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Organisational characteristics and student dropout dynamics in technical and vocational higher education: a Forrester-based simulation study

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Introduction: Student dropout in technical and vocational higher education (TVHE) is commonly explained through individual or socioeconomic variables, relegating the structural role of organisational characteristics to the background. This study models the influence of organisational characteristics on the student dropout rate in TVHE and addresses this gap through a System Dynamics perspective, conceptualising dropout as an emergent phenomenon arising from dynamic interactions among institutional capacities, organisational pressures, and mediating processes such as academic burnout.

Methods: System Dynamics methodology was employed to model the influence of organisational characteristics on student dropout. Based on a causal loop diagram, a Forrester diagram was constructed incorporating stocks, flows, and auxiliary variables, and simulated over a ten-year horizon. The model integrates institutional coordination, organisational flexibility, support capacity, institutional climate, and perceived organisational support as structural levers, considering academic burnout as the central accumulation variable. Sensitivity analyses and policy scenario simulations were conducted to assess structural robustness and the effects of different organisational interventions.

Results: The baseline scenario shows that, even when the absolute number of dropouts may stabilise, the student dropout rate tends to increase due to the sustained growth of academic burnout and support staff burnout, revealing structural fragility. Sensitivity analysis confirms the mediating role of academic burnout and reveals asymmetries between mechanisms of institutional erosion and strengthening. Simulations indicate that isolated interventions produce only partial effects, whereas combined organisational strategies generate more stable and resilient retention trajectories.

Discussion: The main contribution of this study lies in endogenising organisational characteristics as structural dynamic determinants of dropout, moving beyond approaches that treat them as external contextual variables. By mathematically formalising feedback loops and cumulative processes, the model extends the theoretical understanding of dropout in TVHE and provides a prospective tool for institutional decision-making. The findings suggest that strengthening student retention requires systemic coherence among organisational capacities rather than isolated or reactive interventions.

KEYWORDS

academic workload, educational sustainability, Forrester model, institutional coordination, organizational flexibility, student dropout rate, support capacity, technical-professional education

1 Introduction

Student dropout in higher education remains one of the most persistent and costly phenomena in contemporary educational systems, with implications that extend beyond individual trajectories to affect institutional efficiency, system equity, and the sustainability of public funding policies (Barragán Moreno and González Támara, 2024; Guzmán et al., 2021). The dominant literature has historically approached this phenomenon from a student-centred perspective, emphasising variables such as academic, social, or economic integration as primary determinants of persistence or withdrawal (Bean and Metzner, 1985; Ministerio de Educación Nacional de Colombia, 2015; Tinto, 1975). While these approaches have consolidated a substantial body of relevant evidence, they have simultaneously contributed to obscuring the structural role of organisational conditions in shaping educational trajectories, particularly in subsystems with non-traditional student profiles, such as Technical and Vocational Higher Education (TVHE) (McCubbin, 2003).

TVHE constitutes a differentiated subsystem within higher education, internationally recognised as a strategic mechanism for strengthening economic competitiveness, reducing skills gaps, and promoting social mobility (Makinde and Bamiro, 2023; Sublett and Plasman, 2025; UNESCO, 2023; Wagiran et al., 2017). Unlike traditional university education, TVHE is oriented towards the development of applied competencies linked to specific occupations (Mehner et al., 2024) and concentrates a significantly higher proportion of non-traditional students, such as working individuals, adults with family responsibilities, and historically disadvantaged populations (Gonzalez et al., 2025; Lavi and Achituv, 2025; Thaler, 2025). This student profile operates under conditions of high structural vulnerability, which limits the applicability of classical dropout models. Bean and Metzner (1985) noted that non-traditional students follow distinct persistence logics, in which social integration loses relative importance compared to external factors (for example, employment obligations, family responsibilities, and economic constraints), and particularly in relation to the organisational conditions of the institution they attend.

TVHE institutions also face an increasing set of organisational pressures that amplify these vulnerabilities. Policies aimed at massification and free access have significantly expanded enrolment, but have not always been accompanied by proportional increases in infrastructure, human resources, or organisational capacities (Vera Velázquez et al., 2021). Sublett and Plasman (2025) document how reforms intended to close gaps for special populations may generate additional tensions when equivalent support conditions are not ensured, thereby deepening processes of educational stratification. At the same time, the growing demand for student support, particularly in mental health, has overloaded support teams, increasing institutional burnout and reducing the effectiveness of support systems (Aspan et al., 2025; Bedoya-Ávalos et al. 2025; McKinney and Gischlar, 2025; Priya et al., 2025). These pressures configure an organisational system in which institutional capacities—coordination, flexibility, academic support, and organisational climate—are eroded by the very dynamics they are intended to manage, generating feedback loops that static approaches cannot adequately capture (Bedoya-Ávalos et al., 2025; Maquera et al., 2025).

Despite increasing recognition of the institutional role, organisational factors are still predominantly treated as contextual, control, or descriptive variables in explanatory models of dropout rather than as endogenous, dynamic determinants of the system. Dominant analytical approaches in the recent literature, such as logistic regression models, decision trees, survival analysis, and, more recently, machine learning algorithms, have demonstrated high individual predictive capacity, but reproduce a static logic in which organisational characteristics operate as fixed covariates, without capturing how they evolve under the pressure of the very dropout processes they seek to explain (Barragán Moreno and González Támara, 2024). This limitation is particularly problematic in contexts where institutional capacities are subject to cumulative erosion.

In addition to this first gap, two further shortcomings can be identified. First, the existing literature has not systematically incorporated the cumulative, non-linear, and time-delayed nature inherent to complex socio-educational systems, in which variables such as academic burnout or institutional support capacity operate as stocks that accumulate and dissipate according to management decisions (Bianchi, 2016; Cosenz, 2022; Sterman, 2000). Second, available evidence is disproportionately concentrated in traditional university education, leaving TVHE underrepresented in international academic production, despite concentrating more vulnerable student profiles and consistently higher dropout rates (Gonzalez

et al. 2025; Sublett and Plasman, 2025). This triple gap—lack of dynamic endogenisation of organisational factors, absence of a cumulative systemic perspective, and scarcity of TVHE-specific evidence—justifies a methodological approach capable of mathematically formalising feedback interactions between organisational capacities, mediating pressures, and student dropout.

In response to this triple gap, the present study adopts System Dynamics as its methodological approach and develops a Forrester model that endogenises organisational characteristics as dynamic accumulative variables. The research objective is to model the dynamic influence of organisational characteristics on the student dropout rate in TVHE, formalising institutional capacities (coordination, flexibility, support capacity, organisational climate, and perceived organisational support) as stocks that erode and strengthen, and academic burnout as the central mediating variable. In line with this objective, the study is guided by the following research questions:

1. RQ1. How do organisational characteristics, operating through feedback loops, shape the trajectory of the student dropout rate in TVHE over a ten-year horizon?
2. RQ2. Which combinations of organisational interventions —isolated or integrated—produce more stable retention trajectories in prospective scenarios?

This study contributes to the literature in three dimensions. At the theoretical level, it extends classical dropout models (Bean and Metzner, 1985; Tinto, 1975) by shifting the analytical focus from individual integration to organisational responsibility, endogenising academic burnout as a mediating stock and mathematically formalising structural asymmetries between mechanisms of institutional erosion and strengthening. At the methodological level, it provides a reproducible modelling architecture that integrates causal loop diagrams, Forrester modelling, and sensitivity analysis, applicable to other higher education subsystems. At the practical level, it derives institutional management guidelines supported by scenario simulation, offering direct relevance for leadership teams, retention units, and quality assurance systems in TVHE institutions.

The remainder of the article is organised as follows. Section 2 presents the theoretical framework, linking classical dropout models with the organisational specificity of TVHE. Section 3 describes the System Dynamics methodology employed. Section 4 presents the simulation results, including the baseline scenario, sensitivity analysis, and policy scenarios. Section 5 discusses the theoretical and practical implications, as well as the study limitations. Finally, Section 6 presents the conclusions.

2 Theoretical framework

2.1 Classical dropout models and their limitations in TVHE

Classical models of student dropout have been fundamental in understanding persistence in higher education; however, they were largely developed under the assumption of a traditional student profile: young individuals, fully dedicated to study, and highly integrated into university life. Tinto (1975) model of academic and social integration exemplifies this perspective, positing that student persistence depends on the degree of involvement in the academic and social systems of the institution.

Within this framework, academic integration encompasses both academic performance and intellectual development. In contrast, social integration refers to the quality and frequency of interactions with peers and faculty, as well as participation in extracurricular activities. Commitment to the goal of graduation is primarily influenced by academic integration, while institutional commitment depends more strongly on social integration. Overall, higher levels of integration reduce the likelihood of dropout (Donoso and Schiefelbein, 2018).

However, this model presents significant limitations when applied to working students, adult learners, or those with family responsibilities—profiles that are highly prevalent in TVHE. Limited time availability and fewer opportunities for social participation constrain the applicability of the social integration approach in these contexts (Barragán Moreno and González Támara, 2017). Even within traditional perspectives, the model proposed by Bean and Metzner (1985) recognised that non-traditional students follow distinct persistence logics. For these profiles, social integration becomes less important relative to external factors such as employment obligations, family responsibilities, and economic constraints, which play a decisive role in persistence decisions.

Consequently, understanding dropout in TVHE requires moving beyond a paradigm centred exclusively on institutional integration and addressing the external and organisational conditions that decisively influence academic continuity. Advancing in this direction also requires an analytical lens capable of capturing the dynamic interactions among these conditions, a task for which static or correlational approaches are insufficient. The following subsection introduces System Dynamics as a theoretical framework that enables the articulation of this perspective.

2.2 System dynamics as a theoretical framework for the study of dropout

System Dynamics is a theoretical and methodological framework developed by Forrester (1961) and subsequently advanced by scholars such as Meadows (2008) and Sterman (2000), aimed at understanding the behaviour of complex systems over time. Its conceptual core is structured around four key notions. First, stocks are understood as accumulations of resources, conditions, or states that build up or erode gradually. Second, flows, which represent the rates of change that modify these stocks. Third, causal loops, which describe how changes within the system feed back into its own behaviour through reinforcing or balancing mechanisms. Fourth, delays, which are temporal lags between causes and effects that explain many of the counterintuitive behaviours observed in social systems (Sterman, 2000). This framework enables the analysis of emergent, non-linear phenomena with historical memory, which cannot be adequately captured through static or cross-sectional approaches.

In the field of education, System Dynamics has been increasingly applied to the analysis of student trajectories, institutional efficiency, and the sustainability of retention policies. Shinde and Kaynak (2016) model educational dropout processes as the result of interactions among educational quality, institutional capacity, public policies, and labour market conditions, demonstrating that dropout patterns respond to systemic dynamics rather than isolated individual causes. Complementarily, dynamic performance management approaches in education (Bianchi, 2016; Cosenz, 2022) have shown that institutional capacities operate as cumulative intangible resources, whose erosion under pressure generates delayed effects on educational outcomes. These contributions contrast with dominant approaches in the recent dropout literature—such as regression models, decision trees, survival analysis, and machine learning algorithms—which, although offering strong predictive capacity, treat institutional variables as fixed covariates and fail to capture their dynamic transformation under the processes they seek to explain (Barragán Moreno and González Támara, 2024).

Three main arguments support the relevance of System Dynamics for studying organisational dropout in TVHE. First, it allows the endogenisation of organisational factors (for example, coordination, flexibility, support capacity, and institutional climate) as stocks subject to erosion and strengthening, overcoming their conventional treatment as static control variables. Second, it explicitly incorporates cumulative, nonlinear, and delayed processes characteristic of socio-educational systems, in which academic burnout accumulates progressively, support capacity deteriorates under sustained pressure, and management decisions produce delayed effects on dropout rates. Third, it enables the simulation of prospective scenarios and the assessment of the structural robustness of organisational interventions, providing relevant evidence for decision-making in subsystems underrepresented in the international literature, such as TVHE. From this systemic perspective, the following subsection reviews the multidimensional determinants of dropout identified in the literature, which will subsequently be operationalised as dynamic variables in the model.

2.3 Multidimensional determinants of student dropout

The literature on student dropout in higher education has consistently identified a set of explanatory variables that are grouped into four broad determinants: individual, academic, institutional, and socioeconomic (Table 1). These determinants encompass the variables most commonly associated with the decision to withdraw from studies and allow for capturing the multidimensional nature of the phenomenon (Barragán Moreno and González Támara, 2024; Guzmán et al., 2021; Ministerio de Educación Nacional de Colombia, 2015).

However, the relative influence of these variables is neither homogeneous nor universal. Their explanatory weight varies significantly depending on institutional contexts, student profiles, and the socioeconomic and organisational conditions under which education takes place. Consequently, rather than assuming a fixed set of causes, it is necessary to examine how these determinants interact within specific educational environments, particularly in technical and vocational higher education.

TABLE 1 Explanatory variables of student dropout in higher education.

Determinant	Explanatory variables of student dropout
Individual	Student age; sex; marital status; pregnancy or parenthood; family responsibilities; physical and mental health; academic motivation; unmet expectations; compatibility between study, work, and personal life; self-regulation skills; level of personal integration; perceived self-efficacy; academic burnout
Academic	Type of institution or programme; perceived programme quality; prior vocational guidance; performance in admission or national examinations; number of enrolled courses; academic workload; study strategies; academic performance; course failure; curricular alignment; mode of study; academic demands; digital divide
Institutional	Availability of scholarships and financial aid; funding mechanisms; academic support (tutoring, remedial programmes); psychological and psychosocial support; institutional resources; infrastructure; availability of academic and support staff; institutional climate; student support policies; campus environment; institutional stability; governance and academic management
Socioeconomic	Parental educational level; socioeconomic status; number of dependants; student employment status; household income; financial dependency; employment conditions; job stability; macroeconomic context; social inequality; local and national contextual conditions

Source: Authors' own elaboration based on Barragán Moreno and González Támara (2024), Guzmán et al. (2021), Gonzalez et al. (2025), and Ministerio de Educación Nacional de Colombia (2015).

Evidence from different national contexts supports this perspective. In Brazil, the expansion of higher education has increased institutional concerns regarding student retention, dropout reduction, and graduation rates, leading institutions to strengthen financial assistance, pedagogical support, and student services aimed at improving persistence (Sampaio et al., 2017). Similarly, research conducted in France suggests that educational outcomes are influenced not only by students' individual characteristics but also by institutional arrangements, support mechanisms, and programme-level practices, highlighting the importance of organisational factors in shaping student trajectories (Bonnard, 2023). Together, these findings reinforce the need to analyse student dropout as a multidimensional phenomenon emerging from the interaction between individual conditions and institutional structures.

2.4 Nature and role of TVHE in the education system

TVHE constitutes a differentiated subsystem within higher education, characterised by its applied orientation and its direct linkage to the labour market. Unlike university education, which

is traditionally centred on research and theoretical knowledge, TVHE prioritises the development of technical competencies associated with specific occupations, emphasising the practical application of knowledge (Gonzalez et al., 2025; Sublett and Plasman, 2025; Thaler, 2025).

A structural feature of TVHE is the early timing of vocational decision-making, which typically occurs during adolescence. This early tracking shapes subsequent educational and labour trajectories and contributes to the reproduction of patterns of occupational segregation, particularly in technical fields with lower prestige or remuneration (Gutfleisch and Nennstiel, 2025). In addition, the literature recognises TVHE as a key instrument for social mobility and economic development, as it helps close skills gaps and expand opportunities for historically disadvantaged populations (Ibrahim et al., 2025; Sublett and Plasman, 2025).

The profile of technical and vocational students reflects structural conditions of vulnerability that directly affect academic persistence. A significant proportion of these students combine study with full-time or intensive employment, generating physical and emotional fatigue and limiting academic integration, particularly in evening education contexts (Lavi and Achituv, 2025). Moreover, TVHE institutions tend to concentrate "special populations", including low-income students, racial minorities, individuals with disabilities, and second-language learners, who are often overrepresented in technical fields with lower economic returns (Sublett and Plasman, 2025).

These conditions create a high-risk context for dropout, associated with the difficulty of balancing work, family, and study responsibilities, insufficient emotional and professional support, and a perceived mismatch between overly theoretical curricula and the applied orientation of training (Gonzalez et al., 2025; Lavi and Achituv, 2025). In this context, academic burnout emerges as the strongest and most direct predictor of student dropout, acting as a mediating mechanism that translates structural and organisational pressures into withdrawal (Gonzalez et al., 2025; McKinney and Gischlar, 2025).

2.5 Organisational factors in student dropout in TVHE

The influence of the explanatory variables of student dropout cannot be understood in isolation from the organisational context in which educational trajectories unfold. Organisational characteristics act as moderating factors that amplify or attenuate the effects of individual, academic, and socioeconomic determinants, thereby configuring a space of intervention that is directly controllable by institutions.

Organisational culture and leadership styles constitute the first critical dimension. Perceptions of low organisational support and leadership styles insensitive to the well-being of both staff and students increase stress and burnout, weakening protective factors associated with persistence (Priya et al., 2025). In TVHE contexts, where students already face significant external demands, this lack of institutional support amplifies pre-existing vulnerabilities.

A second dimension relates to the management of academic workload and curricular design. The absence of coordination across courses and the concentration of assessments generate peaks of stress that disproportionately affect working students, intensifying academic burnout (Gonzalez et al., 2025). Likewise, the lack of differentiated instruction based on prior experience may lead to feelings of incompetence or demotivation, thereby reinforcing the impact of academic and vocational variables (Lavi and Achituv, 2025).

Support systems and institutional climate constitute a third key organisational domain. The absence of structured mechanisms for emotional and professional support, such as tutoring or peer mentoring, increases academic isolation and reduces students' capacity to cope with the demands of the educational environment (Gonzalez et al., 2025). This situation is exacerbated when institutions reproduce "toxic positivity" cultures that obscure distress and discourage the expression of difficulties (McKinney and Gischlar, 2025).

Finally, organisational infrastructure and institutional flexibility interact directly with the living conditions of technical and vocational students. Rigid scheduling structures hinder the balance between work, study, and personal life, reinforcing role overload and sustained strain (Lavi and Achituv, 2025). This is further compounded by fatigue derived from constant digital availability in the absence of institutional programmes aimed at wellbeing and digital disconnection (Barragán Moreno and Guzmán Rincón, 2025; Gonzalez et al., 2025).

In summary, student dropout in TVHE cannot be explained solely by individual, academic, or socioeconomic variables considered in isolation (Tables 1, 2), but rather by the way in which organisational characteristics shape the environment in which these variables operate. This perspective is central to the objective of the present study, as it allows for a more precise modelling of the influence of organisational characteristics on student dropout, shifting the analytical focus from individual deficit to organisational responsibility in sustaining educational trajectories.

Ultimately, dropout in TVHE must be understood through the combined effect of individual, academic, and socioeconomic variables (Tables 1, 2), together with how organisational characteristics configure the context in which these variables operate. This perspective is essential for modelling the influence of organisational characteristics on student dropout more accurately, moving beyond individual deficit explanations towards an organisational responsibility framework for the sustainability of educational trajectories.

The theoretical framework developed highlights that student dropout in TVHE does not respond to linear relationships or isolated causes, but rather emerges from the dynamic interaction among individual, academic, socioeconomic, and centrally organisational variables. These interactions are characterised by cumulative processes, mediating effects (such as academic burnout), feedback loops, and time delays, which together shape trajectories of persistence or withdrawal over time. In this context, analysing dropout through exclusively static or correlational approaches is insufficient to capture the complexity of the phenomenon.

For this reason, the present study adopts System Dynamics as its methodological approach, as it enables the explicit modelling of causal structures, feedback loops, and non-linear processes through which specific organisational characteristics progressively influence student dropout in TVHE. This approach also enables the simulation of alternative scenarios and the

TABLE 2 Explanatory variables of student dropout in TVHE.

Determinant	Type of variable	Explanatory variables in TVHE
Individual	Psycho-emotional	Academic burnout, emotional fatigue, cognitive exhaustion, and academic burnout syndrome
	Vocational	Vocational misfit; low identification with the technical programme
	Personal resources	Academic self-efficacy; perceived competence
Socioeconomic	Economic conditions	Financial difficulties; challenges in funding studies or learning materials
	Living conditions	Working student status; full-time employment; evening classes
	Role overload	Balancing work, study, family, and continuous technological learning
Academic	Curricular design	Academic overload, rigid curricula, and a lack of coordination across courses
	Relevance of training	Perceived overemphasis on theory; theory–practice disconnect
	Academic demands	Assessment peaks; perception of unproductive effort; academic frustration
Institutional	Support and guidance	Perceived organisational support; academic tutoring; peer mentoring
	Culture and leadership	Leadership styles are insensitive to well-being; low institutional prioritisation of student support.
	Organisational conditions	Lack of scheduling flexibility; insufficient resources; inadequate infrastructure
	Institutional climate	Weak social connection to campus; absence of support networks; "toxic positivity" cultures

Source: Authors' own elaboration based on McKinney and Gischlar (2025), Khatun et al. (2025), Lavi and Achituv (2025), Priya et al. (2025), Ibrahim et al. (2025), Sotomayor and Rodríguez (2020), and Zhang et al. (2025).

derivation of institutional management guidelines grounded in a systemic understanding of the phenomenon, aimed at strengthening student retention.

3 Methodology

3.1 Study design

This study is designed as an applied, exploratory, explanatory, and prospective investigation aimed at developing and validating a dynamic model that simulates how specific organisational characteristics progressively influence student dropout in TVHE through mediating variables, such as academic burnout. A mixed-methods design is adopted, following Anguera et al. (2018), integrating qualitative and quantitative components within a single modelling process.

In terms of System Dynamics typology, the model developed can be characterised as a *policy model* with a *theory-building* component (Bianchi, 2016; Sterman, 2000). It is considered *policy-oriented* insofar as its primary purpose is to evaluate the effects of institutional management decisions on the systemic trajectory of dropout (von Bertalanffy and Sutherland, 1974). Simultaneously, it contributes to *theory-building* by mathematically formalising the endogenous role of organisational characteristics and academic burnout as a mediating stock, thereby extending the theoretical understanding of dropout in TVHE. This typological positioning guides both the validation criteria—focused on structural coherence and behavioural plausibility rather than point prediction accuracy—and the interpretation of the results.

In the first phase, a causal loop diagram (CLD) was developed to identify feedback structures linking organisational variables (such as leadership, institutional support, curricular design, organisational flexibility, and institutional climate) with mediating variables and dropout outcomes. Following the methodological approach of Shinde and Kaynak (2016), the CLD was used to formulate dynamic hypotheses about how organisational quality and management decisions generate reinforcing or balancing dynamics that influence student dropout.

In the second phase, these qualitative structures were operationalised through a stock-and-flow model in the form of a Forrester diagram, which formalises the system using equations connecting stock variables, flow rates, and auxiliary variables. The direct integration of the CLD and the simulation model constitutes the core of the mixed-methods design, as qualitative hypotheses are translated into a mathematical representation that enables analysis of system behaviour over time (Aracil and Gordillo, 1997; Bala et al., 2017; Bianchi, 2016; Cosenz, 2022).

3.2 System boundaries and time horizon

Simulations were conducted over a ten-year time horizon, allowing for the analysis of cumulative and delayed effects of institutional management decisions on key variables such as academic burnout and student dropout. This prospective horizon is appropriate, given that the effects of organisational and policy decisions are not immediate but manifest in delayed, accumulative ways (Bianchi, 2016; Cosenz, 2022; Shinde and Kaynak, 2016).

The model includes as key actors TVHE students, technical and vocational institutions, teaching and support staff, and management teams responsible for academic and organisational governance. Unlike models focused on labour market dynamics, this study delimits the system to the institutional domain of TVHE, emphasising organisational characteristics as central explanatory variables, in line with the study objective.

3.3 Model structure and variables

The model was developed through a three-phase sequential process. First, constructs and causal relationships identified in

the theoretical framework were represented in a causal loop diagram. Second, the CLD was translated into a Forrester diagram, converting qualitative relationships into a formal structure of stocks, flows, and auxiliary variables. Third, each relationship was specified by mathematical equations that defined rates of change and interdependencies, enabling the computational simulation of system dynamics.

The System Dynamics architecture was designed to represent causal relationships between organisational characteristics, mediating variables (particularly academic burnout), and student dropout. Following Shinde and Kaynak (2016), the model distinguishes between endogenous and exogenous variables and defines system boundaries based on organisational control, incorporating only those variables that institutions can influence through management decisions.

Organisational characteristics function as modulators that amplify or attenuate the impact of individual, academic, and socioeconomic variables. Accordingly, the model does not aim to predict individual trajectories but to simulate aggregate behavioural patterns, consistent with System Dynamics principles (Sterman, 2000).

Student dropout is conceptualised as the outcome of multiple interacting pressures—organisational, academic, and psycho-emotional—rather than as the effect of a single isolated factor. In line with this systemic perspective, the equations incorporate intensity terms that act as amplification mechanisms, allowing variables such as academic burnout, vocational misfit, and student performance problems to increase the baseline probability of dropout through cumulative, non-linear effects. These terms make the model both calibrable and operational for scenario analysis, as they reflect the magnitude with which each factor influences the dynamics of dropout.

In addition, the model includes a set of parametric constants (k coefficients), whose function is not to represent directly observable values but to act as elasticities or adjustment factors that regulate the speed of processes (accumulation, recovery, erosion, or improvement) and the sensitivity of causal relationships between variables. The inclusion of these parameters enables calibration to specific institutional contexts, sensitivity analysis, and policy-scenario exploration without altering the conceptual structure of the system, consistent with the explanatory and exploratory nature of System Dynamics.

3.4 Data sources and parameterisation

The model was parameterised using secondary, aggregated, and publicly available information from the Higher Education Information System (SIES) of the Chilean Ministry of Education. Specifically, higher education enrolment reports (SIES, 2019a; SIES, 2023) and first-year undergraduate retention reports for the 2014–2018 cohorts (SIES, 2019b) and the 2017–2021 cohorts (SIES, 2022) were consulted. Additionally, reference values drawn from Sotomayor and Rodríguez (2020) were incorporated for the case of a Chilean technical training centre, in order to anchor baseline dropout parameters and student labour participation to contextualised empirical evidence.

The parameterisation follows a referential rather than institution-specific criterion: the initial values of the stocks (for example, Active students = 26,600; initial Academic burnout = 0.2; Effective tutoring/mentoring capacity = 0.7) and key structural parameters (for example, Base dropout rate = 0.2215; Working students = 0.2927) were established based on the aggregated proportions of the Chilean TVHE subsystem reported in the aforementioned sources. The k coefficients, in turn, were set within plausible ranges derived from the System Dynamics literature applied to education (Bianchi, 2016; Shinde and Kaynak, 2016), recognising their function as adjustment elasticities rather than directly observable values. This parameterisation strategy allows the model to be operationalised on a real case without aiming to represent a specific institution, in line with the prospective and explanatory nature of the study.

The selection of the Chilean system is based on three reasons. First, it provides systematised, publicly available, and auditable information on retention and enrolment within the technical and vocational subsystem. Second, its TVHE system presents structural features (high participation of working students and a strong presence of differentiated technical institutions) that are typical of Latin American contexts, which enhances the transferability of the model to other regional settings. Third, there is prior academic literature on dropout in Chilean TVHE (Barragán Moreno and González Támara, 2024; Sotomayor and Rodríguez, 2020), which enables comparisons between simulated behaviours and documented empirical patterns.

3.5 Simulation environment and numerical configuration

The construction of the causal loop diagram (CLD), the Forrester diagram, and the execution of simulations and sensitivity analyses were carried out using Vensim® PLE software, version 10.4.0. This tool enables the integration of the systemic structure of the model with the dynamic analysis of variables, ensuring technical consistency in robustness testing and in the evaluation of the different simulated scenarios. The simulation horizon was set at ten years, with a time step (TIME STEP) of one year, which is consistent with the unit of educational analysis (annual cohort) and with the temporal scale of the institutional management decisions being modelled. Numerical integration was performed using the software's default method, and the initial conditions of the stocks were established according to the values reported in Table 3 and detailed in the Results section.

3.6 Model validation and sensitivity analysis

Model validation was conducted following the methodological recommendations of Bala et al. (2017), including both structural and behavioural validation. In line with Shinde and Kaynak (2016), it is recognised that, in complex educational systems, validation is not limited to predictive accuracy but also to the causal coherence of the model and its ability to reproduce plausible patterns of system behaviour.

Consistent with the above, two complementary procedures were applied. First, a univariate sensitivity analysis was conducted by applying ±10% perturbations around the baseline

TABLE 3 Technical specifications of variables for student dropout in TVHE.

Variable	Equation	Interpretation
Academic burnout (stock)	*INTEG*(*Burnout accumulation* − *Burnout recovery*, 0.2	Accumulated level of academic burnout among active students. It acts as the central mediating variable, translating organisational, academic, and personal pressures into a higher probability of dropout.
Burnout accumulation	*k ccumulation* ∗ *Perceived academic workload* ∗ (1 + *K role* ∗ *Role overload*) ∗ (1 − *Academic burnout*)	Inflow to academic burnout. It increases with perceived academic workload and role overload, and decreases as burnout approaches its maximum.
Burnout recovery	*k recovery* ∗ *Quality institutional support* ∗ (1 − *Academic burnout*)	Recovery flow from academic burnout. It represents the institutional capacity to mitigate burnout through effective support.
Active students (stock)	*INTEG*(*Enrollment* − *Dropout* − *Graduation*, 26600)	Active student population. It constitutes the demographic base of the system and determines the potential volume of dropout and support demand.
Enrollment	*Enrollment rate* ∗ *Net growth target*	Annual inflow of new students, defined as a system growth scenario.
Graduation	*Active students* ∗ *Graduation rate*	Outflow through graduation. It closes the population balance of the system.
Dropout	*Active students* ∗ *Student dropout rate*	Annual number of students leaving the system. Aggregated model outcome.
Student dropout rate	*Base dropout rate* ∗ (1 + *k burnout*∗*Academic burnout*) ∗ (1 + *k misfit*∗*Vocational misfit*) ∗ (1 + *k performance*∗*Student performance problems*)	Effective dropout rate. It scales a baseline rate through non-linear amplification effects associated with burnout, vocational misfit, and performance problems.
Base dropout rate	0.2215	Structural dropout rate without additional pressures—empirical baseline value.
Student performance problems	*MIN*(1, *MAX*(0, 0.1 + 0.55∗*Academic burnout* + 0.35∗*Perceived academic workload*))	Index of academic difficulties (absenteeism, low performance, late submissions) induced by pressure and burnout.
Student support demand	*ctive students* ∗ (0.03 + 0.07∗*Student performance problems* + 0.06∗*Academic burnout*)	Aggregate demand for institutional support generated by the active student population and their academic and emotional difficulties.
Effective tutoring/ mentoring capacity (stock)	*INTEG*(*Capacity build* − *up* − *Capacity decay*, 0.7)	Accumulated capacity of the system to provide tutoring and academic support.
Capacity build-up	*K capacity build* − *up* ∗ *Support investment policy*	Increase in support capacity resulting from institutional investment decisions.
Capacity decay	*k capacity decay* ∗ *Effective tutoring*/*mentoring capacity* ∗ *Support staff burnout*	Loss of capacity due to wear and burnout of support staff.
Quality institutional support	*MIN*(1, *Effective tutoring*/*mentoring capacity* / (*Student support demand* + 0.001))	Proportion of support demand effectively covered. Key variable reflecting system saturation.
Support staff burnout (stock)	*INTEG*(*Staff burnout accumulation* − *Staff burnout recovery*, 0.15)	Accumulated level of burnout among teaching and support staff.
Staff burnout accumulation	*Faculty and support staff pressure* ∗ *k support accumulation*	Inflow to staff burnout generated by institutional pressure.
Staff burnout recovery	*k srecovery* ∗ (1 − *Faculty and support staff pressure*) ∗ (1 − *Support staff burnout*)	Recovery from staff burnout when pressure decreases.
Faculty and support staff pressure	*INTEG*(*Coordination improvement* − *Coordination erosion*, 0.65)	Index of operational pressure on staff. It increases with demand and decreases with effective support.

(*Continued*)

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TABLE 3 Continued

Variable	Equation	Interpretation
Institutional coordination (stock)	*INTEG*(*Coordination improvement* − *Coordination erosion*, 0.65)	Institutional capacity to coordinate schedules, assessments, and academic processes.
Coordination improvement	*Coordination investment policy* ∗ *k coordination investment policy*	Improvement in coordination through deliberate institutional intervention.
Coordination erosion	*k coordination erosion* ∗ *Faculty and support staff pressure* ∗ *Institutional coordination*	Loss of coordination under organisational pressure.
Evaluation peaks	*Base peaks* ∗ (1 − *Institutional coordination*)	Intensity of assessment peaks and deadlines; increases when coordination is low.
Institutional flexibility (stock)	*INTEG*(*Flexibility improvement* − *Flexibility erosion*, 0.55)	Organisational flexibility (schedules, modalities, logistics). Key lever for working students.
Flexibility improvement	*Flexibility investment policy* ∗ *k flexibility improvement*	Increase in flexibility through institutional action.
Flexibility erosion	*k flexibility erosion* ∗ *Faculty and support staff pressure* ∗ *Institutional flexibility*	Loss of flexibility due to operational pressure.
Work–study compatibility	*MIN*(1, *MAX*(0, 0.01 + 0.03∗*Institutional flexibility* − 0.015∗*Role overload* − 0.003∗*Working students*))	Capacity to balance study and work. Bridging variable between organisation and perceived workload.
Perceived academic workload	0.025 + 0.01∗*Evaluation peaks* − 0.36∗*Work* − *study compatibility* + 0.24∗*Theory* − *practice gap*	Subjective academic workload perceived by students.
Theory–practice gap	0.5	Perceived gap between curriculum and labour market reality (scenario parameter).
Vocational misfit	*MIN*(1, *MAX*(0, 0.12 + 0.55∗*Theory* − *practice gap* + 0.25∗*Academic burnout*))	Vocational mismatch intensified by training gaps and burnout.
Role overload	0.5	Role overload (work, family, study, digitalisation). Structural parameter of the TVHE profile.
Working students	0.2927	Proportion of working students. Conditions work–study compatibility.
Institutional climate	*MIN*(1, *MAX*(0, 0.012 − 0.023∗*Faculty and support staff pressure*))	Perceived institutional climate is sensitive to organisational pressure.
Perceived organisational support	*MIN*(1, *MAX*(0, 0.003 + 0.025∗*Institutional climate* − 0.014∗*Support staff burnout*))	Organisational support perceived by students and staff.
TIME STEP/FINAL TIME	TIME STEP = 1; FINAL TIME = 10	Ten-year time horizon with annual time step.

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scenario values for the model's endogenous parameters, using the Sensitivity2All tool in Vensim PLE. The ±10% range was selected as a moderate perturbation interval commonly used in System Dynamics studies to evaluate the robustness of model behaviour under plausible parameter uncertainty (Bala et al., 2017; Sterman, 2000). Because the k coefficients operate as adjustment elasticities rather than directly observable empirical values, varying them within ±10% enables the assessment of the stability of the model's causal structure and behavioural patterns without imposing unrealistic changes in system dynamics. This approach facilitates the identification of dominant parameters, non-linear effects, and structural asymmetries while preserving the plausibility of the simulated educational context. The analysis focused on two critical system variables: the student dropout rate as the outcome variable and institutional flexibility as a strategic organisational lever, with the aim of identifying dominant variables, non-linear behaviours, and structural asymmetries within the system.

Second, stress tests were conducted to evaluate the robustness of the model under extreme configurations, in three modalities: stress associated with the TVHE student profile (ST1), which combines high levels of working student proportion, role overload, and theory–practice gap; stress associated with organisational erosion (ST2), which increases by 10% the erosion coefficients of flexibility and institutional coordination; and institutional response capacity testing (ST3), which combines the conditions of ST1 with the full activation of all organisational policy levers.

3.7 Simulation scenarios

A total of 40 simulation scenarios were designed, organised into three groups: (1) baseline system behaviour; (2) interventions focused on institutional coordination, organisational flexibility, and support capacity; and (3) strategic combinations of these levers.

Within each intervention block, policy parameters were varied across three levels—Low (0.3), Medium (0.5), and High (0.7)—which respectively represent low-, medium-, and high-intensity institutional efforts applied to the management variable under consideration. The Medium level (0.5) corresponds to the baseline scenario, while the Low and High levels introduce symmetric perturbations of approximately ±40%. This design allows for the comparison of system trajectories under conditions of underinvestment, regular operation, and strengthened institutional commitment, providing a parametric interpretation of the system's sensitivity to management decisions.

The individual blocks (A–F) examine the effect of perturbations on a single variable at a time (Coordination, Flexibility, and Support investment policies, Working students, Role overload, and Theory–practice gap). In contrast, the combined blocks (CF, FS, CS, and ALL) analyse synergies and interactions among multiple levers simultaneously.

In each simulation, three categories of variables are monitored: outcome variables (Dropout and Student dropout rate), mediating variables (Academic burnout and Student support demand), and organisational capacities (Institutional coordination, Institutional flexibility, Quality institutional support, and Support staff burnout). This structure enables analysis of how management decisions dynamically shape burnout and institutional pressure, and how these changes influence student dropout in TVHE.

3.8 Ethical considerations

The study was conducted exclusively using secondary, aggregated, and publicly available data (SIES, 2019a, 2019b, 2022, 2023; Sotomayor and Rodríguez, 2020). No personal or identifiable institutional data were collected or processed. The research and modelling adhered to the ethical principles of transparency, model traceability, and proper citation of all scientific sources used, consistent with international standards of research integrity applicable to modelling studies based on secondary data.

4 Results

This section presents the results of the study in two complementary blocks. The first block describes the outputs of the modelling process, including system boundary definition through the Bull's Eye diagram, the identification of feedback structures represented in the causal loop diagram, and the formalisation of the Forrester model with its technical variable structure. The second block presents the dynamic results derived from simulations: baseline scenario behaviour, sensitivity analysis, isolated intervention scenarios, combined scenarios, and system stress tests. In line with the methodological conventions of System Dynamics, this section is limited to describing observed behaviours; interpretation of the findings and their comparison with the literature are developed in Section 5.

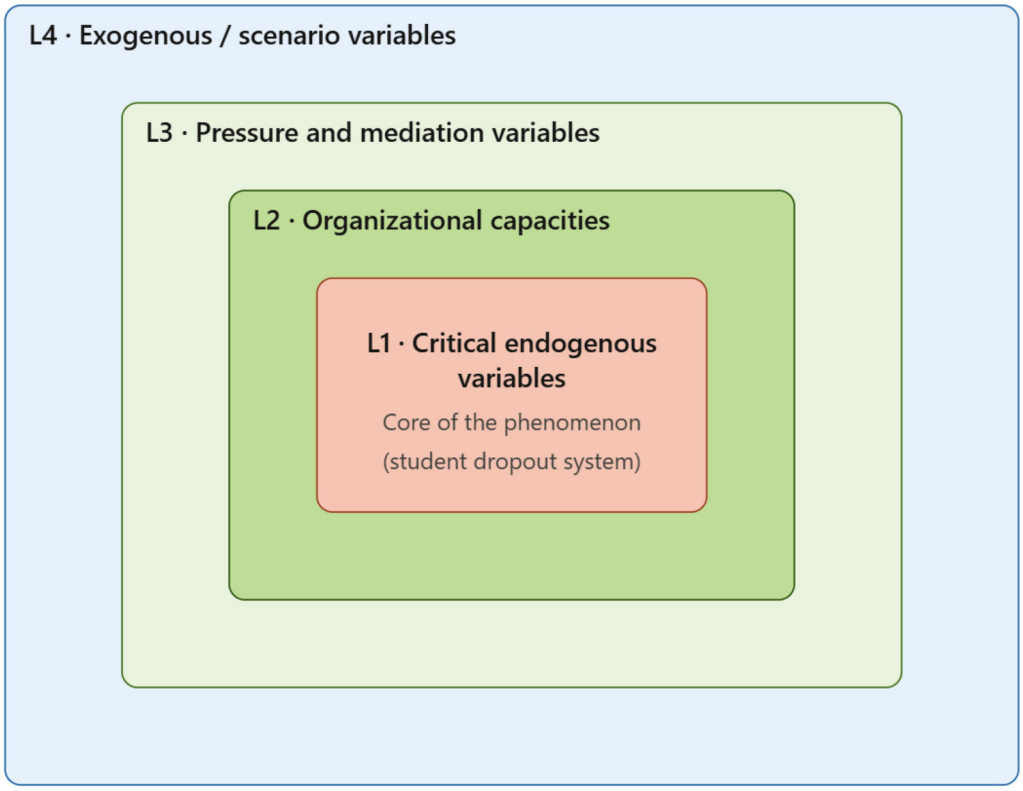
4.1 Outputs of the modelling process

4.1.1 System boundary: bull's eye diagram

Figure 1 presents the Bull's Eye diagram defining the system boundary of the model. The central endogenous variables include student dropout, academic burnout, and student support demand. Organisational capacities—such as institutional coordination, organisational flexibility, and support capacity—are modelled as key intervention levers. Mediating pressures (for example, perceived academic workload, evaluation peaks, and pressure on teaching and support staff) translate organisational conditions into processes of burnout and dropout. Finally, structural characteristics of the student population and policy instruments are treated as exogenous scenario variables.

4.2 Causal loop diagram

The causal loop diagram presented in Figure 2 supports modelling the influence of organisational characteristics on student dropout in TVHE by identifying a broad set of feedback



L1 · Critical endogenous variables

- Student dropout
- Active students
- Academic burnout
- Student performance problems
- Student support demand

L3 · Pressure and mediation variables

- Perceived academic workload
- Evaluation peaks
- Faculty and support staff pressure
- Support staff burnout
- Work-study compatibility
- Role overload
- Vocational misfit · Theory-practice gap

L2 · Organizational capacities

- Institutional coordination
- Organizational flexibility
- Quality institutional support
- Tutoring/mentoring capacity
- Institutional climate
- Perceived organizational support

L4 · Exogenous / scenario variables

- Working students
- Digital wellbeing programs
- External financial difficulties
- Baseline academic intensity
- Policy investment parameters (coordination, flexibility, support investment policy)

FIGURE 1
Bull's Eye diagram de la deserción estudiantil en la ESTP. Source: Elaboración propia con base en Shinde and Kaynak, 2016.

structures that explain dropout as an endogenous, cumulative, and non-linear phenomenon. From the complete diagram, fifteen loops involving student dropout, either directly or indirectly, were identified. Six loops were selected as particularly representative for the study objective: three reinforcing loops (R6, R7, and R13) and three balancing loops (B1, B2, and B3).

The selection criteria were their organisational centrality, their capacity to represent endogenous dynamics of accumulation and feedback, and their relevance as institutional management levers. Reinforcing loops capture the structural mechanisms through which deterioration in the institutional climate, academic miscoordination, and insufficient organisational flexibility amplify academic burnout and pressure on support systems, thereby reinforcing dropout over time. In contrast, balancing loops represent key institutional interventions—organisational flexibility, strengthening of support capacity, and digital wellbeing programmes—that mitigate these dynamics and support student retention. Together, these six loops constitute the causal core of the model and guide the transition to stock-and-flow modelling.

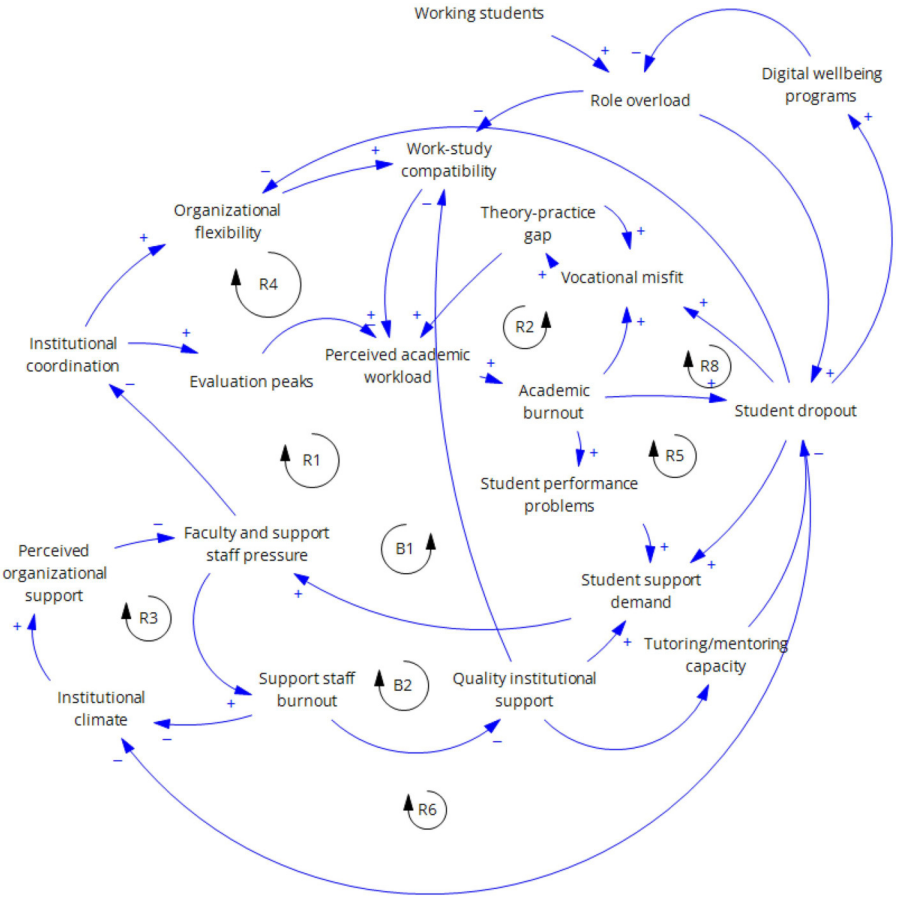


FIGURE 2
Causal Loop Diagram of Student Dropout at the ESTP.

R7: Institutional coordination–evaluation peaks–burnout loop. In this reinforcing loop, student dropout increases demand for student support, intensifying pressure on faculty and support staff. Under higher pressure, institutional coordination weakens, leading to evaluation peaks. These peaks increase perceived academic workload, thereby raising academic burnout. The increase in academic burnout, in turn, reinforces student dropout, closing the loop. Dynamic hypothesis: If student support demand increases without a proportional strengthening of institutional coordination, pressure on faculty and support staff will intensify, generating evaluation peaks that increase perceived academic workload and academic burnout, thereby reinforcing student dropout over time.

R13: Organisational flexibility–support capacity erosion loop. In this reinforcing loop, student dropout reduces organisational flexibility, deteriorating work–study compatibility. Lower compatibility increases perceived academic workload and academic burnout. Burnout leads to student performance problems, thereby increasing demand for student support. This increase intensifies faculty and support staff pressure, leading to support staff burnout and reducing the quality of institutional support and tutoring/mentoring capacity. Reduced support capacity, in turn, reinforces student dropout. Dynamic hypothesis: If organisational flexibility and institutional support capacity are not strengthened in response to increasing dropout, work–study incompatibility, and academic burnout, they will trigger a cycle of performance deterioration and institutional overload that reinforces dropout over time.

R6: Institutional climate–support the sustainability loop. In this reinforcing loop, student dropout deteriorates institutional climate and reduces perceived organisational support. This reduction increases pressure on faculty and support staff, leading to burnout among support staff. Staff burnout reduces the quality of institutional support and limits tutoring/mentoring capacity, weakening the sustainability of institutional support and reinforcing student dropout. Dynamic hypothesis: If the deterioration of institutional climate and perceived organisational support is not contained, pressure and staff burnout will erode institutional support capacity, cumulatively reinforcing student dropout.

B1: Organisational flexibility–burnout mitigation loop. In this balancing loop, student dropout triggers institutional responses to increase organisational flexibility. Greater flexibility improves work–study compatibility, which reduces perceived academic workload. As a result, academic burnout decreases, attenuating the upward trend in student dropout. Dynamic hypothesis: If the institution increases organisational flexibility in response to signals of student withdrawal, work–study compatibility will improve, reducing perceived academic workload and academic burnout, thereby contributing to containing dropout over time.

B2: Institutional support capacity stabilisation loop. In this balancing loop, an increase in student dropout raises student support demand, increasing faculty and support staff pressure

and support staff burnout. In response, the institution may strengthen the quality of institutional support and expand tutoring/mentoring capacity, thereby stabilising support demand and mitigating future pressures. Dynamic hypothesis: If the growth in student support demand is accompanied by sustained strengthening of tutoring and mentoring capacity, the institutional system will be able to buffer pressure on staff and prevent burnout spirals that increase dropout.

B3: Digital well-being and role overload buffering loop. In this balancing loop, student dropout drives the implementation of digital well-being programmes, which reduce role overload. Reduced overload improves work–study compatibility, lowering perceived academic workload and academic burnout, thereby helping slow the growth of student dropout. Dynamic hypothesis: If digital wellbeing programmes effectively reduce role overload associated with digitalisation, academic burnout will be mitigated, and student retention trajectories will stabilise.

4.3 Forrester diagram

Figure 3 presents the Forrester model constructed to represent the dynamics through which organisational characteristics influence student dropout in TVHE. The model formalises the relationships identified in the causal loop diagram by translating them into a structure of stocks, flows, and auxiliary variables, enabling the simulation of cumulative and non-linear behaviours over a ten-year time horizon.

Within the model architecture, student dropout is represented as a systemic outcome mediated by academic burnout, which accumulates as a function of perceived academic workload, role overload, and organisational conditions. Institutional capacities—coordination, organisational flexibility, institutional climate, and academic support capacity—are modelled as stocks subject to processes of erosion and strengthening, acting as structural levers that amplify or buffer pressures on students and staff.

Table 3 details the technical structure of the model presented in Figure 3, including the definitions of each variable, the equations, and their interpretations, which constitute the basis for the simulation of scenarios and the sensitivity analysis presented in the following sections.

4.4 Baseline scenario

The baseline scenario represents the evolution of the system under current organisational conditions, keeping structural parameters constant and without introducing additional policy interventions. The simulated trajectories of the student dropout rate, academic burnout, and support staff burnout over the ten-year horizon are presented in Figures 4A–C, respectively.

The student dropout rate (Figure 4A) exhibits a monotonically increasing trajectory over the simulated horizon, rising from 0.37 in year 1 to 0.55 in year 10, with an average slope of approximately 0.020 units per year. The relative increase between the initial and final year is 48.6%. No inflexion points or regime shifts are observed in the trajectory.

The trajectory of academic burnout (Figure 4B) shows sustained growth throughout the simulation period, starting

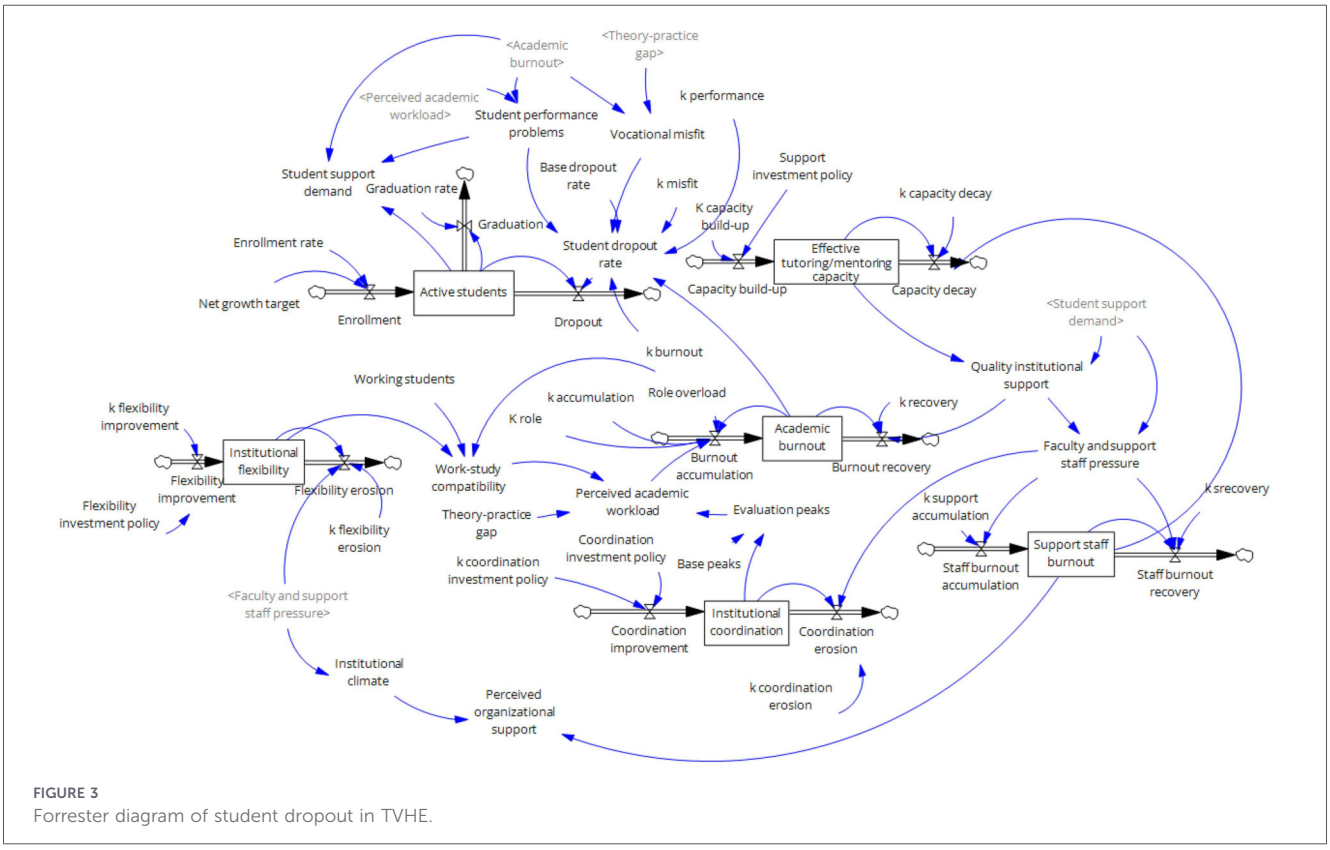


FIGURE 3
Forrester diagram of student dropout in TVHE.

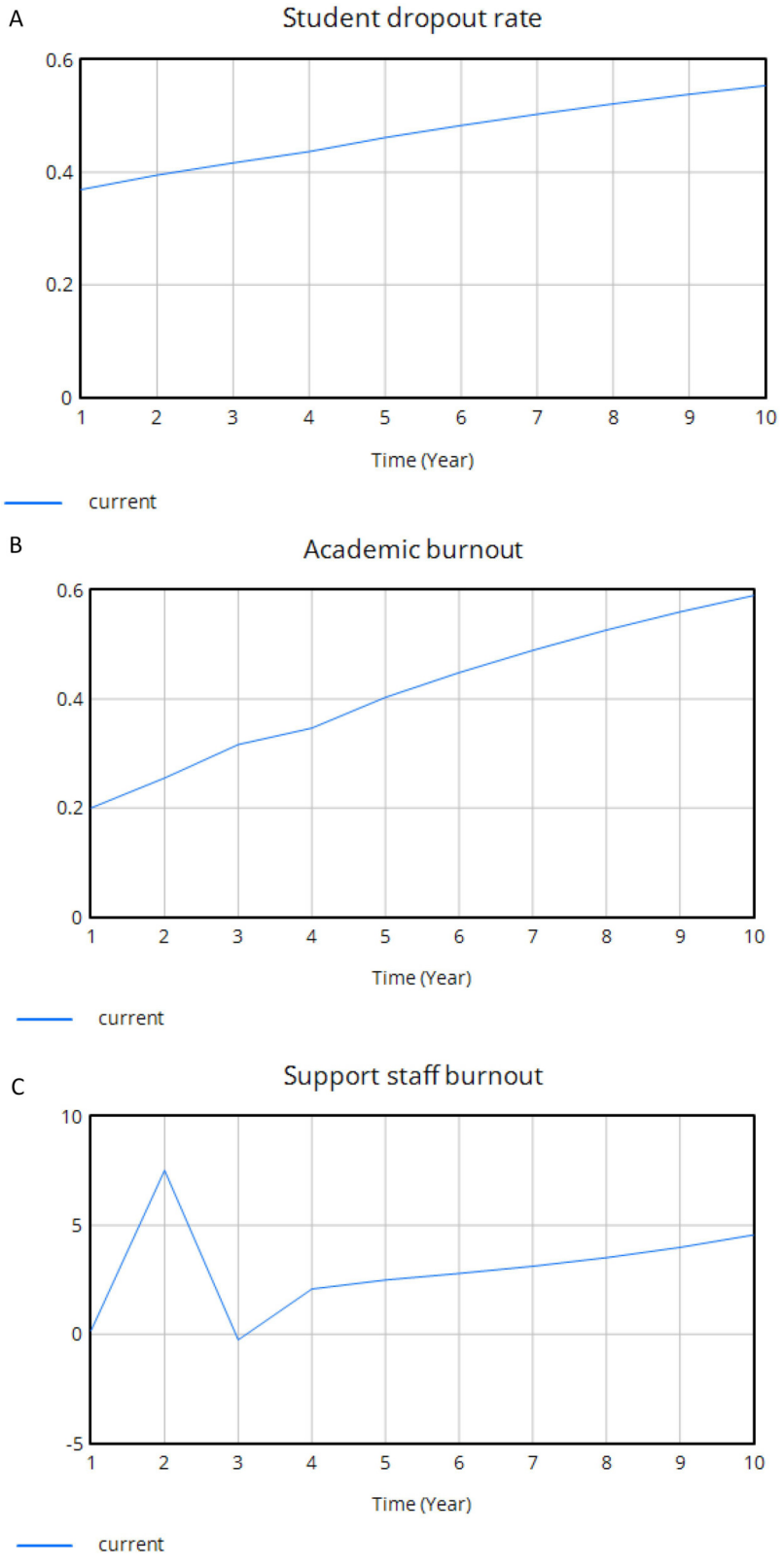


FIGURE 4
Trajectories in the baseline scenario for student dropout in TVHE.

from an initial value of 0.2 and reaching 0.58 by year 10, representing an increase of 0.38 units over the horizon. The trajectory maintains an approximately constant slope, with no saturation or decline phases during the observed period.

The trajectory of support staff burnout (Figure 4C) displays two distinct phases: an initial phase of higher variability during the first four years, with oscillations around levels above the initial level (0.15), followed by a phase of gradual growth,

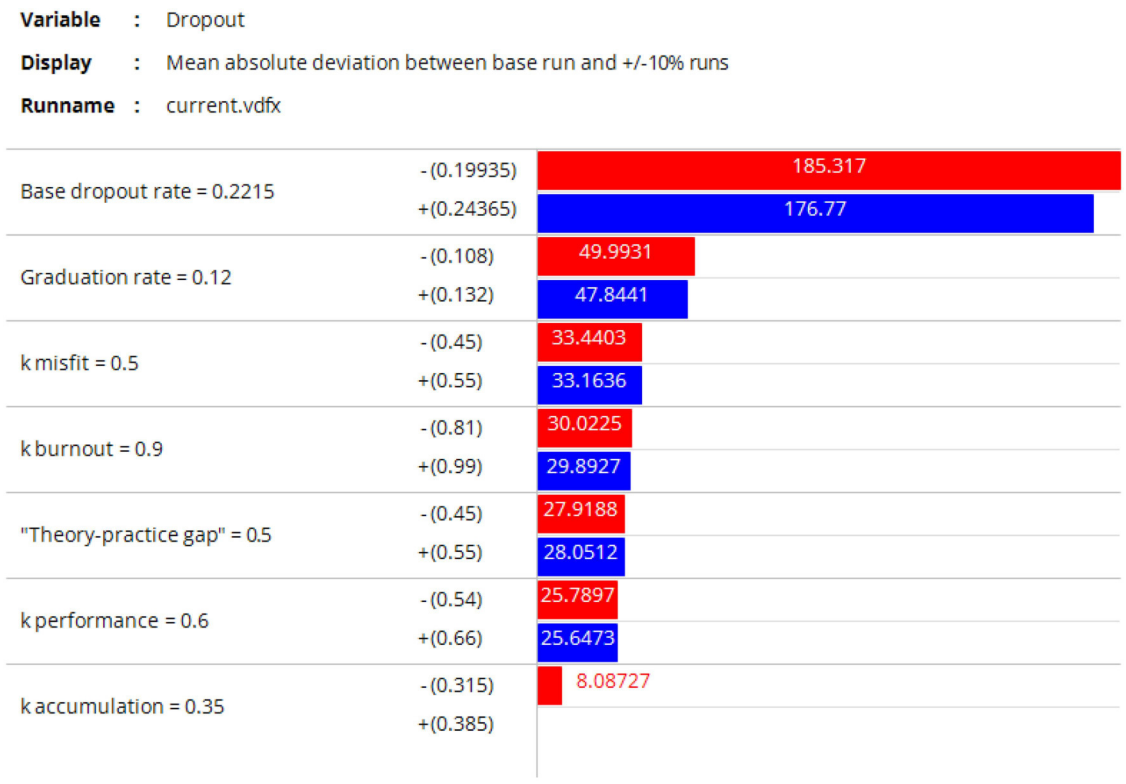


FIGURE 5
Sensitivity analysis for institutional flexibility in TVHE.

reaching values close to 4.55 by year 10. Unlike academic burnout, which follows a monotonically increasing trajectory, support staff burnout exhibits a non-monotonic pattern in its initial phase.

4.5 Sensitivity analysis

To assess the robustness of the model behaviour and examine the relative influence of the main parameters, a univariate sensitivity analysis was conducted using ±10% variations around the baseline scenario values. The analysis focused on two system variables: student dropout and institutional flexibility, given their roles as a critical outcome variable and a strategic organisational lever, respectively.

The results shown in Figure 5 indicate the following ranking of parameters by their relative influence on student dropout: the base dropout rate has the greatest effect, followed by the parameters associated with academic burnout (*k burnout*) and vocational misfit (*k misfit*), which exhibit effects of comparable magnitude. The effect of academic performance problems (*k performance*) falls in the middle, whereas the parameters linked to the speed of burnout accumulation show lower sensitivity.

For institutional flexibility (Figure 6), the analysis shows that the flexibility erosion parameter (*k flexibility erosion*) has the greatest effect, exceeding the set of parameters associated with improvement or institutional investment. The effects of the base dropout rate and the graduation rate appear to be of secondary magnitude.

4.6 Isolated intervention scenarios

Table 4 presents the results of the 40 simulations performed. All reported values correspond to the end of the simulation horizon (year 10), allowing for comparison of final system configurations under different policy interventions. This subsection describes the results of the isolated intervention scenarios, organised into six blocks (A–F), in which a single parameter is varied at a time across three levels: Low (0.3), Medium (0.5, baseline scenario), and High (0.7).

In blocks A, B, and C, corresponding respectively to institutional coordination, organisational flexibility, and support capacity investment policies, the student dropout rate at year 10 remains constant at 0.55 across the three levels of intensity (Low, Medium, High), with only marginal variations in final academic burnout between 0.58 and 0.59. Institutional coordination shows proportional changes in response to policy A (0.00/0.19/0.39), while institutional flexibility responds similarly to policy B (0.20/0.40/0.59). Quality institutional support fluctuates between 0.01 and 0.02 across all levels. The absolute number of dropouts remains at 14 students per year, and support staff burnout remains at 4.55 across all sub-scenarios in blocks A–C.

Blocks D, E, and F examine perturbations in structural parameters rather than institutional policies (working students,

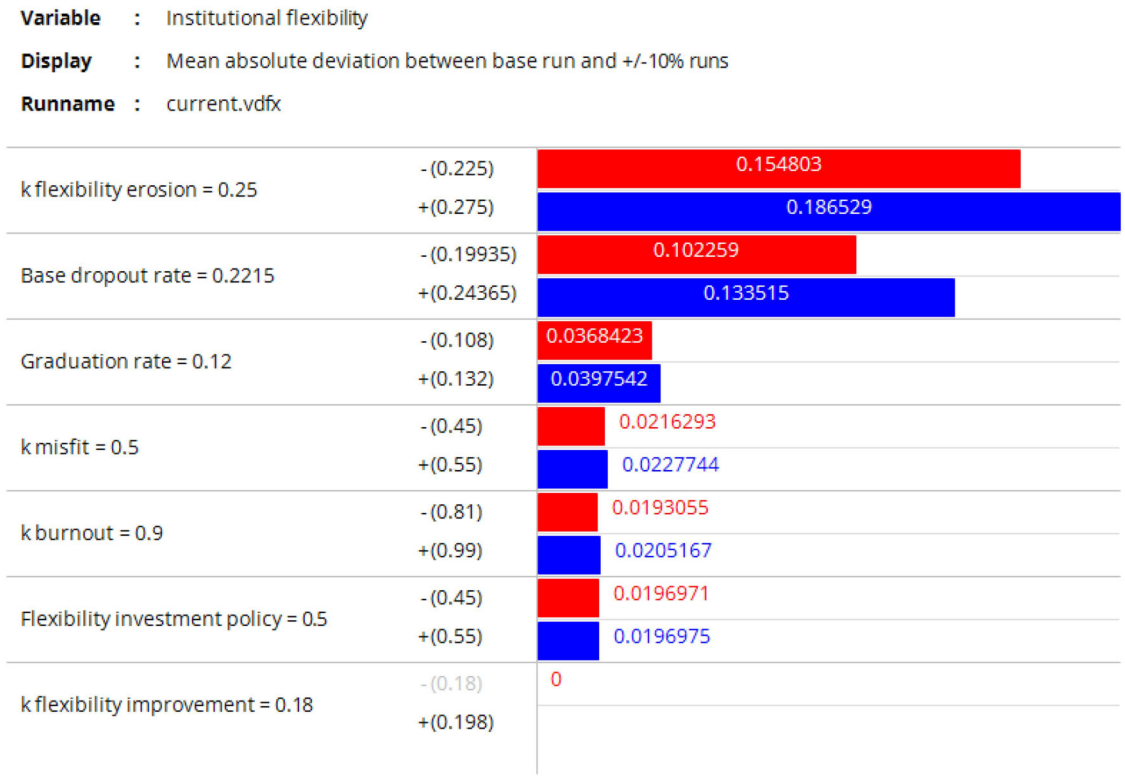


FIGURE 6
Análisis de sensibilidad para Institutional Fexibility en la ESTP.

role overload, and theory–practice gap). Block D (working students) shows stable values of student dropout rate = 0.55 and academic burnout between 0.58 and 0.59 across the three levels. Block E (role overload) presents greater variation: with role overload = 0.3, the student dropout rate decreases to 0.53 and academic burnout to 0.55; with role overload = 0.7, the student dropout rate increases to 0.57 and academic burnout to 0.62. Block F (theory–practice gap) exhibits the greatest variation among all scenarios: with theory–practice gap = 0.3, the student dropout rate is 0.47, academic burnout is 0.48, student support demand is 4.21, and dropout is 22; with theory–practice gap = 0.7, the student dropout rate increases to 0.62, academic burnout to 0.67, student support demand decreases to 1.91, and dropout is 11.

4.7 Combined organisational policy scenarios

The combined scenarios examine the simultaneous effect of two or more organisational policies. Blocks CF (coordination and flexibility), FS (flexibility and support), and CS (coordination and support) evaluate pairs of policy levers, while the ALL block activates all organisational policies simultaneously.

In blocks CF, FS, and CS, the student dropout rate at year 10 remains constant at 0.55 across the three levels evaluated (Low, Medium, High). Changes are reflected in the stocks of organisational capacities and in the quality of institutional support. In the CF-High scenario (0.7, 0.7), institutional coordination reaches 0.39 and institutional flexibility 0.59, whereas in CF-Low (0.3, 0.3), coordination drops to 0.00 and flexibility to 0.20. A similar pattern is observed in the FS and CS blocks, with proportional variations in the stocks affected by each pair of policies.

The ALL block, representing the integrated institutional strategy, largely reproduces the values observed across the combined scenarios: a student dropout rate of 0.55 and academic burnout between 0.58 and 0.59 across all three levels. The main difference compared to the isolated scenarios lies in the simultaneous strengthening of institutional coordination and institutional flexibility (0.39 and 0.59 in ALL-High compared to 0.00 and 0.20 in ALL-Low).

4.8 Stress tests

The stress tests evaluate the behaviour of the system under extreme configurations. Scenario ST1 simultaneously activates high values (0.7) for working students, role overload, and theory–practice gap, representing a student profile of maximum vulnerability. Scenario ST2 increases the erosion coefficients for flexibility and institutional coordination by 10%, simulating a context of heightened organisational pressure. Scenario ST3 combines the conditions of ST1 with the full activation of all organisational policies (ALL-High strategy), assessing institutional response capacity.

In ST1, the student dropout rate reaches 0.62, academic burnout reaches 0.67, student support demand decreases to 1.91, institutional coordination decreases to 0.00, and institutional

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TABLE 4 Simulation plan and results.

ID	Scenario/parameter	Value	SD (n)	DR	AB	SSD	IC index	IF	QIS	SSB
Block S0 — Baseline scenario										
S0	Baseline (all policies)	0.5	14	0.55	0.58	2.64	0.19	0.40	0.02	4.55
Block A — Coordination investment policy										
A1	Low coordination	0.3	14	0.55	0.59	2.63	0.00	0.40	0.02	4.55
A2	Medium coordination	0.5	14	0.55	0.58	2.64	0.19	0.40	0.02	4.55
A3	High coordination	0.7	14	0.55	0.58	2.64	0.39	0.40	0.02	4.55
Block B — Flexibility investment policy										
B1	Low flexibility	0.3	14	0.55	0.59	2.64	0.19	0.20	0.02	4.55
B2	Medium flexibility	0.5	14	0.55	0.58	2.64	0.19	0.40	0.02	4.55
B3	High flexibility	0.7	14	0.55	0.58	2.64	0.19	0.59	0.02	4.55
Block C — Support investment policy										
C1	Low support	0.3	14	0.55	0.59	2.64	0.19	0.40	0.01	4.55
C2	Medium support	0.5	14	0.55	0.58	2.64	0.19	0.40	0.02	4.55
C3	High support	0.7	14	0.55	0.59	2.64	0.19	0.40	0.01	4.55
Block D — Working students										
D1	Low proportion	0.3	14	0.55	0.58	2.64	0.19	0.40	0.02	4.55
D2	Medium proportion	0.5	14	0.55	0.59	2.63	0.19	0.40	0.02	4.55
D3	High proportion	0.7	14	0.55	0.59	2.63	0.19	0.40	0.02	4.55
Block E — Role overload										
E1	Low overload	0.3	15	0.53	0.55	2.83	0.20	0.40	0.02	4.54
E2	Medium overload	0.5	14	0.55	0.58	2.64	0.19	0.40	0.02	4.55
E3	High overload	0.7	13	0.57	0.62	2.47	0.18	0.39	0.02	4.57
Block F — Theory–practice gap										
F1	Low gap	0.3	22	0.47	0.48	4.21	0.32	0.38	0.01	4.64
F2	Medium gap	0.5	14	0.55	0.58	2.64	0.19	0.40	0.02	4.55
F3	High gap	0.7	11	0.62	0.67	1.91	0.00	0.42	0.03	4.35
Block CF — Coordination × Flexibility synergy										
CF−	Low synergy	0.3/0.3	14	0.55	0.59	2.63	0.00	0.20	0.02	4.55
CF0	Medium synergy	0.5/0.5	14	0.55	0.58	2.64	0.19	0.40	0.02	4.55
CF+	High synergy	0.7/0.7	14	0.55	0.58	2.64	0.39	0.59	0.02	4.55
Block FS — Flexibility × Support synergy										
FS−	Low synergy	0.3/0.3	14	0.55	0.59	2.64	0.19	0.20	0.01	4.55
FS0	Medium synergy	0.5/0.5	14	0.55	0.58	2.64	0.19	0.40	0.02	4.55
FS+	High synergy	0.7/0.7	14	0.55	0.58	2.64	0.19	0.59	0.031	4.55
Block CS — Coordination × Support synergy										
CS−	Low synergy	0.3/0.3	14	0.55	0.59	2.64	0.00	0.40	0.013	4.55
CS0	Medium synergy	0.5/0.5	14	0.55	0.58	2.64	0.19	0.40	0.02	4.55
CS+	High synergy	0.7/0.7	14	0.55	0.58	2.64	0.39	0.40	0.03	4.55
Block ALL — Integrated institutional strategy										
ALL−	Low integrated	0.3	14	0.55	0.59	2.64	0.00	0.20	0.013	4.55
ALL0	Medium integrated	0.5	14	0.55	0.58	2.64	0.19	0.40	0.02	4.55

(*Continued*)

TABLE 4 Continued

ID	Scenario/parameter	Value	SD	DR	AB	SSD	IC	IF	QIS	SSB
			(n)				*index*			
ALL+	High integrated	0.7	14	0.55	0.58	2.64	0.39	0.59	0.031	4.55
Block ST — Stress tests and institutional response										
ST1	ESTP high-vulnerability profile	0.7	11	0.62	0.67	1.91	0.00	0.42	0.033	4.35
ST2	Organizational erosion	10%	15	0.55	0.58	2.68	0.66	0.20	0.022	4.47
ST3	ST1 with ALL + rescue strategy	0.7	11	0.62	0.66	1.91	1.33	0.62	0.04	4.35

SD, student dropout (absolute headcount); DR, dropout rate; AB, academic burnout; SSD, student support demand; IC, institutional coordination; IF, institutional flexibility; QIS, quality institutional support; SSB, support staff burnout. Student dropout values are expressed as absolute number of students; all remaining variables correspond to normalized model indices (0–1 scale or relative model units). Baseline parameters: dropout rate = 0.2215; all institutional policy levers = 0.5. Scenario suffixes −/0/+ denote low, medium, and high configurations of the modified parameter(s). Source: authors' simulation output, ESTP system dynamics model.

flexibility reaches 0.42. The absolute number of dropouts is 11, and the support staff burnout is 4.35.

In ST2, the student dropout rate remains at 0.55, academic burnout at 0.58, institutional coordination increases to 0.66, and institutional flexibility decreases to 0.20; absolute dropout rises to 15, and support staff burnout to 4.47.

In ST3, the student dropout rate remains at 0.62 and academic burnout at 0.66, with institutional coordination increasing to 1.33 and institutional flexibility to 0.62; dropout remains at 11, and support staff burnout at 4.35.

5 Discussion

5.1 Discussion of results

The study achieved its general objective of modelling the dynamic influence of organisational characteristics on the student dropout rate in TVHE by mathematically formalising institutional capacities as stocks subject to erosion and strengthening, and academic burnout as the central mediating variable. This achievement is materialised in three verifiable outputs: (i) a causal loop diagram identifying fifteen feedback structures, six of which —three reinforcing (R6, R7, R13) and three balancing (B1, B2, B3) —constitute the causal core of the model; (ii) a Forrester diagram with its complete technical structure of stocks, flows, and auxiliary variables; and (iii) a set of 40 simulated scenarios over a ten-year horizon, complemented by a univariate sensitivity analysis and three stress tests. These outputs enable moving from a correlational understanding of dropout to a systemic, dynamic, and cumulative interpretation of the phenomenon.

About the first research question (RQ1), concerning how organisational characteristics shape the trajectory of the dropout rate over time, the baseline scenario results show a monotonically increasing trajectory of the student dropout rate, rising from 0.37 in year 1 to 0.55 in year 10, with an average slope close to 0.020 units per year and a relative increase of 48.6% over the simulated horizon. Under current organisational conditions and in the absence of deliberate intervention, the system tends to intensify the individual probability of withdrawal over time, suggesting that organisational pressures (evaluation peaks, deterioration of coordination, erosion of flexibility, and limitations in support capacity) accumulate progressively, strengthening the reinforcing loops identified in the CLD (R6, R7, R13). The trajectory described responds to an endogenous dynamic dominated by organisational feedback structures rather than external shocks.

Regarding the second research question (RQ2), the mediating role of academic burnout in translating cumulative organisational pressures into dropout decisions, the findings confirm this role through two converging strands of evidence. First, the trajectory of academic burnout in the baseline scenario shows sustained growth from 0.2 in year 1 to 0.58 in year 10, following a pattern parallel to that of dropout. Second, the sensitivity analysis shows that student dropout is highly sensitive to parameters associated with burnout (k burnout) and vocational misfit (k misfit), with comparable magnitudes of effect and clearly greater influence than parameters related to the rate of burnout accumulation. These results demonstrate that dropout in technical and vocational higher education is strongly mediated by psycho-emotional pressures and by the perception of low training relevance (Gonzalez et al., 2025; McKinney and Gischlar, 2025), empirically confirming that burnout operates as a central mediating factor that translates organisational conditions into effective dropout trajectories.

A first finding is the disconnection between the evolution of the absolute volume of dropouts and the effective dropout rate in the baseline scenario. Although the annual volume of dropouts may stabilise or even slightly decrease, the student dropout rate shows an increasing trajectory, associated with the sustained growth of academic and support staff burnout. This pattern is consistent with findings reported by Priya et al. (2025) and McKinney and Gischlar (2025), who document how the accumulation of burnout among staff and the erosion of institutional support generate organisational feedback loops of progressive deterioration. A plausible explanation is that the system may appear stable in aggregate terms while accumulating latent structural tensions that undermine its organisational sustainability: student attrition mechanically reduces enrolment. However, it does not dissipate the accumulated pressures on staff nor restore previously eroded support capacities. This disconnection has direct implications for the interpretation of institutional indicators that rely on absolute volumes as the primary monitoring variable.

A second finding is the structural asymmetry between mechanisms of erosion and those of strengthening organisational capacities. The sensitivity analysis shows that

institutional flexibility is highly sensitive to the parameter k flexibility erosion, greatly exceeding the effect of parameters associated with improvement or institutional investment. This behaviour is consistent with dynamic performance management approaches (Bianchi, 2016; Cosenz, 2022), where the accumulation of pressures may exceed the institution's adaptive capacity in the absence of adequate preventive mechanisms, and aligns with evidence from Priya et al. (2025) regarding the vulnerability of support capacities under sustained load. The explanation lies in the non-linear structure of the model: erosion coefficients operate multiplicatively on institutional pressure, implying that marginal increases in pressure produce disproportionate losses in flexibility, whereas investments in improvement operate incrementally and with delays. This asymmetry suggests that preventive containment strategies may be systemically more efficient than reactive recovery strategies.

A third finding is the relative insensitivity of the final student dropout rate to isolated organisational interventions. In blocks A (coordination), B (flexibility), and C (support capacity), the rate at year 10 remains at 0.55 regardless of the policy level (Low, Medium, or High) applied, despite proportional changes in organisational capacity stocks. This pattern is consistent with the results of Shinde and Kaynak (2016), who show that in educational systems, dominant reinforcing loops may neutralise targeted interventions when acting on single levers, as well as with systemic evidence from Barragán Moreno and González Támara (2024) regarding the multidimensional nature of dropout factors. The systemic explanation is that reinforcing loops R6, R7, and R13—linking dropout, staff pressure, capacity erosion, and burnout—operate simultaneously and reinforce one another, such that a single organisational lever is insufficient to alter the system's attractor state within the evaluated horizon. This finding nuances the institutional tendency to prioritise sectoral interventions over integrated systemic processes.

A fourth finding, complementary to the previous one, is the structural weight of two student profile parameters, theory–practice gap and role overload, which produce the largest variations in outcome variables across all simulated scenarios. In block F (theory–practice gap), the student dropout rate varies between 0.47 and 0.62 and academic burnout between 0.48 and 0.67, depending on the parameter level. In block E (role overload), although the variation is smaller, it remains clearly higher than that observed in blocks corresponding to purely institutional policy interventions. This result aligns with findings from Lavi and Achituv (2025), Gonzalez et al. (2025), and Ibrahim et al. (2025), who identify training relevance, vocational misfit, and role overload as primary determinants of dropout in TVET contexts and among non-traditional students. The explanation is that these parameters operate as exogenous conditions that directly modulate academic burnout and support demand, without being mediated by the institutional capacities modelled. Consequently, purely institutional management interventions reach a structural ceiling when student profile conditions and curricular relevance are not addressed simultaneously.

A fifth finding is the stabilising superiority of combined interventions over isolated ones, together with evidence of institutional rescue capacity under stress. Block simulations show that isolated interventions—whether in coordination, flexibility, or support capacity—produce partial improvements, but the strongest stabilising effects emerge when organisational levers operate in combination, as in the integrated scenarios (CF, FS, CS, and ALL). The contrast between stress tests ST1 and ST3 reinforces this interpretation: in ST1, a highly vulnerable student profile generates a student dropout rate of 0.62, with institutional coordination collapsing to 0.00 and institutional flexibility at 0.42; in ST3, which combines ST1 conditions with full policy activation, the rate remains at 0.62, but organisational capacities increase substantially (institutional coordination = 1.33; institutional flexibility = 0.62). This suggests that, even when full policy activation does not completely reverse dropout rates under extreme stress, it does preserve the institutional architecture necessary to sustain response capacity in the medium term. This behaviour is consistent with Sterman (2000) and Cosenz (2022) regarding the resilience of systems managed through multiple levers. Dropout in TVHE responds to interdependent structural configurations rather than isolated interventions, which explains why systemic coherence among institutional capacities, organisational climate, and support mechanisms is critical for the sustainability of student retention.

5.2 Theoretical implications

From a theoretical perspective, the study extends classical dropout models (Bean and Metzner, 1985; Tinto, 1975) by shifting the analytical focus from individual integration to organisational responsibility as a structural generator of dropout trajectories. In line with System Dynamics (Shinde and Kaynak, 2016; Sterman, 2000), dropout is conceptualised as the result of reinforcing and balancing feedback loops linking coordination, flexibility, institutional climate, and support capacity with mediating processes such as burnout. The model provides three main theoretical contributions. First, the endogenisation of academic burnout as a mediating variable that translates cumulative organisational pressures into a higher probability of dropout, offering a mathematical representation of its mediating role that goes beyond the predominantly static treatment in the literature. Second, the identification and formalisation of structural asymmetries between mechanisms of institutional erosion and strengthening, which operate with unequal intensities and speeds, as demonstrated in the sensitivity analysis. Third, the mathematical formalisation of the causal structure of the phenomenon enables an operational linkage between organisational theory and prospective simulation. In this way, the study proposes a structural interpretation of dropout in TVHE, consistent with dynamic performance management approaches (Bianchi, 2016; Cosenz, 2022).

5.3 Practical implications

The findings yield four institutional management guidelines with direct grounding in the simulation results:

- The prevention of academic burnout should be considered a strategic retention policy, rather than solely an individual psycho-emotional issue. This guideline is supported by the central mediating role of burnout evidenced in the response

to RQ2 and in Finding 1: academic burnout increases steadily even when the absolute volume of dropouts stabilises, which requires institutional monitoring and containment mechanisms that operate before burnout translates into effective dropout.

- Organisational flexibility emerges as a critical yet vulnerable lever; therefore, it requires protection mechanisms against operational pressure. Finding 2 on the erosion/strengthening asymmetry implies that flexibility must not only be built through investment, but also protected through institutional arrangements that contain operational pressure on staff before it erodes accumulated capacities.
- The strengthening of support capacity (tutoring and mentoring) must accompany enrolment growth in order to avoid saturation cycles. The dynamics of support staff burnout observed in the baseline scenario show an early phase of volatility followed by sustained growth: the scaling of the support system must anticipate increases in enrolment to avoid activating the reinforcing loop R13 (erosion of support capacity).
- Isolated strategies have limited effects; integrated interventions produce greater systemic stability. Findings 3 and 5 empirically show that the final dropout rate is insensitive to isolated organisational policies (blocks A, B, C) but responds to combined configurations under stress conditions (contrast ST1–ST3), supporting the adoption of integrated management approaches over sectoral interventions.

An additional cross-cutting guideline, derived from Finding 4, is that purely institutional management interventions encounter a structural ceiling when student profile conditions and curricular relevance (theory–practice gap, role overload) are not addressed simultaneously. This implies that organisational retention policies must be aligned with curricular adjustments, vocational guidance programmes, and student wellbeing mechanisms to realise their full potential. In governance terms, the model supports integrated and preventive management approaches aimed at containing pressures before they translate into cumulative organisational erosion.

5.4 Limitations and future research opportunities

The study presents several limitations. First, parameterisation was based on aggregated information from the Chilean system, implying that the values do not represent a specific institution but rather a reference context. Second, the model does not explicitly incorporate macroeconomic variables or labour market dynamics, which could affect dropout over longer time horizons. It should be noted that, as with any System Dynamics model, its validity lies in structural coherence rather than point prediction.

Future research could: incorporate longitudinal institutional data for specific calibrations; integrate public funding variables or economic cycles; analyse differential effects across population groups (gender, first-generation graduates, students with disabilities) (Sotomayor and Rodríguez, 2020); or explore multi-institutional or comparative international simulations.

Data availability statement

The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

Author contributions

SB: Visualization, Data curation, Validation, Writing – original draft, Project administration, Formal analysis, Methodology, Investigation, Conceptualization, Supervision, Writing – review & editing, Software, Resources, Funding acquisition. AG: Methodology, Visualization, Conceptualization, Resources, Investigation, Validation, Formal analysis, Writing – original draft, Software, Writing – review & editing. PS: Writing – original draft, Formal analysis, Resources, Data curation, Writing – review & editing, Validation.

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