Child Development Project Report: Predictive Analysis of Early Childhood Development Deficits

NGO Applied Project - BREIT

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Executive Summary

This report presents a comprehensive predictive analysis of early childhood development deficits for Asociación Taller de los Niños (TANI), a Peruvian NGO with over 45 years of experience serving vulnerable children and families. Through data science methodologies, we analyze pre- and post-pandemic health records to develop actionable predictive models that identify children at highest risk of developmental delays.

Methodology Overview:

- Multi-phase data consolidation from pre/post-pandemic periods
- Strategic population filtering to address class imbalance
- Feature engineering

Key Findings:

- Identification of critical risk factors for targeted intervention

Impact: This work provides TANI with a decision-support framework to optimize early intervention strategies, improving outcomes for vulnerable children through data-driven prioritization.

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1. Introduction and Context

1.1. Background on TANI

Asociación Taller de los Niños (TANI) is a non-governmental organization based in Peru, dedicated to improving the quality of life for children and families in vulnerable situations. With over 45 years of operational experience, TANI focuses particularly on the critical early years of life (0-5 years), implementing a comprehensive approach that integrates:

- **Health and Nutrition:** Growth monitoring, nutritional assessment, and intervention programs
- **Community Strengthening:** Family engagement and capacity building
- **Preventive Care:** Systematic health check-ups and early detection of developmental issues

1.2. Child Development Deficit Context

Fundamental Concepts of Growth and Development:

Child growth and development constitute two interrelated sets of indicators of critical utility for determining health status. Growth refers to the physical increase in weight and height/length measurements while development encompasses the progressive improvement of functional capacity and skills across multiple domains (motor, cognitive, language, and socio-emotional). Both processes are fundamentally dependent on the interaction of genetic, nutritional, and environmental factors. Therefore, systematic monitoring of normal developmental trajectories is essential to identify risk factors that may interfere with these processes, ensuring that each child achieves their full developmental potential.

The Global Burden of Early Childhood Development Deficits:

Early childhood development (ECD) deficits represent a critical public health challenge in low- and middle-income countries. According to WHO estimates, approximately 250 million children under five years in these settings are at risk of not reaching their developmental potential due to poverty and stunting (Black et al., 2017). These deficits manifest across multiple, often overlapping dimensions:

- **Stunting (Chronic Malnutrition):** Linear growth failure resulting from prolonged nutritional deficiencies, affecting approximately 22% of children globally (UNICEF, 2021)
- **Wasting (Acute Malnutrition):** Low weight-for-height indicating recent or current severe nutritional deficit
- **Developmental Delays:** Failure to achieve age-appropriate milestones in gross motor, fine motor, cognitive, language, or social-emotional domains
- **Micronutrient Deficiencies:** Particularly iron-deficiency anemia, affecting cognitive development and immune function

The Peruvian Context:

In Peru, despite significant economic growth over recent decades, substantial disparities persist in child health outcomes:

- **Chronic Malnutrition:** Affects 12.1% of children under 5 nationally, with rates exceeding 25% in rural Andean regions (INEI-ENDES, 2023)
- **Anemia Prevalence:** Reaches 43.1% in children aged 6-35 months, a critical window for brain development (INEI-ENDES, 2023)
- **Developmental Delays:** Studies indicate that children exhibit delays in one or more developmental domains, with higher rates among socioeconomically disadvantaged populations (Diaz et al., 2017)
- **Geographic Inequities:** Urban-rural and coastal-highland disparities create vastly different developmental trajectories for children

The Critical Window: First 1,000 Days:

The period from conception to age 3 (approximately 1,000 days) represents a critical window for brain architecture development. During this time, neural connections form at a rate exceeding 1 million per second, establishing the foundational circuitry for all future learning, behavior, and health (Shonkoff & Phillips, 2000). Nutritional and environmental insults during this window can result in:

- **Irreversible Stunting:** Chronic undernutrition affecting linear growth and cognitive capacity
- **Neurodevelopmental Impairment:** Compromised executive function, memory, and academic readiness
- **Immunological Vulnerability:** Increased susceptibility to infectious diseases
- **Intergenerational Transmission:** Girls who experience stunting are more likely to have low-birth-weight infants, perpetuating cycles of disadvantage

Multidimensional Determinants:

Following Bronfenbrenner's ecological systems framework (1979), child development results from interactions across multiple levels:

- **Individual Factors:** Genetic endowment, birth characteristics (gestational age, birth weight), sex
- **Family/Microsystem:** Maternal nutrition and health, breastfeeding practices, caregiver-child interactions, household food security
- **Community/Exosystem:** Access to healthcare services, availability of nutritious foods, water and sanitation infrastructure
- **Societal/Macrosystem:** Economic policies, health system organization, cultural beliefs about child-rearing

This multidimensional causality necessitates comprehensive assessment approaches that capture not only anthropometric measurements but also functional developmental capacity and contextual risk factors.

1.3. Project Objectives

This project aims to leverage TANI's data to develop actionable predictive models. Specific objectives include:

Primary Objective

Develop and validate machine learning models to predict early childhood development deficits, enabling proactive identification of at-risk children for targeted interventions.

Secondary Objectives

1. **Exploratory Analysis:** Conduct comprehensive exploratory data analysis (EDA) to identify patterns, risk factors, and data quality issues
2. **Feature Engineering:** Transform raw clinical measurements into actionable predictive features
3. **Model Development:** Compare multiple predictive algorithms and select the optimal approach for deployment
4. **Actionable Insights:** Provide evidence-based recommendations for TANI's operational and strategic decisions
5. **Data Infrastructure:** Document data quality issues and recommend improvements for future data collection

1.4. Scope and Limitations

Scope

- **Temporal Coverage:** Analysis covers post pandemic observations.
- **Population:** Children aged 0-5 years receiving services at TANI health centers
- **Predictive Modeling:** Focus on classification models for binary outcomes (deficit vs. normal)

Limitations

- **Data Quality:** As with most real-world clinical data, missing values and measurement inconsistencies are present
- **Selection Bias:** Population consists of families actively seeking TANI services, which may not represent the broader vulnerable population
- **Data Bias:** Some variables like deficit may be bias due to the nurse in turn who diagnosed the children. TANI have each age group assigned to certain nurse.
- **Causality:** While we identify predictive associations, establishing causal relationships requires additional study designs
- **External Validity:** Models will be optimized for TANI's specific population and may require recalibration for other contexts

1.5. Key Stakeholders

Primary Beneficiaries

- **Children (0-5 years):** Direct beneficiaries through improved early detection and intervention

- **Families:** Receive targeted support and guidance based on predictive risk assessments
- **TANI Clinical Staff (nurses):** Gain decision support tools for prioritizing cases and planning interventions

Secondary Stakeholders

- **TANI Leadership:** Use insights for strategic planning, resource allocation, and fundraising
- **Public Health Authorities:** Evidence base for policy recommendations and scaling interventions
- **Research Community:** Methodological contributions to applied machine learning in global health

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2. Data Reception and Consolidation

2.1. Data Sources

The analysis utilizes three primary data sources provided by TANI:

Internal Data

1. **MALNUTRITION Sheet:** Longitudinal records of children's growth monitoring and nutritional assessments
2. **DEVELOPMENT Sheet:** Developmental screening results across five domains
3. **INITIAL DIAGNOSIS Sheet:** First medical diagnosis when taking the program
4. **MEDICAL ADVICE Sheet:** Relevant medical recommendations given by the nurses

2.2. Data Challenges and Quality Issues

Initial data exploration revealed several challenges common to clinical registries:

Structural Issues

- **Inconsistent Formatting:** Age represented in mixed formats (days, months, years: "4d", "6m", "1a8m")
- **Variable Types:** Anthropometric measurements stored as text instead of numeric values
- **Categorical Encoding:** Multiple encoding schemes for the same concept (e.g., "SI"/"Normal" for development)

Data Quality Issues

- **Missing Values:** Inconsistent handling of "not applicable" vs. "not measured" vs. "refused"
- **Measurement Errors:** Outliers in weight, height, and head circumference requiring validation
- **Temporal Inconsistencies:** Some records show impossible sequences (e.g., height decreasing over time)
- **Duplicate Records:** Need to establish deduplication rules for repeated visits

2.3. Consolidation Process

To address these challenges, first we implemented a systematic data consolidation pipeline which consist in merging two main datasets excluding duplicates validated by TANI:

Phase 1: Data Profiling

```
============================================================
DATASET: MALNUTRITION
============================================================

Shape: 257,178 rows × 27 columns

Data Types Distribution:
object            23
float64            3
datetime64[ns]     1
Name: count, dtype: int64

Top 10 Variables with Missing Values:
                        Missing_Count  Missing_Percentage
```

```
Tam_graha                      253123              98.42
Tam_para                       252117              98.03
Recuperado                     247952              96.41
Tam_hb                         243562              94.71
Razón                          238809              92.86
Mantiene_Diag_Fav/Desf         188524              73.30
Lactancia                      186632              72.57
CN-CA                          167056              64.96
ACA                            112621              43.79
P/E                             47695              18.55

============================================================
DATASET: DEVELOPMENT
============================================================

Shape: 257,178 rows × 18 columns

Data Types Distribution:
object            15
float64            2
datetime64[ns]     1
Name: count, dtype: int64

Top 10 Variables with Missing Values:
            Missing_Count  Missing_Percentage
(M) - FF           130726               50.83
CabPC               42520               16.53
(S) - Soc           12915                5.02
(L) - Len           12902                5.02
(C) - Cog           12905                5.02
(M) - FG            12902                5.02
Talla                  18                0.01
Nº_HC                   9                0.00
Peso                    7                0.00
Nº_Control              1                0.00

============================================================
DATASET: MALNUTRITION (PRE PANDEMIC)
============================================================

Shape: 197,832 rows × 28 columns

Data Types Distribution:
```

```
object            22
float64            4
datetime64[ns]     1
int64              1
Name: count, dtype: int64

Top 10 Variables with Missing Values:
                        Missing_Count  Missing_Percentage
Tam_hb                         197832              100.00
Tam_graha                      197832              100.00
Tam_para                       197832              100.00
Recuperado                     195054               98.60
Razón                          187570               94.81
CabPC                          133848               67.66
Lactancia                      129627               65.52
ACA                             68300               34.52
Mantiene_Diag_Fav/Desf          39477               19.95
CN-CA                           38391               19.41

============================================================
DATASET: DEVELOPMENT (PRE PANDEMIC)
============================================================

Shape: 197,832 rows × 19 columns

Data Types Distribution:
object            16
datetime64[ns]     1
float64            1
int64              1
Name: count, dtype: int64

Top 10 Variables with Missing Values:
           Missing_Count  Missing_Percentage
(M) - FF          197831              100.00
CabPC             133848               67.66
(S) - Soc            395                0.20
(L) - Len            390                0.20
(C) - Cog            390                0.20
(M) - FG             392                0.20
Nº_HC                 95                0.05
Talla                  5                0.00
Peso                   2                0.00
```

```
Enfermera              6                0.00
```

Note: The following datasets of 'Initial diagnosis' & 'Medical advice' were given after first exploratory analysis which have the objective of narrow down the population. Therefore these dataset considered just recent years.

```
============================================================
DATASET: INITIAL DIAGNOSIS
============================================================

Shape: 35,705 rows × 45 columns

Data Types Distribution:
object            31
float64            7
bool               5
datetime64[ns]     2
Name: count, dtype: int64

Top 10 Variables with Missing Values:
                         Missing_Count  Missing_Percentage
Motivo_baja                      35704              100.00
Otros_Motivos                    35705              100.00
Motivo_Relactancia               35705              100.00
Diag_Nutricional                 35672               99.91
Talla_actual                     35659               99.87
PC_actual                        35659               99.87
Condicion_mama                   35643               99.83
Dx 2                             35642               99.82
Dx 1                             35081               98.25
complicacion_parto_bebe          35069               98.22

============================================================
DATASET: MEDICAL ADVICE
============================================================

Shape: 78,918 rows × 14 columns

Data Types Distribution:
bool              7
object            3
```

```
int64             2
datetime64[ns]    1
float64           1
Name: count, dtype: int64

Top 10 Variables with Missing Values:
            Missing_Count  Missing_Percentage
Nº_Control              2                 0.0
```

Phase 2: Data Cleaning Functions

Functions for parsing variables like Age, Date, Development area, and others were implemented.

Phase 3: Data Integration

```
Data Cleaning Results:
Original records (Malnutrition): 257,178
Original records (Development): 257,178
Original records (Malnutrition Pre-pandemic): 197,832
Original records (Development Pre-pandemic): 197,832
After cleaning and consolidation (pre and post pandemic datasets): 454,901
```

2.4. Consolidated Dataset Characteristics and created features

2.4.1 Consolidated dataset overview

```
<class 'pandas.core.frame.DataFrame'>
RangeIndex: 454901 entries, 0 to 454900
Data columns (total 32 columns):
 #   Column                  Non-Null Count   Dtype
---  ------                  --------------   -----
 0   Fecha                   454901 non-null  object
 1   N_HC                    454901 non-null  float64
 2   Tipo_Paciente           454901 non-null  object
 3   Categoría               454901 non-null  object
 4   Sexo                    454901 non-null  object
 5   Edad                    454901 non-null  object
 6   N_Control               454900 non-null  float64
 7   Peso                    454892 non-null  object
```

```
 8   Talla                   454878 non-null  object
 9   CabPC                   278593 non-null  object
 10  Diag_Nacimiento         454901 non-null  object
 11  P/T                     407210 non-null  object
 12  T/E                     407216 non-null  object
 13  P/E                     407210 non-null  object
 14  Ganancia_Peso_Talla     412822 non-null  object
 15  Dx_Nutricional          454894 non-null  object
 16  CN-CA                   249503 non-null  object
 17  Mantiene_Diag_Fav/Desf  226959 non-null  object
 18  Recuperado              12003 non-null   object
 19  Lactancia               138719 non-null  object
 20  Razón                   28618 non-null   object
 21  ACA                     274016 non-null  object
 22  Tam_para                5061 non-null    object
 23  Tam_graha               4055 non-null    object
 24  Tam_hb                  13614 non-null   float64
 25  Acompaña_control        454901 non-null  object
 26  Enfermera               454890 non-null  object
 27  (M) - FG                441618 non-null  object
 28  (M) - FF                126435 non-null  object
 29  (C) - Cog               441617 non-null  object
 30  (L) - Len               441620 non-null  object
 31  (S) - Soc               441602 non-null  object
dtypes: float64(3), object(29)
memory usage: 111.1+ MB
None

Consolidated Dataset Summary Statistics:

Numeric variables:
              count          mean           std  min      25%      50%  \
N_HC       454901.0  66360.885111  17133.564981  0.0  52871.0  67695.0
N_Control  454900.0      4.246393      2.783653  0.0      2.0      4.0
Tam_hb      13614.0     11.411892      1.295860  6.6     10.8     11.4

               75%      max
N_HC       81026.0  95801.0
N_Control      6.0     14.0
Tam_hb        12.0    107.0
```

2.4.2 Features created for exploratory analysis

ORIGINAL FEATURES:

- **Fecha:** Medical care date for the child
- **N_HC:** Medical record number assigned to the patient
- **Sexo:** Child's gender. F: Female; M: Male
- **Peso:** Recorded weight of the child in kilograms
- **Talla:** Recorded height/stature of the child in centimeters
- **CabPC:** Head circumference of the child in centimeters
- **Diag_Nacimiento:** Birth diagnosis. Values: Normal, Pretérmino (Preterm), BPN (Low Birth Weight), Macrosómico (Macrosomic)
- **Ganancia_Peso_Talla:** Weight and height gain (adequate or inadequate). Combinations: GIP/GIT, GAP/GIT, GIP/GAT, GAP/GAT
- **Dx_Nutricional:** Nutritional diagnosis. N: Normal, O: Obesity, R: Risk, S: Overweight, DC: Chronic M., DA: Acute M., DG: Global M.
- **CN-CA:** Continuity of Nutritional Dx. CN: New Case, CA: Old Case
- **Mantiene_Diag_Fav/Desf:** Nutritional diagnosis follow-up. Fav: Favorable, Desf: Unfavorable
- **Recuperado:** Recovery in nutritional diagnosis (e.g.: Global M. to Normal, Risk to Normal, etc.)
- **Lactancia:** Current breastfeeding type (up to 6 months). LME: Exclusive Breastfeeding, LMX: Mixed Breastfeeding, LA: Artificial Feeding
- **Razón:** Reason for LMX or Artificial. 1: Others, 2: Own Will, 3: Low Production, 4: Study/Work, 5: Medical Indication
- **ACA:** Active complementary feeding. YES/NO
- **Tam_para:** Parasite test result. Positive/Negative
- **Tam_graha:** Graham test result. Positive/Negative
- **Tam_hb:** Hemoglobin dosage result
- **T/E_cat:** Height/Age percentile category. N: Normal, R: Risk, DC: Chronic M.
- **P/E_cat:** Weight/Age percentile category. N: Normal, R: Risk, DA: Acute M.
- **P/T_cat:** Weight/Height percentile category. N: Normal, O: Obesity, S: Overweight, DA: Acute M.

TRANSFORMATIONS:

- **edad_meses:** Child's age expressed in months
- **flg_cognitivo:** Binary flag for cognitive development area (0: Normal, 1: Deficit)
- **flg_lenguaje:** Binary flag for language development area (0: Normal, 1: Deficit)
- **flg_motora_fina:** Binary flag for fine motor development area (0: Normal, 1: Deficit)
- **flg_motora_gruesa:** Binary flag for gross motor development area (0: Normal, 1: Deficit)
- **flg_social:** Binary flag for social development area (0: Normal, 1: Deficit)

- **flg_alguna:** Flag indicating if there is any deficit in any development area (0: No, 1: Yes)
- **flg_total:** Flag indicating if there is deficit in all development areas
- **flg_social_lenguaje:** Binary flag for language or social development area (0: Normal, 1: Deficit)
- **control_esperado:** Expected check-up number according to child's age
- **primer_alguna:** Check-up number where the first deficit was detected (flg_alguna=1)
- **primer_control_esperado:** First expected check-up number according to child's age
- **ultimo_control:** Last recorded check-up number
- **cant_controles_primer_alguna:** Number of check-ups until first deficit detection
- **cantidad_controles:** Total number of check-ups performed
- **num_controles_previos_deficit:** Number of previous check-ups before deficit detection
- **nro_control_recreado:** Recreated or recalculated check-up number
- **num_controles_posteriores_deficit:** Number of check-ups after detected deficit

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3. Exploratory Data Analysis (EDA)

3.1. Defining population

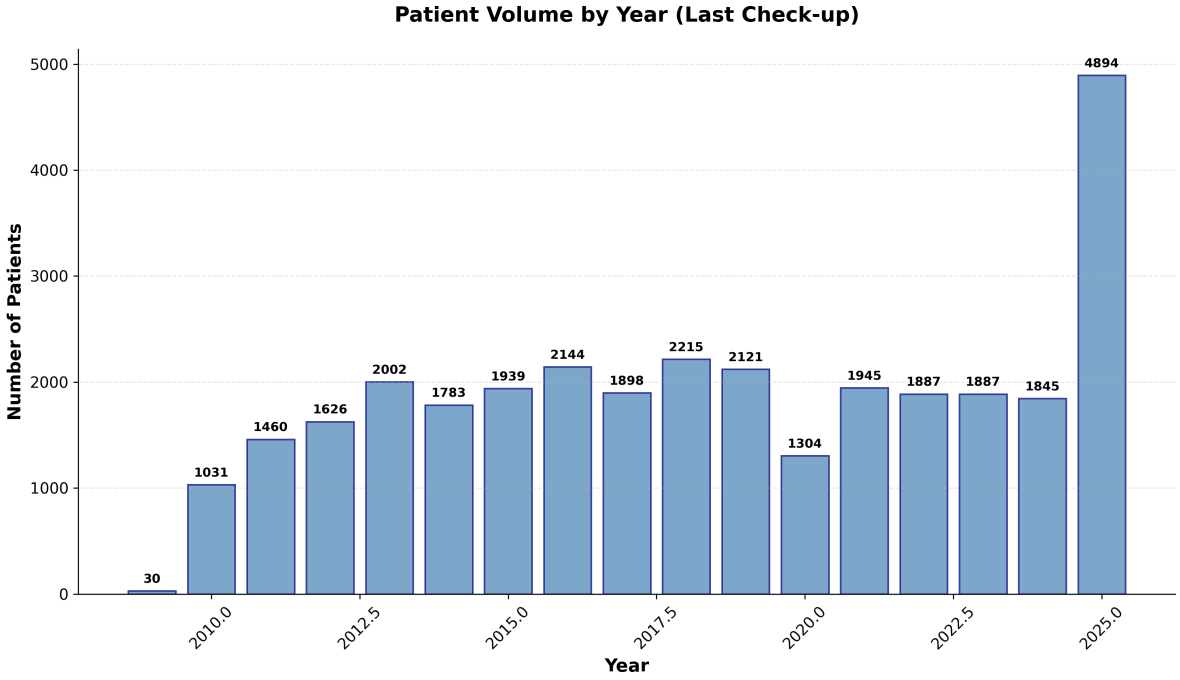
For the definition of the population to work with TANI recommended to focus on social and language areas. This due to the rare cases in motor development deficits. On the other hand, the election of records since 2023 were defined because of imbalanced target in previous years. When validating with TANI they confirmed that there had been changed when defining "deficits" and that is why there is more cases in recent years.

```
================================================================================
EXPLORATORY ANALYSIS: POPULATION DEFINITION (BY PATIENT N_HC)
================================================================================

 Total records in dataset: 454,901
 Total unique patients (N_HC): 32,011

 DEFICIT PREVALENCE BY PATIENT
--------------------------------------------------------------------------------
Any deficit                   :    100 ( 0.31%)
Language deficit              :     91 ( 0.28%)
Social deficit                :     15 ( 0.05%)
Social OR Language deficit    :     86 ( 0.27%)
```

```
Chart saved as: patient_volume_by_year.png
```



PREVALENCE BY YEAR (LAST CHECK-UP OF EACH PATIENT)

year	Patients	flg_alguna	%_alguna	flg_lenguaje	%_lenguaje	flg_social	\
2009	30	0	0.00	0	0.00	0	
2010	1031	0	0.00	0	0.00	0	
2011	1460	0	0.00	0	0.00	0	
2012	1626	0	0.00	0	0.00	0	
2013	2002	0	0.00	0	0.00	0	
2014	1783	0	0.00	0	0.00	0	
2015	1939	0	0.00	0	0.00	0	
2016	2144	0	0.00	0	0.00	0	
2017	1898	0	0.00	0	0.00	0	
2018	2215	0	0.00	0	0.00	0	
2019	2121	7	0.33	6	0.28	0	
2020	1304	21	1.61	22	1.69	1	
2021	1945	5	0.26	4	0.21	0	
2022	1887	2	0.11	1	0.05	1	

2023	1887	6	0.32	5	0.26	1
2024	1845	8	0.43	8	0.43	1
2025	4894	51	1.04	45	0.92	11

year	%_social	flg_social_lenguaje	%_soc_leng
2009	0.00	0	0.00
2010	0.00	0	0.00
2011	0.00	0	0.00
2012	0.00	0	0.00
2013	0.00	0	0.00
2014	0.00	0	0.00
2015	0.00	0	0.00
2016	0.00	0	0.00
2017	0.00	0	0.00
2018	0.00	0	0.00
2019	0.00	6	0.28
2020	0.08	17	1.30
2021	0.00	4	0.21
2022	0.05	1	0.05
2023	0.05	5	0.26
2024	0.05	8	0.43
2025	0.22	45	0.92

The final population meets the following filters:

```
3. FILTER CRITERIA ANALYSIS (YEAR >= 2023)
--------------------------------------------------------------------------------
Total patients with last check-up 2023+: 8,626

Patients with primer_alguna en [1,2,3]: 8,059
Patients with cant_controles_primer_alguna >= 6: 7,527
Patients with ultimo_control >= 19: 4,218
Patients with ALL criteria: 3,721

 FILTERED POPULATION:
   Total: 3,721 patients
   With deficit (flg_social_lenguaje=1): 47
   Without deficit (flg_social_lenguaje=0): 3,674
   Positive class balance: 1.26%
```

3.2. Descriptive Statistics

3.3. Outlier Detection and Treatment

Some numeric variables were treated with the 99th percentile after validating that most of the outliers were human error when transcribing to their databases from physical records.

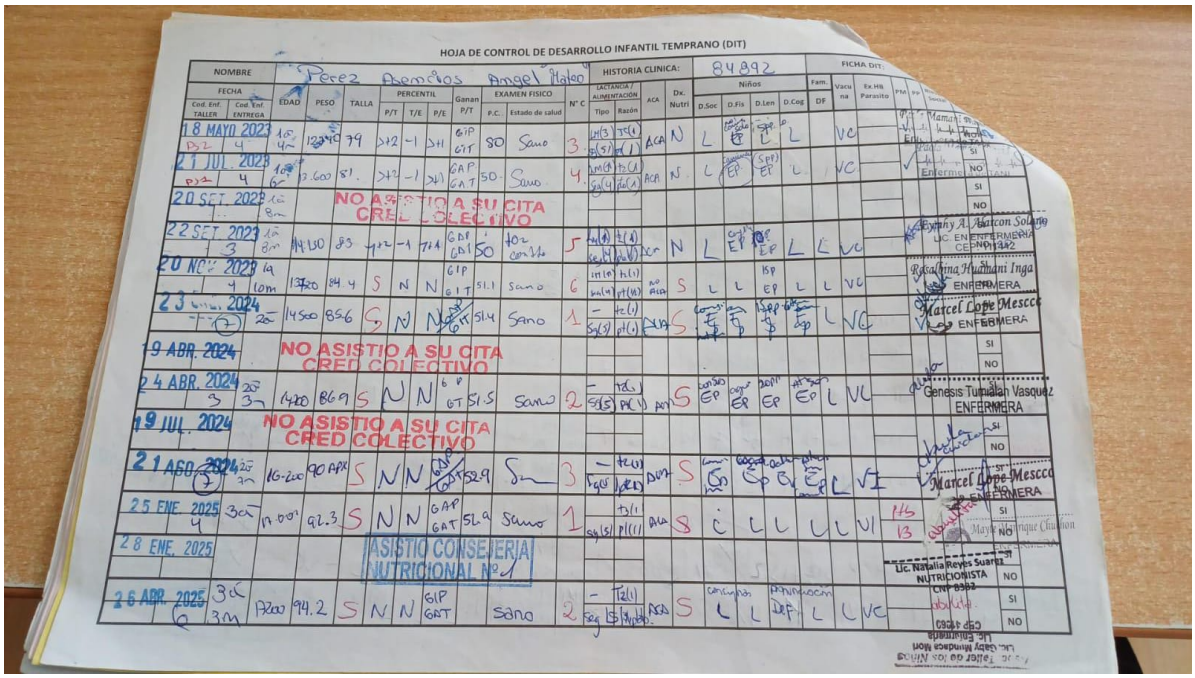
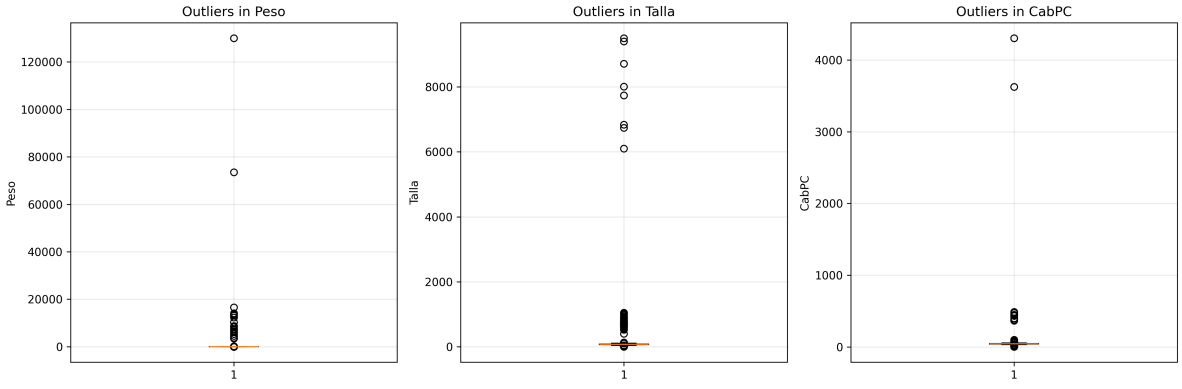
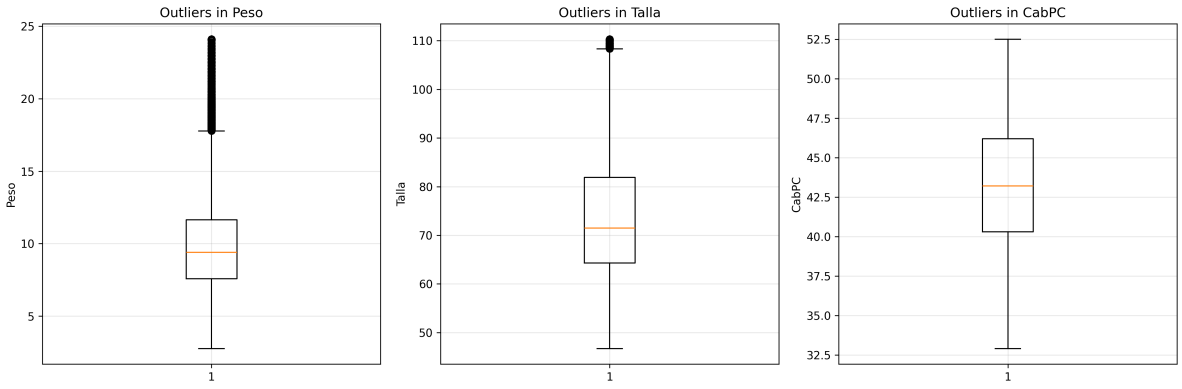


Figure 1: Original records TANI

Before treatment:

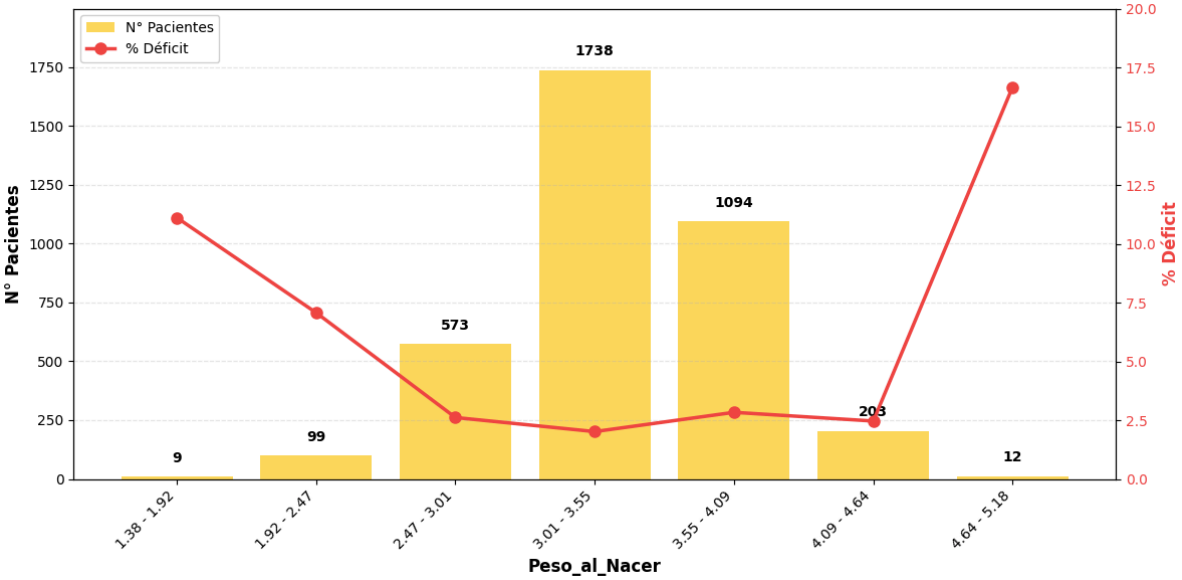


After imputation:

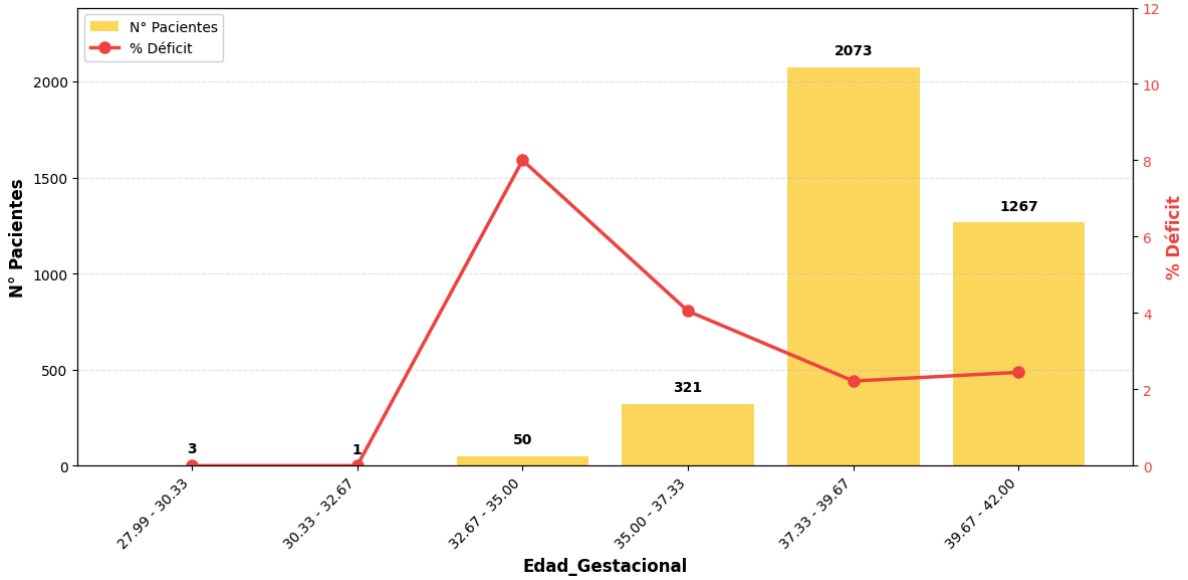


3.4. Preliminary Insights

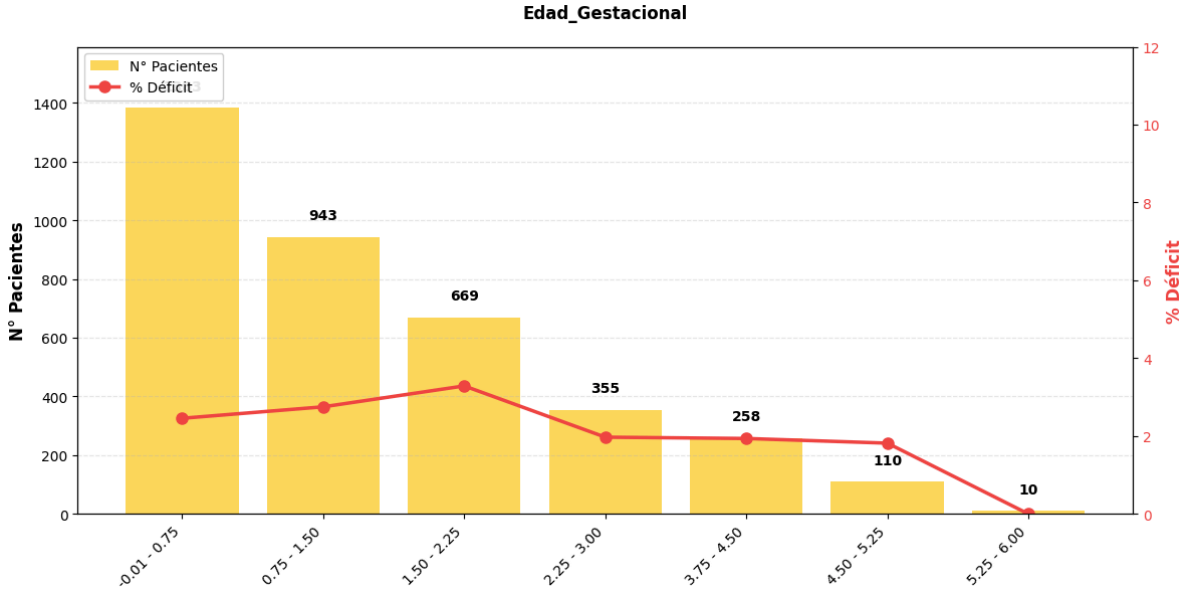
From the new definition population analice de main variables that affect that impact in development children. The objective is find patterns related to social and language deficit, to this we made bins graphic of our variables



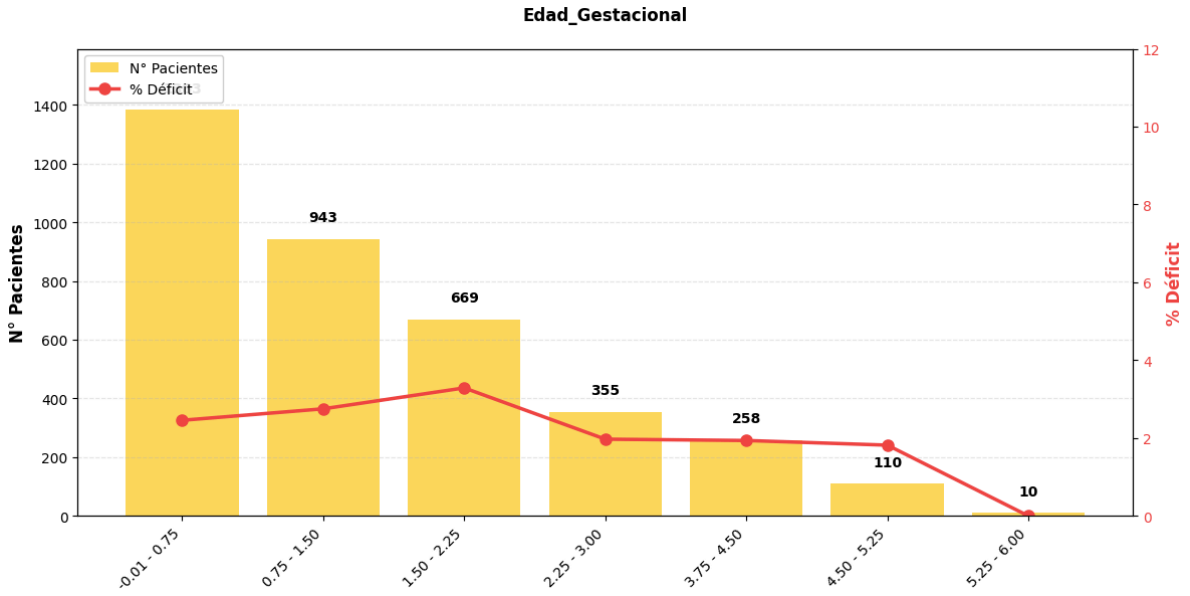
The weight distribution shows an accumulation of range from 3.2-3.9kg and minimum cases of deficit, as a good pregnant follow. That not happened in extremes of the graph, where to a lower (desnutrition) o higher (metabolic issues) weight there are more cases of deficit. That occurs



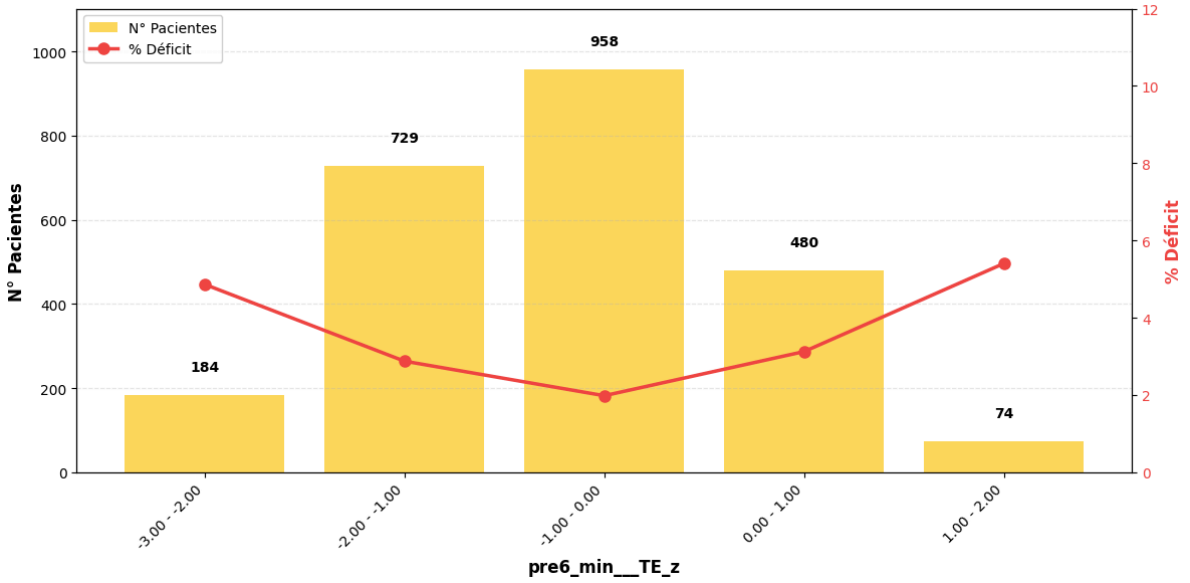
Patients born after 37 weeks have lower values of deficit (<3%). In the other hand, premature cases have more deficient patients. This case, show us the preterm impact where the incomplete development increase the nutritional sistem



The graph show a inverse relation between the number of vaccine session and % of deficit. A child with low participation show a highest deficit rate in contrast the other one received it.



The age analysis explain that most deficits cases are in earlier ages than older (0 to 12 months). The deficit rate of childreen with 28 moths decreases to 0. That explain that the firsts 12 months are critical to prevent and made a good monitoring of the childreen. Those to prevent nutritional and development problems



One of the metrics or limitles that help make monitoring of development. The values down the limit of -2 are related to nutritional deficit and up values like +2 or more has overweight. This trend of hieght for age value help to monitore the growth curve

Conclusion: From the new findings of the study population shows that early ages and factors

(weight,premature,counseling,monitoring, height-age value) that has a negative impact on risk growth patterns and will be so helpfull to focus on especific preventions interventions.

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4. Predictive Modeling

[To be developed in next phase]

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5. Recommendations for TANI

[To be developed based on model results]

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6. Conclusions and Next Steps

[Final synthesis]

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