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IPEN RADIOPHARMACEUTICAL MARKET TRENDS: AN APPROACH TO SYSTEM DYNAMICS

*[1]Rita de Cássia Mutarelli, [2]Ana Cecília de Souza Lima, [2]Joaquim Rocha dos Santos and [2]Gaianê Sabundjian

[1]Avenida Professor Lineu Prestes, 2242 zip code: 05508-000
[2]Estrada do Campo Limpo, 6903, Brazil

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ABSTRACT

The Instituto de Pesquisas Energéticas e Nucleares (IPEN) is today responsible for providing radiopharmaceuticals for 80% of nuclear medicine procedures in Brazil. The aim of this study is to analyze the impact of different radiopharmaceutical demands on IPEN production. The methodology used in this study is based on the system dynamics simulation paradigm, combined with empirical data obtained from the institutions and regulatory authorities. The results from the simulations suggest that the IPEN's response to different demands depends on how it balances policies acting on the supply and demand for the resources. Sustainable and long-term management of this market requires active monitoring to support events caused by changes in demand. This study contributes to the systems dynamics and also to the radiopharmaceutical management literature, presenting an integrative model to evaluate the resilience of a specific market. Although there are previous studies on this subject in other countries, the present one focuses on the role that IPEN plays in this market and integrates several variables in a simulation process to understand the market as a whole. For this reason, this work is original in the area of radiopharmaceuticals.

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INTRODUCTION

Radiopharmaceuticals are pharmaceutical preparations for diagnostic or therapeutic purposes which, when ready for use, contain one or more radionuclides. They also include non-radioactive labeling components and radionuclides, including components extracted from radionuclide generators (ANVISA RDC Nº 64, 2009). Millions of nuclear medicine procedures are performed each year and the demand for radiopharmaceuticals is increasing rapidly. Radiopharmaceuticals are used in diagnostics, therapies and, more recently, diagnostics and therapies using the same molecules in a process called teranostics. Currently, its main use is in the diagnosis and treatment of various types of cancer, but its use is increasing in procedures aimed at heart and neuroendocrine diseases. (OLIVEIRA, 2010). Most of the national demand, that is, 95% is met through the *Comissão Nacional de Energia Nuclear* (CNEN), a autarchy of the *Ministério da Ciência, Tecnologia, Inovação e Comunicação* (MCTIC).

Corresponding author: **Rita de Cássia Mutarelli,**
Avenida Professor Lineu Prestes, 2242 zip code: 05508-000

Until 2006, CNEN had a monopoly on the production and use of radioisotopes to label new molecules through the *Instituto de Pesquisas Energéticas e Nucleares* (IPEN). In Figures 1 and 2, Brazilian radiopharmaceutical producers are represented (DANTAS, 2014). Radionuclides, which are the raw materials used in the production of radiopharmaceuticals, can be produced in nuclear reactors or cyclotrons. Brazil's main nuclear research reactor is IPEN's IEA-R1. According to information obtained from the *Centro de Reator de Pesquisa* (CRPq), this reactor is responsible for important research activities and was a producer of radionuclides until June 2015. Today this reactor produces only samarium-153 sporadically. IPEN imports 100% of the radionuclides used in the production of radiopharmaceuticals. Today the *Reator Multipropósito Brasileiro* (RMB) project is under development. This reactor will be a nuclear reactor for radioisotope research and production. Its development is in charge of CNEN and will be built in Iperó (SP) next to the Navy's Aramar Experimental Center, where the prototype of the Brazilian nuclear submarine is also being developed. The RMB will have the power and capacity to meet current national demand, making Brazil self-sufficient in the production of radioisotopes and radioactive sources used in nuclear medicine, industry, agriculture and the environment. The basic engineering project for this investment is completed and the project already has the prior licenses of the *Instituto Brasileiro do Meio Ambiente* (IBAMA) and CNEN's Directorate of Radioprotection and Safety. The detailed engineering project of the reactor and associated systems was started, with the participation of the state-owned company Amazul Tecnologia de Defense SA, which, from 2017, became co-executor of the RMB implementation steps in partnership with CNEN. . It is important to highlight the participation in this stage of the Argentinean company INVAP, whose contract was signed on 12/21/2017 at the Mercosur Summit in Brasilia. (CNEN, 2018).

Technological innovations and the necessary planning to ensure long-term radioisotope supply are being made, but the market continues to face challenges such as the government's goal of removing supply chain support and the level of Outage Reserve Capacity (ORC)[1] remain unpaid for the services they provide (CHARLTON, 2017). Today the supply of radionuclides is sufficient in Brazil. In order for it to be maintained, it must be well planned and programmed, it must be able to manage interruptions with the use of the ORC. There must also be a high degree of cooperation among the participants in this supply chain and regular monitoring should take place, especially in the referring to new market capacities (CHARLTON, 2017). Brazil has a low per capita use of nuclear medicine. Brazil occupies the 25th position in the world ranking of quantity of procedures. Canada is the world leader with 64.6 exams per 1,000 population, followed by Germany with 34.1 and the United States with 31.5. In Latin America, Argentina is in first place with 11.1 exams. Brazil, in turn, performs 2.5 procedures per thousand inhabitants per year (DANTAS, 2014). Brazil has 435 diagnostic clinics and nuclear medicine hospitals, 75% of which are located in the South and Southeast. Although there is pent-up demand throughout the country, nuclear medicine still faces obstacles that prevent its benefits from being extended to the entire Brazilian population. According to Dantas (2014) the main impediments are:

- ^{99}Mo import dependence (100%);
- the low supply of nuclear medicine courses in the country and the concentration of existing ones in the South and Southeast;
- the low value of procedures remuneration, the difficulty of incorporating new procedures by health operators and the *Sistema Único de Saúde* (SUS);
- the complex and costly process of regulation and registration of radiopharmaceuticals;
- the strictness of the current civil servant legislation, which makes it difficult to set up a sustainable process for the production of radiopharmaceuticals by CNEN's production units.

Still, the International Atomic Energy Agency (IAEA) estimates that the Latin American market has grown by around 20% in recent years and is forecast to maintain this growth rate over the next decade.

[1]Radionuclide supply chain participants coordinate the operating hours and interruptions of their facilities to ensure that available supply capacity always exceeds market demand. This guaranteed availability also means that production capacity will inevitably be idle, ie in reserve. To mitigate against unexpected events in the molybdenum-99 supply this reserve has become known as an outage reserve capacity (ORC) (CHARLTON, 2017).

According to the *Sociedade Brasileira de Medicina Nuclear* (SBMN), at the beginning of the use of radiopharmaceuticals, everything that involved imaging used technetium and the only supplier was IPEN. This Institute saved Nuclear Medicine (NM) in its early stages. It was initially funded by the government, but then there were no more financial resources and NM was limited to the resources available. According to the International Agency for Research on Cancer, the estimated number of new cancer cases varies according to the Human Development Index (HDI). The main increase will occur in countries with low and medium HDI. The projected increase of cancer cases in Brazil to 2035 is 46% (SARACCI e WILD, 2015). In this context, several factors such as the increased incidence of cancer in the Brazilian population, the growth and aging of its population, the increase in Brazil's Human Development Index (HDI), the possible crisis in the importation of radionuclides, the search for self-sufficiency in production of radioisotopes, the difficulties in the health sector and the policies of the Brazilian nuclear sector contribute to a perception regarding the future market of radiopharmaceuticals. However, a study that can link the main variables of this complex market is lacking. Several important works present different aspects of the industry, however the literature review shows that there is a gap in understanding the industry as a whole. A Research that develops a model that encompasses all aspects of the radiopharmaceutical industry seems to surpass the possibilities imposed by a single work, so this research will focus on IPEN as the radiopharmaceutical industry as it is responsable for 80% of NM procedures in Brazil. This research uses a simulation model using System Dynamics, a method developed by prof. Jay W. Forrester in the second half of the 1950s in the USA and to this day is not widespread in Brazil (STERMAN, 2000). For the above reasons, the research question of this paper is: "How much radiopharmaceutical will IPEN need to produce to meet demand by 2030?". The relevance of this study is focused on the importance that IPEN has today for Brazilian society, to ensure that its 36 products reach the 435 clinics and hospitals ensuring the completion of approximately 1.5 million procedures per year and continue to ensure this care throughout of the next years. Failure to meet this demand will cause health problems to the population.

Objectives: As in similar works involving Systems Dynamics, the main objective of this work is to contribute to the understanding of the structure of the radiopharmaceutical market and its main aspects: demand from an exogenous perspective, which will affect supply from an endogenous perspective, ie, highlighting the internal agents of the IPEN radiopharmaceutical industry, as causative agents of its behavior.

MATERIALS AND METHODS

According to Severino (2016) the construction of knowledge, carried out through science, involves three major dimensions: an epistemological dimension, a methodological dimension and a technical dimension. It can be said that this work fulfills these three requirements, since, through bibliographic research and the conception of a model, it was possible to build knowledge and act in the epistemological dimension. Adopting exploratory methods and in some descriptive research cases, the methodological dimension was worked and, finally, trying to understand, discuss and apply the knowledge acquired in a real life context, the technical dimension was exercised.

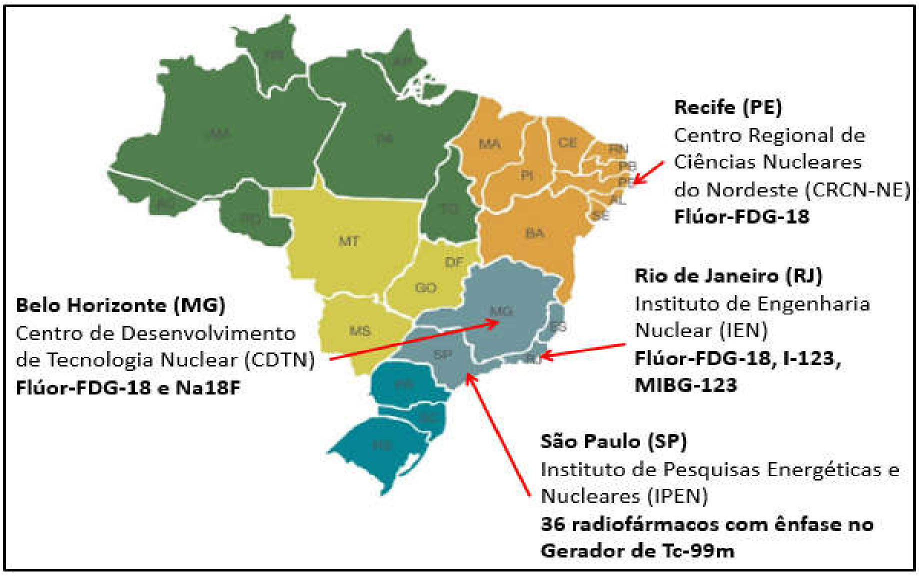

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Figure 1. CNEN units producing radiopharmaceuticals

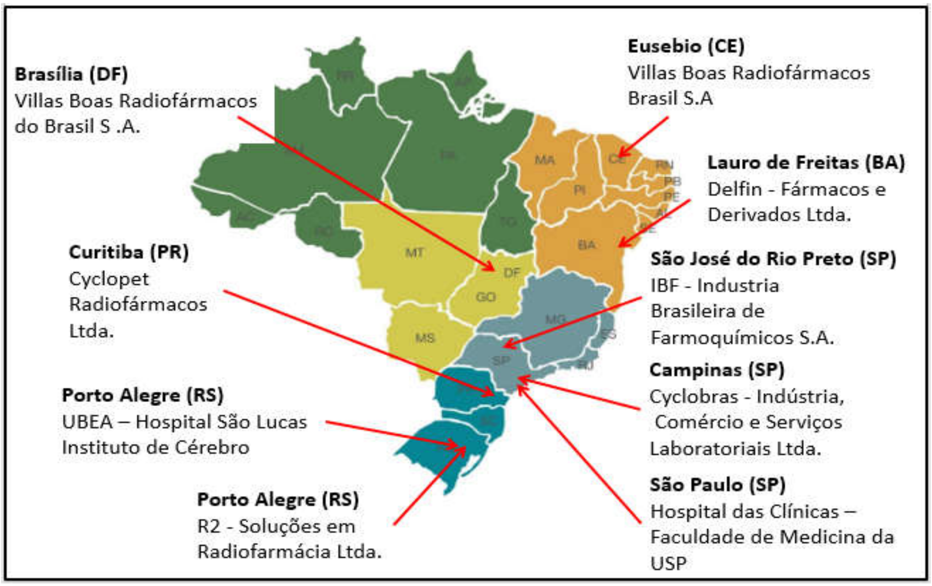

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Figure 2. Non-CNEN radiopharmaceutical manufacturing facilities

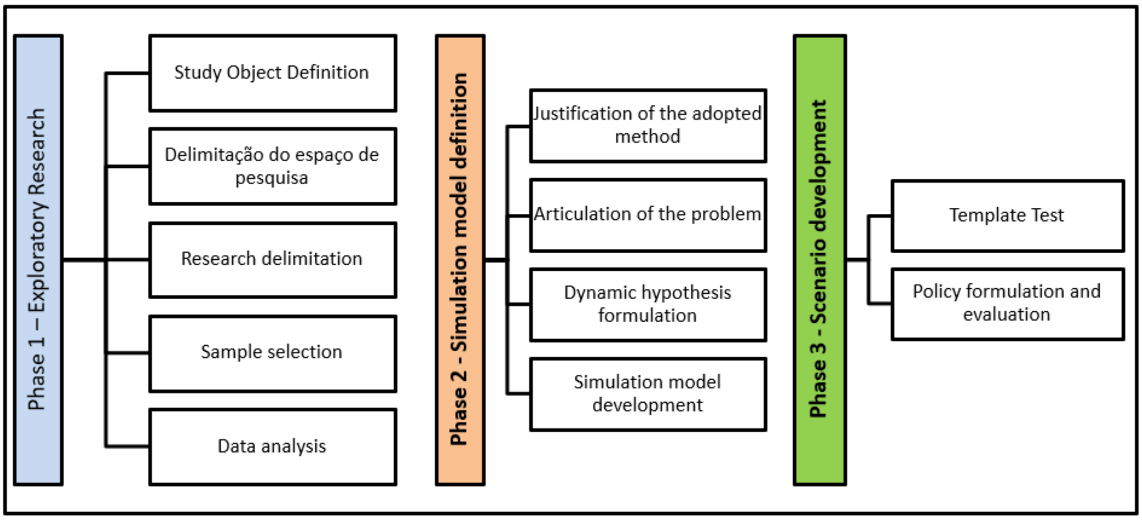

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Figure 3. Project Steps

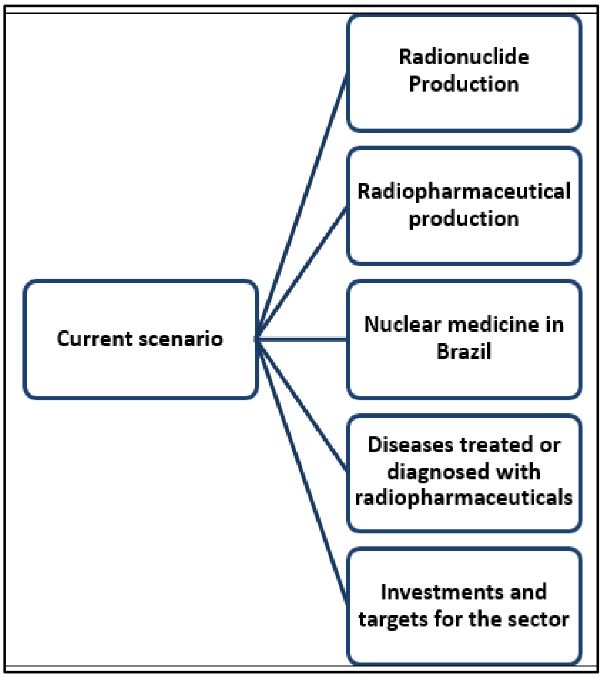

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Figura 4. Itens estudados para avaliação do cenário atual

(SEVERINO, 2016). This work was developed in several phases described below, as shown in Figure 3.

Phase 1 - Exploratory research

Study Object Definition: From the formulation of the problem, the objects related to this study were identified, creating a list of items that should be researched initially to compose the object of this work and maintain focus during exploratory research.

Space delimitation: The research space was restricted to Brazil as a whole. The Brazilian population was estimated at 208.5 million, according to the *Instituto Brasileiro de Geografia e Estatística* (IBGE), published on July 1, 2018 in the *Diário Oficial da União* (DOU) and IPEN as the producing industry.

Study of the current scenario: To determine the current scenario of the radiopharmaceutical market, some items were studied separately, as shown in Figure 4.

Sample Selection: Survey with specialists from some national entities that use radiopharmaceuticals directly or indirectly. Professionals were selected from the following areas:Sistema Único de Saúde (SUS);

- science, technology and development;
- companies operating public and private health plans;
- establishments producing equipment and materials for medical and hospital use;
- establishments producing radiopharmaceuticals for medical use;
- Oncologists and radiologists;
- regulatory agencies.

Data collection instrument definition: Basic interview scripts were developed specifically for each audience to be interviewed.

All participants were informed of the study objectives and signed the "Informed Consent Form". The project was approved by the Research Ethics Committee of CEFAC - Health and Education, process No. 65639617.8.0000.5538.

- semi-structured face-to-face interviews were conducted with a pre-defined script;
- interviews were conducted by e-mail, within the ethics committee procedures, with adaptation of the questionnaire, making it more concise;
- interviews that were already conducted by reliable, duly referenced entities, with relevant people, whose theme and questions fit the object of study of this work;
- Important, relevant and up-to-date information was collected in the lectures given at the XXXII Brazilian Congress of Nuclear Medicine held from August 10 to 12, 2018.

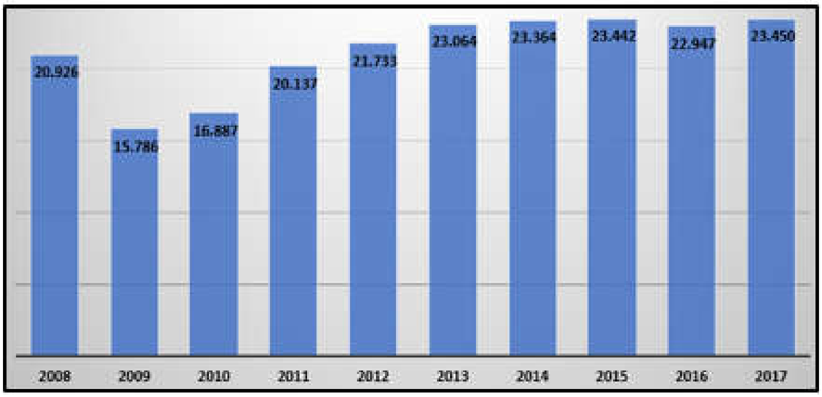
Data analysis

- All interviews and lectures were digitally recorded and all emails were read, analyzed and compiled.
- The data from the literature review, databases and stakeholder research provided the basis for the construction of the current and future radiopharmaceutical market model and scenarios.

Justification of the adopted method: A relevant aspect in choosing the best problem analysis tool is the type of complexity that the problem presents. According to Santos (2011), the complexity of a system is represented by three axes: the uncertainty level, the number of variables and its dynamic characteristic. The level of uncertainty can be understood as the number of factors that are beyond the control of the decision maker, a large number of relevant variables, make it harder to analyze the problem and finally the dynamic complexity that can be understood as the degree to which variables affect others through chains of cause and effect relationships, closing feedback loops (SANTOS e MARTINS, 2011). According to Sterman (2000), the System Dynamics approach is suitable for modeling and understanding systems with high dynamic complexity. Therefore, the method option for the simulation was System Dynamics, which over time proves to be a appropriate tool for the radiopharmaceutical industry.

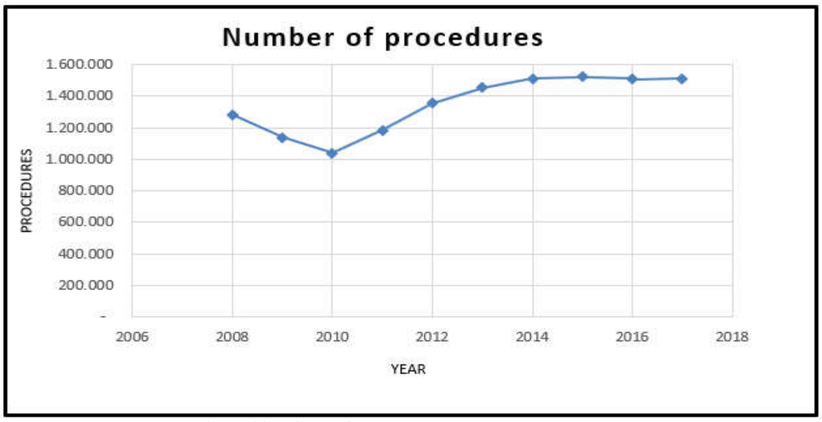
Articulation of the problem: The most important step in system dynamics modeling is the articulation of the problem (STERMAN, 2000). To achieve the desired goal, the articulation phase of the problem has to have four steps:

- **Theme selection:** where two essential questions must be answered: What is the problem? and Why is this a problem? The answer to the first question defines what should be studied and the answer to the second should clarify why the problem to be studied is important;
- **Variables that should be considered:** it is necessary to reflect on which elements are important for the study of the problem;
- **Time horizon:** is the period between the start and end of the simulation. According to Sterman (2000), it must extend into the past to capture the emergence of the problem and its origins and should extend into the future until delays in the effects of potential suggested policies at work can be observed;



Source: IPEN (2019) adapted by the author.

Figure 5. IPEN radiopharmaceutical production per year (Ci)



Source: IPEN (2019) adapted by the author.

Figure 6. Number of Nuclear Medicine Procedures performed per year

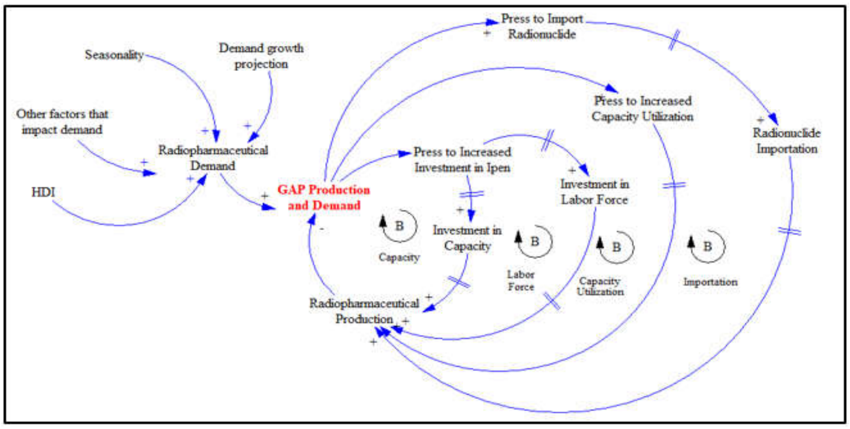


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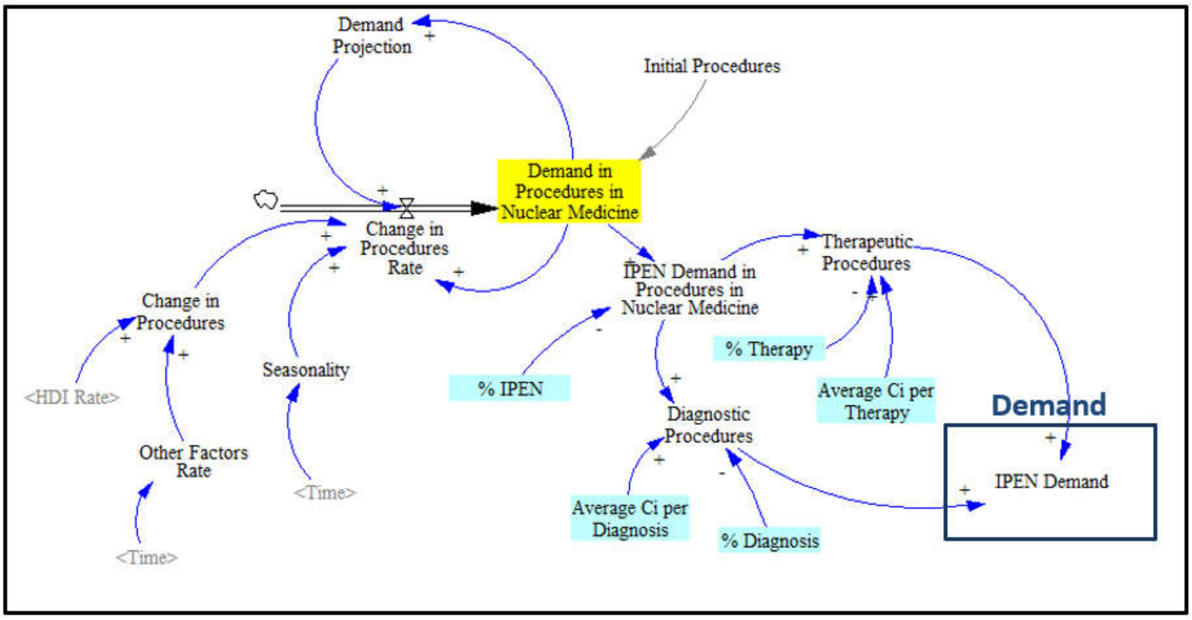
Figure 7. Causal Diagram

Table 1. Main variables considered in the System Dynamics model

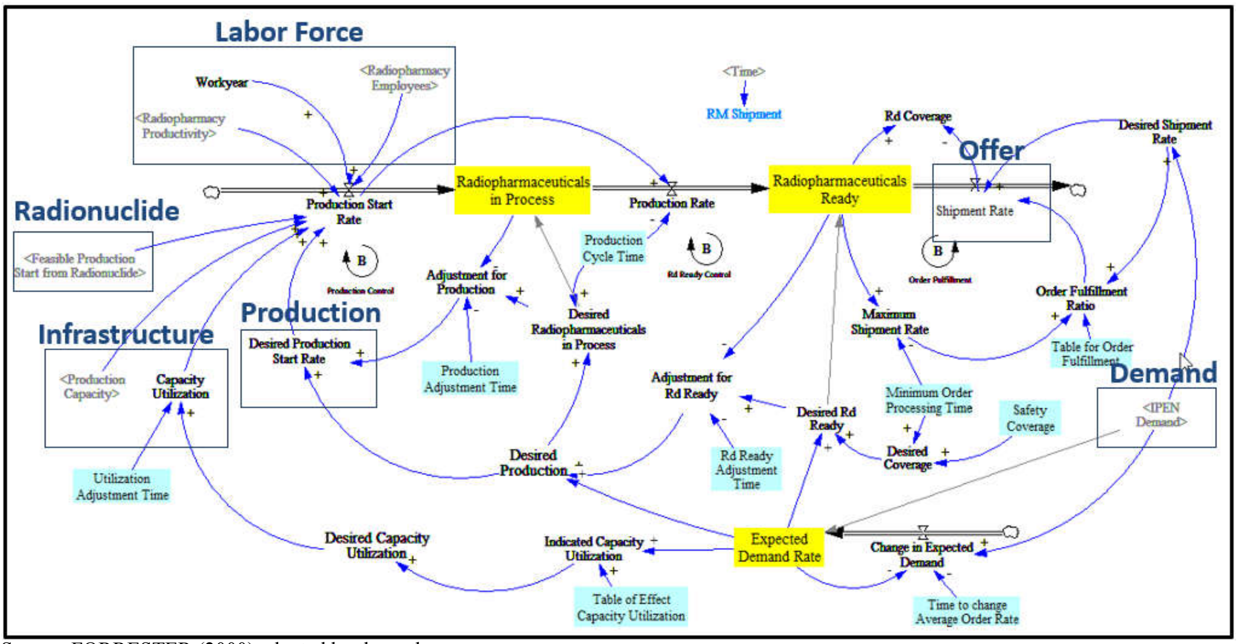
Endogenous Variables	Exogenous Variables	Excluded Variables
Radiopharmaceutical production (Ci / year)	Human Development Index (HDI / year)	Gross Domestic Product (GDP) growth rate (% / year)
Radiopharmacy staff (person / year)	Fatores exógenos que afetam a demanda (adimensional)	Population Growth (people / year)
Total effective experience of radiopharmacy staff ((weeks * people) / year)	Seasonality (dimensionless)	
Radiopharmacy productivity (Ci / (weeks * person))	Projeção da demanda (procedimentos/ano)	
Radiopharmaceutical Production Capacity (capacity unit)		
Capacity productivity (Ci / year)		
Capacity utilization (dimensionless)		
Radionuclide consumption (Ci / year)		

Source: author.



Source: FORRESTER (2000) adapted by the author.

Figure 8. Forrester Diagram - Demand



Source: FORRESTER (2000) adapted by the author.

Figure 9. Forrester Diagram - Supply and Demand

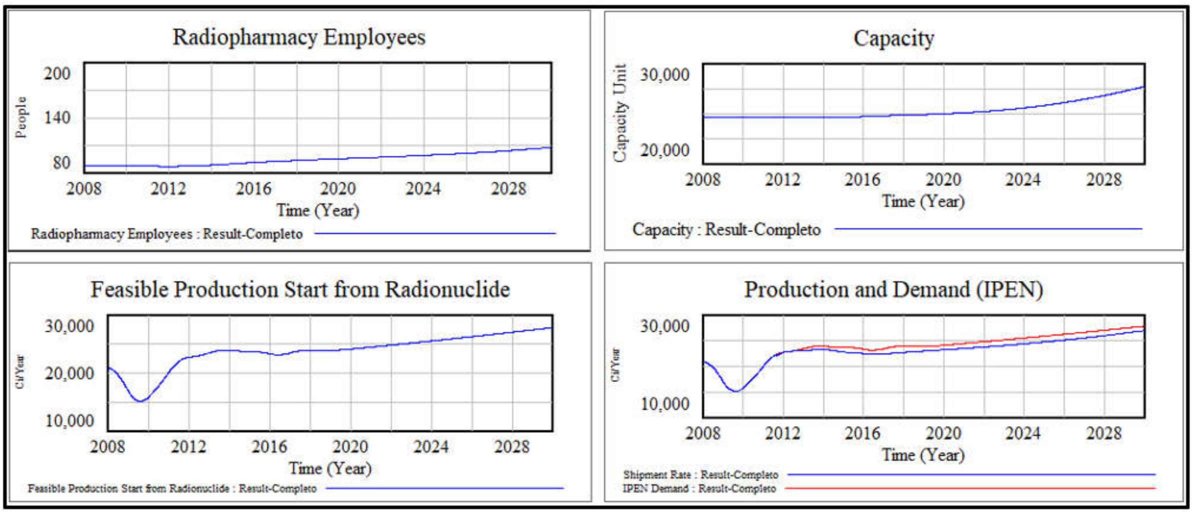


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Figure 10. Model Results for the Standard Case

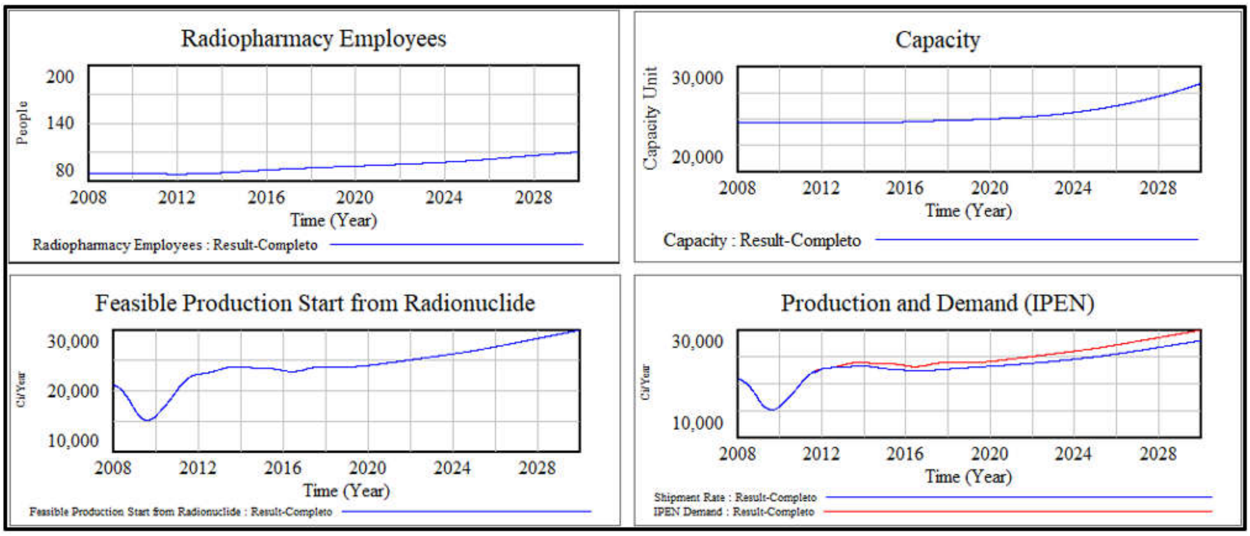

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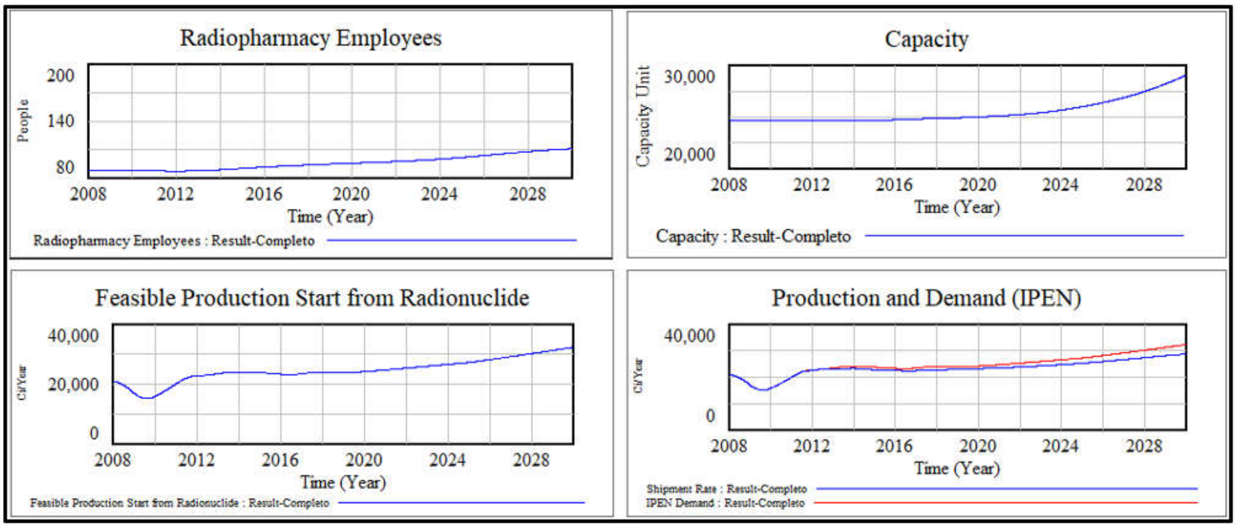
Figure 11. Result of the model for case 1



Source: author.

Figure 12. Result of model for case 2

- **Reference mode:** where whenever possible, data should be collected on the behavior of the variables that describe the problem over time under study. The reference mode will guide the entire simulation process. If reference data is not available, the behavior of the problem-defining group's mental model should be considered.

Formulation the dynamic hypothesis: A System Dynamics model seeks to explain the behavior of a system through an endogenous perspective. One step towards this purpose is the elaboration of the hypothesis, which in the case of Systems Dynamics is called Dynamic Hypothesis. This hypothesis should explain the problematic behavior of the system as a result of its internal structure. The formulation of this hypothesis encompasses three activities: (1) Generation of an initial hypothesis based on current theories; (2) Formulation of hypothesis with endogenous focus; (3) Mapping of system variables by drawing the following maps or diagrams: model boundary maps, subsystem diagrams, and causal diagram (STERMAN, 2000).

Development the simulation model: This phase comprises three activities: (1) Model structure specification, including material and information flows, and decision frameworks specification; (2) Estimation of parameters, behavioral relationships and initial conditions; (3) Tests for verification of suitability of model for purpose and predefined limits (STERMAN, 2000).

Template Test: An important aspect of the model is that it is thoroughly tested. According to Sterman (2000), a model must be subjected to a series of tests so that people will use it and have confidence in its results. Models should stimulate reflection and understanding of the study problem, not defend the modeler's ideas.

Policy formulation and evaluation: This step comprises five activities: (1) Scenario setting; (2) draft policies; (3) Analysis and evaluation of suggested policies; (4) Analysis of the robustness of policies given the uncertainty of the assumed parameters; (5) Analysis of the interaction between policies, in order to evaluate which policies present synergy (SANTOS, 2012).

Radiopharmaceuticals market: Supply and demand are forces that guarantee the functioning of the market, which can be determined by the prices and quantity of products offered. Briefly, the offer refers to the available quantity of a product, that is, what the companies want or can sell, is related to medium term actions.

Demand is the amount consumers want or can buy from this product, ie their demand and is related to short term actions. There are some products whose price is fixed by law or regulation and this impacts on the supply and demand ratio (BLANCHARD, 2001). The Ministry of Science, Technology, Innovation and Communication (MCTIC) and the National Nuclear Energy Commission (CNEN) present the Management Report annually to internal and external control bodies and also to society. It is an annual report that is required by the Federal Constitution. In this report, when referring to the characterization and behavior of CNEN's market, it is emphasized that the main focus of CNEN's routine products and services offer is the nuclear sector companies. Since much of the nuclear sector's activities are a monopoly of the union, market behavior is restricted and essentially depends on federal government policies and guidelines. As for the other business sectors served by CNEN, these depend on the country's economic situation and federal government incentive policy (MCTI E CNEN, 2018).

Supply: From the perspective of supply, IPEN is responsible for 80% of nuclear medicine procedures in Brazil (CNEN, 2017). For this reason, this paper will model IPEN's behavior as supply. The other institutes of CNEN will not be considered, as they have a very small production and the other producers of short-lived radiopharmaceuticals administered by the private sector also will not be considered. Figure 5 shows the production of IPEN radiopharmaceuticals in Curie[2] (IPEN, 2019). According to Sterman (2000), the minimum order fulfillment time is determined by the company's order fulfillment process, the product's complexity and the customers' proximity to the company's distribution centers. In the case of IPEN, there are no backlogs, all orders are immediately fulfilled, as customers seek alternative suppliers if they are not fulfilled. Another important point about supply is that companies serve based on what they can deliver or what they want to deliver, whichever is smaller. This formula is valid when the company has only one product, however, the models most often represent companies that have many different products. It is generally not necessary for the purpose of the model to represent each item separately. The stock level in such models represents the aggregate of all items. The mix of items ordered by customers varies unpredictably, as do individual item inventory levels (STERMAN, 2000). In the case of IPEN radiopharmaceuticals, the offer will be represented as a mixture of all radiopharmaceuticals produced, which today total 32 radiopharmaceuticals. According to Blanchard (2001), supply variations occur in a decade or two (medium term) and this supply is usually related to limiting factors: workforce, technology, production capacity and availability of raw materials. In many situations, decision makers strive to optimize a system but are unaware of the system structure that can help them identify the optimal operating point. Companies, for example, don't know what the right mix of manpower and capital is, they must find it by figuring out whether there is too much work or too much capital and then adjusting the mix in the right direction.(STERMAN, 2000).

2Curie (symbol Ci) is a radionuclide activity inity defined as: 1 Ci = 3.7 x 1010 disintegrations per second. This is approximately 1 gram activity of the radio-226 isotope, a substance studied by radiology pioneers in 1898, Marie and Pierre Curie (where the unit name comes from)(OKUNO e YOSHIMURA, 2010).

Demand: The demand from the radiopharmaceutical sector has many specificities. The decision to purchase the products is not of the end user, thus making it difficult to evaluate this market regarding the quantity demanded (SILVEIRA e GUSBERTI, 2007). Demand for radiopharmaceuticals comes from the need for hospitals and clinics using nuclear medicine services and is measured by the number of procedures. Nuclear medicine faces obstacles that prevent its benefits from being extended to the entire Brazilian population, so there is a pent-up demand, besides that today there is a growing demand (MCTI & CNEN, 2018). According to Blanchard (2001), variations in demand occur from year to year (short term). Changes in demand may be caused by fluctuations in consumer confidence or any other cause that may lead to a fall in output (recession) or an increase in output (expansion). According to Sterman (2000), the company is supposed to calculate the demand forecast using the first order exponential smoothing of the actual order rate. Customer orders are modeled as the product of underlying industry demand and the effect of other factors on demand, an exogenous input that captures noise, and other short-term variations in demand, such as the business cycle. This work will model the demand based on the number of procedures that use radiopharmaceuticals, both for therapy and diagnosis. There is not the exact amount of NM procedures using radiopharmaceuticals to model. For this reason, actual demand up to 2017 was calculated based on IPEN's history of supply of radiopharmaceuticals, considering that it meets 80% of MN procedures (Figure 6).

Problem articulation: As mentioned earlier, the research question of this paper is: "How much radiopharmaceutical will IPEN need to produce to meet demand by 2030?" The relevance of this study is focused on the importance that IPEN has today for Brazilian society. Failure to meet this demand will cause problems in the health area and for the population as a whole. The main variables considered in this model are represented in Table 1, where the endogenous variables represent the internal agents responsible for the model behavior, the exogenous variables are those that will affect the model behavior, but the model cannot affect them. Excluded variables are relevant variables but are not part of the model. The time horizon considered for this study is from 2008 to 2030. The choice of the year 2008 is due to the fact that the market is already more stable due to CNEN's loss of monopoly on short-lived radiopharmaceuticals that occurred in 2006. The projection for 10 years from now is a time considered by economists to be medium term and apparently adequate to answer the research question. The reference mode was focused on the main variables that describe the problem over time, which are the production of radiopharmaceuticals (supply) and the number of procedures in nuclear medicine (demand).

Dynamic Hypothesis: The Dynamic Hypothesis presents a theory with endogenous focus that explains the reasons of the undesirable behavior presented by the system. Figure 7 presents the Causal Diagram, which is restricted to the aspects covered by the simulation model, where the most relevant parts to explain the behavior of the model were prioritized. Production adjusts to demand with delay, that is represented by the time required to adjust production. Demand increases or decreases based on short-term exogenous factors, which vary from year to year. The Human Development Index (HDI) aggregates important factors such as life expectancy at birth, years of schooling and per capita income, where all together contribute to the population having greater access to health and impact on increased demand. Factors such as increased technology, training of professionals in nuclear medicine, equal access between regions of Brazil, regulation and registration, asymmetry of public and private access, low remuneration of procedures, etc., also constitute exogenous variables that impact the variation of demand, named in the model as other factors. Seasonality represents specific and temporal factors, such as the molybdenum supply crisis (99Mo) that occurred in 2009 and 2010, which had a direct impact on the production of radiopharmaceuticals, not attending the demand, causing customers to look for other alternatives. The projected growth in demand refers to indices disclosed in the Management Reports that serve as the basis for production planning and future follow-up of goals and objectives (MCTI AND CNEN, 2018). In the production of radiopharmaceuticals, capacity represents the infrastructure that is a limiting factor of production. There is a delay between identifying the need for new capacity, purchasing it and installing it. The workforce is also a limiting factor in production, as there is a bureaucratic hiring process, and hired people have no experience. As for experienced people, many of them are already retiring. Capacity utilization varies according to company policies and adjusting capacity utilization also causes a delay. Increased production leads to an increase in the importation of radionuclides, which today is with several international suppliers. Orders must be placed in advance and also incur delays.

Simulation Model: The proposed model was constructed and simulated using the software VENSIM PLE plus version 7.3.5 (VENSIM, 2018). Forrester Diagrams detail the relationships presented in the Causal Diagram, emphasizing the physical structure, flow, and accumulation of materials and information through the system (STERMAN, 2000). The Forrester Diagram presented in Figure 8 shows the demand view and in Figure 9 the supply and demand view, developed in this work.

The dynamic view of demand is represented based on exogenous variables represented by the HDI (Human Development Index - HDI), seasonality and other factors affecting demand. The supply vision is based on the dynamic behavior of radiopharmaceutical production and its restrictive factors represented by labor, infrastructure and imported radionuclides.

RESULTS

The purpose of this item is to present the behavior of the model, first simulated with the standard data, that is, with the expected data as mentioned in the CNEN Management Report and to simulate the behavior of this model by changing some exogenous variables. In Figure 10 the model simulation was performed considering an increase in demand based on the HDI increase in the last year, seasonality and other factors described above. This case was called the "default case". For this standard case, the model simulation provided the following results: for the production of 26,978 Ci with demand of 27,828 Ci the IPEN needs 107 employees, with 27,741 capacity units and 27,828 Ci of radionuclides. In this case, IPEN will meet 97% of demand in 2030, because in the proposed model the difference between production and demand is at most 3% in this period.

Figure 11 presents the model simulation considering the demand based on the standard case, plus 0.5% increase every 5 years (2020, 2025 and 2030). This case was called "case 1". In this case, the model simulation provided the following results: For the production of 27,974 Ci with demand of 29,995 Ci, 109 employees are required, with 28,383 units of capacity and 29,995 Ci of radionuclides. For this case, IPEN will meet 93% of demand in 2030, because in the proposed model the difference between production and demand is at most 7% in this period. Figure 12 presents the model simulation results considering the standard case demand, with an increase of 1% every 5 years (2020, 2025 and 2030). This case was called "case 2". In this model simulation the following results were obtained: for the production of 28,734 Ci with a demand of 32,331 Ci will require 110 employees, with 29,054 units of capacity and 32,331 Ci of radionuclides. Therefore, IPEN will meet 89% of demand in 2030, because in the proposed model the difference between production and demand is a maximum of 11% in this period.

Conclusion

The proposed model represents a simplified view of the radiopharmaceutical market, with the purpose of reproducing IPEN demand and supply behavior to assess how much radiopharmaceuticals the institute will have to produce to meet demand in 2030. The model was developed and tested, proved adequate to reality and adhered to its reference modes. The assumptions considered were based on the production history of the last 10 years and other considerations described in the previous items. Simulations were performed where three scenarios were considered. A standard scenario where demand growth indicators were based on historical growth and also on the HDI. In this standard scenario, IPEN will be able to meet 97% of demand in 2030. In addition to the standard scenario, two more scenarios were analyzed, one with a demand increase of 0.5% every 5 years and another with an increase of 1% each. 5 years. In the first case, IPEN will meet 93% of demand in 2030 and in the second case will meet 89% of demand in this period. It is verified, therefore, that with the increase of the demand there will be a distance in percentages of the production, being able to reach values superior to 11%.

In all scenarios, the values of endogenous variables that affect the behavior of the model were presented. These variables were combined and represent factors that restrict production. The results of these scenarios were described in the time horizon from 2008 to 2030 and were able to meet the objective of this work which is to contribute to the understanding of the structure of the radiopharmaceuticals market and its main aspects: the demand from an exogenous perspective, which will affect the offer, from an endogenous perspective, that is, highlighting the internal agents of the IPEN radiopharmaceutical industry, as causative agents of its behavior. For future work, we suggest the use of other short-lived radiopharmaceutical producers that are not part of CNEN, as additional actors composing the offer.

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