Causal Complexity of Perinatal and Late Neonatal Mortality in the Department of Cauca, Colombia from the Perspective of Systems Thinking

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ABSTRACT

Description of Background: Causes of perinatal and neonatal death are complex due to the multiple groups of factors, including clinical (biomedical), demographic, social, economic, and even political factors, as well as the interactions among them. The specific combination and interaction of those factors faced by one individual makes it more or less likely to have access to healthcare; in particular, they condition the effectiveness of key interventions to prevent perinatal and neonatal death such as accurate prenatal care. A holistic analysis of these variables and factors and interactions among them for subnational areas that lag in infant mortality is necessary to identify entry points to accelerate progress on mortality reduction results.

Methods: Systemic and dynamic thinking methodology was applied to construct a causal loops diagram through brainstorming process among experts and executors and adapted to the Department of Cauca in Colombia, following the techniques of Williams B and Sturminster JP.

Results: Many more reinforcing loops were found than balancing loops, while specific regional barriers were identified, facilitating the location of points for effective preventive interventions in the dynamic system that would allow the achievement of the United Nations Sustainable Development Goals (UN-SDG,2030). The causal loops diagram and referrals were validated through surveys of a group of first- and second-line experts in maternal and childcare, who provided feedback.

Conclusions: The causal loops diagram adapted to regional particularities improves the Colombian path of compliance with the United Nations sustainable development goals and equity at the departments and subregions level.

Relevance: In the Colombian case, because the main barrier in the Cauca Department, as others in the country, is the diversity in perinatal and late neonatal deaths by subregions when the whole Department average is acceptable in relation with UN-ODS, 2030.

Keywords: Causal loop diagram, health systems research, maternal health care, neonatal mortality, perinatal mortality, systems analysis, systems thinking.

I. INTRODUCTION

The right to dignity and life of the child has been ratified in the convention on the rights of the child by the United Nations since 1990 [1]. UNICEF and the United Nations inter-agency group for the estimation of child mortality (UN IGME) point out that about 2.4 million newborns die each year during the neonatal period with a ratio of 17 (CI 17-19) deaths per 1000 live births, the vast majority (99%) occurring in low- and middle-income countries (LMIC) [2]. Most worryingly, recent progress reports on global trends in neonatal mortality have shown slow progress in reducing death rates among newborns. In 2019, 47% (CI 45-49) percent of all deaths in children under five occurred in the neonatal period, increasing their proportion from 40% (CI 39-41) percent in 1990 [2]. The National Institute of Health of Colombia (INS) reported an average of 16.1, 15.0, 15.1 and 14.1 perinatal and late neonatal deaths per 1,000 live births (PLND) during 2017, 2018, 2019 and 2020 respectively [3]. In turn, the UN IGME estimated for Colombia 7.48 neonatal deaths (IC 8.28-16.6) and 7.1 stillbirths (IC 5.18-9.9) per 1,000 live births during 2019 with a slightly downward trend [2]. The objective of the Sustainable Development Goal (SDG) for Colombia in this indicator is 12 neonatal deaths per 1,000 NV and the goal of the Colombian Ten-Year Health Plan 2012-2021 is 15 per 1,000 live births [3].

For 10 years, the indicators showed a slightly increasing
trend and the main factors of neonatal death declared by researchers are low birth weight (LBW) and poor adherence to Prenatal Care (CPN) [4]. The diversity of results by regions, despite the good coverage of this health service, suggests that there are problems in its implementation in some regions of the country. For example, in 2019 there were MPNT indicators as high as 36.0, 35.0 and 29.8 per 1,000 live births in Vichada, Chocó and Buenaventura, respectively [3]. Factors such as untimely care due to difficult access of pregnant women to health services or fears of violence due to the presence of an armed conflict due to drug trafficking influence the food security of women and their newborns [4].

The Department of Cauca is a representative territory of these regions for the investigation of the variability problem of the BPN and its consequences as the PLND, due to their similarity in ethnic and geographical diversity their economic situation and social conflict. It is of great interest that the Department of Cauca, with a coverage of public health insurance of 88.5% and a frequency of use of healthcare of more than 4 controls for 68% of pregnant women, a great variability of the BPN is observed among the municipalities that comprise it, with an 8.2 ± 2.9% average [5].

The state of the art through multiple scientific publications attributes PLND to three main factors: Low birth weight (LBW), Intrauterine growth restriction (IUGR) and failures in the quality of the implementation of Prenatal Control (CPN). These factors, which are generally affected by the social determinants of health, have also been observed in Colombia [6]-[10].

In addition to better access to and quality of care, it is necessary to address other determinants of low birth weight. Care must be adaptable to the cultural environment and considers the beliefs and preferences of women regarding their health, imbalances in the relationships, inequalities between groups of women in terms of ethnicity and differences in places of residence. Gender-equitable interventions are essential to reach women who face the greatest barriers to accessing health care [11], [12].

A complex system is a system of large networks of components without central control and simple operating rules that macroscopically give rise to non-trivial emergent elements and self-organizing behaviors that involve sophisticated information processing and adaptation through learning or evolution. Systems thinking, as a vitally important approach from complexity theory to explore the dynamics arising from the neonatal health complexity, its non-linearity and interplay and the influence of these dynamics in the health system factors. The tool is useful to understand the effect that health interventions have on the entire system to locate, target, and evaluate more effective interventions in health systems and their related subsystems. Today some systemic methodologies are available to analyze complex systems, including the dynamic synthesis model (DSM) and causal loop diagrams (CLD) tool helps to understand and describe the feedback mechanisms which include relationships, dynamics, and delays combined in reinforcing and balancing loops. They offer a practical way to depict the system interrelated parts and the links of influence among them for the problem under study [13], [14].

Health systems are constantly changing and adapting to changes in other parts of the system. They are history dependent and naturally resistant to new directions. Social Determinants of Health reveal this type of emergent behavior composed of interlocking networks of structural and intermediate rules that influence public health, its health system and feed into each other [14].

The CLD construction process follows the recommendations originally developed by [15], [16] then discussed by [17] in 2013 and later by the synthesis developed and presented by [18], process known as dynamic synthesis model (DSM). The DSM process has six stages: 1) problem statement and preliminary data collection; 2) field studies; 3) CLD and DSM building; 4) case study and empirical exploration; 5) simulation; and 6) policy analysis [18].

The objective of this article is to propose a causal loops diagram that involves the entire gestational and perinatal process, the factors and determinants affecting pre-postnatal care and late perinatal and neonatal mortality for the Department of Cauca, Colombia. The first three stages of the DSM process led to the construction of a CLD as a preamble to model building.

II. METHODOLOGY

As was mentioned before, this article applied the first three stages of the DSM to build the CLD allowing the possibility for further building a dynamic model. The diagram shows the variables or factors, relationships and feedback loops that act on the demand for maternal, perinatal, and postnatal health and the provision of these health services, without attempting to establish a causal-effect relationship between the variables or factors relationships that are most the proposal of one DMS [16].

For the first stage, brainstorming sessions, were held to propose the CLD with five (5) health PhD students and six (6) professors of Universidad del Valle Medicine Faculty and with one director of the Social Protection and Health Economics Studies Center of ICESI University. In a second stage this brainstorming product was validated through International and local recent literature review, showing the reference numbers of the related influencing factors findings around each arrow of the CLD. Simultaneously, internal sessions were held with the article authors to discuss the results found and proceed to develop and propose the causal loops diagram which was finally validated by local and international expert health actors.

Final validation instrument includes objectives of validation process, meaning of the elements used in the CLD as well as a general guide. Validation of the CLD and the concepts involved was carried out by nine (9) external expert researchers and local executors of Department of Cauca, nationals of Colombia and international ones interested in neonatal and maternal health. This panel of experts was asked to indicate whether all variables and relationships in the CLD existed and if important causal factors were missing, they were asked to describe them. In addition, they evaluated if the addresses of each of the links were correct or needed redirection. Suggested modifications since validation were discussed within the investigators and used as feedback to improve the development of the final CLD showing in this article as was mentioned before. This article shows the
validation process, the experts’ profiles, and the validation results.

In the preparation of the article there was no contact or intervention of patients or animals so there was no need for informed consents, but as part of a doctoral process it is covered by the certification of the Institutional Committee of Human Ethics-ICHE- of the Faculty of Health of the Universidad del Valle, Act No. 19-0020 of November 3, 2020.

III. RESULTS

It is important to remember that numerical references (#) appearing above or below the directional arrows in the CLD indicate the bibliographic source that supports influencing variables or factors and their positive (blue arrows) or negative (red arrows) influence. In the same sense, a reinforcing loop (R) is that cyclical sequence of events where the previous ones are positive causes of the following, that is, if one grows the other also or vice versa.

Under these considerations seven causal loops were identified in the analysis of the diagram, identified as R1, R2, R3, R4, R5, R6 and R7 and 6 balancing loops identified as B1, B2, B3, B4, B5, and B6, which will be described in detail below Fig. 1 (Diagram of causal loops of the gestational process in the Department of Cauca). The loops and directional arrows were not categorized and only described as it was a qualitative analysis. Its quantitative categorization requires a data collection model and processes (DSM) that are beyond the scope of this research.

R1 begins with the participation of the pregnant woman in the prenatal control process, leading to a greater probability of safe deliveries, while R2 begins the same and leads to an improvement in the mother’s health status, which in turn translates into greater maternal care for the newborn. Both loops close positively in the demand for pre and postnatal controls.

The R3, R4 and R5 loops also start with the demand for pre- and postnatal controls and have common events such as maternal care of the risks of neonatal death; for R3 and R4 and institutional support; the highest level of awareness about perinatal health for R4 and R5. Again, all of them closing the cycles positively in the demand for pre and postnatal controls.

Other short reinforcing loops with different point of origin, but key to the functioning of the general system, R6 and R7, were identified in the diagram. R6 on the management of human talent translates into better skills, better salaries, and greater motivation of the health service personnel in the institutions and R7 on the positive impact of conditioning education to local cultural characteristics with positive effects derived in health care of the mother and her family for the newborn.

A balancing loop (B) is that cyclical sequence of events where the previous ones are causal to the following, but not positively or negatively in the whole sequence, avoiding completely positive or negative causal spirals.

Balancing causal loops B1 and B2 are associated with health system effectiveness, the demand for pre and postnatal controls and the trust it generates in the pregnant users of the service. B1 is based on the demand for pre-natal and postnatal controls, which negatively impacts health system effectiveness due to the increase in demand in face of budgetary limitations. In turn, B2 loop has the same origin, negatively affecting health system effectiveness due to negative budget effect limitations over the trust of pregnant women in health system.

B3 is associated with the training of the workforce of health institutions that would improve their work capacity by reducing their workload. B4 associates pre and postnatal control with more safe deliveries that positively lead to less negative neonatal death because it reduces newborn survival, which in turn positively demands greater pre- and post-natal control.

Fig. 1. Causal Loop Diagram of the gestational process in the Department of Cauca *. The numerical references (#) that appear above or below the directional lines of causality in the diagram indicate the bibliographic source that supports the causal directions and their positive (blue arrows) or negative (red arrows) influence.

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B5 with the same origin as B4 associates it with the reduction of preterm infants or those with intrauterine growth retardation that produce a higher low birth weight. B6 starts from the level of health system effectiveness which, by increasing budget limitations, leads to the need for Public Policies that through regulations, norms, and laws, improve health system effectiveness.

Specific events in this region characterizing the specificity of this CLD could be identified and evidenced by other social and health research carried out in countries of medium and low development, such as the armed conflict expressed in intrauterine growth delay (IUGR) and failures in the quality of the implementation of Antenatal Control (ANC). These facts affect positively the critical situations of PLND, as it achieves an integrated supply and demand diagram of care for the mother-child binomial and its influence that affect it locally, such as acts of violence, poor nutrition, environmental and ethnic-cultural diversity of the region, being able to offer a complete vision of the systemic phenomenon. The originality of this CLD lies in the fact that it achieves an integrated supply and demand diagram of care for the mother-child binomial and its influential contexts.

Another original characteristic of this CLD is the implication of ethnic plurality in the educational process of pregnant women. This process should respect and adapt to the cultures of these ethnic groups, including their traditions, myths, and legends about the gestational process, reflected in the facts of the institutional daily reality with native indigenous and Afro-descendant populations [12].

In the literature generated in medium and low-developed countries, there is evidence that geographical and cultural access barriers and those produced by rurality, poverty or marginality affect logistics and hospital referrals with a clear effect on the health system effectiveness and consequently on the MPNT rate [20], [21].

The expertise of the nine external experts who run the final validation process is described in Table I. These experts rated the validity of causal loop diagram through a survey of four questions with selection of single answer to four possibilities as it appears in Table II. The main observations received from experts appears in supplementary file 1.

IV. DISCUSSION

There is no CLD in Colombia applied to a political-geographic unit of the country. In this CLD, the supply of health services and their demand are integrated in an original way while incorporating events external to the health system that affect it locally, such as acts of violence, poor nutrition, environmental and ethnic-cultural diversity of the region, being able to offer a complete vision of the systemic phenomenon. The originality of this CLD lies in the fact that it achieves an integrated supply and demand diagram of care for the mother-child binomial and its influential contexts.

CLD clearly identify 7 reinforcing loops and 6 balancing loops which have influence on the newborns survival and would be a good base of knowledge to take decisions affecting positively the critical situations of PLND. As mentioned before, multiple scientific publications attributes PLND to three main factors: Low birth weight (LBW), Intrauterine growth delay (IUGR) and failures in the quality of the implementation of Antenatal Control (ANC). These

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### Table I: Group of Experts in the Validation of the Causal Loops Diagram

<table>
<thead>
<tr>
<th>Experts Name</th>
<th>Current Position</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luz Angela Torres de la Roche</td>
<td>Nurse, Msc in Public Health, PhD in Nursing</td>
<td>Germany</td>
</tr>
<tr>
<td>Zaid Gloria Triviño Vargas</td>
<td>Obstetrician gynecologist, PhD in Medicine</td>
<td>Germany</td>
</tr>
<tr>
<td>Alexander Lovera Montilla</td>
<td>Nurse Neonatology, Msc in Epidemiology, PhD (e)</td>
<td>Spain</td>
</tr>
<tr>
<td>Aníbal Nieto Díaz</td>
<td>MD, Obstetrician gynecologist, PhD Medicine</td>
<td>Mexico</td>
</tr>
<tr>
<td>Jaime Salvador Moysén</td>
<td>MD, Msc in Public Health, PhD in Public Health</td>
<td>Spain</td>
</tr>
<tr>
<td>Julián A. Herrera M.</td>
<td>MD, FACS, PhD in Medicine</td>
<td>Spain</td>
</tr>
<tr>
<td>Jaime Lee Isaza</td>
<td>MD, Msc in Epidemiology</td>
<td>Mexico</td>
</tr>
<tr>
<td>Javier Torres Muñoz</td>
<td>MD, Msc Neonatology, Pediatric, PhD Medicine</td>
<td>Colombia</td>
</tr>
<tr>
<td>José Ivo Montaño Caicedo</td>
<td>MD, Msc Economics</td>
<td>Colombia</td>
</tr>
</tbody>
</table>

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### Table II: Causal Loop Diagram Qualification by Experts

<table>
<thead>
<tr>
<th>Questions</th>
<th>Options of answer</th>
<th>Number of answers out of nine (9)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Does the proposed CLD reflect the systemic causal reality of the MPNT of the Department of Cauca?</td>
<td>Very reasonably</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Reasonably</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Enough</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Not reasonably</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Good</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Good enough</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>In no way good</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Very useful</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Useful enough</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>In no way helpful</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Very useful</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Useless</td>
<td>5</td>
</tr>
<tr>
<td>Is the CLD useful to communicate these causal processes and their problems?</td>
<td>Useless</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Useful enough</td>
<td>1</td>
</tr>
<tr>
<td>Is the proposed CLD a useful tool for decision-making processes?</td>
<td>Very useful</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Useless</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>In no way helpful</td>
<td>1</td>
</tr>
</tbody>
</table>

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factors, which are generally affected by the social determinants of health, have also been observed in Colombia [6]-[10]. The CLD loops identified are showing all those effects on newborns survival.

International literature on the methodology used for the research usually shows partial diagrams showing demand or supply in separate diagrams such as those of [22]-[29], presenting causal loops of specific parts of maternal perinatal health services. The framework developed in these studies recognizes the fact that a series of feedback structures can have major implications for maternal health care policies by identifying points of intervention and allowing a shared understanding of the problem and its possible solutions. The diagram proposed here aims to demonstrate the same fact on a more detailed holistic scale of feedback structures.

Reference [30] and [31], were able to identify that feedback in the health system studied by them would be determined by limited resources of the households, the technical quality of the health service, trust in the service, knowledge of the pregnant women on maternal health services and the perception of service quality. Similarly, [12] identified restrictive cultural aspects for Bolivian indigenous pregnant women with respect to sexuality, contraception, antenatal care with male gynecologists, and social stigmatization of teenagers pregnant outside of marriage. These causes have also been detected in the design of the diagram presented in this article as cultural factors.

Reference [11] was able to identify in contexts of violent insurgency in Nigeria several causes that we share in the diagram of this article, among them insecurity that produces anguish and fear, displacement, restrictions on mobility and access to health services at the same time as influence factors of commitment and motivation of institutional human resources such as recruitment, workload, capacity, and availability were identified by [32].

References [33]-[36] found in their research that the effect of intrafamily abuse, anxiety, and stress processes in pregnant women in the face of abuse and biopsychosocial risk during the process of gestational factors affect LBW and PLND. By virtue of these biopsychosocial findings, especially for [36], Colombian Ministry of Health and Social Protection of Colombia established, through Resolution 3280 of 2018, technical and operational guidelines of the Comprehensive Route of Care in Health for the Maternal-Perinatal Population including the assessment of biopsychosocial risk [37].

There are coincidences in the identification of reinforcing and balancing loops carried out by [22]-[25], especially in the finding of more reinforcing loops than balancing ones in the demand aspects than in the supply of health services. On the other hand, the CLDs of [27], and [30]. Although they were very general and for the entire health system, they show similarities in influence factors and coverage with the one proposed.

Study by [38] in Colombia found that the absence of NPCs increases the risk of LBW with an OR 8.20 and a CI95%: 3.22-20.87, likewise the study by [39] also in Colombia shows that an inadequate CPN produces a higher risk of LBW with an OR 1.7 and a 95% CI of 1.1-2.8, p<0.001. Attendance at more than 4 prenatal controls as a protective factor for LBW has been recorded by [40] in 2017 with an OR: 0.34 and a 95% CI of 0.14-0.84. Other Colombian study has shown relationship between birth weight and some biological and socioeconomic variables like in [41] and internationally LBW with psychological stress in [42] and with intrauterine growth restriction in [43].

Although the validation by experts was quite positive, its greatest observation was related to the complexity of the CLD that makes it difficult to understand for non-experts as it could be the case for some decision makers. This CLD being holistic by synthetically displaying as many factors as possible affecting pre and postnatal control services (ANC/PNC) omit details of influential sequences that could be displayed better. This tradeoff has been inevitable since the intention of the proposed CLD is to be briefly but highly comprehensive of as many influence factors as possible on offer and demand for ANC/PNC services and the survival of neonates.

Other limitation is the fact of have a developed the CLD throughout a brainstorming of experts and incumbents specifically for Department of Cauca, which would only make it useful for decisions for that Department. However, and given that the Department of Cauca was selected for its multi-ethnic and geographically diverse character, this CLD would has potential to guide decisions in other similar regions in Colombia.

In conclusion, the findings presented by the CLD adapted to these realities in whole picture, like the 7 reinforcing loops and 6 balancing loops, contribute to the greater understanding of the complexity of the adverse maternal-perinatal outcome so that maternal and reproductive health service institutions can be more effective by combining health factors maternal and reproductive factors in their environment and identify strategic points of preventive or corrective intervention to reduce PLND in Colombia to accomplish United Nations 2030 SDG number 3.

The proposal for the future would be to advance with the following stages of the dynamic synthesis model (DSM) mentioned in the methodology that would complete the design and development of a quantitative simulation model whose objective is to look for causal-effect relations and simulate more concrete and specific effective strategic interventions in the construction of public health policies for the reduction of the PLND rate. This would imply a great effort in data collection and field work, as has been seen in quantitative modeling work carried out in other countries [25].

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The expert collaboration of the members of the CLD validation group and some of the brainstorming sessions, doctors, and professors Luz Angela Torres de La Roche, Zaider Triviño Vargas, Alexander Lovera Montilla, Aníbal Nieto, Jaime Salvador Moysén, Jaime Lee Isaza, Javier Torres Muñoz, and José Ivo Montaño Caicedo, is highly appreciated.

CONFLICT OF INTEREST

Authors declare that they do not have any conflict of interest.
REFERENCES


