# A Method to Optimize Technical Debt Management in Timed-boxed Processes

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***Abstract*—Technical debt is currently receiving great attention from researchers, because it is believed to affect software development to a great extent. However, it is not yet clear how technical debt should be managed. This is specifically true in time-boxed development processes (e.g., in agile processes organized into development sprints of fixed duration), where it is possible to remove technical debt as soon as it is discovered, or wait until the debt reaches a given threshold, or wait until a whole sprint can be dedicated to technical debt removal, etc. We aim at investigating the consequences of different technical debt management options, especially as far as debt removal and program enhancements are concerned. We are interested in the consequences on both the amount of functionality and the quality of the delivered software. We propose a System Dynamics model that supports the simulation of various scenarios in time-boxed software development and maintenance processes. The proposed model is conceived to highlight the consequences of management decisions. Since this is our focus, our model abstracts from a few confounding factors that may be present in software projects, which would basically introduce some noise and blur the effect we want to study. Nonetheless, the model can be easily extended and adapted to represent these other factors adequately. The proposed model shows how productivity and product quality depend on the way technical debt is managed. Our model yields quantitative indications that can support the estimation of the economic consequences of different management strategies. Our study shows that different strategies for managing technical debt in a time-boxed development and maintenance process may yield different results—in terms of both productivity and delivered software quality—depending on a few conditions. Software project managers can use customized System Dynamics models to optimize the development and maintenance processes, by making the proper decisions on when to carry out maintenance dedicated to decreasing the technical debt, and how much effort should be devoted to such activities.**

***Keywords–Technical debt; System Dynamics; Technical debt management.***

## I. INTRODUCTION

Both practitioners and researchers are dedicating a growing amount of attention to Technical Debt (TD). In general, TD is connected with a lack of quality in the code. The idea is that, if maintaining a piece of software of "ideal" quality has a given cost, maintaining a piece of software of "less than ideal" quality implies an extra cost.

It is also common knowledge that if no action is performed to improve code quality, a sequence of maintenance interventions will decrease quality, that is, TD increases and the cost of maintenance increases as well. Not managing TD at all could lead to code that is not maintainable.

These considerations pose the problem of managing TD: project managers need to identify the best TD management strategies and methods, and evaluate their effectiveness before putting them in practice.

For this purpose, we propose a System Dynamics model that represents the development of software via a sequence of time-boxed development phases (e.g., Scrum sprints). Like any System Dynamics model, the proposed model can be simulated, thus providing quantitative indications concerning the effectiveness of development in terms of amount and quality of code delivered. The proposed model is used in this paper to illustrate a few development scenarios and the consequences of TD and the adopted TD management practices.

The paper is organized as follows. In Section II, we provide background concerning Technical Debt and System Dynamics. In Section III, we introduce our model of software development and maintenance, characterized by time-boxed incremental phases. In Section IV, the model is used to simulate the behavior of the process when different strategies for allocating effort to repay the technical debt are used. In Section V, we discuss the outcomes of simulations, especially as far as productivity and delivered quality are concerned. Section VI accounts for related work. Finally, in Section VII we draw some conclusions and outline future work.

## II. BACKGROUND

In the last few years, TD has received great attention from researchers. For example, a recent Systematic Mapping Study on TD and TD management (TDM) covering publications from 1992 and 2013 detected 94 primary studies to obtain a comprehensive understanding on the TD concepts and an overview on the current state of research on TDM [1].

An updated Systematic Mapping Study identified elements that are considered by researchers to have an impact on TD in the industrial environment [2]. The authors classified these twelve elements in three main categories: (1) Basic decision making factors, (2) Cost estimation techniques, and (3) Practices and techniques for decision-making. They mapped these elements to the stakeholders' point of view, specifically, for business organizational management, engineering management, and software engineering areas.

Several authors proposed definitions for TD and its interests. Nugroho et al. [3] define TD as *"the cost of repairing*

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*quality issues in software systems to achieve an ideal quality level"* and the interests of the debt as *"the extra maintenance cost spent for not achieving the ideal quality level."* Other works try to empirically correlate TD with software size, software quality, customer satisfaction, and other software properties, in the context of enterprise software systems [4].

In a recent Dagstuhl Seminar [5], the following definition of TD was proposed: *"In software-intensive systems, technical debt is a collection of design or implementation constructs that are expedient in the short term, but set up a technical context that can make future changes more costly or impossible. Technical debt presents an actual or contingent liability whose impact is limited to internal system qualities, primarily maintainability and evolvability."*

The Software Quality Assessment based on Lifecycle Expectations (SQALE) method [6] addresses a set of external qualities (like Reliability, Efficiency, Maintainability, etc.). Each of these qualities is associated with a set of requirements concerning internal qualities, each provided with a *"remediation function,"* which represents the cost of changing the code so that the requirement is satisfied. Based on these functions, the cost of TD is computed for each external quality and for all qualities.

The Object Management Group has published a beta version of the specification of a measure of TD principal, defined as *"The cost of remediating must-fix problems in production code"* [7]. The measure can be computed automatically as a weighted sum of the *"violations of good architectural and coding practices,"* detected according to the occurrence of specific code patterns. The weight is computed according to the expected remediation effort required for each violation type.

System Dynamics was developed by Jay Forrester [8] as a modeling methodology that uses feedback control systems principles to represent the dynamic behavior of systems. The elements of System Dynamics models are levels, constants, auxiliary variables and rates. The dynamics of systems is determined by how levels work: given a level $L$, its value in time is always determined by an equation $L(t + \Delta t) = L(t) + (in(t) - out(t))\Delta t$, where *in(t)* and *out(t)* are rates. Levels and rates can concern anything (e.g., people, rabbits, bricks, lines of code, etc.), depending on the application scope and goal of the model. The value of a rate at time $t$ is defined based on the values of auxiliary variables, other rates and levels at time $t$. Likewise for auxiliary variables, which are not necessary, but are useful to write readable models.

The elements of a System Dynamics model are interconnected just like in the real world, to form a network, where causes and effects are properly represented. Models can be executed, so that the behavior of the modeled system can be simulated. Via System Dynamics models it is quite easy to perform what-if analyses: you obtain different behaviors by changing the initial state of the system (given by the values of levels), how rates and variable are computed, how they depend on each other, etc.

## III. THE PROPOSED MODEL

As already mentioned, the proposed model describes in an operational way the time-boxed development process, especially in terms of maintenance activities concerning the reduction of Technical Debt. The proposed model aims at evaluating the productivity of development and maintenance activities, and the quality of the released product. Here productivity is defined as the ratio of the amount of product—measured in Function Points (FP) [9][10]—developed in a time period to the amount of effort/resources used.

To focus on the main objectives, we abstract from all those aspects of the model that deal with activities and software products that are not directly connected with TD management. For instance, in a real process, the productivity of individuals tends to increase because of learning effects, the number of developers allocated may change during a project, etc.: we exclude all of these variables because they would introduce noise in our investigation, which focuses on the effects of TD management decisions.

### A. Assumptions

The main reason why practitioners and researchers are interested in TD is that maintaining code burdened with a big TD (i.e., low-quality code) costs much more than maintaining code with little TD (i.e., high-quality code). This is because more work is needed to carry out any code-related activity when code is of low quality (e.g., difficult to understand, poorly structured, full of hidden dependencies, etc.).

To account for the relation that links TD to maintenance cost, we need a measure of TD. To this end, we measure TD via a "TD index," an indicator that takes into account the internal qualities of code that concur to determine the amount of TD embedded in the code. Here, we are not interested in defining precisely the TD index, based on the measures of individual internal qualities, because this is not relevant for our purposes. Clearly, accurately modeling individual internal qualities of code would make the model more apt at reproducing the behavior of real development environments. But this is not our purpose: we aim at building a model that shows—at a fairly high level—the effects of decisions concerning TD management in a generic realistic development environment.

We assume that the TD index ranges between 0 (highest quality) and 1 (worst quality). The extreme values represent limiting cases, which may not occur in practice. When the TD index is 1, maintenance is so difficult that one is better off by simply throwing away the code and building a new version from scratch, and productivity is null, i.e., *prod* = 0. When the TD index is 0, maintenance activities attain their optimal productivity $prod_{opt}$. When 1>TD index>0, *prod* steadily increases from 0 to $prod_{opt}$ when the TD index decreases.

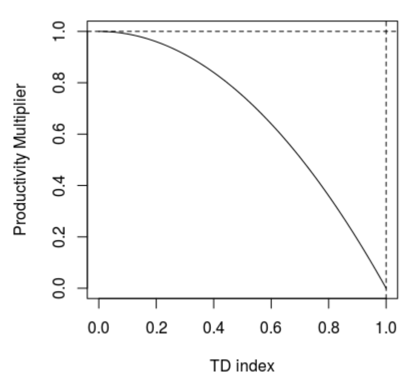


Figure 1. Effect of technical debt on productivity.

The value of productivity for a given value of the TD index *prod(TDindex)* can be expressed as *prodMult(TDindex)* $\times prod_{opt}$. Figure 1 shows a possible behavior of *prodMult(TDindex)*. We use the function illustrated in Figure 1 to build models to exemplify our proposal. Other monotonically decreasing functions that go through points $(0, 1)$ and $(1, 0)$ could be used as well, but that would not change the way we build models in our proposal.

Here, we assume that development is carried out in a time-boxed way. This is coherent with the organization of development in most agile processes. We assume that the development is composed of a sequence of "sprints," each of which has a fixed duration and involves a constant number of developers, hence a sprint "consumes" a fixed number of Person Days (PD). For instance, if sprints last 20 work days and involve 5 developers, then each sprint "costs" 100 PD. If at the end of 5 sprints 416 FP are released, we have achieved a productivity of 416/(5·100)=0.832 FP/PD; if at the end of these sprints 378 FP are released, we have achieved a productivity of 378/500=0.756 FP/PD. Quite clearly, in the former case the management of technical debt was more effective, a higher productivity was achieved, more functionality was released, and bigger returns can be expected.

A consequence of our assumptions is that the amount of effort spent is strictly proportional to development duration, which can be expressed in number of sprints. Given this proportionality between effort and the number of sprints, we can express productivity as the amount of code released after $N$ sprints. Thus, we measure the productivity values above as 416/5=83.2 FP/Sprint (instead of 416/500=0.832 FP/PD) and 378/5=75.6 FP/Sprint (instead of 378/500=0.756 FP/PD).

During each sprint, the developers can carry out two types of activities: 1) increase the functionality of the system, by adding new code, and 2) decrease TD, by refactoring code structure, removing defects and improving the qualities that make development and maintenance easier. Since in each sprint the amount of work is fixed, managers have to decide what fraction of work has to be dedicated to new code development—the remaining fraction being dedicated to TD management. Several different criteria can be used in setting such fraction, as illustrated in Section IV.

We assume that during each sprint a constant fraction of the new code affected by quality problems (hence, increasing the technical debt) is released. This fraction depends on several factors, like the experience and ability of developers, the availability of sophisticated tools, problem complexity, etc. We assume that these factors are constant throughout all the sprints: in this way, we do not generate noise and we can highlight the effects of TDM decisions.

## B. The Model

The proposed System Dynamics model involves two level variables: `CodeSize` (measured in FP) and `TDIndex`.

The constants in the model are:
`nominal_maintenance_productivity`, the productivity in FP/Sprint in ideal conditions, i.e., when the TD index is zero. We assume that the nominal productivity is 80 FP/Sprint, corresponding to 0.1 FP/PersonHour, a fairly typical value [11].
`nominal_TDimprovement_productivity`, the amount of code that can be optimized—i.e., whose TD is completely repaid—in a sprint, when the effort is completely devoted to TD improvement. We assume that this value is 40 FP/Sprint. In real developments, this amount is not necessarily constant: a sprint could be sufficient to "clean" 40 FP or relatively good code, but not to "clean" 40 FP of very bad quality code.
`bad_fraction_of_new_code`, the fraction of the new code (released at the end of each sprint) that contributes to increasing TD. We here assume that the value of this constant is 0.2.
`available_effort`: the effort available at each sprint. As already mentioned, we assume it to be a constant. The actual value is not relevant, however, we can take 100 PD as a reference value.

The rate and auxiliary variables of the model are:
`fraction_of_effort_for_quality_maintenance`: the fraction of `available_effort` dedicated to repaying TD. This variable is computed via function `fracEffortForQuality`, which has the TD index as an argument.
`quality_maintenance_effort`: the effort available for improving the quality of code in a sprint.
`maintenance_effort`: the effort available for developing new code in a sprint.
`maintenance_productivity`: the productivity of developing new code in a sprint. It depends on the `nominal_maintenance_productivity`, the `maintenance_effort` and the decrease of productivity due to the TD (computed via function `productivity_considering_TD`).
`TD_dec_rate`: the TD decrease rate.
`TD_inc_rate`: the TD increase rate.

The values of the aforementioned variables are determined by the following equations:

```
available_effort=1
fraction_of_effort_for_quality_maintenance=
 fracEffortForQuality(TDindex)
quality_maintenance_effort=available_effort*
 fraction_of_effort_for_quality_maintenance
maintenance_effort=
 available_effort-quality_maintenance_effort
maintenance_productivity=
 nominal_maintenance_productivity*
 maintenance_productivity_considering_TD(TDindex)
TDimprovement_productivity=
 nominal_TDimprovement_productivity*
   quality_maintenance_effort
TD_inc_rate=bad_fraction_of_new_code*
 maintenance_productivity/CodeSize
TD_dec_rate=TDimprovement_productivity/CodeSize
```

where the following functions are used:
`maintenance_productivity_considering_TD(TDindex)`: the loss of productivity due to TD, as described in Figure 1.
`fracEffortForQuality(TDindex)`: this function describes the strategy used for tackling TD. In Section IV, we use a few different strategies, hence, a few different function definitions.

The levels are computed as follows (where all auxiliary and rate variables are computed at time t):

```
CodeSize(t+Δt)=CodeSize(t)+
    Δt*maintenance_productivity
TDindex(t+Δt)=TDindex(t)+
    Δt*(TD_inc_rate-TD_dec_rate))
```

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## IV. Simulating the Model

We simulate the model with a few different TD management strategies. The considered case is characterized as follows. Initially, the software system to be maintained has size 80 FP and its TD index is 0.2 (representing the quality gap between the "ideal" quality and the actual initial quality accepted to speed up development and release the product early). The nominal productivity (i.e., new code development productivity in ideal conditions, when no extra effort is due because of TD) is 80 FP/Sprint. The nominal TD repayment productivity (i.e., the amount of functionality for which the TD is completely repaid in a sprint) is 40 FP/Sprint. At the end of every sprint, 20% of the added code is "bad" code.

Our software organization goes through a sequence of 30 maintenance sprints. We assume that there are always enough new requirements to implement to use up the development capacity of sprints. This is a situation that occurs quite often in practice. We also assume that the same amount of effort is allocated to all sprints. In actual developments, this does not always happen. Anyway, simulations that do not depend on variations in the available effort provide better indications of the effects of TD management strategies, since they do not depend on accidental phenomena, like the amount of available workforce.

### A. *Constant Effort for TD Management*

In the first simulation, we assume that the considered software development organization allocates a constant fraction of the effort available in each sprint, to tackle the technical debt. It is reasonable to expect that the achieved results depend on how big the fraction of effort dedicated to TD management is. Hence, we run the simulation a few times, with different fractions of the available effort dedicated to TD management, ranging from zero (i.e., nothing is done to decrease the TD) to 40%. The main results of the simulation are given in Figure 2, which shows, from left to right: the functional size of the software product version released after each sprint; the functional size increment due to each sprint (i.e., the enhancement productivity of each sprint); the evolution of the TD through sprints (i.e., the quality of the software product versions released after each sprint).

We can examine the achieved results starting with the solid black lines, which represent the case in which no effort at all is dedicated to repaying the TD. It is easy to see that the results obtained by this TD management strategy (a no-management strategy, actually) are quite bad. In fact, after 30 sprints we get only 1248 FP: about 500 FP less than the most efficient TD management strategy. Not only: the final product has TD index = 0.84, that is, a very low quality, probably hardly acceptable in practice. The effects of TD on maintenance productivity are apparent: the continuously growing TD makes maintenance less efficient over sprints and, at the end, more than 60% of the initial productivity is lost, due to TD. So, just ignoring the TD is not a good practice. Definitely, we have to allocate some effort to decrease the TD, but how much effort should we dedicate to repaying TD?

By looking at Figure 2, it is easy to see that dedicating 10% of the available effort to repaying TD improves the situation with respect to not managing the TD at all: the final size (1580 FP) is bigger, and the final TD index (0.64) is better, though not really good. When we dedicate 20% of the available effort to repaying TD the results improve further: the final size (1743 FP) is bigger, and the final TD index (0.41) is better, though still not very good.

In summary, by increasing the fraction of effort dedicated to repaying TD from 0 to 20% we improve both the amount of functionality that we are able to release, and the quality of the software product. Hence, it would be natural to hypothesize that, by further increasing the fraction of effort dedicated to repaying TD, we obtain improvements in both the amount and quality of delivered software. Actually, this is not the case: when 30% of the available effort is dedicated to repaying TD, we obtain a fairly good product (the final TD index is 0.13, better than it was initially) but the amount of released functionality is slightly less (1723 FP). When an even bigger fraction (40%) of effort is dedicated to repying TD, we achieve practically ideal quality (the final TD index is 0.007), but substantially less functionality (the final size being 1517 FP).

The explanation of these results is that it is clear that increasing the fraction of effort dedicated to TD improvement improves maintenance productivity by decreasing TD, but at the same time subtracts effort from enhancement maintenance activities. Hence, one should look for a trade-off, to achieve both a reasonably high productivity level and an acceptable quality level (i.e., a sufficiently small TD).

Via a series of simulations, it is possible to find the fraction of effort dedicated to repaying TD that maximizes the released functionality, hence maintenance productivity. In the considered case, allocating 24% of the available effort to TD improvement eventually results in yielding 1758 FP. However, the final TD index is 0.31: not a small debt, and a bigger debt than initially. So, one could easily prefer to go for a bit less functionality but a much better code.

Finally, it should be noticed that in the short term—i.e., in the first 10 sprints or less—not managing TD does not seem to cause relevant negative consequences. For instance, in the considered case, if the goal is to achieve a 500 FP software product, not managing the TD may be a viable choice: you get the product faster than by managing TD. Of course, one should be sure that no further maintenance will be needed, otherwise maintenance cost would be quite high, that is, one has just postponed paying the debt.

### B. *Variable Effort for TD Management*

In the previous section, the fraction of effort dedicated to quality improvement was fixed, i.e., it was constant over the sprints. This is not a good managerial choice, for at least the following two reasons. First, the initial TD could be greater than in the case described in Section IV-A. Hence, it would be a good practice to devote a substantial amount of effort to improve quality at the beginning of development, with the objective of decreasing the TD, and then proceed with easier and more productive maintenance. This corresponds to repaying (all or a substantial part of) the TD in the first sprints: the following sprints will have to pay low or null interests.

Second, the effort dedicated to TD management could be excessive. Consider the evolution of the TD index through sprints illustrated in Figure 2: when the fraction of effort dedicated to quality improvement is 40%, the TD is practically nil after 10 sprints. In the following sprints, the fraction of effort for TD management is partly used to balance the increase

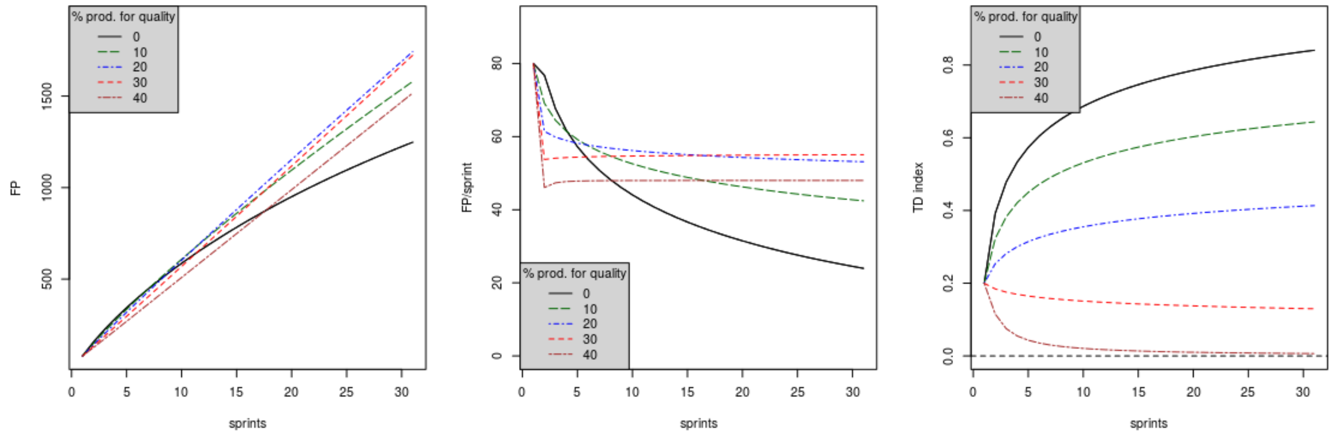


Figure 2. Size of delivered code, Sprint productivity and TD index, depending on a constant fraction of effort allocated to improving the TD.

of debt caused by new code, and part is wasted. This effect is easy to see when you compare the effects of dedicating 30% and 40% of the available effort to TD management. After a few sprints, in both cases the TD index is practically constant (about 0.18 in the former case, about 0.01 in the latter case). Maintenance productivity is also constant in the two cases, but higher in the former case. How is it possible that when 30% of effort is dedicated to TD management, we are using some effort to manage a higher TD, and still we get a higher productivity? Because the effort needed to keep TD close to zero is much less than the allocated 40%: the exceeding part is wasted.

A better strategy for TD management would be to allocate to TD improvement a fraction of effort that is larger when the TD is large and smaller when the TD is little. Of course, there are various ways to decide the fraction of effort to be dedicated to decrease TD. We adopt the function shown in Figure 3, which defines the fraction of effort for TD improvement as $1-(1-TDindex)^k$. By changing the value of $k$ we decide how aggressive the approach to debt repayment is: with $k=1$ the fraction of the effort dedicated to debt repayment is proportional to the debt, with $k>1$ as soon as TD index raises above zero, a substantial fraction of the effort (the greater $k$ the bigger the fraction) is dedicated to decrease TD.

In this section, the fraction of effort dedicated to TD management is decided at every sprint, as $1-(1-TDindex)^3$: a moderately aggressive policy. When debt increases, we try to decrease it fairly soon, to avoid paying large interests. Figure 4 shows the results of the simulation. The adopted policy provides good results: at the end of the sprints we get 1764 FP, more than in any of the simulations performed in Section IV-A. The final TD index is 0.11: a good result.

It is interesting to note that after a few sprints, the TD index remains constant, and, as a consequence, productivity remains constant as well. The reason is that, at the beginning of each sprint, the effort dedicated to TD management is adequate for repaying the existing TD, but, during the sprint, new TD will be created. This situation is perpetuated over the sprints. To completely repay TD, a policy should allocate enough effort to both repay the existing TD, and to *anticipate* the new TD, by performing maintenance in a way that preserves optimal code structure and quality.

In conclusion, dedicating a large fraction of effort to decrease the TD in the first sprints guarantees optimal results, in terms of both the amount of functionality delivered and the delivered quality.

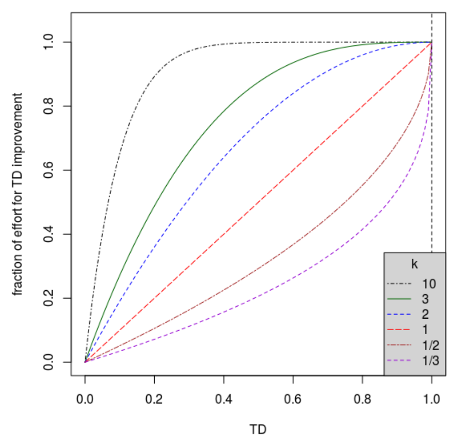


Figure 3. Percentage of effort dedicated to TD improvement, as a function 1-(1-TDindex)$^k$ of TD.

### C. *Managing TD over a Threshold*

In time-boxed development, it is often the case that a sprint is either completely dedicated to enhancement or to decreasing TD (especially via refactoring). So, the policy for allocating effort to TD management is simple: if the TD index is sufficiently high, the next sprint will be completely dedicated to TD repayment; otherwise, the next sprint will be dedicated completely to maintenance. In our case, if a sprint is dedicated completely to TD management, developers will be able to optimize a portion of code 40 FP large. Hence, we can allocate a sprint to TD management when a portion of code of at least 40 FP is affected by TD.

We simulated development with this criterion for allocating effort to TD management and we obtained the results illustrated in Figure 5. It is easy to see that the first sprints are

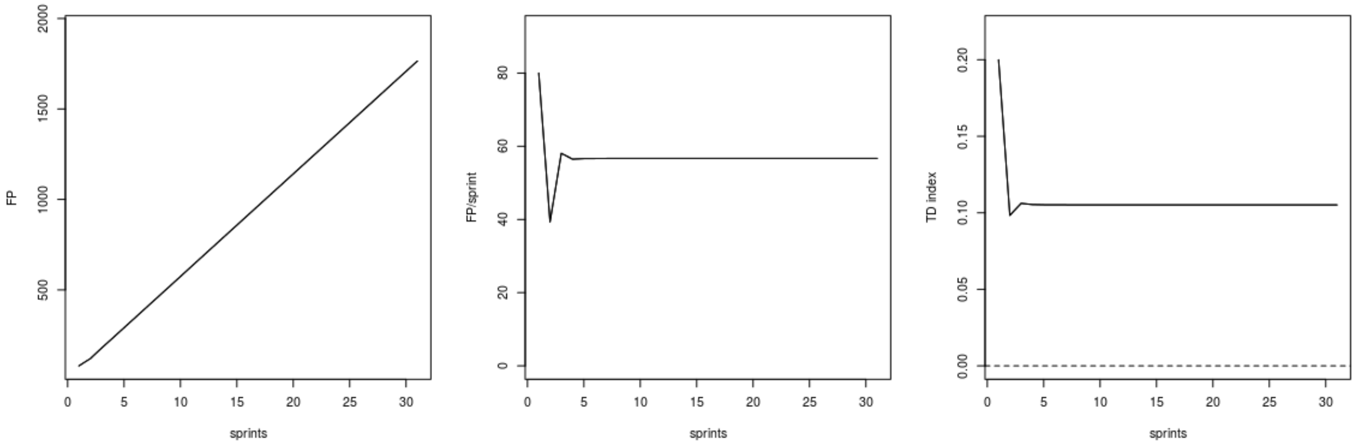


Figure 4. Size of delivered code, Sprint productivity and TD index through sprints, when the fraction of effort for TD improvement is 1-(1-TDindex)$^3$.

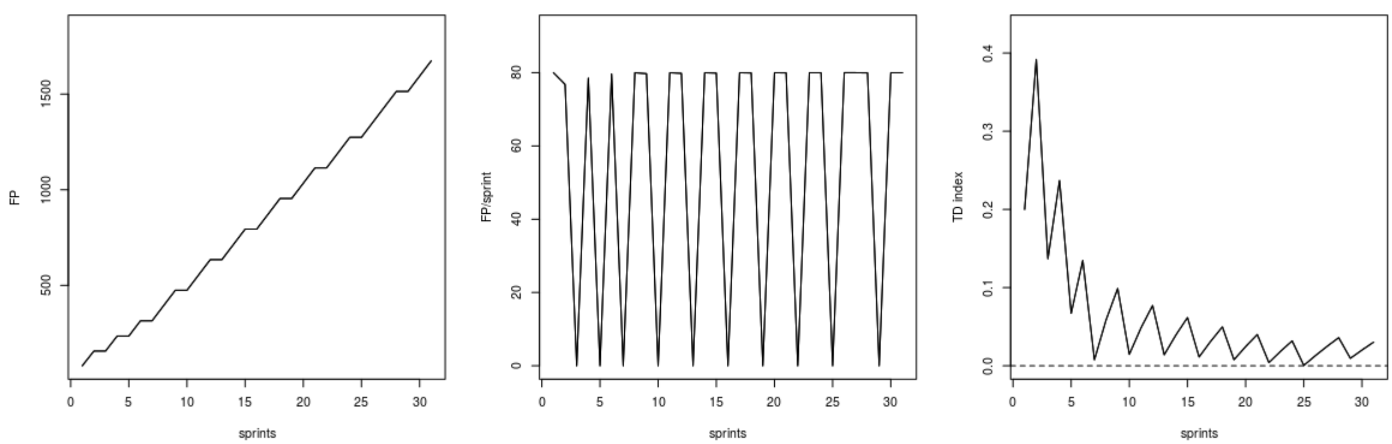


Figure 5. Size of delivered code, Sprint productivity and TD index through sprints, when sprints are dedicated to either TD management or maintenance.

dedicated to TD improvement and enhancement maintenance alternatively. Then, when TD has improved enough, we have a TD improvement sprint every two enhancement sprints. TD progressively decreases until it becomes practically nil (oscillating between 0.01 and 0.03). At the end of sprints, 1674 FP are released, that is, a bit less than with the policy described in Section IV-B. However, the achieved TD index is much better, compared to the 0.11 achieved in Section IV-B.

TABLE I. RESULTS WITH VARIOUS CRITERIA

| Criterion | Delivered size | Final TD index |
|---|---|---|
| Constant (0%) | 1248 FP | 0.84 |
| Constant (10%) | 1580 FP | 0.64 |
| Constant (20%) | 1743 FP | 0.41 |
| Constant (30%) | 1723 FP | 0.13 |
| Constant (40%) | 1517 FP | 0.007 |
| 1-(1-TDindex)$^3$ | 1764 FP | 0.11 |
| 1-(1-TDindex)$^{1/3}$ | 1601 FP | 0.51 |
| Threshold | 1674 FP | 0.01–0.03 |

## V. DISCUSSION

The results obtained with the different criteria for allocating effort to TD improvement are summarized in Table I. Note that in Table I, we have added the results—not given in Section IV-B—obtained when the fraction of effort dedicated to TD improvement is 1-(1-TDindex)$^{1/3}$. In such case, the fraction of effort dedicated to TD improvement decided at the beginning of each sprint, is based on the current TD index, but the approach is not aggressive, on the contrary, a substantial fraction of effort is dedicated to TD improvement only when the TD index is relatively large.

The results given in Table I, along with the more detailed results reported in Section IV, suggest a few observations.

First, allocating a constant amount of effort to TD improvement does not seem a good idea. In fact, if the chosen fraction of effort allocated to TD improvement is too high or loo low, the productivity of enhancement maintenance will be lower than possible. Also, the final quality of the product (as indicated by the TD index) could be quite low. In practice, allocating a constant amount of effort to TD improvement works well only if the right fraction of effort is allocated, but choosing such fraction may not be easy.

On the contrary, computing the amount of effort for TD improvement at the beginning of each sprint, based on the current TD index seems very effective, especially as far as optimizing the productivity of enhancement maintenance is concerned.

One could observe that in some situations it may be hard to separate clearly the effort devoted to enhancements from the effort devoted to TD improvement. This is particularly true when developers perform refactoring activities while they are enhancing the existing code. For this reason, an organization may want to have sprints entirely dedicated to refactoring and other TD improving activities, and sprints entirely dedicated to enhancements. In this case, the evaluations given in Section IV-C show that allocating an entire sprint to TD improvement whenever there is enough TD to absorb one spring effort provides quite good results, in terms of both productivity and quality.

In any case, we have to stress that all the presented strategies for TD management are based on the quantitative evaluation of TD, which results in the TD index. So, devising a way to measure TD appears fundamental to managing TD effectively and efficiently.

## VI. Related Work

System Dynamics was first applied in Software Engineering by Abdel-Hamid and Madnick [12], who proposed a model that accounted for human resource management, software development, and planning and control. System Dynamics was then extensively used to model software development and its management. A survey of System Dynamics applied to project management was published by Lyneis and Ford [13], while in [14] De Franca and Travassos propose a set of reporting guidelines for simulation-based studies with dynamic models in the context of SE to highlight the information a study of this type should report.

Cao et al. [15] proposed a System Dynamics simulation model that considers the complex interdependencies among the variety of practices used in Agile development. The model can be used to evaluate—among others—the effect of refactoring on the cost of implementing changes.

Glaiel et al. [16] used System Dynamics to build the Agile Project Dynamics model, which captures each of the Agile main characteristics as a separate component of the model and allows experimentation with combinations of practices and management policies.

Although less comprehensive than the mentioned models, our proposal allows for better undrstanding the consequences of technical debt and the effectiveness of its management strategies.

## VII. Conclusions

The term "Technical Debt" indicates several concepts and issues related to software development and maintenance. The latter are complex and multifaceted activities: accordingly, it is not surprising that managing TD is quite difficult [5].

In this paper, we have provided a formal, executable model of time-boxed software development, where the effects of TD are explicitly and quantitatively represented and accounted for. The model is usable to show—via simulation—the effects that TD have on relevant issues such as productivity and quality, depending on how TD is managed, with special reference on how much effort is dedicated to TD repaiment and when—in a sequence of sprints—such effort is allocated.

The model can be used to prove or disprove concepts and hypotheses, to perform what-if analyses, etc. However, our model is not intended to be used in practical software project management as-is, becase, the model illustrated above is too abstract and contains hypotheses that could not match the target development environment. Whoever wants to use the presented model for practical project management should first enhance it; examples of models representing all the main aspects of software development can be found in the papers by Cao et al. [15] and Glaiel et al. [16].

We plan to extend the presented model in several directions: to account for different effects of TD on productivity (i.e., with functions different from the one in Figure 1), to explicitly model defects, to test different debt management policies, etc.

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