstrate result of each strategy, I provide values of 3 variables :

- Actual workweek
- Assignment Backlog
- Average grade

First two are shown "in dynamics" on the graph, while for last one we just write final value. To retrieve this value we use Display as Table function in Vensim tool. As a result we get table with calculate values for each of 13 weeks. But this variable called Average grade. So we are only interested in final result at week 13.

Below I provide results of strategy simulations:

1. **Extra Ant:** do everything as fast as possible, even at cost of delivering bad quality. Just fast.

Input

- Not enough time: 8
- Strategy: 2

Output

- Avg grade: 0.64
- All tasks completed
- Desired Grade: 0.7
- Dynamics of Actual workweek and Assignment Backlog are shown on Figure 21

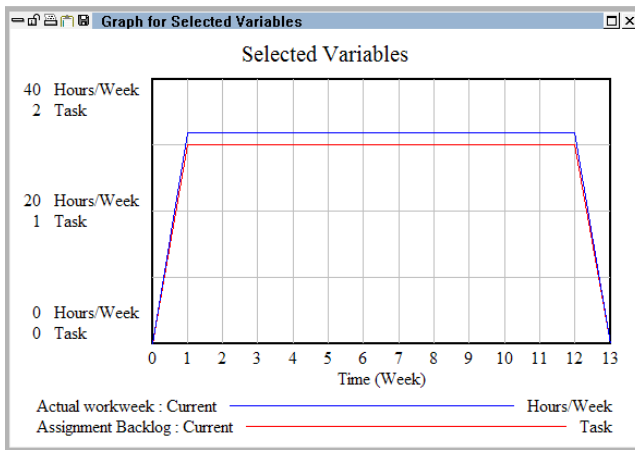


Figure 21: Strategy 1 Extra Ant

Analysis

X axis on all graphs displays Time(Week). In this case it is 13 weeks. So as it can be seen, on the 13 week Assignment backlog value equal to 0. This means that there are no tasks left at the end of the term.

Y axis displays 2 different values: Assignment backlog(Tasks) and Actual workweek(Hours/week). Using Vensim tool it is possible to build these 2 variables on the same axis for better visualization. So it is possible to analyze how many hours per week student have to work according to this strategy.

As it seen from output of this strategy, student received relatively low grades but was able to complete all tasks.

2. **Ant:** do on time, with highest quality possible, preferably without overworking

Input

- Not enough time: 8
- Strategy: 4
- Desired Grade: 0.77

Output

- Avg grade: 0.77
- All tasks completed
- Dynamics of Actual workweek and Assignment Backlog are shown on Figure 22. Red line (Assignment Backlog) is not visible, as it has exactly same shape as Actual Workweek

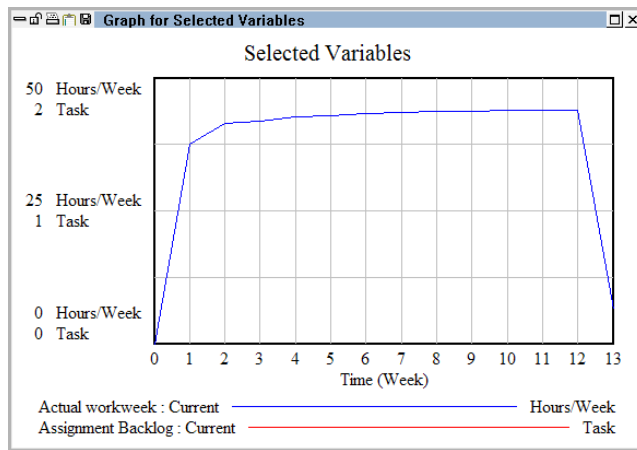


Figure 22: Strategy 2 Ant

Analysis

Student achieved initial goals of their strategy in terms of grades and task completion.

3. **Excellent Ant**: complete all tasks on time aiming at A grade as average

Input

- Not enough time: 6
- Strategy: 4
- Desired Grade: 0.9

Output

- Avg grade: 0.90
- All tasks completed
- Dynamics of Actual workweek and Assignment Backlog are shown on Figure 23

Analysis

Student achieved initial goals of their strategy in terms of grades and task completion. Compared to strategy 2, demonstrated higher workweek, but without too much overworking- hence was able to maintain high productivity.

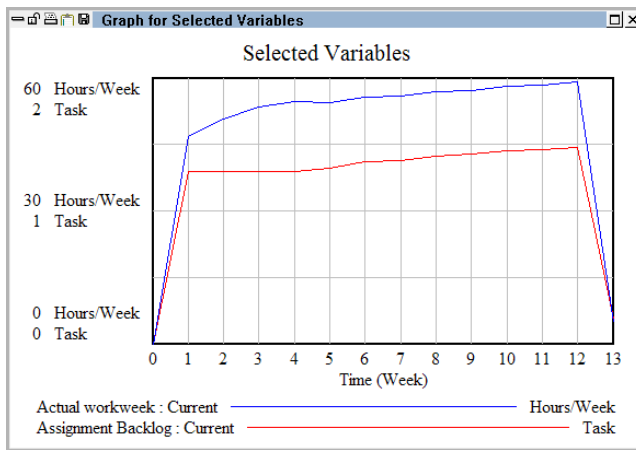


Figure 23: Strategy 3 Excellent Ant

4. **Grasshopper with desire for high grades** Student, who prefers to postpone work on assignments (i.e. Grasshopper), however plans to achieve high grades

Input

- Not enough time: 7
- Strategy: 30
- Desired Grade: 0.77

Output

- Avg grade incl. F: 0.58. Avg. grade without F is 0.79
- 7 tasks (55% of all) not completed
- Dynamics of Actual workweek and Assignment Backlog are shown on Figure 24

Analysis

Student has not completed more than half of the tasks. Student achieved desired average grade, but if we take into account tasks not submitted- actual average grade is much lower. Student was overworking (100h/week) in last weeks.

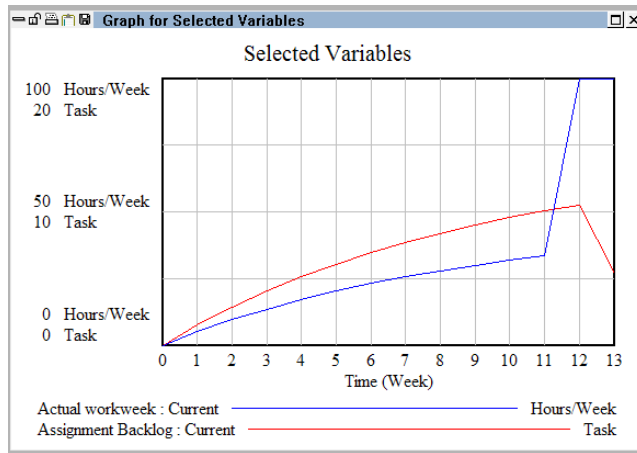


Figure 24: Strategy 4 Grasshopper with desire for high grades

5. **Grasshopper with desire to complete all tasks** Student aiming to submit all tasks, at least at minimum sufficient level

Input

- Not enough time: 7
- Strategy: 20

Output

- Avg grade: 0.48
- All of the tasks completed
- Dynamics of Actual workweek and Assignment Backlog are shown on Figure 25

Analysis

Student achieved goals of defined strategy, however If compared to strategy 2 (ant) average grade is much lower

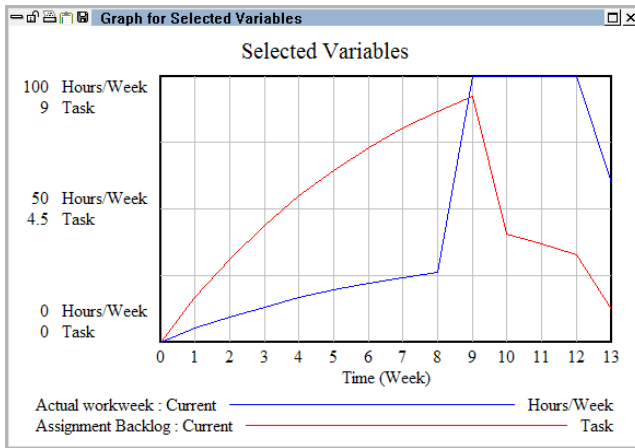


Figure 25: Strategy 5 Grasshopper with desire to complete all tasks

6. **Grasshopper with desire to complete all tasks at descent grade** Strategy of not willing to start early, but finishing with good grades and all tasks completed

Input

- Not enough time: 5
- Strategy: 15
- Desired Grade: 0.65

Output

- Avg grade: 0.61
- All of the tasks completed
- Dynamics of Actual workweek and Assignment Backlog are shown on Figure 26

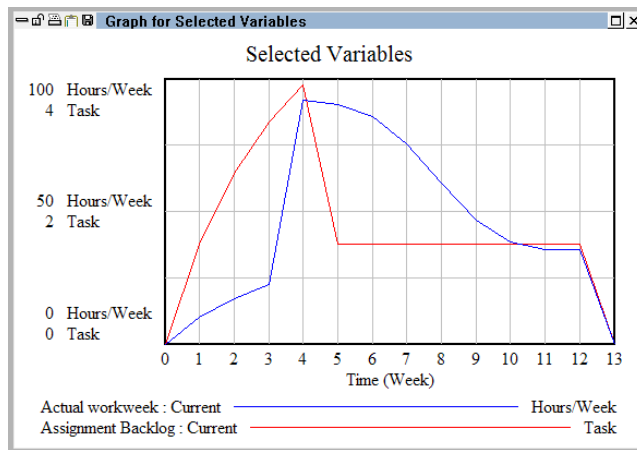


Figure 26: Strategy 6 Grasshopper with desire to complete all tasks at descent grade

Analysis

Student was able to complete all tasks, however failed to achieve desired average grade

More precise analysis of strategies is performed in Section 6.1

5.3 Questionnaire

In order to make parameters of the model more precise and ensure that model behaviour is close to real world questionnaire was created. According to Figure 18 main variable describing process of student working is Work Completion. Hence we have to verify correct formulation of it. Variable depends on several parameters, but with this data collection we can verify 2 of those parameters: formulation of Energy Level and Work Pressure.

If answers of participants will not correspond to model output, they will be statistically analyzed and necessary model parameters adjusted, so that model provides correct output for variable Average grade and Assignment backlog.

Another goal was to verify that our model has educational value for players.

To achieved above mentioned goal, we opted to have two questionnaires. Students start with questionnaire 1, than play developed simulation and do post - questionnaire. 15 students that were doing Bachelor degree at NTNU in Gjovik participated in our experiment.

5.3.1 Experiment design

In first questionnaire students were given textual description of 6 strategies. For each strategy that had to characterize outcome. In order to focus, on main goal, and

keeping in mind that one can not conceptualize the problem in couple of minutes, we reduced output characterization to only 2 questions presented on Figure 28, 29. Moreover, we do not ask exact average grade, rather a letter representing grade (i.e. interval of grades).

We also asked additional question, to understand which of our 6 strategies students use (or want to use the most). Below question 1 with possible answers is displayed on Figure 27.

Which one among these strategies do you usually use in your study process?

- Strategy 1 Extra Ant: do everything as fast as possible, even at cost of delivering bed quality. Just fast
- Strategy 2 Ant: do on time, with highest quality possible
- Strategy 3 Excelent Ant: complete all tasks at A grade
- Strategy 4 Grasshooper with desire for high grades
- Strategy 5 Grasshooper with desire to complete all tasks
- Strategy 6 Grasshooper with desire to complete all tasks at descent grade

Figure 27: Question 1

Question 2 with possible answers displayed on Figure 28

What do you think will be average grade? *

	F (below 40)	E (41-52)	D (53-64)	C(65-76)	B(77-88)	A(over 88)
Extra Ant	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Ant	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Excelent Ant	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Grasshooper with desire for high grades	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Grasshooper with desire to complete all tasks	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Grasshooper with desire to complete all tasks at descent grade	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Figure 28: Question 2

Question 3 with possible answers displayed on Figure 29

Will they be able to complete all tasks?

	Yes	No, 92% completed (1 task remaining)	No, 84% completed (2 tasks remaining)	No, 60%-76% completed (3-5 tasks remaining)	No. less than 60% completed
Extra Ant	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Ant	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Excelent Ant	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Grasshooper with desire for high grades	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Grasshooper with desire to complete all tasks	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Grasshooper with desire to complete all tasks at descent grade	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Figure 29: Question 3

After completing this questions, students were asked to simulate strategies in our Forio game. Experiment concludes with post questionnaire containing same questions as pre questionnaire. The goal of post questionnaire is:

- Eliminate probability of students giving not correct answers in first questionnaire due to incorrect understanding of task
- Verify learning effect
- If student in both questionnaires provides answer that differs from model output- model parameters might need adjustment

5.4 Results of questionnaire

Which one among these strategies do you usually use in your study process?

15 ответов

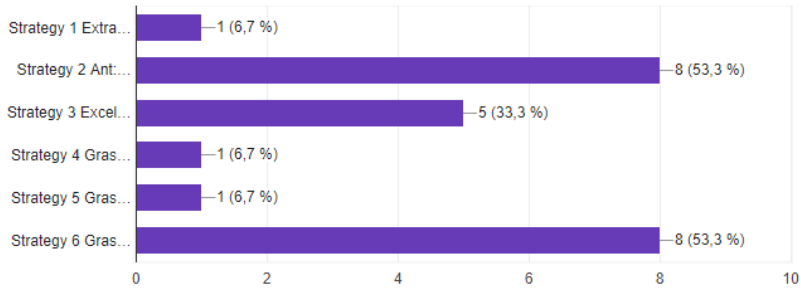


Figure 30: Answers question 1

Figure 30 shows participant answers for first question. Answers are quite expected, as most students choose the strategies that according to description should convey positive result.

Figure 31 present participants expectations of average grade under each of strategy. Most of participants gave approximately the same average grade as model simulation for Ant strategies, however gave better grades for Grasshopper strategies compared to model.

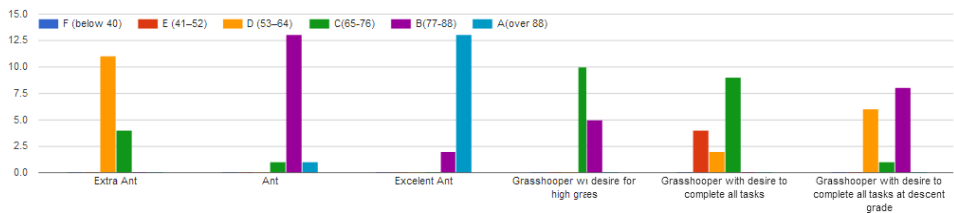


Figure 31: Questionnaire 1, Answer question 2: What is the average grade for each strategy

On Figure 32 participants answered, weather student is able to complete all tasks under selected strategy. Most of the students gave the same results as model, however in case of Strategy 4, students thought that it would be possible to complete more tasks.

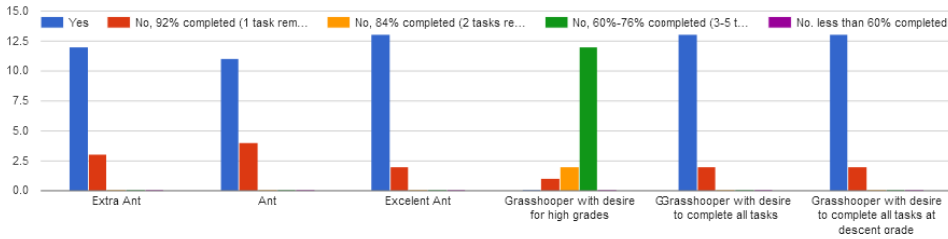


Figure 32: Questionnaire 1, Answer question 3: For each strategy, where students able to complete all tasks

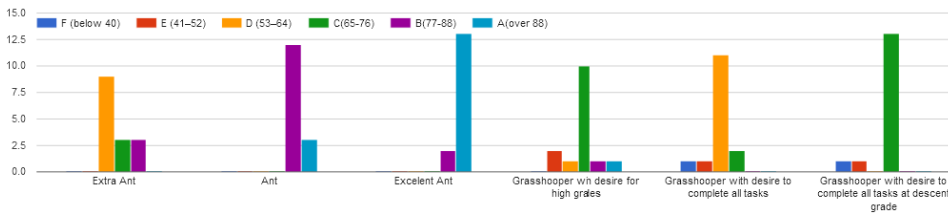


Figure 33: Questionnaire 2, Answer question 1: What is the average grade for each strategy

After the first questionnaire students had to simulate strategies in the model and than answer second questionnaire. Analyzing responses to question 1 on Figure 33 we see that participants gave exactly same answers as in the first questionnaire and as model simulation results:

- For Extra Ant 9 persons chose D grade(from 53 to 64). In pre questioner 11 participants chose D grade. According to the model average grade using this strategy should be 64%. So option that was chosen mostly by students is within the range of values according to the model.
- For Ant strategy 12 persons chose B grade(from 77 to 88). While in pre questioner the same option was chosen by 13 participants. According to the model average grade using Ant strategy should be also B, if more precise-77%.
- For Excellent Ant in pre and post questioner 13 persons chose A grade(over 88). According to the model average grade using Excellent Ant strategy should be 90%.

However some differences were in perception of Grasshopper strategies:

- For strategy Grasshopper in both questioners most of participants chose C grade as average, while model output displays 79% (B).

- For Grasshopper with desire to complete all tasks majority chose D (from 53 to 64), while in pre questioner most common answer was C. According to the model average grade using this strategy should be 48% (E).
- For Grasshopper with desire to complete all tasks at descent grades the situation is similar: at first majority of respondents chose B, than C, while model delivers 59% (D).

Statistical analysis of average grade in Grasshopper strategies

In order to find out real average grade for Grasshopper strategies, I will build a 95% Confidence interval as suggested in [42]. For given set of data I can calculate expected value and standard deviation and than use the formula on Figure 34.

$$\left(\bar{x} - z^* \frac{\sigma}{\sqrt{n}}, \bar{x} + z^* \frac{\sigma}{\sqrt{n}} \right)$$

Figure 34: Confidence interval boundaries with known standard deviation

As a result I get boundaries of confidence interval and than check if model output belongs to this interval.

- Strategy 4: Confidence interval is (D;C). Model output shows B as average grade without accounting not completed tasks
- Strategy 5: Confidence interval is (E;D). Model output is E
- Strategy 6: Confidence interval is (E;D). Model output is D

From results above it can be concluded that model should be calibrated only in case of Strategy 4.

Regarding answer to Question 3, displayed on Figure 35, participants agreed with model output and their responses in first questionnaire, however in strategy 4 participants are more optimistic than model- claiming that student under this strategy will complete as much as 60-76% of all tasks, while model says only 45%.

If we apply the same procedure of finding confidence interval, the resulting interval would be (less than 60% completed; 60%-76% completed). Model output shows that 45% of tasks were completed, hence it belongs to confidence interval and parameters do not have to be changed.

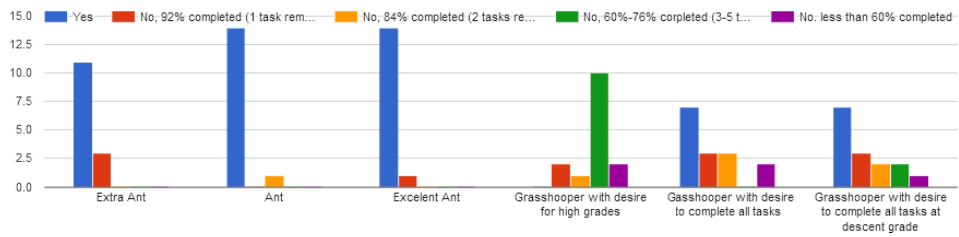


Figure 35: Questionnaire 2, Answer question 2: For each strategy, where students able to complete all tasks

Learning effect

The learning effect from model can be verified from question 3 displayed on Figure 36. Participants claimed that they will avoid choosing strategies, leading to poor performance (strategies 1,4,5). Fewer participants, compared to questionnaire 1 chose, Strategy 6, which, if applied too late leads also to poor performance.

Which one among these strategies will you use in your study process in future?

12 ОТВЕТОВ

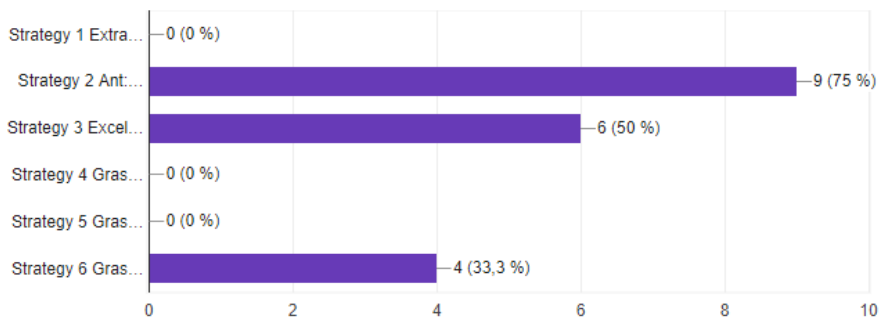


Figure 36: Answers question 3

6 Discussion

6.1 Discovered insights

As it is seen from previous chapter, some strategies are leading to the positive results (high average grade and balanced workweek), while the others convey opposite (negative result). In this chapter I will find out patterns of behavior preventing positive result. In order to do so, I will explore model structure in detail, analyze values of variables at different time step, compare simulation results and analyze result of questioner.

6.1.1 Grasshopper or Ant strategy

Consider what strategies chose students in the Questioner. Most of them chose either Ant strategy or Grasshopper with desire to complete all tasks at descent grades. Now if we refer to results of simulation, under both strategies student is able to complete all tasks. However average grade in case of Grasshopper is significantly lower: 0.59 (D) compared to 0.77 (C) at Ant strategy.

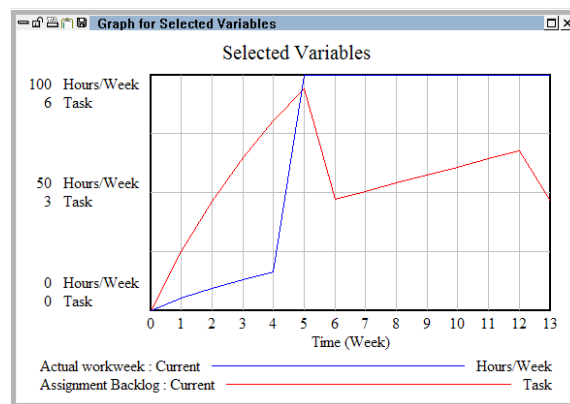


Figure 37: Strategy 6: Grasshopper who started too late

However, if student starts too late, no matter how hard they work- they will not complete all tasks at descent grade. Refer to the Figure 37 below, if compared to Figure 26, we see that student started only 1 week later, however was unable to complete all of the assignments. Student tried his best, as it seen from graph, they worked maximum hours per week from week 5 to week 13, but have not completed

3 tasks. One of the reasons for such different behaviour compared to reference strategy is that Balancing loop B3: Burnout on casual loop diagram (see Figure 10) created huge resistance. While Work completion was insufficient, Energy level was at minimum, preventing increase in Work completion, even though utilizing all available time.

Another factor decreasing student performance in case of Grasshopper strategy is procrastination. Consider how slow increases Actual workweek in case of Grasshopper compared to Ant. Even though student would like to put effort in working, they are tempted to delay more and more. This same observation describe authors of [43]. Grasshopper stops procrastination only when they get a critical value of Assignment Backlog.

Key insight 1

Successful behavioural pattern is to start as early as possible. If student is determined to start late, there is a risk that it will be too late to complete all tasks. According to [10] accumulated tiredness influences productivity (maximum tiredness results in productivity decrease 3 times from normal), hence one should keep max. workweek not more than 1,2 from normal workweek.

6.1.2 Precise planning

Compare Extra Ant strategy displayed on Figure 21 and Grasshopper with desire for high grades strategy displayed on Figure 24. In both strategies low average grade (0.64 (D) and 0.58 (D)) is partially due to incorrect short-term planning.

Extra Ant keeps their workweek low: most of the time they work only 32 hours per week. This is a cause of setting a goal for low grades. If the goal would be for higher grades performance would be the same as in Ant strategy: 30% higher workweek results in grade 0.77 (C)

Grasshopper in strategy 4 does opposite mistake: they keep their expectations high and finish semester with more than 50 % of tasks not completed. If desired grade would be lower, this will result in more work completion. This can be verified from strategy 6, displayed on Figure 26 by lowering grade expectations, student gets 0.59 (D) as average compared to 0.58 (C), however they are able to complete all tasks.

Key insight 2

Authors of [10] suggest to keep track on time spent working and on number of assignments completed. In this way student can more precisely adjust their grade expectations, hence being able eventually to perform at better grade and completing more tasks.

Exclusion from this suggestion are situations, where student can drop assignments, without being prohibited to submit further assignments. Then strategy 4

shows that in such extreme situations it is better to drop some assignments and focus on remaining ones. Strategy 4 proves this concept, as student has grade 0.79 (C) as average for actually completed assignments.

6.1.3 How to overwork correctly

Consider again Strategy 4 on Figure 24. Persuaded by the stress, student decides to allocate maximum time available to work on assignments. As they are not tired they are able to achieve increase in Work Completion proportional to hours worked—almost 2.5 times more task were completed compared to average completion in Ant strategy.

As a result student gets decrease no productivity, which can be verified from Figure 38. The reason is that productivity decrease happens with delay and will actually influence the week after the end of semester, when no work is expected.

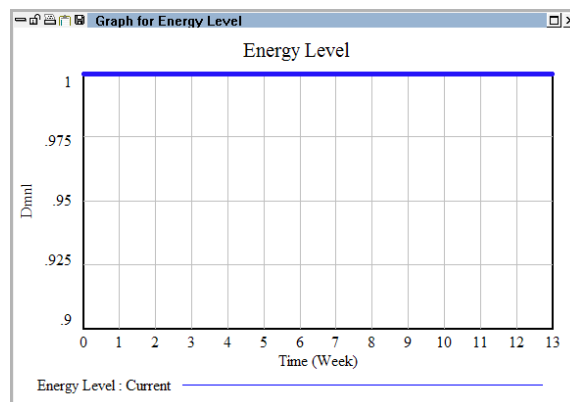


Figure 38: Productivity level when overworking in last week

Key insight 3

Working at maximum workweek is effective only in the last week of semester: student experiences subsequent decrease in workload when semester has already finished.

6.2 Validity of results

In order to confirm value of achieved results, I will examine validity, according to the method suggested in [44]. Researchers distinguish between internal validity and external validity. First is a measure of how trustworthy are achieved results: how accurate do they fit to the problem in focus and weather there are any errors, influencing the flow of the research[45].

On the other hand external validity is a metric showing, how generic are results.

If results possess high external validity- this means they can be utilized in similar problem domains [46].

From the above mentioned criteria, it can be concluded, that most of the research cannot possess high external and internal validity at the same time.

6.2.1 Internal validity

From the very beginning of this research it was stated that the problem in focus is student workload, hence literature containing specific research was analyzed. Accounting for such field-specific factors increased internal validity.

More arguments in favour of high internal validity were provided in Section 5.1. In that section I carried out specific System Dynamics tests suggested by authors of [18]. I conducted 3 tests, which fit the best to the Workload model. The aim of running those tests was to see, if the model will deliver correct outputs for arbitrary inputs. All of 3 tests were passed successfully, which increases confidence of the reader and gives argument for high internal validity.

Another measure to ensure high internal validity was a questionnaire. System dynamics tests mentioned above can verify that the model does not violate any basic rules of system dynamics. However, they can not confirm that the model corresponds to a real life problem, not an artificially created problem. By asking students to play with the model and providing them a questionnaire we get more confidence in the beneficial learning effect and verified that our model corresponds to a field-specific problem.

6.2.2 External validity

It might seem that the research in focus possesses low external validity, due to relying on data available regarding student workload. Indeed there are some different behaviour patterns between students and other people having a workload problem. For example, consider an office employee with predefined working hours. It is not likely that they are able to utilize the Grasshopper strategy by keeping very low workload in the beginning.

However, when we consider the results of the research they do not sound too specific and can be extrapolated to another problem domain. Moreover it can be shown, that adding simple structure or changing power of some of the relations can accommodate our model to another domain of workload problem.

Hence external validity of this research is on a decent level.

7 Conclusion

7.1 Contributions and Outcomes

This thesis had focus on problem of students workload planning. Inspiration for investigation in this area came from research showing that students poor performance can be a result of poor course design, as well as a result of poor workload planning.

In order to better understand problem I did thorough review of solutions proposed by another researchers for the workload planning. My review showed that problem of student workload was mostly considered from the side of course scheduling, but little was mentioned about learning students to plan better.

Hence, I decided to develop a serious game, based on System Dynamics. Purpose of the game was to make players learn insight of proper workload planning from hands on experience (i.e. by playing the game).

Key assumptions of game were: game runs through one study semester, with known rate of new assignments published. In the beginning of each week student has to make a plan, how many hours he will work in a week. Decision is based on time til the end of semester, assignment backlog and other factors. Goal of the game is to complete all tasks within deadline and at descent grade.

To develop a game I completed all the stages below:

- Gathered all qualitative and quantitative data related to student workload problem
- Based on conceptual understanding from previous step I was able to argue for proper Casual loop diagram, showing relations between system entities.
- Developed rate and flow- quantitative diagram. To ensure correct operation I accounted factors like subjective perception, decrease in energy and influence of dissatisfaction with grades.
- Validity of the model was verified using System Dynamics field specific tests and data collection, where participants provided subjective output, later compared with model output
- To allow more people to access my model, and provide GUI, I developed and published online simulation using Forio Epicenter Framework.
- I found out insights, giving more knowledge regarding proper workload planning. Specifically: what patterns of behavior lead to good student performance and what can be done to improve performance during semester that

is already running. I discovered those insights by analyzing structure and behaviour of the model

The resulting product is desktop model, online-published serious game and list of insights for better student workload planning. This work will be interesting for students in colleges and universities. Moreover conceptual ideas will fit also to people experiencing workload planning issues in other domains.

Primary aim of the work was educational effect, which can be achieved in various ways. For general audience, the educational effect comes from simulating the model with pre defined behavioural strategies and comparing results of them. While students familiar with system dynamics can also explore casual loop diagram to get better understanding of underlying processes.

Both groups should review insights, discovered during this project:

- Behavioural patterns where one start working early in general deliver better results, compared to those who delay start of work
- Regular review of work accomplished and time spent allow more precise short-term planning. As a result one does not get unintended effects of goal overshoot or underachievement
- If overworking is inevitable, one should plan it in the end of the term, so that negative effect of tiredness will affect them after actual deadline

To increase trust into insights, readers are also provided with argumentation coming from model structure.

7.2 Limitations and Future Work

This thesis presents a finished product, containing system dynamics model, online serious game and list of derived insights. Some room for improvement can be found in situations where interested audience has more specific characteristics than general educational process in college or university. For example, nursing students have a lot of lab sessions, conducted on fixed dates, with no possibility to be postponed. In such cases model parameters can be adjusted to fit the problem.

In those cases more behaviour strategies can be developed and proposed to the students. Naturally strategies will be a result of observation of students learning in specific field.

Also educational value can be tested better. We can add additional questions to the questionnaire to check if the students gained knowledge. Increasing number of observers can bring more statistically significant results, i.e. we will have more data to make decisions, how to adjust our model to deliver accurate outcome.

During our data collection we tested perceived educational effect of the model. However the actual effect can be measured by comparing group of participants

who played our game and those who did not.

Another improvement that can be made relates to game itself. Currently, it is just a simple implementation which interface displays graphs. Users can change parameters of the strategies in order to understand what results these behavioural strategies can cause. Gamification elements can be added to increase interest of the audience to the system.

Nevertheless, author of thesis showed that approach of allowing participants to explore problem by playing educational game is beneficial. Therefore it might be of interest to develop serious games for another audience, suffering from improper workload planning.

For example, students of school or employees of companies can be a target group for serious game. As mentioned in Section 6.2, Existing Rate and Flow model can be used with minor changes. By adding necessary structure and changing some relations between entities, it can be adjusted to workload problem of another audience.

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A Model equations

In this Appendix I present full list of Model equations, representing my Stock and Flow diagram. List was created from Vensim PLE, by accessing Document All function

1. *Actual workweek* = *Work completion/Speed of work* **Units:** Hours/Week
2. *Assignment Backlog* = **INTEG** (*Assignment rate-Work completion*, 0) **Units:** Task
3. *Assignment rate* = **IF THEN ELSE** (*Time remaining < 2*, 0, 1.5) **Units:** Task/Week
4. *Assignments completed* = **INTEG** (*Work completion*, 0) **Units:** Task
5. *avg grades* = **IF THEN ELSE** (*Assignments completed >= 1*, *Grades/Assignments completed*, 0) **Units:** Dmnl
6. *avg grades including F* = **XIDZ**((*Grades+Assignment Backlog*0.4*), (*Assignments completed+Assignment Backlog*), 0) **Units:** Dmnl
7. *Desired Grades* = **GAME**(0.65) **Units:** Dmnl
8. *Effort Devoted to assignments* = **ACTIVE INITIAL** (**IF THEN ELSE** (*work Pressure <= 0.4*, *Desired Grades*, **MAX**(*Desired Grades/(0.6+work Pressure)*, 0.4)), *Desired Grades*) **Units:** Dmnl
9. *Energy erosion* = **DELAY FIXED**(*Actual workweek*, 1, 40) **Units:** Hours/Week
10. *Energy Level* = **WITH LOOKUP** (*Energy erosion*, ([[0,0)-(100,1)], (0,1), (40,1), (100,0.3)]) **Units:** Dmnl
11. *FINAL TIME* = 13 **Units:** Week **The final time for the simulation.**
12. *Grades* = **INTEG** (*grades received*, 0) **Units:** Task
13. *grades received* = *Effort Devoted to assignments*Work completion* **Units:** Task/Week
14. *INITIAL TIME* = 0 **Units:** Week **The initial time for the simulation.**

15. *Max completion* = *Assignment Backlog*/*TIME STEP* **Units:** Task/Week
16. *Max Productivity* = 1/40 **Units:** Task/Hours
17. *max work flow* = 500 **Units:** Drawing/Month
18. *Max Workweek* = 100 **Units:** Hours/Week
19. *Not enough time* = (*Assignment Backlog*+**MAX**(*Assignment rate**(*Time remaining*-2), 0))/(*Time remaining*+0.0001)/**MAX**(*Assignments completed*, 1)/**MAX**(*Time*, 1)**Step*(5000, 9) **Units:** Task/Week
20. *Perceived work completion* = **DELAY FIXED**(*Work completion*, 1, 2.5) **Units:** Task/Week
21. *Planned Workweek* = *Max Workweek***work Pressure* **Units:** Hours/Week
22. *Productivity* = *Max Productivity***Energy Level* **Units:** Task/Hours
23. *SAVEPER* = *TIME STEP* **Units:** Week **The frequency with which output is stored.**
24. *scheduled completion date* = 10 **Units:** Month
25. *scheduled time remaining* = **MAX**(0, *scheduled completion date*-*Time*) **Units:** Month
26. *Speed of work* = *Productivity*/*Effort Devoted to assignments* **Units:** Task/Hours
27. *Strategy* = **MAX**(30) **Units:** Task
28. *Time remaining* = (*FINAL TIME*)-(*Time*) **Units:** Month
29. *TIME STEP* = 1 **Units:** Month **The time step for the simulation.**
30. *Work completion* = **MIN**(*Planned Workweek***Speed of work*, *Max completion*) **Units:** Month
31. *work Pressure* = **IF THEN ELSE** (*Not enough time*>20, 0.4***MIN**(*Not enough time*, 2.5), **MIN**(*Assignment Backlog*/*Strategy*, 1)) **Units:** Dmnl