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System Dynamics Model for Simulating Patient-Centered Healthcare Management of Chronic Obstructive Pulmonary Disease using implementation of Integrated Scenario based Strategies

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ABSTRACT
In this research work, a Computer Simulation Framework based System Dynamics model of Chronic Obstructive Pulmonary Disease (CSF-SD-COPD model) for patient-centered health care management is designed and developed for strategic management of rate of COPD progression by the implementation of formulated and generated integrated scenario based strategies. The CSF-SD-COPD model consists of four sub-models: COPD: Undiagnosed and Grade 1 Patient Population (COPD-UG1PP) sub-model, COPD: Grade 2 Patient Population (COPD-G2PP) sub-model, COPD: Grade 3 Patient Population (COPD-G3PP) sub-model, and COPD: Grade 4 Patient Population (COPD-G4PP) sub-model which are based on international guidelines of Global Initiative for Chronic Obstructive Lung Disease (GOLD) and play an important role in improving the strategic health care management and overall quality of life of COPD population in India. Total eight integrated Scenario based Strategies (SS) -- SS-I: Educating GOLD guidelines to Pulmonologist, SS-II: Educating GOLD guidelines to Health Care Physicians and Specialists (HCPS), SS-III: Developing enrichment in consciousness of Pulmonologist for the role of Health Care Physicians and Specialists (HCPS), SS-IV: Health care coordination between Health Care Physicians and Specialists (HCPS) and Pulmonologist, SS-V: Synergism between SS-I and SS-II, SS-VI: Synergism between SS-I and SS-III, SS-VII: Synergism between SS-I and SS-IV, and last SS-VIII: Synergism between SS-I, SS-II, SS-III, and SS-IV with ninth Baseline scenario based strategy (SS-Baseline) are formulated, generated and then implemented for strategic management of rate of COPD progression. The developed model is validated, and a sensitivity test is used for the optimum management of the system. The simulation results clearly indicate that the implementation of SS-VIII has all in all the maximum effect on the prevalence of COPD and it increases both "TG-COPD-G2PP" and "TG-COPD-G3PP", whereas implementation of SS-VI and SS-VII have a maximum effect on reducing the rate of COPD progression from "TG-COPD-G2PP" to "TG-COPD-G3PP" and from "TG-COPD-G3PP" to "TG-COPD-G4PP" respectively when minimum implementation cost is criteria. If implementation cost is not an issue, then implementation of SS-VIII is best from "TG-COPD-G2PP" to "TG-COPD-G3PP" and from "TG-COPD-G3PP" to "TG-COPD-G4PP".

Keywords: System Dynamics Model, Simulation, Integrated Scenario based Strategies, Quality of Life, Chronic Obstructive Pulmonary Disease.

Introduction

Chronic Obstructive Pulmonary Disease (COPD) is a preventable, complex, treatable common disease characterized by chronic restrictions of lung airflow and persistent breathing symptoms caused by anomalies in alveolar sacs or airways and is not at all fully reversible and requires correct classification for identification of suitable therapies. COPD can be easily defined as being stable when there is minimization in pulmonary weakening and COPD symptoms are soundly managed whereas unstable is more lethal and challenging where COPD patients experience fast decay in respiratory functions and severe or recurring exacerbations. COPD is the seventh leading root of poor health measured by Disability-Adjusted Life Years (DALYs) and the third major cause of death worldwide and the second foremost cause of death and DALYs in India. The COPD has major symptoms like wheezing, difficulty in breathing, simple cough, cough with phlegm and tiredness, and due to COPD, the lungs get clogged or damaged with phlegm. COPD is also called chronic bronchitis which refers to a chronic cough with phlegm due to inflammation in the airways inside the lungs. COPD is also known as emphysema which has damaged bronchi and alveoli and refers to the destruction of the tiny air sacs in lungs. Severe COPD Patient Population (COPD-PP) have a very high risk of other serious health related problems like lung cancer, brittle bones and weak body muscles, infection in lungs like pneumonia or flu, cardiovascular problems, anxiety and depression.

Chronic Obstructive Pulmonary Disease is increasingly being considered as a significant public health issue, with elevated rates of morbidity and mortality. According to Zysman & Raherison-Semjen (2022), hormonal, environmental and genetic variables contribute to a higher prevalence of the disease in women than men, especially among nonsmokers. Even with modern approaches for early detection and treatment, Florez et al. (2023) suggested that there is a persistence of specific gender-related disparities. Zhang et al. (2023) studied that hormonal changes after the intake of contraceptives might contribute both to the development and exacerbation of asthma and highlight the need for more research into hormonal influences on respiratory health. Pulmonary hypertension is predominantly a woman's disease; sex-specific factors, such as hormonal influences, seem to be critical in its pathogenesis and strongly argue for the need for sex-oriented strategies for diagnosis and treatment as studied by Park & Safdar (2024). According to Alsayed & Gunosewoyo (2023), Tuberculosis is still one of the major global health problems, with huge morbidity and mortality. The authors elucidated TB pathogenesis's complexities and current therapeutic regimens' shortcomings. Gärtner et al. (2023) focused on how sex differences influence disease progression and treatment outcomes. The authors also highlighted the need for personalized medicine approaches that considered sex-specific factors to improve patient care and clinical management of cystic fibrosis. Interstitial lung disease as studied by Althobiani et al. (2024), can result from exposure to the environment, autoimmune illnesses, and idiopathic pulmonary fibrosis, with symptoms like shortness of breath and chronic cough. Thachil et al. (2022), highlighted the need for improved diagnostic protocols and gender-specific treatment strategies for Pulmonary embolism (PE), which is often underdiagnosed in women due to nonspecific symptoms. See & Lau (2023) studied that bacteria, viruses, or fungi may cause pneumonia. It may be a relatively minor disease, but most disease flare-ups and life-threatening outbreaks always happen among the elderly whose immune system function has also weakened. According to Schubert et al. (2023), acute bronchitis is usually a short-lived disease that improves in some weeks and may be severe in cases of individuals with previous respiratory diseases. Earl et al. (2021) discussed that pulmonary fibrosis can be caused by various factors, including long-term exposure to environmental pollutants, certain medications, or autoimmune diseases. Sreeja et al. (2022) discussed that sarcoidosis is an inflammatory disease, which leads to symptoms like shortness of breath, fatigue, and chest pain, and may resolve on its own or require treatment depending on severity. Rahaghi (2021), studied that alpha-1 antitrypsin deficiency is a genetic disease that may affect the lungs and can result in illnesses like chronic obstructive pulmonary disease and emphysema, especially in individuals who smoke or are exposed to environmental pollutants. Alsaggaf et al. (2022) discussed that chronic sinusitis may be caused by infections, allergies, or other structural problems in the nasal passages, with a duration greater than 12 weeks.

System dynamics is a mathematical modelling approach based computer simulation modelling method for designing, understanding, solving and managing complex real world problems and issues by combining both quantitative and qualitative information. System dynamics is used to simulate the real life top-level dynamic time-varying nonlinear complex systems. According to Wang et al. (2021), chronic diseases spread serious health challenges globally, where system dynamic models can be utilised to understand the complex connection among chronic diseases and the method of preventing chronic diseases. However, Davahli, Karwowski & Taiar (2020), stated that to identify healthcare challenges, complex healthcare systems should identify different effects of the preventing factors using system dynamics simulation model. According to Heshmat & Eltawil (2018), to support chemotherapy planning, a dynamic-based decision is required to help developed countries to increase their projects and diagnosis cases. The authors also defined connection between the systems and models used for chemotherapy planning. Sy et al. (2020), focuses on the system dynamics approach to expand the connection between the novel coronavirus and precautions. Hanlon et al. (2021), stated that to control blood sugar levels, it is required to focus on system dynamics and control type 2 diabetes by understanding self-management approaches. Using system dynamic modelling approach, Omwenga et al. (2023) illustrated that to maintain plasma glucose levels, it is required to manage diabetes and create a connection between the health issue and its precautions. Abdolhamid et al. (2022), used system dynamics framework and added policy making and considered hospital constraint due to COVID-19 pandemic situation. Suphanchaimat et al. (2020), stated that the system dynamic modelling depends on the cost-effectiveness and also helps in healthcare prevention. Pornphol & Chittayasothorn (2020) discussed and elaborated conceptual dynamics models to fight against the coronavirus situation and also included social distancing initiative. Shukla, Tomer & Singh (2021) discussed a system dynamic model that mitigates economic growth, as well as, challenges faced by laborers during the Coronavirus disease. Wongseree et al. (2023) enhanced the role of cancer treatment by using a system dynamic-based model and discussed the role of different diagnoses and treatments in low and middle-income countries. Harpring et al. (2021) used system dynamics methodology for analysis of factors that have an impact on cholera and used causal loop diagram for the representation of complexities arising due to humanitarian situations. Guynn et al. (2022) discussed that system dynamic modelling approach supports child healthcare and concentrates on several health precautions, including required vaccines.

A Computer Simulation Framework based System Dynamics Model of Chronic Obstructive Pulmonary Disease (CSF-SD-COPD Model) for patient-centered health care management is designed and developed in this research work for strategic management of the rate of COPD progression by the implementation of formulated and generated integrated scenario based strategies and policies. The model plays an important role in improving the strategic health care management and overall quality of life of COPD Patient Population (COPD-PP) in India. A very limited literature is available for the management of COPD and improvement of quality of life of COPD patient in India, but the literature related to implementation of integrated scenario based strategies and policies for strategic management of rate of COPD progression using SD modelling technique is almost negligible. Therefore, to fill this vast research gap in literature, an innovative first-time effort is being made in this research work.

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Computer Simulation Framework based System Dynamics Model of Chronic Obstructive Pulmonary Disease
In this research work, a Computer Simulation Framework based System Dynamics model of Chronic Obstructive Pulmonary Disease (CSF-SD-COPD model) for patient-centered health care management is designed and developed on four interrelated sub-models: COPD: Undiagnosed and Grade 1 Patient Population (COPD-UG1PP) sub-model, COPD: Grade 2 Patient Population (COPD-G2PP) sub-model, COPD: Grade 3 Patient Population (COPD-G3PP) sub-model, and COPD: Grade 4 Patient Population (COPD-G4PP) sub-model for strategic management of rate of COPD progression by the implementation of formulated and generated integrated scenario based strategies and policies on the basis of validation and sensitivity analysis. The CSF-SD-COPD model is based on three main assumptions: COPD: grade patient population flow is from lower grade to higher grade only because COPD is a progressive disease and gets worse over the passage of time, COPD: grade patient population just after diagnosis are initially Not In Health Care Management (NIHCM) and are only engaged in Health Care Management (HCM) once they interact with Health Care Physicians and Specialists (HCPS) and Pulmonologists during and after diagnosis, COPD: grade patient population remain engaged in HCM status only after moving from a non-engaged position. The structure of the CSF-SD-COPD model with the relationship of four sub-models: COPD-UG1PP sub-model, COPD-G2PP sub-model, COPD-G3PP sub-model, and COPD-G4PP sub-model is shown in Figure 1.

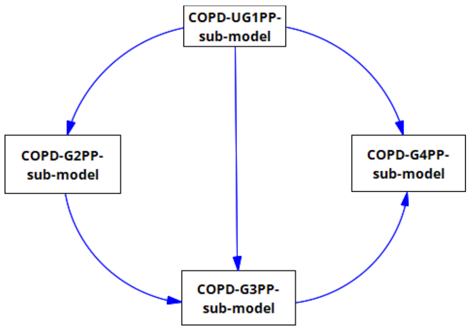

Figure1. Structure of CSF-SD-COPD Model

COPD: Undiagnosed and Grade 1 Patient Population sub-model
In COPD: Undiagnosed and Grade 1 Patient Population (COPD-UG1PP) sub-model of CSF-SD-COPD model, COPD: Grade 1 Patient Population (COPD-G1PP) is merged with COPD: Undiagnosed Patient Population (COPD-UPP) on account of infrequency and unnecessary problems of diagnostic procedure. COPD-UPP signifies that population who is suffering from COPD but due to certain reasons, there is no diagnosis. Such patient populations should be diagnosed quickly to slow down the COPD development and also to prevent the COPD progression of more advanced grades. COPD-G1PP is having no symptoms and also not aware of their abnormal lung function but may feel sometimes short of breath during walking fast on plain ground. Here Forced Expiratory Volume FEV-1(the volume of air breathed out in the first second after a forced exhalation) is 80% or more predicted and this grade is characterized by mild airflow limitation.

COPD: Grade 2 Patient Population sub-model
In this COPD: Grade 2 Patient Population (COPD-G2PP) sub-model, the FEV-1 lies between 50% and 79% predicted. There is intensification of symptoms in COPD-G2PP, like coughing, breath shortness during exertion, wheezing, increase in mucus, and fatigue due to progress in airflow limitations. During this grade, the COPD-G2PP gets an awareness about symptoms and seeks medical attention because of dyspnea or an exacerbation of their disease. There is a negative impact on the quality of life of COPD-G2PP due to repeated exacerbations, and hence there is an urgent need for a proper COPD management.

COPD: Grade 3 Patient Population sub-model
During this COPD: Grade 3 Patient Population (COPD-G3PP) sub-model, there is a severe decrease in the function of the lungs of COPD-G3PP, and the air sacs walls of their lungs progress towards further deterioration. Here FEV-1 lies between 30% and 49% predicted. In this grade there is sudden flare-ups due to more severity in symptoms- thicker mucus, frequent wheezing or coughing, acute shortness of breath, severe weakness, severe congestion and chest infections. Due to exacerbations, there are severe unexpected airways muscle constrictions and severe mucus clogging in bronchial tubes. In this case, there is a need for an urgent action plan to manage such flare-ups. Oral steroids like dexamethasone, methylprednisolone, and prednisone can easily treat acute COPD exacerbations. During recurrent flare-ups, inhaled corticosteroids like Qvar Redihaler®, Flovent® HFA and expectorants can thin and loosen mucus or oxygen therapy is also a solution. This flare-up may lead to hospitalization also of COPD-G3PP.

COPD: Grade 4 Patient Population sub-model
In this COPD: Grade 4 Patient Population (COPD-G4PP) or COPD: End Stage Patient Population (COPD-ES PP) sub-model there is very low lung function of patient population and FEV-1 is less than or equal to 30 % predicted. In this

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grade respiratory failure or lung infections or hospitalizations are very common and sudden flare-ups are life threatening. The most common symptoms of this grade are- delirium, crackling sound during breathing, fast or irregular heartbeat, pulmonary hypertension, barrel chest, and weight loss. The treatment options for this grade patient population are oxygen therapy using a nasal cannula device and lung transplants or lung surgery. Surgical procedures may be used to treat end stage COPD patients by using Lung Volume Reduction Surgery (LVRS) in Emphysema by removing damaged tissue of lung and allowing for overall improved breathing; Bullectomy Surgery (BS) for reduction of air quantity trapped in the lungs due to bronchiectasis or emphysema; Lung transplant (LT) in very severe COPD patients; and Bronchoscopic Lung Volume Reduction (BLVR) by placing a valve to support the flow of air in very severe COPD patients. End Stage COPD (COPD-ES) is the final stage of COPD. At this stage, there is significant shortness of breath during resting also and patient is having very high risk of respiratory failure and severe lung infections. The end stage can be related to grave disability or imminent death, and a very high risk of death is associated at this stage, but a COPD patient may survive for years with this stage. In this stage, quality of life is gravely impaired.

Stock Flow Diagram of CSF-SD-COPD Model

A Stock Flow (SF) Diagram of the designed and developed CSF-SD-COPD model using Vensim® PLE 10.1.0 software platform of Ventana Systems, Inc. is developed to epitomize the flow of COPD: grade patient population for patient-centered Health Care Management (HCM) and is mainly focused on "Target Group of COPD: Grade 2 Patient Population (TG-COPD-G2PP)", "Target Group of COPD: Grade 3 Patient Population (TG-COPD-G3PP)", and "Target Group of COPD: Grade 4 Patient Population (TG-COPD-G4PP)" or "Target Group of COPD: End Stage Patient Population (TG-COPD-ES PP)".

Figure 2 shows a SF Diagram of CSF-SD-COPD model where the number of COPD patient at different grades of chronic disease are represented by stocks and thus consist of total 8 stocks. The stock # 1 "Target Group of COPD: Undiagnosed and Grade 1 Patient Population (TG-COPD-UG1PP)" denotes the merged "Target Group of COPD: Undiagnosed Patient Population (TG-COPD-UPP)" and "Target Group of COPD: Grade 1 Patient Population (TG-COPD-G1PP)" and this target group is unaware of the symptoms of chronic disease due to lack of awareness, infrequency, and unnecessary problems of diagnostic procedure. The stock # 2 "Target Group of COPD: Grade 2 Patient Population (TG-COPD-G2PP-NIHCM)", stock # 3 "Target Group of COPD: Grade 3 Patient Population (TG-COPD-G3PP-NIHCM)", stock # 4 "Target Group of COPD: End Stage Patient Population (TG-COPD-ES PP-NIHCM)" denote the number of COPD patients who are diagnosed with COPD: grade 2 or COPD: grade 3 or end stage COPD respectively, but this patient population is Not In Health Care Management (NIHCM). The stock # 5 "Target Group of COPD: Grade 2 Patient Population (TG-COPD-G2PP-HCM)" and stock # 6 "Target Group of COPD: Grade 3 Patient Population (TG-COPD-G3PP-HCM)" denotes the number of COPD patients who are diagnosed with COPD: grade 2 or COPD: grade 3 respectively but this patient population is getting support of Health Care Management (HCM). The stock # 7 "Target Group of COPD: End Stage Patient Population On Surgery (TG-COPD-ES PP-HCM-OS)" denote the number of COPD patients who are diagnosed with End Stage COPD and getting support of HCM and are On Surgery (OS) and stock # 8 "Target Group of COPD: End Stage Patient Population on End-of-Life Issues (TG-COPD-ES PP-HCM-EoLI)" denotes the number of COPD patients who are diagnosed with End Stage COPD and getting support of HCM and are on End-of-Life Issues (EoLI).

After the diagnosis of "TG-COPD-UPP" with the help of symptoms and signs, medical and family history, chest X-ray, CT scan of lungs, arterial blood gas analysis, special laboratory tests, and pulmonary function tests (resting lung volume, diffusion capacity measurements capacity, airway resistance evaluations, and cardiopulmonary exercise test), the chest physician can easily detect the grade of COPD. The diagnosed COPD patient population with COPD: Grade 2 or COPD: Grade 3 or End Stage COPD are assigned to respective stocks-- stock#2 "TG-COPD-G2PP-NIHCM" or stock#3 "TG-COPD-G3PP-NIHCM" or stock#4 "TG-COPD-ES PP-NIHCM". The moderate "Target Group of COPD: Grade 2 Patient Population (TG-COPD-G2PP-NIHCM)" of stock#2 can shift to severe "Target Group of COPD: Grade 3 Patient Population (TG-COPD-G3PP-NIHCM)" of stock#3 due to severity of COPD and severe "Target Group of COPD: Grade 3 Patient Population (TG-COPD-G3PP-NIHCM)" of stock#3 can shift to end stage "Target Group of COPD: End Stage Patient Population (TG-COPD-ES PP-NIHCM)" of stock#4 due to explosive severity of COPD.

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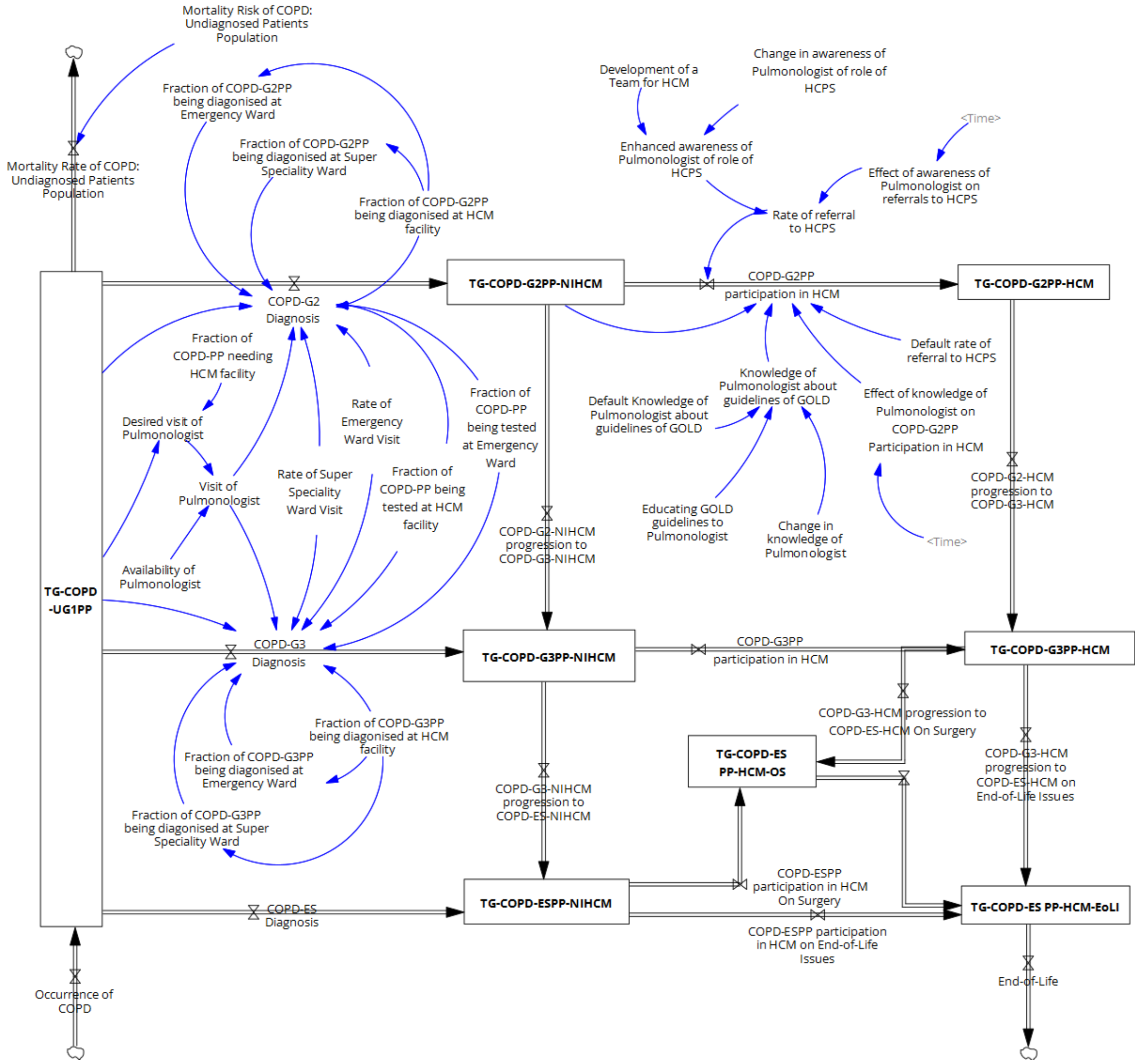

Figure 2. SF Diagram of the CSF-SD-COPD Model

CSF-SD-COPD Model Validity and Sensitivity

The parameters of the CSF-SD-COPD are continuously modified and adjusted during the course of development of interrelation between different parameters and quantification of the model to reduce the error between actual data and simulated data and ultimately to improve the reliability of the model. Now to check the validity of the model, for ensuring the credibility of designed and developed CSF-SD-COPD model simulation results, 2000 is selected as the base year, and the actual historical data on the prevalence, deaths, and disability adjusted life years (DALYs) of COPD-PP (https://vizhub.healthdata.org/gbd-compare/ ; https://www.who.int/) is selected from 2000 to 2023 and then the model is simulated using the baseline scenario to predict the related simulated data from 2000 to 2035. The Error Rate (ER), Error Variance (EV), Mean Absolute Percentage Error (MAPE), and Root Mean Square Percentage Error (RMSPE) of the key parameters are calculated using the following equations respectively:

$$ER = \frac{|Simulated\ Value - Absolute\ Value|}{Absolute\ Value} \times 100 \quad (1)$$

$$EV = \frac{|Average\ Rate\ of\ Simulated\ Value - Average\ Rate\ of\ Absolute\ Value|}{Average\ Rate\ of\ Absolute\ Value} \times 100 \quad (2)$$

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{Simulated\ Value - Absolute\ Value}{Absolute\ Value}\right| \times 100 \quad (3)$$

$$RMSPE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left|\frac{Simulated\ Value - Absolute\ Value}{Absolute\ Value}\right|^2} \times 100 \quad (4)$$

Figure 3 depicts the comparison between actual historical data and output simulated data on the prevalence, deaths, and disability adjusted life years (DALYs) of COPD-PP and this figure shows the fitting of the baseline graph with actual historical population data graph after simulation. The baseline graph signifies the situation where no scenario based strategy is implemented. There are very minor variations between actual historical population data and the model simulation data, and the ER and EV for data on the prevalence, deaths, and disability adjusted life years (DALYs) of COPD-PP are 0.43 and 7.74 respectively, while the MAPE and RMSPE for this parameter are 0.20 and 2.21 respectively. The pattern of graphs clearly depicts that the developed CSF-SD-COPD model is an excellent prognosticator of the performance of the total system and is totally effective, valid, and generating reliable simulated results because the values of ER and EV of all the key parameters are less than or equal to 5% and 30% respectively, while MAPE and RMSPE are also very close to zero, which clearly shows that the error is very low and the model's prediction ability is best. The sensitivity analysis of the developed CSF-SD-COPD model is also conducted to examine how much sensitive the model is due to alterations in the different values of the selected parameters and due to changes in the basic structure of the developed model. The results of the sensitivity analysis showed that the default rate of referral to HCPS and change in awareness of pulmonologist of role of HCPS had a large impact on TGCOPD-G2PP-NIHCM. Thus, sensitivity analysis assessed the effect of parameter variations on model results and proved that the designed and developed CSF-SD-COPD model is totally under control and is totally fit for simulation to see the impact of the implementation of formulated and generated integrated Scenario based Strategies (SS).

Table 1. Comparison between simulated data and actual data of key parameter

e	Simulated Data	Actual Data	Error %	Time (Year)	Simulated Data	Actual Data	Error %
2000	13155400	13155445	0.00	2012	19199000	19429928	1.19
2001	13576400	13569798	0.05	2013	19813400	20121077	1.53
2002	14010900	13999222	0.08	2014	20447500	20764499	1.53
2003	14459300	14614061	1.06	2015	21101900	21182804	0.38
2004	14922100	15020070	0.65	2016	21777300	21557157	1.02
2005	15399600	15233815	1.09	2017	22474200	22385912	0.39
2006	15892500	15767457	0.79	2018	23193500	23335172	0.61
2007	16401100	16771439	2.21	2019	23935700	23842302	0.39
2008	16926000	17505884	3.31	2020	24701800	23909715	3.31
2009	17467700	17675195	1.17	2021	25492300	24018380	6.14
2010	18026700	18219236	1.06	2022	26308200	25118380	4.74
2011	18603600	18987347	2.02	2023	27150100	26218380	3.55

ER: 0.43, EV: 7.74, MAPE: 0.20, RMSPE: 2.21

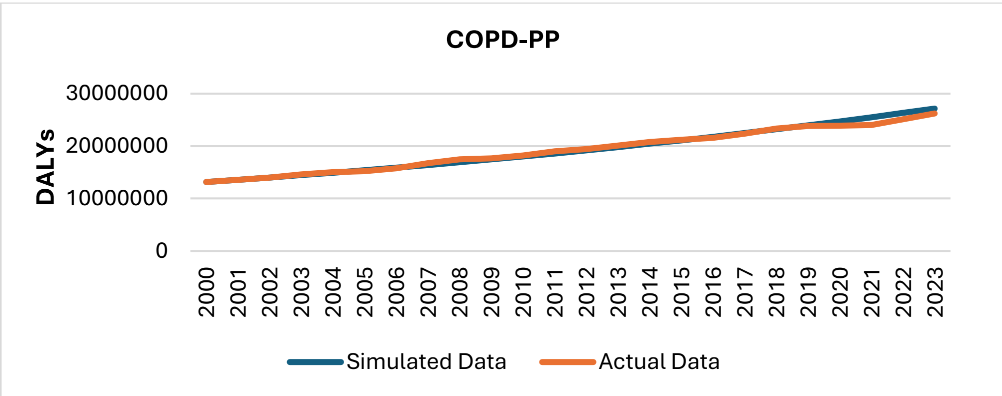

Figure 3. Comparison between Actual Historical Data and Output Simulated Data on the prevalence, deaths, and disability adjusted life years (DALYs) of COPD-PP

Generation of Integrated Scenario based Strategies

GOLD recommends particular treatment guidelines based on history and symptom severity to classify COPD patient's future exacerbation risk stratification (ABCD Assessment Tool): Bronchodilators; Long-Acting Bronchodilators [Long-Acting Muscarinic Antagonist (LAMA) / Long-Acting β_2-Agonist (LABA)] combinations over Inhaled Corticosteroid (ICS); LAMA; and LAMA or LAMA+LABA* [if COPD Assessment Test (CAT) > 20] or ICS + LABA** [if eos = eosinophil counts (cells/μL) ≥ 300]. Recurrent exacerbations in COPD patients are bound to lead to significant economic burden, and due to severity can result in the need for ICU or emergency visits and will significantly affect COPD progression and the COPD patient population's health related quality of life. Total eight integrated Scenario based Strategies (SS) -- SS-I: Educating GOLD guidelines to Pulmonologists, SS-II: Educating GOLD guidelines to Health Care Physicians and Specialists (HCPS), SS-III: Developing enrichment in consciousness of Pulmonologists for the role of

Health Care Physicians and Specialists (HCPS), SS-IV: Health care coordination between Health Care Physicians and Specialists (HCPS) and Pulmonologists, SS-V: Synergism between SS-I and SS-II, SS-VI: Synergism between SS-I and SS-III, SS-VII: Synergism between SS-I and SS-IV, and last SS-VIII: Synergism between SS-I, SS-II, SS-III, and SS-IV with ninth Baseline scenario based strategy (SS-Baseline) are formulated, generated and then implemented for strategic management of rate of COPD progression using the output of the sensitivity test of the key parameters of the CSF-SD-COPD model. The simulated outcome pattern from 2000 to 2035 is analysed on 'COPD patient population of TG-COPD-G2PP and TG-COPD-G3PP', 'rate of COPD progression from TG-COPD-G2PP to TG-COPD-G3PP", and 'rate of COPD progression from TG-COPD-G3PP to TG-COPD-ES PP' to observe the impact of the implementation of formulated and generated integrated Scenario based Strategies (SS).

SS-I: Educating GOLD Guidelines to Pulmonologists
Regular enrichment and assessment of knowledge of pulmonologists by the education of the latest GOLD guidelines is bound to improve the quantity of early COPD diagnosis and quality of HCM. SS-1 affects knowledge of pulmonologists on HCM engagement and in the long term improves the quality of health of COPD-PP and so prevents the migration of COPD-PP from lower grade to higher grade. This will help in delaying the rate of COPD progression, but this solid positive outcome is totally dependent on the quantity and availability of pulmonologists. Pulmonologists have a very hectic schedule and workload, and this situation is becoming critical day by day and due to this there is a delay in the diagnosis of lower grade COPD-PP, which leads to poor HCM over the passage of time. This situation is resulting in a very fast progression of COPD-PP in India.

SS-II: Educating GOLD Guidelines to HCPS
Educating GOLD guidelines to HCPS will improve their responsibility and delegation skills and power to manage multiple directions of HCM of COPD-PP. The COPD-PP who are screened in multi-specialty clinics by such HCPS have a better diagnostic advantage. HCPS can play a major role to improve the outcome of COPD-PP by opening the door of participation of COPD-PP in HCM. Educating GOLD guidelines to HCPS is bound to reinforce their role as supporters of COPD-PP. HCPS are bound to bridge gaps in HCM which is not possible for COPD-PP during a very short consultation with their Pulmonologists. The COPD-PP gets rich clinical information about COPD due to positive fruitful communications between HCPS and COPD-PP. HCPS helps in enthusiastically engaging COPD-PP in HCM and thus results in avoiding medical complications and delay in progression of COPD to the next grade. SS-2 affects the flow of COPD advancement from "TG-COPD-G2PP-HCM" to "TG-COPD-G3PP-HCM".

SS-III: Developing Enrichment in Perception of Pulmonologists for the Role of HCPS
HCPS generally do thorough medical checkups of COPD-PP, referred mostly by pulmonologists. These pulmonologists have a better knowledge of the physical condition and clinical needs of COPD-PP, and they are also more aware of the critical roles of HCPS, hence they regularly send COPD-PP to HCPS. The HCPS are regularly interacting with large number of COPD-PP; hence a good number of COPD-PP are likely managing their health condition in a better and efficient way. This will lead to prevention of progression of COPD. SS-III is basically development of a team work for HCM.

SS-IV: Health Care Coordination between Health Care Physicians and Specialists (HCPS) and Pulmonologists
The joint collaboration of two main diagnostic and treatment parties is bound to develop a solid platform for pulmonologists to generate a sound collaborative COPD-PP health care road map. Pulmonologists have the sound clinical knowledge to efficiently and tactfully handle the risk of developed complications due to specific lines of clinical care action advised by HCPS. Sound health care coordination between HCPS and pulmonologists is bound to enable and improve timely COPD: End Stage Patient Population's referrals to On Surgery (OS) or on End-of-Life Issues (EoLI) which in turn improves the quality of the best and correct treatment. The timely refer of serious COPD: End Stage Patient Population by HCPS to pulmonologists due to their sound coordination, will definitely benefit a large number of such serious COPD: End Stage Patient Population with latest and expert clinical knowledge of pulmonologists and this move will set a goal to prevent the stage of OS or EoLI in a well-timed way. The delay in consultation with pulmonologists by serious COPD: End Stage Patient Population will result in very limited clinical options and will increase the end stage COPD complications like death of COPD patients due to cardiovascular disease or lung cancer or progressive respiratory dysfunction and will increase hospital treatment costs. SS-IV affects the flow of COPD advancement from "TG-COPD-G3PP-HCM" to "TG-COPD-ES PP-HCM-OS" and the flow of COPD advancement from "TG-COPD-G3PP-HCM" to "TG-COPD-ES PP-HCM-EoLI".

SS-V: Synergism between SS-I and SS-II
Educating GOLD Guidelines to Pulmonologists and to HCPS

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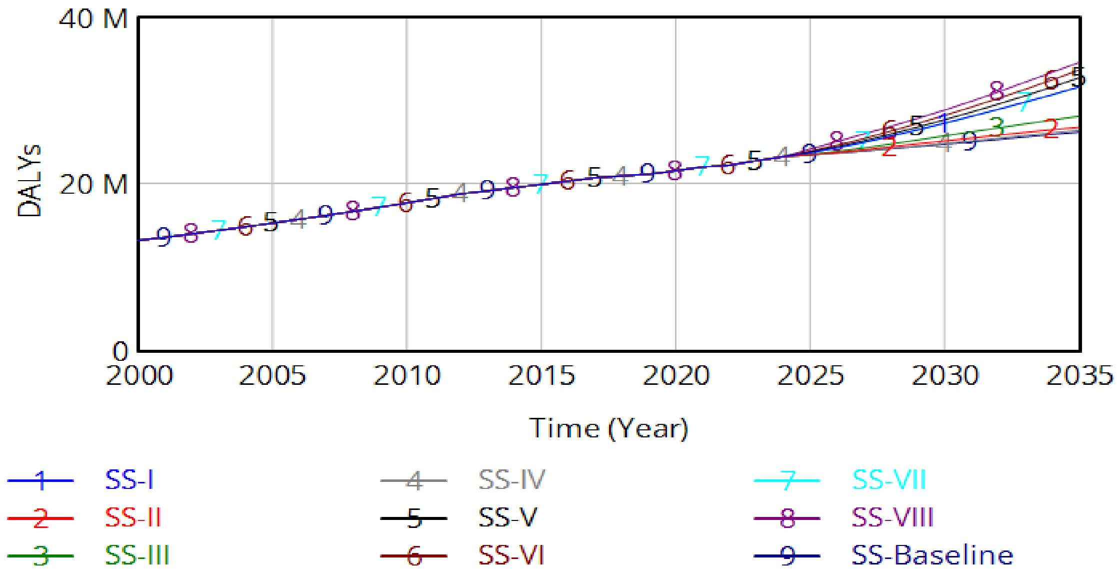
SS-VI: Synergism between SS-I and SS-III
Educating GOLD Guidelines to Pulmonologists and Developing Enrichment in Perception of Pulmonologists for the Role of HCPS

SS-VII: Synergism between SS-I and SS-IV
Educating GOLD Guidelines to Pulmonologists and Health Care Coordination between HCPS and Pulmonologists

SS-VIII: Synergism between SS-I, SS-II, SS-III, and SS-IV
Educating GOLD Guidelines to Pulmonologists and to HCPS, Developing Enrichment in Perception of Pulmonologists for the Role of HCPS, and Health Care Coordination between HCPS and Pulmonologists

Simulation Results
The simulation results of designed and developed CSF-SD-COPD model in the form of simulated outcome pattern on 'COPD patients population of TG-COPD-G2PP and TG-COPD-G3PP' , 'rate of COPD progression from TG-COPD-G2PP to TG-COPD-G3PP' and 'rate of COPD progression from TG-COPD-G3PP to TG-COPD-ES PP' by the implementation of formulated and generated eight integrated Scenario based Strategies (SS) with ninth SS-Baseline are shown in Figure 4, Figure 5 and Figure 6 respectively.
Figure 4 shows simulated outcome patterns on COPD-PP of (A) "TG-COPD-G2PP" and (B) "TG-COPD-G3PP" respectively by the implementation of SS-I, SS-II, SS-III, SS-IV, SS-V, SS-VI, SS-VII, and SS-VIII with SS-Baseline. The implementation of SS-I increases the "TG-COPD-G2PP" and decreases the "TG-COPD-G3PP" and thus has a maximum effect on the prevalence of COPD. The implementation of SS-III also increases the "TG-COPD-G2PP", but this increase is considerably less than due to the implementation of SS-I. It is to be noted that due to the implementation of SS-III, there is a minute increase in "TG-COPD-G3PP". There is an impact on "TG-COPD-G3PP" due to the implementation of SS-IV, but this effect is small in comparison to the implementation of SS-I and SS-III. The implementation of SS-VIII has all in all maximum effect on prevalence of COPD and it increases both "TG-COPD-G2PP" and "TG-COPD-G3PP". The implementation of SS-V and SS-VI depicts an increase in "TG-COPD-G2PP" and decrease in "TG-COPD-G3PP" in comparison to pattern of SS-Baseline. The implementation of SS-V or SS-VI in comparison to SS-I shows a slight increase in "TG-COPD-G2PP".



(A) TG-COPD-G2PP

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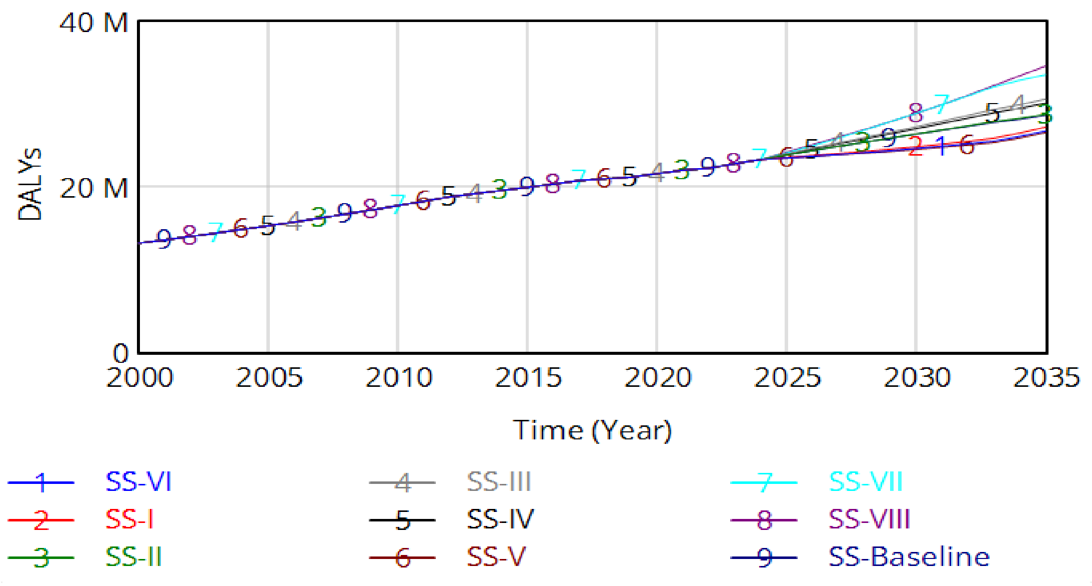

(B) TG-COPD-G3PP

Figure 4. Simulated Outcome Pattern on COPD Patients Population of (A) "TG-COPD-G2PP" and (B) "TG-COPD-G3PP" by the implementation of SS-I, SS-II, SS-III, SS-IV, SS-V, SS-VI, SS-VII, and SS-VIII with SS-Baseline

The COPD is a complex progressive disease and can worsen over time, and its progression is very much heterogeneous. The rate of COPD progression can be easily computed using the following:

$(\text{Rate of COPD Progression})_{i,t}$= [COPD Patients Population who is moving from Grade i to Grade $(i+1)$ during time t] / [COPD Patients Population in Grade i in the beginning of time t]

Figure 5 shows the simulated outcome pattern of the rate of COPD progression from "TG-COPD-G2PP" to "TG-COPD-G3PP" by the implementation of SS-I, SS-II, SS-III, SS-IV, SS-V, SS-VI, SS-VII, and SS-VIII with SS-Baseline on "TG-COPD-G2PP". The implementation of SS-I on "TG-COPD-G2PP" decreases the rate of COPD progression from "TG-COPD-G2PP" to "TG-COPD-G3PP" and has the highest momentous declining effect among SS-I, SS-II, SS-III, and SS-IV. The implementation of SS-I on "TG-COPD-G2PP" decreases the rate of COPD progression by nearly 33% at the maximum (0.11-0.07). The implementation of SS-II on "TG-COPD-G2PP" also decreases the rate of COPD progression from "TG-COPD-G2PP" to "TG-COPD-G3PP" but this declining effect is only 3.3%, which is very minute.

The implementation of SS-V on "TG-COPD-G2PP" significantly reduces the rate of COPD progression from "TG-COPD-G2PP" to "TG-COPD-G3PP" in comparison to the implementation of SS-I on "TG-COPD-G2PP". The reduction pattern of the rate of COPD progression from "TG-COPD-G2PP" to "TG-COPD-G3PP" is further greater due to the implementation of SS-VI on "TG-COPD-G2PP" but the implementation of SS-VII on "TG-COPD-G2PP" have no extra paybacks on the output. It is interesting to note that there is a maximum reduction pattern of the rate of COPD progression from "TG-COPD-G2PP" to "TG-COPD-G3PP" due to the implementation of SS-VIII on "TG-COPD-G2PP" among all SS. But there is a need to evaluate the total cost effectiveness of the implementation of SS-VIII on "TG-COPD-G2PP" in comparison to the implementation of SS-V or SS-VI or SS-VII on "TG-COPD-G2PP". The U-shaped decreasing pattern is totally related to the declining effectiveness of the implementation of SS over a time period.

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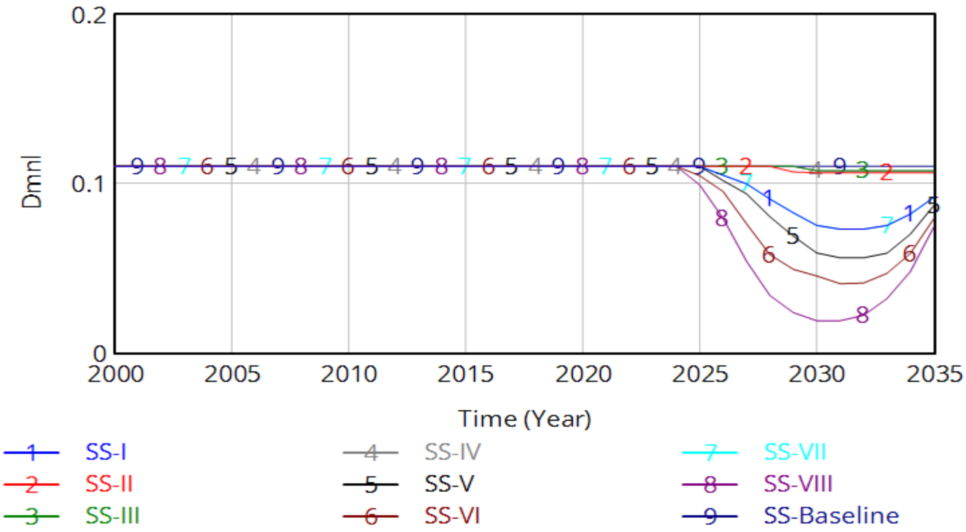

Figure 5. Simulated Outcome Pattern of Rate of COPD Progression from "TG-COPD-G2PP" to "TG-COPD-G3PP" by the Implementation of SS-I, SS-II, SS-III, SS-IV, SS-V, SS-VI, SS-VII, and SS-VIII with SS-Baseline on "TG-COPD-G2PP"

Now Figure 6 shows the simulated outcome pattern of rate of COPD progression from "TG-COPD-G3PP" to "TG-COPD-G4PP" by the implementation of SS-I, SS-II, SS-III, SS-IV, SS-V, SS-VI, SS-VII, and SS-VIII with SS-Baseline on "TG-COPD-G3PP". The implementation of SS-I and SS-III on "TG-COPD-G3PP" decreases the rate of COPD progression from "TG-COPD-G3PP" to "TG-COPD-G4PP" but this declining effect is very small, only 1% (0.26-0.2574) and 1.2% (0.26-0.2564) respectively. In contrast, the implementation of SS-IV on "TG-COPD-G3PP" also decreases the rate of COPD progression from "TG-COPD-G3PP" to "TG-COPD-G4PP" but this declining effect is comparatively significant at around 5% (0.26-0.247).
It is interesting to note that there is a maximum reduction pattern of the rate of COPD progression from "TG-COPD-G3PP" to "TG-COPD-G4PP" due to the implementation of SS-VIII on "TG-COPD-G3PP" followed by the implementation of SS-VII. But there is a need to evaluate the total cost effectiveness of the implementation of SS-VIII on "TG-COPD-G3PP" in comparison to the implementation of SS-VII on "TG-COPD-G3PP". Implementation of SS-V and SS-VI on "TG-COPD-G3PP" in comparison to SS-Baseline depicts a minute decrease in the rate of COPD progression from "TG-COPD-G3PP" to "TG-COPD-G4PP", which clearly depicts that the implementation of SS-V and SS-VI on "TG-COPD-G3PP" are not at all critical and important for deceleration of the rate of COPD progression of "TG-COPD-G3PP".

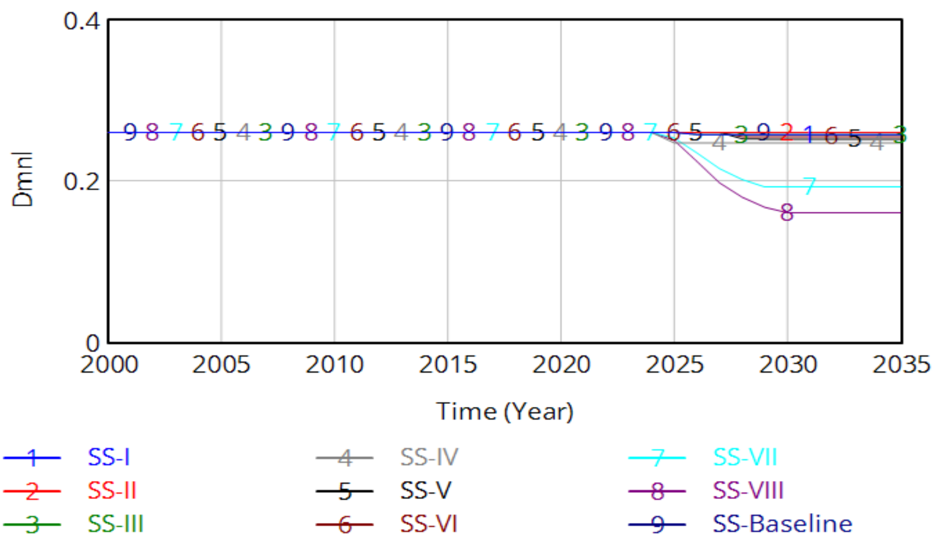

Figure 6. Simulated Outcome Pattern of Rate of COPD Progression from "TG-COPD-G3PP" to "TG-COPD-G4PP" by the Implementation of SS-I, SS-II, SS-III, SS-IV, SS-V, SS-VI, SS-VII, and SS-VIII with SS-Baseline on "TG-COPD-G3PP"

Discussions

The CSF-SD-COPD model helps in estimating the dynamic impacts of the implementation of formulated and generated eight integrated Scenario based Strategies (SS) with ninth SS-Baseline on COPD-PP based on their present COPD grade and is an innovative continuous decision-making step to improve the strategic health care management and overall quality of life of COPD population in India. The developed robust model also delivers a wide range of additional paybacks such as COPD patient education, patient follow-up appointments, inhaler training, patient aftercare, and pulmonary rehabilitation. The simulation results clearly indicated that the implementation of SS-I increases the "TG-COPD-G2PP" and decreases the "TG-COPD-G3PP" and thus has the maximum effect on the prevalence of COPD while the implementation of SS-VIII has all in all maximum effect on the prevalence of COPD and it increases both "TG-COPD-G2PP" and "TG-COPD-G3PP". The simulation results also indicated that implementation of SS-I has maximum effect on "TG-COPD-G2PP" and will definitely help in decreasing the rate of COPD progression to "TG-COPD-G3PP", which will be bound to have a higher "TG-COPD-G2PP". The implementation of SS-I also has some effect on "TG-COPD-G3PP" but now the direction of decreasing the rate of COPD progression is from "TG-COPD-G3PP" to "TG-COPD-G4PP" but the magnitude is different from the effect on "TG-COPD-G2PP".

The implementation of SS-IV will not be critical to decrease the rate of COPD progression from "TG-COPD-G2PP" to "TG-COPD-G3PP" but will be significantly effective on "TG-COPD-G3PP" to decrease the rate of COPD progression from "TG-COPD-G3PP" to "TG-COPD-G4PP". The reduction pattern of the rate of COPD progression from "TG-COPD-G2PP" to "TG-COPD-G3PP" is further greater due to implementation of SS-VI on "TG-COPD-G2PP" and there is a maximum reduction pattern of the rate of COPD progression due to the implementation of SS-VIII on "TG-COPD-G2PP" among all SS, but there is a need to evaluate the total cost effectiveness of the implementation of SS-VIII on "TG-COPD-G2PP" in comparison of the implementation of SS-VI on "TG-COPD-G2PP". Now there is a maximum reduction pattern of the rate of COPD progression from "TG-COPD-G3PP" to "TG-COPD-G4PP" due to the implementation of SS-VIII on "TG-COPD-G3PP" followed by the implementation of SS-VII, but again there is a need to evaluate the total cost effectiveness of the implementation of SS-VIII on "TG-COPD-G3PP" in comparison of the implementation of SS-VII on "TG-COPD-G3PP". The simulation results also highlight the critical role of Pulmonologists in HCM engagement and in the long-term improvement of the quality of health of COPD-PP, not only by the implementation of SS-I but also other SS. The designed and developed CSF-SD-COPD model can act as a solid supporting decision making tool for hospitals and nursing homes to prioritize SS-I or SS-II or SS-III or SS-IV or SS-V or SS-VI or SS-VII or SS-VIII on the basis of COPD-G1PP or COPD-G2PP or COPD-G3PP or COPD-ES PP of these hospitals and nursing homes. The medical decision makers can easily fix their priorities related to COPD-G1PP or COPD-G2PP or COPD-G3PP or COPD-ES PP and also fix the implementation of SS-I or SS-II or SS-III or SS-IV or SS-V or SS-VI or SS-VII or SS-VIII.

The CSF-SD-COPD model for patient-centered health care management clearly depicts that the model is a very powerful and effective decision making research tool due to mathematical functions and incorporated data and evaluates integrated SS and policies from a holistic perspective and tends to overcome the limitations of other techniques, which generally concentrate on the linear effect of integrated SS and policies and on a target group of COPD: Grade Patients Population without taking into consideration its methodical effect on the total system. The analysis of integrated SS and policies using CSF-SD-COPD model for patient-centered health care management will be a milestone in the area of research on COPD and is bound to help the physicians and medical decision makers in understanding integrated SS and policies in a better way, due to comparing their impacts on different target group of COPD: Grade Patients Population and total system. The designed and developed CSF-SD-COPD model for patient-centered health care management will become an innovative practical research instrument to help and support strategic, tactical and operational decision making for hospitals and nursing homes.

Conclusion

The designed and developed CSF-SD-COPD model provides insights into formulated and generated eight integrated Scenario based Strategies (SS) and policies with the ninth SS-Baseline by evaluating their multiple implementations and also estimating the limit of their critical impacts. In Indian COPD: Grade Patients Population scenario, the volume of COPD progression is much higher than the volume of COPD mortality. This clearly implies that different changes in COPD progression will have a larger influence on changes in the COPD patient population compared to changes in the rate of COPD mortality. The model is very powerful in understanding the dynamics of COPD system and in formally evaluating formulated and generated eight integrated Scenario based Strategies (SS) and policies. This model offers a more universal medical apparatus for a wider class of real-life complex semi-structured or unstructured medical decision tasks, situations and optimization problems and has not been so far exploited in literature for computational purposes and will improve the overall quality of life, lifespan, and strategic healthcare management of the COPD population of India.

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