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Data-Driven Decision-Making in K-12 Institutional Management: A Case Study

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Abstract— This study presents a digital transformation initiative within a private Uruguayan K-12 institution, focusing on the modernization of core academic management systems and introducing innovative views to facilitate data-driven decision-making (DDDM), with direct participation of personnel as well as students preferences. While optimization research in education has extensively addressed logistical challenges—such as facility allocation and complex scheduling in higher education— there remains a significant gap regarding social group dynamics at the K-12 level. This research addresses that, by developing an optimization model for social dynamics and, crucially, integrating it directly into the school's daily operational environment.

Keywords—Education Management, Class Optimization, Data Driven, Digital Transformation.

I. INTRODUCTION

According to [1], Digital Transformation is "the combined effects of several digital innovations bringing about novel actors (and actor constellations), structures, practices, values, and beliefs that change, threaten, replace or complement existing rules of the game within organizations, ecosystems, industries or fields".

While extensive research exists on Digital Transformation in education [2] [3] the majority of studies focus on pedagogical delivery — learning and teaching methods, such as remote or hybrid learning— and how the use of digital technologies impacts the academic performance [4], [5] rather than the strategic planning required to optimize the in-person student experience.

Private sector enrollment in Uruguay remains relatively consistent across education levels, capturing 15% of primary students and 16.1% of secondary students nationwide [6], [7]. The majority of private primary and secondary educational institutions operate either as nonprofit organizations or Small and Medium-Sized Enterprises (SMEs). Consequently, they encounter the traditional hurdles associated with digital adoption, including significant resource constraints, specialized skill gaps, and systemic structural limitations that often impede the integration of new technologies.

Despite this situation, digital tools are increasingly integrated into educational settings to enhance operational efficiency and mitigate systemic problems that institutions encounter periodically.

Furthermore, due to a declining birth rate and the post-pandemic climate, the number of private schools has dwindled. Improving operational efficiency and identifying new ways to offer a better service and engage students are now vital to survive.

Management at school involves planning and several tasks to prepare for the academic year. This includes teachers' management including recruiting, performance evaluation, class assignments, as well as planning the student's experience.

In the research process, a school expressed interest in optimizing its processes or even innovating existing ones through the novel use of technology, involving parents and students more deeply to identify opportunities and areas for improvement. The discussion yielded several innovative approaches to addressing systemic challenges within educational institutions, specifically: optimizing classroom climate, integrating parental feedback into evaluations, and implementing algorithmic bias detection on that feedback.

This paper details a strategic intervention within a private K-12 educational institution in Uruguay, in the context of a digital transformation initiative, aimed at optimizing core academic management processes that would improve climate in class and academic outcomes.

This document is organized as follows. Section 2 presents the proposed objectives of the intervention. Section III describes the concepts needed for this research. Section IV details the implementation of the intervention. Section V discusses the results obtained, and finally Section VI presents the conclusions and future work.

II. OBJECTIVES

The private K-12 institution under study had positioned itself to embrace technology as a key enabler for improving performance, reducing operational timelines, and minimizing human errors inherent in manual processes. The primary objective was to facilitate data-driven decision-making. One such critical task involved the assignment of students to classroom groups. Traditionally, this process relied on sociometric data—students' preferences submitted via paper forms—alongside complex pedagogical and psychological constraints. These 'sociograms' typically consist of manual lists where students nominate five to ten peers for future placement. The objective is to maximize fulfilled requests—ensuring each student is placed with at least one preferred peer—while strictly adhering to administrative mandates, such as balancing class sizes or separating specific individuals. Manually navigating this combinatorial complexity is exceptionally time-consuming and makes identifying a truly optimal solution virtually impossible.

The core functional requirements of the platform include:

- Automated Cohort Generation: Constructing student groups while adhering to administrative constraints and psychologists indications and maximizing peer-sharing requests.
- Data Visualization: Providing structured rosters and comprehensive views of the classes within each academic generation.
- Historical Data Tracking: Maintaining a repository of previous years' group configurations for trend analysis.
- Student Information Management: Securely storing personal and academic data for the entire student body.
- Data integrity: providing a secure environment for students to log their individual preferences. Unique access tokens ensure that each response is attributed to the correct student and that only one submission is permitted per user.

III. THEORTICAL FRAMEWORK

A. Digital Transformation in SMEs

SMEs need to evaluate both the benefits and challenges associated with digital transformation, translating their digital awareness into concrete strategic actions. This strategic planning is the basis for successful digital integration, ensuring sustainable growth and competitive advantage in an increasingly digitalized landscape. According to a Microsoft survey [8] conducted among Uruguayan SMEs, the digital transformation process is primarily driven by three strategic pillars: data optimization for business intelligence (50%), technology adoption (34%), and the acquisition or development of digital talent (27%). Furthermore, a majority of respondents (51%) identify technological integration as a key driver for market expansion and customer acquisition. Notably, cybersecurity has gained prominence within the corporate agenda, with 46% of SME leaders identifying it as a primary strategic concern.

One of the primary barriers to digital transformation for SMEs is the lack of dedicated resources for strategy development and implementation planning. In Uruguay, the National Development Agency [9] is a public institution dedicated to fostering national growth through strategic programs designed to enhance business and territorial competitiveness, with a primary focus on MSMEs (Micro, Small, and Medium Enterprises). ANDE promotes digital transformation offering assessment, free tools, as well as methodology to enable MSMEs development. According to data from the ANDE Observatory [9], MSMEs account for 65.04% of total employment in Uruguay. Education segment plays a key role in society. While most children attend public schools, there are still an important number of private schools struggling to survive. To successfully integrate digital technologies, they must perceive these tools as inclusive, utilitarian, and reliable. This necessity is magnified when the target demographic includes children and adolescents, requiring rigorous ethical safeguards. Consequently, this project adopted a collaborative design approach, involving educators and psychologists to critically analyze the opportunities and systemic constraints of technology.

B. Classroom Climate

Classroom climate, [10] though difficult to define and assess, affects student learning [11] especially in elementary and high schools. While teacher behaviors establish the foundational classroom climate, the interpersonal actions and reactions of peers significantly shape the socio-emotional experience for individual students.

All students maintain relational networks that give the group its unique structure. Furthermore, the active involvement of every member impacts the overall academic outcomes. It is essential to remember that human beings are inherently social; indeed, cognitive psychology suggests that the learning process is more effective when undertaken collectively rather than in isolation.

Consequently, a primary concern for school psychologists and educators is the strategic formation of groups to foster positive relationships and minimize the risk of social isolation.

Sociometric procedures are frequently utilized in classroom composition, providing a data-driven basis for deciding student placements to enhance group cohesion and minimize conflict.

While numerous online platforms facilitate the creation of sociograms, a significant gap remains in the transition from data to action. Typically, student group assignments are still performed manually, a process that attempts to balance student preferences with the qualitative insights provided by teachers and psychologists.

C. Sociograms

Sociometric procedures allow for a rapid and valid assessment of peer relationships. These tools make it possible to determine each student's level of integration and the social contexts in which they operate [12]. Their application involves surveying all members of a specific group about their peers to identify social status, affinity for forming friendships, and the most prominent perceptual attributes of each student.

The round-robin design [13] is the gold standard for sociometric assessment, where every group member evaluates all peers across various dimensions while excluding self-evaluation. This methodology establishes that sociometric status is intrinsically linked to a specific peer group; since it is context-dependent, a student's social standing can vary significantly between different environments, such as a classroom versus a sports team.

The criteria for these evaluations are divided into two categories:

- Emotional: Captures subjective, personal preferences (e.g., "Who do you like the most?").
- Reputational: Focuses on observable, objective behaviors (e.g., "Who helps others the most?").

By analyzing these data points, individuals can be classified into distinct social categories—such as popular, rejected, neglected, or controversial—providing a comprehensive map of the group's social architecture.

D. Class formation optimization

Extensive research exists on the mathematical optimization of classroom assignments across various contexts—predominantly within higher education. Existing literature covers a wide range of variables, including school proximity, faculty preferences, facility allocation, scheduling, and resource distribution.

From a computational standpoint, the problem is categorized as NP-hard.

Historically, researchers have addressed this complexity using exact optimization methods—such as linear, mixed-integer, and quadratic programming—as well as metaheuristic approaches, including genetic algorithms, local search, and tabu search. This is a sample list of articles which focus on these topics, with some variations: [14], [15], [16], [17], [18], [19], [20], [21], [22].

In this research [23], a genetic algorithm is used to optimize group formation in active reading at high school. using marker data. In contrast with our goal, this is a very specific topic, but the novel idea es to introduce students personality characteristics. In [24] the authors propose a genetic algorithm to promote problem-based learning in elementary school in Taipei.

Mathematical optimization can be performed using specialized software and solvers, ranging from high-performance commercial engines like Gurobi [23] and CPLEX [24] to robust open-source alternatives such as HiGHS [25], which is particularly effective for linear programming, just to mention a few examples.

Another possible approach is graph-partitioning . Using a graph-partitioning approach for class assignment optimization shifts the focus from traditional linear programming to a topological perspective, representing students as nodes in a network where the edges indicate desired (or undesired) relationships. This promises better performance, in case of massive sociograms, which is not the case for this type of organizations.

While many of these algorithms prioritize mathematical optimization, they risk introducing unintended biases or undermining student autonomy. To mitigate these risks, this project integrated school psychologists—who maintain daily interaction with the students—into the design, requirements specification, and validation phases, as explained earlier.

The objective of this paper is not to outperform existing models, but rather to propose a framework that is readily implementable within the specific context of the intervention. While the problem is computationally complex in theory, our proof of concept demonstrates that the time required to reach a feasible solution remains well within practical limits.

IV. Methodology and Proposed Methods

The Uruguayan educational system utilizes distinct organizational models across grade levels. In primary education, class groups follow a homeroom model, where a single teacher is responsible for all core subjects throughout the academic year. Conversely, secondary education shifts to a model featuring subject-matter specialists; however, students remain in fixed cohorts, sharing the same physical classroom and peer group for the duration of the year. For these reasons, the focus of this study is on group formation.

To address the challenges of classroom composition, a web application was developed that utilizes an optimization algorithm, based on the mathematical model proposed in this research. By processing sociometric data and administrative constraints as inputs, the system generates class lists that maximize student satisfaction while ensuring full compliance with all institutional requirements.

The historical sociograms, as well as the draft class compositions obtained, are saved for further trend analysis.

The users are: i) psychologists and coordinators, and ii) all the students. This puts strong emphasis on UI/UX, as well as fluent communication management to get all the information needed on time.

A. The Mathematical Model

There is a previous work regarding group formation in elementary school, "Optimizing the Assignment of Students to Classes in an Elementary School" by Krauss, Lee y Newman [26], which use x_{ij} variable to represent if i student is in j class. They used a genetic algorithm to improve the feasible solution obtained via integer linear programming, where points are added or subtracted depending on constraint satisfaction, e.g. points are given for each of the parents' "friend requests" satisfied, and the marginal value of satisfying additional requests decreases, with a particularly large drop-off after the first request is fulfilled.

In our project, an integer linear programming model is used, where x_{ij} variable represents if *i* student is in the same class as *j* student.

We define *X*, a $n \times n$ matrix – where *n* is the number of students - to represent students being or not in the same class.

In the sociometric preference matrix S, the element at row *i* and column *j* is assigned a value of 1 if student *i* has nominated student *j* as a preferred peer, and 0 otherwise.

We define *H*, a matrix resulting from applying the Hadamard product to X and S:

$$H = X \circ S.$$

The objective function is obtained by adding all the *H* elements:

$$f = \sum_{i=1}^{n} \sum_{j=1}^{n} h_{ij}$$

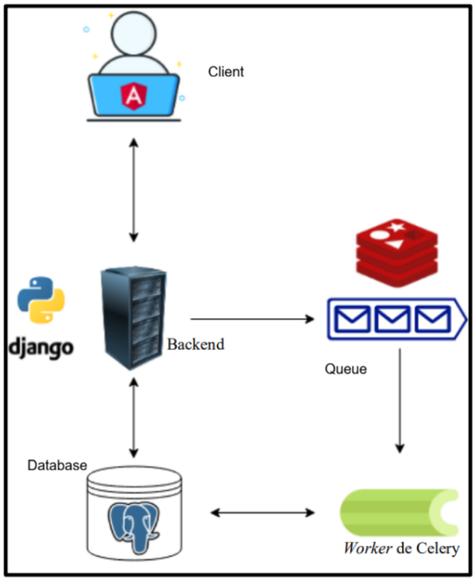

Fig. 1. System Architecture

Constraints definition

1. for convenience

$$x_{ii} = 0$$

2. Symmetry:

$$x_{ij} = x_{ji}$$

3. Transitive:

$$(1 - x_{ij}) + (1 - x_{jk}) \geq (1 - x_{ik}) \rightarrow x_{ij} + x_{jk} - x_{ik} \leq 1$$

4. Defined by the users:

a. Maximum/minimum class size

$$\sum_{j=1}^{n} x_{ij} \leq m\_\max, \forall\, i \in [1, n]$$

$$\sum_{j=1}^{n} x_{ij} \geq m\_\min, \quad \forall\, i \in [1, n]$$

b. Students that must be together (T matrix) or separate (D matrix):

$$x_{ij} = 1, \qquad \forall\, j\ where\ t_{ij} = 1, t_{ij} \in T$$

$$x_{ik} = 0, \qquad \forall\, k\ where\ d_{ik} = 1, d_{ik} \in D$$

c. Students whose satisfied peer requests must exceed the threshold k (P matrix):

$$\sum_{j=1}^{n} x_{lj} \geq k, where\ p_{lj} = 1, \qquad p_{jl} \in P$$

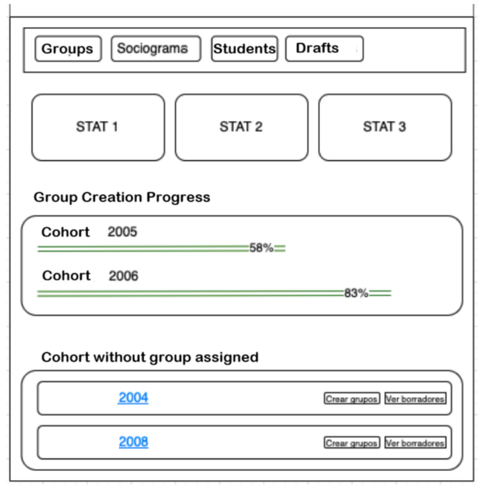

Fig 2. General View

d. Minimum request quantity to be satisfied for all students:

$$\sum_{j=1}^{n} x_{lj} \geq r, \quad \forall i \in [1, n]$$

e. Gender constraints: Let M be the set of male students, and F the set of female students, such that $M \cup F = N$ where N is the set of all students. We establish minimum number of female and male students per class.

$$\sum_{j \in F} x_{ij} \geq f, \quad \forall\, i \in F$$

$$\sum_{j \in M} x_{ij} \geq m, \quad \forall\, i \in M$$

A pertinent constraint involves enforcing minimum intra-gender preferences: specifically, ensuring that each male student is placed with at least one requested male peer, and each female student is placed with at least one requested female peer.

$$\sum_{j \in F} h_{ij} \geq 1, \quad \forall\, i \in F$$

$$\sum_{j \in M} h_{ij} \geq 1, \quad \forall\, i \in M$$

B. *Technology architecture*

It is important to highlight that this functionality was thought of as an additional module for the management information system of the school, and not a dedicated system.

The architecture follows a decoupled client-server model, as shown in Fig 1. The front end, built with the Angular

TABLE I. OPTIMIZATION MODEL

Item	Description
Obetctive function	$f = \sum_{i=1}^{n}\sum_{j=1}^{n} h_{ij}$
Decision variables	$h_{ij} \in H = X \circ S,\ \forall\, x_{ij}, s_{ij} \in [0,1],\ \forall\, i,j \in [1,n]$
Constraints	$x_{ii} = 0,\ \forall\, i \in [1,n]$ $x_{ij} = x_{ji},\ \forall\, i,j \in [1,n]$ $(1 - x_{ij}) + (1 - x_{jk}) \geq (1 - x_{ik}) \rightarrow$ $x_{ij} + x_{jk} - x_{ik} \leq 1, \forall\, i,j,k \in [1,n]$ $\sum_{j=1}^{n} x_{ij} \leq m\_\max, \forall\, i \in [1,n]$ $\sum_{j=1}^{n} x_{ij} \geq m\_\min,\ \forall\, i \in [1,n]$ $\sum_{j=1}^{n} x_{lj} \geq r,\ \forall i \in [1,n]$ $\sum_{j \in F} x_{ij} \geq f,\ \forall\, i \in F$ $\sum_{j \in M} x_{ij} \geq m,\ \forall\, i \in M$ $\sum_{j \in F} h_{ij} \geq 1,\ \forall\, i \in F$ $\sum_{j \in M} h_{ij} \geq 1,\ \forall\, i \in M$

framework, communicates with a Django-based Python backend via RESTful HTTP requests. This backend manages CRUD operations (Create, Read, Update, Delete) within a PostgreSQL relational database.

The core functionality—the class generation engine—requires an asynchronous execution strategy due to the high computational overhead of solving Integer Linear Programming (ILP) problems, which may take several minutes. To prevent request timeouts and improve user experience, the system utilizes a distributed task queue (Celery with a Redis broker). When a grouping request is received, the backend enqueues a background task and immediately returns a non-blocking response to the client. A Celery worker subsequently processes the task, executing the optimization logic. Upon completion, if a feasible solution is found, the results are persisted in the database and the user is notified via an automated email. In the event of an infeasible problem state (where constraints cannot be satisfied), the user is similarly notified of the failure.

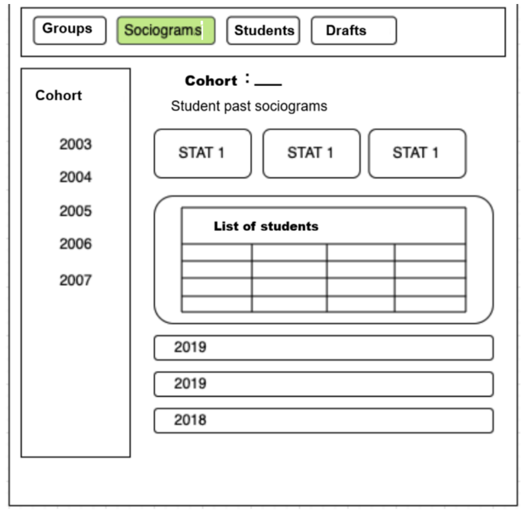

Fig. 3 Sociograms View

C. Main tools and libraries used

A challenge in this project involved evaluating various optimization frameworks, such as Gekko, SciPy, PuLP (they are all Python libraries for optimization, but they differ in their scope, the types of problems they handle, and their underlying approach), and Google's OR-Tools. Ultimately, OR-Tools was selected due to its industry-leading reputation, comprehensive documentation, and versatility in handling diverse optimization models, including linear, integer, and assignment problems.

Following the selection of the library, it was necessary to determine the most appropriate solver for our specific con straints. We conducted a comparative analysis of the two primary engines for Integer Linear Programming (ILP): MPSolver and CP-SAT. MPSolver [27] and CP-SAT [28] are two different optimization solvers within Google's OR-Tools

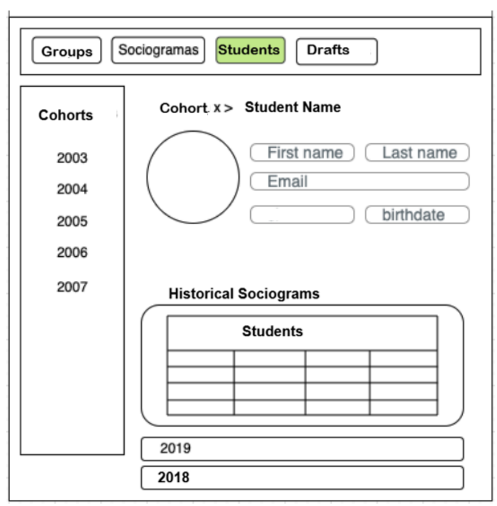

Fig. 4 Students View

library, each designed for specific types of problems. While MPSolver is optimized for problems involving arbitrary integers, Google recommends the CP-SAT (Constraint Programming - Satisfiability) solver for models dominated by binary variables. Given that our classroom assignment model relies exclusively on binary decision variables, we implemented the CP-SAT solver to ensure maximum computational efficiency.

D. Quality attributes

1) Security

Security is an important quality attribute for the development of the application, as the system manages children and teenagers' personal data. To manage secure access, the application utilizes token-based authentication. Following the standard email-and-password verification process, the application issues a secure token to the client. This token acts as a temporary credential, transmitted within each HTTP request header. Access is governed by a 24-hour expiration policy, ensuring that sessions are periodically refreshed through re-authentication.

2) User experience / ease of use

The web platform was designed for administrative users responsible for the formation and management of student cohorts within an educational institution.

Given that the target users typically possess limited technical proficiency with web interfaces, the platform prioritizes UI/UX intuitiveness. The primary design objective is to deliver a streamlined, user-friendly experience that minimizes the cognitive load required to navigate complex optimization tasks.

The platform facilitates sociogram collection by distributing unique, tokenized links to students via email. These links point to a preference form for the next school year. Because each link is tied to a specific user ID, the system ensures that all sociogram data is accurately associated with the correct student record upon submission

TABLE II. SECURITY COMPLIANCE

Component	Security Measure
Frontend Storage	S3 Private Access: Prevents direct public access to source files; only accessible via the CDN..
Content Delivery	AWS CloudFront: Masks the origin server and provides an additional layer against DDoS and unauthorized direct access.
Data in Transit	SSL/TLS Encryption: All Port 80 (HTTP) traffic is automatically redirected to Port 443 (HTTPS) via an Apache2 reverse proxy.
Remote Management	Bastion Host (Jump Box): Isolates the production server from the public internet for administrative tasks.
Access Control	IP Whitelisting: Restricts SSH access exclusively to specific, authorized administrator IP addresses.
Environment Isolation	Docker Containerization: Isolates the Django API and PostgreSQL services, ensuring a consistent and hardened runtime environment.
Network Exposure	Port Minimization: Only standard web ports (80/443) are publicly exposed; all management ports are hidden behind the Bastion.

V. RESULTS

In this section we describe the application results, and the functional and non-functional requirements fulfilled.

A. Implemented Functionalities

The user interface is comprised of five primary modules: the Main Dashboard, Groups, Sociograms, Students, and Class Drafts. Fig. 2 shows the main dashboard.

The top navigation bar provides clear orientation, allowing users to move intuitively between the platform's core functionalities. Below this, key metric panels display high-level statistics, such as the approval/rejection rates of student sociograms.

The lower section features progress cards for cohorts currently undergoing the mathematical grouping process, alongside clear indicators for generations where the process has yet to be initiated.

The Groups by Cohort view provides a historical record of student groupings for both the current and previous academic years. Each year is represented by an expandable card; when toggled, the main section reveals the specific groups formed during that period. For deeper insights, users can click a detail button to trigger a centered modal, displaying a comprehensive table of all students assigned to that particular group.

The Sociograms view, shown in Fig. 3, incorporates key statistical panels, featuring metrics such as the percentage of student sociograms honored versus omitted. Below these metrics, a yearly history is displayed via expandable cards. Expanding a year reveals a student table for that cohort; clicking a student row then toggles a nested table showing their specific sociogram requests. To maintain a clean and intuitive interface, only one year and one student record can be expanded at a time—opening a new entry automatically collapses the previous one.

The Students View features a comprehensive table of all individuals within a selected cohort. Each row includes a dedicated action button that navigates the user to a detailed profile (as shown in Figure 4). This specific view displays the students' personal information alongside a historical record of their sociogram requests.

B. The Optimization Model Results

The system was tested with one cohort classes chosen by the organization. The psychologists manually created a potential distribution of students into classes. In addition, the classes were successfully generated using the platform, receiving high praise from the client's psychology team. Ultimately, the counselors chose the generated distribution over their manual drafts. Objectively, the platform significantly outperformed the manual process in terms of fulfilled sociogram requests: the automated model satisfied 237 requests, compared to only 187 in the manual draft—a 26.7% improvement.

It is important to note that infeasibility cases are rare due to the method proposed by the psychologists and school administrators for the students preferences gathering. Beyond raw numbers, the application strictly enforced the 'minimum of two requested peers' constraint for every student, a requirement the manual draft failed to meet. Furthermore, the platform maintained additional complex constraints that the team had previously discarded to simplify the manual task. Had the application been run under the same relaxed parameters as the manual draft, the gap in fulfilled requests would likely have been even wider than the recorded 237.

In optimization research, it is an ordinary practice to analyze the performance as the problem size increases. In this case, the N, number of students on each level is under a few hundreds, so in practice, solver time is not critical.

C. Security Compliance

Security was one of the main concerns. This is the basis for users trust, which will enable system adoption and long-term benefits. Table I details the security measures taken to protect data at rest and transit in every stage.

VI. Conclusions and Future Work

Private educational institutions are now obligated to undergo digital transformation. To maintain a competitive edge and guarantee institutional resilience, these schools must integrate modern technological tools into their core operations, taking into consideration those issues that might be more impactful, but at the same time, within their possibilities. This involves not only technology but also processes and people, which might include other stakeholders not envisioned at the beginning.

In this project we developed an application for a K-12 education organization, that aimed at optimizing core academic management processes based on high quality data, that would ensure data driven decisions to improve climate in class and academic outcomes. Special attention was paid to usability and security.

The solution was deployed in the cloud, adopting strong security measures. Furthermore, an optimization algorithm was developed for students placement that fulfills all the students and staff requirements to improve class climate, which, for a proof-of-concept, proved to produce better outcomes than the existing procedures. The following steps involve extending the implementation to other cohorts.

To continue in the digital transformation route, additional innovative ideas were tested as a feasibility study, such as ensuring secure parent participation in teacher evaluations, and bias detection, which may constitute future research lines.

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