A systems perspective of basic education in South Africa

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Declaration

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Abstract

South Africa has one of the highest measures of economic inequality and one of the worst performing basic education systems in the world. The majority of learners from poorer communities are attending dysfunctional schools, while a minority of learners from richer communities are achieving adequately in a functional system. The economic disparity creates an intuition that allocating more funds can solve low academic performance, but this approach has yielded little return for a number of years.

In this dissertation the impact of school leadership on learners' academic performance is considered in the South African context. School management is a systemic concept and elements thereof cannot be analysed in isolation. A series of system dynamics simulation models is developed to understand the effect of various school management interventions on communities, teachers, resources, and learners within the basic education system.

The School Effectiveness Model simulates the South African basic education system and reveals that improvement interventions must be made early, continously and in multiple areas for them to be effective. The Teacher Effectiveness Model simulates the career progression of Western Cape public teachers and reveals that the number of the teachers appointed in a primary school has a greater impact on their effectiveness than the quality of the teachers appointed. The Early Childhood Development Model simulates the preschool career of Western Cape children and reveals that improving the quality of Early Childhood Development programmes has a greater impact on their primary school readiness than increasing the number of children enrolled into programmes. The Primary School Model simulates the progression of learners from Grade 1 to Grade 7 in the Western Cape and reveals that improving learners' social circumstance at home has a greater impact on their academic performance than improving their classroom experience. Finally, the expanded School Effectiveness Model brings all the models together to reveal that a combination of interventions is needed to decrease the academic performance gap between poorer and richer communities within the Western Cape.

Opsomming

Suid-Afrika het een van die hoogste vlakke van ekonomiese ongelykheid en een van die swakste basiese onderwysstelsels ter wêreld. Die meerderheid leerders vanuit armer gemeenskappe woon disfunksionele skole by, terwyl 'n minderheid leerders vanuit ryker gemeenskappe voldoende presteer in 'n funksionele stelsel. Die ekonomiese ongelykheid skep 'n gevoel dat die toekenning van meer fondse die lae akademiese prestasie kan oplos, maar hierdie benadering het die afgelope aantal jare geen vrugte opgelewer nie.

In hierdie verhandeling word die impak van skoolleierskap op die akademiese prestasie van leerders in die Suid-Afrikaanse konteks ondersoek. Skoolbestuur is 'n sistemiese konsep wat nie buite 'n stelselkonteks ontleed kan word nie. 'n Reeks stelseldinamikasimulasiemodelle is ontwikkel om die effek van verskillende bestuursintervensies op gemeenskappe, onderwysers, hulpbronne, en leerders binne die basiese onderwysstelsel te verstaan.

Die Skooleffektiwiteitsmodel simuleer die Suid-Afrikaanse basiese onderwysstelsel en toon aan dat verbeteringsintervensies vroeg, deurlopend en op verskeie faktore nodig is om doeltreffend te wees. Die Model vir Onderwyserseffektiwiteit simuleer die loopbaanvordering van onderwysers in die Wes-Kaap en toon aan dat die aantal onderwysers wat in 'n laerskool aangestel word, 'n groter impak op hul doeltreffendheid het as die kwaliteit van die onderwysers wat aangestel is. Die Model vir Vroeë Kinderjare Ontwikkeling simuleer die voorskoolse loopbaan van kinders in die Wes-Kaap. Dit wys dat die verbetering van die gehalte van die programme 'n groter impak op skoolgereedheid het as om die aantal kinders wat by programme ingeskryf is te vermeerder. Die Laerskoolmodel simuleer die vordering van leerders van Graad 1 tot Graad 7 in die Wes-Kaap en toon aan dat die verbetering van leerders se sosiale omstandighede 'n groter impak op hul akademiese prestasie het as om hul klaskamerervaring te verbeter. Laastens bring die uitgebreide Skooleffektiwiteitsmodel al die modelle bymekaar om aan te toon dat 'n kombinasie van ingrypings nodig is om die akademiese prestasiegaping tussen armer en ryker gemeenskappe in die Wes-Kaap te verminder.

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List of Acronyms

ADT	Advanced Diploma in Teaching
ANA	Annual National Assessments
CESM	Classification of Educational Subject Matter
CIA	Central Intelligence Agency
CPTD	Continuing Professional Teacher Development
CSG	Child Support Grant
DBE	Department of Basic Education
DHET	Department of Higher Education and Training
DT	delta time
ECD	Early Childhood Development
ECDM	Early Childhood Development Model
ELOM	Early Learning Outcomes Measure
EMIS	Education Management Information Systems
eSEM	expanded School Effectiveness Model
FET	Further Education and Training
GHS	General Household Survey
HEMIS	Higher Education Management Information System
ITE	initial teacher education
NIDS	National Income Dynamics Survey
NQF	National Qualifications Framework
NSES	National School Effectiveness Study
NWU	North-West University
OBE	Outcomes Based Education
OECD	Organisation for Economic Co-operation and Development
OHS	October Household Survey
PG	postgraduate
PGCE	Post Graduate Certificate in Education

PIRLS	Progress in International Reading Literacy Study
PSM	Primary School Model
QES	Quarterly Employment Survey
QLFS	Quarterly Labour Force Survey
RMSE	root mean square error
SACMEQ	Southern and East African Consortium for Monitoring Educational Quality
SBG	School Governing Body
SD	System Dynamics
SEM	School Effectiveness Model
SES	socio-economic status
SMT	School Management Team
TEM	Teacher Effectiveness Model
TEQ	Teacher Education Qualification
TIMSS	Trends in International Mathematics and Science Study
UG	undergraduate
UKZN	University of KwaZulu-Natal
UNISA	University of South Africa
WC	Western Cape
WEF	World Economic Forum

CHAPTER 1

Introduction

Contents

For over two decades, a collection of comprehensive datasets detailing the state of the South African education system has been published. Trends in mathematics and science achievement for Grade 4 and Grade 8 learners are recorded in the *Trends in International Mathematics and Science Study* (TIMSS) [51]. The test has been taken every four years by 580 000 learners in 57 countries since 1995. TIMSS 2015 is therefore the sixth assessment. The *Progress in International Reading Literacy Study* (PIRLS) has measured trends in reading comprehension in Grade 4 for nearly two decades starting in 2001 on a regular five year cycle since [52]. The *Southern and East African Consortium for Monitoring Educational Quality* (SACMEQ) dataset for South Africa identifies those factors that have a significant effect on student mathematics and reading performances in Grade 6 [105] while the *National School Effectiveness Study* (NSES) is the first large-scale survey of academic performance at national primary school level. It includes a study of school management and teacher practice factors and is much more thorough than other surveys previously conducted in South Africa [104].

South Africa's education system is in crisis. According to the *Organisation for Economic Co-operation and Development* (OECD) report, fifteen-year-olds in South Africa score second to last behind only Ghana in numeracy and literacy achievement when compared to learners from 76 countries [71]. The *World Economic Forum* (WEF) released its Global Information Technology Report 2015, which ranked South Africa last in the quality of mathematics and science education [33]. The country also finished 139th out of 143 countries when looking at the overall quality of its education system, while the 2015 TIMSS had South Africa at or near the bottom of its various rankings [51]. The 2013 *Annual National Assessments* (ANA) reports that approximately 11% of public school learners in Grade 6 achieved a score below sufficient for assessments on their proficiency of their home language and approximately 36% failed mathematics. ANA 2013 further showed that although 37% of Grade 9 learners passed assesment, only 3.4% scored higher than 50% for mathematics [61]. The 2016 PIRLS tested 12 810 fourth graders from 293 schools and found that 78% of those who could read could not read with comprehension. Of learners who attended school for six years a staggering 27% could not read at all, compared to 4% in Tanzania and 19% in Zimbabwe. After five years of school about half could not do basic arithmetic. Only 37% of children starting school went on to pass the matriculation exam while just 4% earned a degree [51].

Yet, there is an observable group of learners who perform acceptable on local and international tests. That is, when analysing the test results, the median literacy and numeracy scores are significantly lower than the mean. There is a minority of learners (roughly 25%) who attend functional schools delivering good test results. The majority of learners (roughly 75%), however, are attending dysfunctional schools delivering poor test results.

1.1 The bimodality of the South African education system

Spaull [94] found that this bimodal distribution is observed regardless of grade or subject under investigation. Taylor [104] found bimodality in as early as Grade 3 results while Van der Berg [107] found it remained in the national school leaving exam. The 2016 PIRLS show that while only 22% of all South African learners reach the international standard, 71% of all learners from the richest 10% of schools are able to reach this level [52]. Only 11% of Grade 4 learners from the poorest 10% of schools are able to read at a basic level in any language, while 71% of Grade 4 learners in the richest 10% of schools are able to do so [95]. Bimodality can be seen in wealth quartiles, school language quartiles, former-department quartiles, and in the distribution of various home-background factors.

Bimodality makes it difficult to describe an "average" South African learner, yet the national and provincial averages of learner performance remain the most commonly reported measure of achievement in government and international reports. Averages shroud the true picture. For example, national and provincial averages always overestimate the achievement of the majority of South African learners because the median is so far below the mean. There are also factors other than academic outcomes prevalent.

The *Central Intelligence Agency* (CIA) World Fact Book [13] described South Africa as "a middle-income, emerging market with an abundant supply of natural resources; well-developed financial, legal, communications, energy, and transport sectors; and a stock exchange that is Africa's largest and among the top 20 in the world." With a population of 55.6 million and a Gini coefficient which ranges from about 0.660 to 0.696 the country effectively remains a dual economy with one of the highest inequality rates in the world [97]. During 2017, the country achieved an economic growth of only 0.5% with a youth unemployment rate of 50%. Only 10% of the population own 95% of the wealth while 17-million people survive on social grants. There exists only about 7-million income tax payers [58]. Figure 1.1 contains a summary of the average individual income of all South Africans according to the National Income Dynamics Study of 2014 and 2015 [92]. The source of South Africa's social, economic, and educational inequality lies within its difficult history.

South Africa was governed as an apartheid system from 1948 to 1991 where the education system in particular was shaped by the 1953 Bantu Education Act. Educational facilities were racially separated with the schools reserved for the country's white children being of western standards while about a third of the black schools did not have electricity, about a quarter of them had no running water, and less than half of them had plumbing. The education for black african, indian, and coloured learners was substantially cheaper but not free. In the 1970s, the per capita

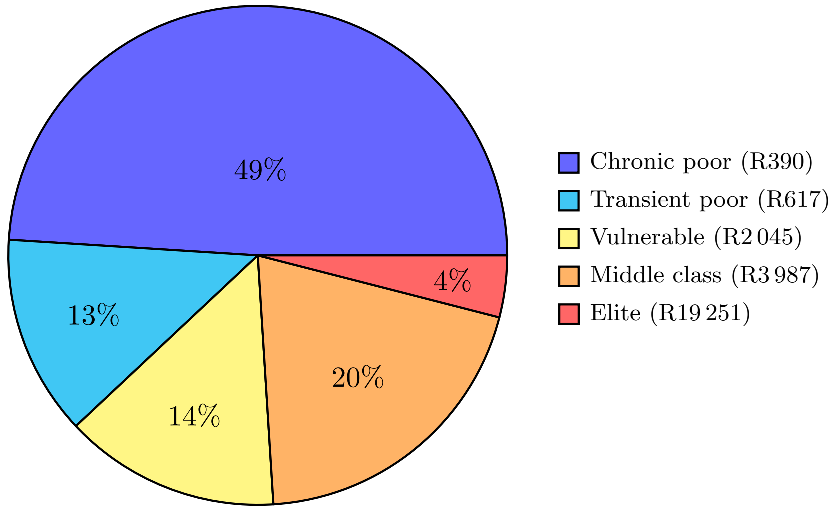

FIGURE 1.1: *South African society by average income per person per month [85].*

governmental spending on black education was one-tenth of spending on white education [14].

In 1994, the country replaced apartheid with a democratic system and access to schooling was expanded. Yet, more than twenty years later, schools that were dysfunctional before the reform remain dysfunctional, while schools that were functional remain thus. Furthermore, the two types of schools have different constituencies: historically black schools remain black, while historically white schools have become more diverse, albeit more racially than socio-economically.

Over the last two decades, the proposed solution has been to allocate more financial resources in an attempt to balance the system [107]. Over the last five years, for instance, an average of the 20% of the national budget was allocated to education [66]. Of this, approximately R20 000 is spent per child on primary education. In contrast, the Kenyan government spends approximately R4 000 per child and achieves better results than South Africa. Despite the substantial increase in resources invested in the historically disadvantaged school system there has not been an improvement in education quality. The problem is systemic and complex with no simple cause and effect relationship. Taylor [104] describes it as: "School functionality or efficiency remains something of a 'black box': Resources flow into the box and differential outcomes emerge, yet little is known or can be proven about what occurs within the box to determine the outcomes".

1.2 Analysing complexity through systems thinking

The United Nations Millennium Development Goals were eight goals that 191 UN member states agreed to achieve by the year 2015. These were put in place to eradicate extreme poverty and hunger, to achieve universal primary education, to promote gender equality and empower women, to reduce child mortality, to improve maternal health, to combat third world diseases, to ensure environmental sustainability, and to develop a global partnership for development. The goals describe humanity's most stubborn and pernicious problems and the attempt to eradicate them has made it clear that there are no simple solutions.

Richmond [80] described the complexity of the systems within which humans observe the planet's problems as growing faster than our ability to understand it. Traditional solutions no longer work as the subsystems in a finite earthly habitat grow across and into each other with unpredictable and poorly understood causality. We are too often caught off-guard by the counter-intuitive implications of the simple solutions we used to employ. Richmond suggests systems thinking, and System Dynamics modelling, as the solution for analysing and solving our most complex problems.

Traditional or boxed thinking is characterised by intuitive, but limiting assumptions about a problem. Richmond [81] called the usual approach of serial cause-and-effect analysis *laundry list thinking*. The first assumption is that causal factors operate independently on the effect that the analyst wishes to understand. In reality factors are often interdependent on one another. The second assumption is that causality only acts on the dependent variable while other variables remain unaffected. In reality, however, cause-and-effect often occurs in feedback loops so that an effect tends to indirectly dampen or exasperate itself. The third and fourth assumptions are expecting linear and immediate relationships between variables. Yet the very presence of feedback loops within a system guarantees that relationships will almost always be non-linear and delayed as the variable impacts accumulate.

Systems thinking can be described by three alternatives to traditional or boxed thinking. During *10 000 meter thinking*, the analyst looks across the breadth of a problem with very little vertical detail in order to gain the "big picture" view. *System as a cause thinking* guides the analyst to consider only the elements of a problem whose interaction is capable of generating the observed behaviour so that no unnecessary complicating external forces muddy the analysis. *Dynamic thinking* adds a level of behavioural thinking so that patterns rather than events can be identified.

1.3 Introduction to system dynamics

System Dynamics (SD) is the simulation of systems thinking where non-linear, first-order differential and integral equations are used to model the flow of data between a system's components. It is used to model aggregate values instead of an individual entity's characteristics as is the case in, for example, agent-based simulation modelling. This enables the modeller to discover the endogenous causes driving a system. Exogenous stimuli may pulse input into a system, but changes over time occur predominantly by means of internal feedback.

1.3.1 The mechanics of system dynamics

The most essential logic of an SD simulation is its feedback loops. A feedback loop is a closed sequence of causes and effects, that is, a closed path of action and information [78]. Reinforcing (or positive) feedback loops exasperate behaviour, whether that behaviour is growth or decay. Its impact can be described as "the more something happens, the more it causes itself to happen". Population growth is an example of a reinforcing feedback loop in that the more individuals are born and maturing, the more individuals are able to be born. Balancing (or negative) feedback loops dampen behaviour. Its impact can be described as "the more something happens, the less it causes itself to happen", or inversely, "the less something happens, the more it causes itself to happen". Population decline is an example of a balancing feedback loop in that the more individuals are dying, the fewer individuals are to die.

Causal loop diagrams are conceptual, visual representations of how different variables within a system are interrelated. A causal loop diagram consists of a set of endogenous and exogenous variables and the set of links that represent a connection or a relation between these variables. A link marked positive indicates an increasing (positive) relation and a link marked negative indicates a decreasing (negative) relation. Endogenous variables affect and are affected by the rest of the system while exogenous variables are external variables that are affecting but are not affected by the behaviour of the system.

Stock flow diagrams contain the quantification and mechanics of causal loop diagrams. State variables are modelled as stocks and act as receptacles where units can accumulate or drain. A stock can be observed during the simulation to see how many units of an element has collected *at* a point in time. Derivatives are modelled as flows and connect stocks to allow units to flow between them. A flow can be observed during the simulation to determine how many units of an element flows *over* a point in time. Converters store information or calculations and receive values from stocks or flows to transmit as rates into flows by means of connectors. Sources and sinks are stocks that lie outside of a model's boundary. They are used to abstract the origin or destination of flows that are irrelevant to the purpose or scope of the simulation.

1.3.2 Time in system dynamics models

An SD model simulates the behaviour of a system over time. The time horizon is the length of the simulation period, from the defined start time to the defined stop time. The time status is the current simulation time, somewhere between the start and stop time. The elapsed time is the amount of time since the simulation commenced. The time unit refers to the chosen unit of time to reporting results, while *delta time* (DT) or the timestep is the fraction of the time unit selected for the execution of flow calculations. The smaller the delta time, the higher the calculation frequency and accuracy.

SD models are solved numerically by approximating the underlying continuous differential and integral equations with difference equations. As analytic solutions for complex models are rarely known, numerical integration is used to determine the solution of the equations. The majority of SD models are approximated by means of Euler integration, though higher order integration methods such as Runge-Kutta are available in most software packages. Delta time must therefore be selected to be short enough to keep the integration error tolerably low.

The simplicity of Euler's method for approximation makes it an easy first choice. During this method the change in stock values at a time interval is estimated by computing the flows over that time interval. Approximating the change in the stock as simply the change in the flow to that stock creates an integration error, especially when the time interval is large (relative to the continuous case). Algorithm 1 contains the steps for Euler's method.

Algorithm 1: Euler's method

time $t = 0$
stock $x_{t=0}$ = initial stock value
converters = initial converter value
flows $f(x,t)$ = initial flow values
while current time < simulation stoptime **do**
  $\Delta x = dt * f(x,t)$
  $x_t = x_{(t-dt)} + \Delta x$
  update converter values according to their function
  update flow values according to their function
  $t = t + dt$
end while

During second-order Runge-Kutta methods, the change in a stock over the time interval is estimated by means of two flow calculations within a given DT. Algorithm 2 contains the steps for this method. A more accurate estimate for new stock values is obtained when the average flow values are computed at the beginning of the time interval.

Algorithm 2: Second-order Runge-Kutta method

time $t = 0$
stock $x_{t=0}$ = initial stock value
converters = initial converter value
flows $f(x, t)$ = initial flow values
while current time < simulation stop time **do**
  $F_1 = dt * f(x, t)$
  $F_2 = dt * f(t + dt, x + F1)$
  $\Delta x = \frac{1}{2} * (F_1 + F_2)$
  $x_t = x_{(t-dt)} + \Delta x$
  update converter values according to their function
  update flow values according to their function
  $t = t + dt$
end while

Fourth-order Runge-Kutta is similar to the second-order approach using four instead of two flow calculations for each time interval to estimate the change in a stock. The average is also weighted instead of uniform for all flows. Algorithm 3 contains the steps for this method. The flow at time t is the rate of stock change F_1. The flow at half an interval into the future is F_2. The stocks are updated with F_1 so that F_2 may be calculated and these are then used to re-calculate the flows. Half of F_1 is used to calculate F_2 since the calculation is made over only half the interval. A new calculation for the flow is given by F_3. It takes F_2 to update the stocks, which then are used to re-calculate the flows. A half F_2 is used to update the stocks since the calculation is made over half an interval. The flow at one full interval in the future is calculated as F_4. It takes F_3 as the flow over the full interval. The stocks are updated using F_3, then F_4 is estimated. The average of F_1 to F_4 yield an estimate of the flow. The stock is updated with this average flow before the next iteration begins.

Algorithm 3: Fourth-order Runge-Kutta method

time $t = 0$
stock $x_{t=0}$ = initial stock value
converters = initial converter value
flows $f(x, t)$ = initial flows values
while current time < simulation stoptime **do**
  $F_1 = dt * f(t, x)$
  $F_2 = dt * f(\frac{t+dt}{2}, x + \frac{1}{2}F_1)$
  $F_3 = dt * f(\frac{t+dt}{2}, x + \frac{1}{2}F_2)$
  $F_4 = dt * f(t + dt, x + F_3)$
  $x = \frac{1}{6} * (F_1 + 2F_2 + 2F_3 + F_4)$
  $\Delta x = x_{(t-dt)} + x_t$
  update converter values according to their function
  update flow values according to their function
  $t = t + dt$
end while

Most system dynamicists use the Euler integration method (Algorithm 1), which is the default in all the SD simulation languages. The disadvantage of using Runge-Kutta (Algorithms 2 and 3) is that typically it requires more computations and memory, which are not necessary for most models, especially when many step or pulse calculations are performed on discrete variables. SD and differential equation modelling differ in their focus and philosophy. Differential equation modelling provides analytic tractability with which a modeller may find solutions using exact analytical methods. SD modellers are less concerned with analytic tractability and are more comfortable with simulating the model and drawing conclusions from observed trajectories.

1.4 Objectives

An SD simulation at the correct level of abstraction and complexity will open up what Taylor [104] calls a "black box" of school functionality and efficiency. By simulating each part of the system, the complex relationships can be studied and manipulated so that the connection between resources invested and outcomes achieved may be better understood.

The South African *Department of Basic Education* (DBE) released a plan with 27 goals to improve the basic education system by 2030 [24]. Thirteen of the goals deal with outputs in relation to learning and enrolments while the rest deal with how these outputs are to be achieved. Five of the goals are considered priority goals. The first priority goal is the improvement of the professionalism, teaching skills, subject knowledge, and computer literacy of teachers throughout their entire careers. The second priority goal is the improvement of children's access to quality *Early Childhood Development* (ECD) below Grade 1. The third priority goal is to ensure that every learner has access to the minimum set of textbooks and workbooks required according to national policy. The fourth priority goal is to ensure that the basic annual management processes take place across all schools in the country in a way that contributes towards a functional school environment. Finally, the fifth priority goal is to improve the frequency and quality of the monitoring and support services provided to schools by district offices. This can be achieved partly through better use of e-Education. A simulation model which examines the success of these goals will show the viability of each goal as well as their intended and unintended impact on the system.

The aim of this dissertation consists of three parts: the development of a simulation model of the South African basic education system with the correct complexity horizontally (reflecting schools from all socio-economic sectors) and vertically (reflecting the local, district and national decisions influencing the schools); the application of what-if scenarios and interventions to minimise bimodality of performance results; and the exploration of interventions to improve the performance of the new distribution so that the system as a whole improves. This is achieved by means of the following seven objectives:

Objective I

a Describe the current state of the South African basic education system to show its complexity and the extent to which it finds itself in crisis;

b Describe systems thinking and SD modelling to argue for its applicability as a method for analysing complex systems;

Objective II

a Develop the *School Effectiveness Model* (SEM) as an abstraction of a South African school to serve as proof of concept for the use of SD simulation in education modelling within the South African context;

b Apply different interventions to the SEM to understand the effect of various intuitive solutions;

Objective III

a Develop the *Teacher Effectiveness Model* (TEM) as an extension of the SEM's complexity to analyse the effect of the quality of the educator pool on the overall quality of the education system.

b Populate the TEM with national data for validation and base case results;

c Apply different interventions to the TEM to understand their effect on the professionalism, teaching skills, subject knowledge, and computer literacy of teachers throughout their entire careers;

Objective IV

a Develop the *Early Childhood Development Model* (ECDM) as an input model to the *Primary School Model* (PSM) to analyse the effect of pre-school programs on the overall achievement of primary school learners.

b Populate the ECDM with recent national data for validation and base case results;

c Apply different interventions to the ECDM to understand their effect on the number of pre-school enrolments and the quality of the programs;

Objective V

a Develop the PSM as an extension of the SEM's complexity to analyse the effect of primary school management on the overall quality of the education system.

b Populate the PSM with national data for validation and base case results;

c Apply different interventions to the PSM to understand their effect on Grade 3 and Grade 6 literacy and numeracy scores;

Objective VI

a Combine all the models to form the *expanded School Effectiveness Model* (eSEM) to analyse the impact of each subsystem on the system as a whole.

b Determine which, if any, of the DBE's five priority goals for 2030 have the greatest impact in fixing the South African basic education system.

1.5 Dissertation organisation

Apart from this introductory chapter, this dissertation contains six additional chapters. In Chapter 2 the School Effectiveness Model is introduced and insight into the mechanics of its design is given. A brief discussion on the input data and assumptions used to populate the model is given. The base case results are shown, followed by three interventions and a discussion of their results. The chapter finishes with some concluding observations on the results. This chapter appeared as an article in the International Journal of Applied Systemic Studies[1].

In Chapter 3 the TEM is introduced to answer the research question whether it is the low teacher quality or low teacher quantity that contributes most to the education crisis. This question is

[1] VENTER L, VOSLOO MM, 2018. *A systems perspective on school improvement approaches.* International Journal of Applied Systemic Studies **8(2)**:151-179

asked within the context of schools within the lower socio-economic communities in the Western Cape province of South Africa. The chapter includes insight into the mechanics of the model's design, followed by a brief discussion on the input data, and the assumptions used to build the model. The base case results are shown, followed by interventions and a discussion of their results. This chapter has been accepted to appear in Systemic Practice and Action Research[2]

In Chapter 4 the ECDM is presented to describe the causal linkages between improved ECD and Grade R learning practices on the education system as a whole. The chapter gives insight into the mechanics of the ECDM's design, followed by a brief discussion on the input data and assumptions used to populate the model. The system status quo is presented as base case results, followed by interventions and a discussion of results. The research question is answered as to whether it is the number of enrolments into ECD programmes that increases a cohort's readiness for primary school education, or whether it is the quality of the ECD programmes into which they were enrolled that increases readiness. This chapter has been submitted for peer review for publication in a scholarly journal.

In Chapter 5 the PSM is presented and the causal linkages between improved primary school management and primary school achievement on the whole education system are described. It gives insight into the mechanics of the model's design, followed by a brief discussion on the input data and assumptions used to populate the model. The base case results are shown, followed by interventions and a discussion of their results. This chapter will be submitted to a scholarly journal for peer review for publication.

In Chapter 6 the eSEM is presented as an expansion of the SEM and final results and interventions are presented. Finally, a short summary of the dissertation is presented in Chapter 7, together with an overview of the contributions made. The chapter closes with suggestions for future work which may improve or build on the work conducted in this study.

[2] Venter L, Viljoen T, 2019. *A systems perspective on school improvement with a focus on teachers.* Accepted to appear in Systemic Practice and Action Research.

CHAPTER 2

Modelling basic education systems

Contents

School management is a highly systemic concept that cannot be analysed out of its context. A change in outcome is a case of generating momentum in a new direction by paying attention to as many factors as possible. As Stigler and Hiebert [102] noted, "It will be difficult, if not impossible, to improve [a system] by changing individual elements or features. If one feature is changed, the system will rush to 'repair the damage,' perhaps by modifying the new feature so it functions the way the old one did. It can backfire and leave things worse than before".

Harvey and Holland [47] agreed that most school variables, considered separately, have small effects on learning. The real pay-off comes when individual variables combine to reach critical mass. Management interventions to improve academic performance should therefore not be considered in a vacuum and are more effective when they are implemented within a broader, systemic approach to school improvement. Simulation attempts to understand the behaviour of complex systems over time. It is therefore an appropriate technique for analysing a system as complex as school management.

Clauset and Gaynor [15] lead the way in applying systems thinking to education systems through System Dynamics modelling. They constructed a model that provides a basis for examining alternative policies for transforming ineffective schools into effective ones. The model examined the feedback patterns where teacher achievement expectation affected instructional responses which in turn affected learner achievement. Schools that are moving toward effectiveness are characterised by raising expectations for low achievers, strong leadership, a disciplined environment, and the ability to attract new staff committed to an effective school philosophy.

Gaynor [41] then constructed a System Dynamics model to illustrate that the typical American public school is structured in such a way that the entry characteristics of its students is reinforced. The system positively reinforces achievement of learners entering with a high level of "readiness", while that same reinforcement keeps learners entering with a low level of "readiness" in a state of below average achievement. The system perpetuates a growing achievement gap that can only be closed through focused intervention.

In his next model, Gaynor investigated the academic achievement gap among students who vary in race, ethnicity and social class [42]. He justified the use of systems modelling by its ability to make implicit assumptions about a system explicit, and its ability to challenge expectations about the time it takes for systemic changes to take effect. While the use of regression analysis is often presented as a better alternative, Gaynor noted that its findings are more predictive than causal and that multiple regression analysis describes additive rather than interactive relationships between systems variables. Complexity modelling allows the analyst to observe the behaviour of various theoretical assumptions, and supports the testing of hypothetical interventions so that ideas can be evaluated virtually instead of through possibly high cost real world implementation.

From this we can conclude that the impact of interventions to improve learner achievement in the South African education system is worth investigating and that a simulation approach is useful. The objective of such a model is to understand the effect of various interventions on an abstraction of a school. The outcome provides a deeper insight into the effect of different interventions to answer the following key question: What does good school management look like and what can be done to develop it?

This chapter introduces the School Effectiveness Model and gives insight into the mechanics of its design. This is followed by a brief discussion on the input data and assumptions used to populate the model. The base case results are shown next, followed by three interventions and a discussion of their results and it finishes with some concluding observations on the results. This chapter appears as an article in the International Journal of Applied Systemic Studies[1].

2.1 The School Effectiveness Model

Currently, no systemic model exists for studying the South African education system. As a first attempt, a School Effectiveness Model at a high level of abstraction is presented. It serves to produce insight into management challenges in the South African context and to inform thinking about effective school management and how to develop it. The simulation enables experimentation and identification of effective interventions so as to understand how feedback loop dominance shifts. Also, it allows for exploration of effective responses to particular contextual challenges.

Education in South Africa is governed by two national departments, namely the DBE, which is responsible for primary and secondary schools, and the *Department of Higher Education and Training* (DHET), which is responsible for tertiary education and vocational training. South

[1] VENTER L, VOSLOO MM, 2018. *A systems perspective on school improvement approaches.* International Journal of Applied Systemic Studies **8(2)**:151-179

Africa's nine provinces each have their own education departments that are responsible for implementing the policies of the national department, as well as dealing with local issues.

The DBE deals with public schools, private (or independent) schools, ECD centres, and special needs schools. The public schools and private schools are collectively known as ordinary schools, and comprise roughly 97% of schools in South Africa with the bulk of learners enrolling into public schools. In 2017, for instance, 12 490 132 pupils were enrolled in public schools compared to only 402 141 at private schools. The DBE currently oversees 23 796 schools and 399 156 educators over 86 districts [26].

A child's education begins at age two through ECD programmes and Grade R. At age six, formal education begins with enrolment into the foundation phase (Grades 1 to 3) with a focus on subjects such as home language, an additional language, mathe- matics, and life skills. Average school hours for this phase totals between 23 and 25 hours per week. The intermediate phase consists of Grades 4 to 6 with a focus on home language, an additional national language, mathematics, natural science and technology, social sciences, and life sciences. The lower secondary (or senior) phase consists of Grades 8 and 9 for children of twelve or thirteen years old. It focuses on home language, an additional language, mathematics, natural science, social science, technology, economic and management sciences, life orientation, and arts and culture. The upper secondary, or *Further Education and Training* (FET), phase lasts through Grade 12, and is not compulsory. Learners are streamed into either an academic or technical track where enrolment into the technical track can take place only at a technical secondary school. Average school hours for these phases are 27.5 hours per week [61].

The School Effectiveness Model simulates the progression of learners from Grade 1 to 7 in a public primary school and from Grade 8 to 12 in a public secondary school. This progression is impacted upon by seven factors: the principal, the *school management team* (SMT), the school's capacity to support learning, the community, the school's sense of order, the strength of the educator pool, and the receptiveness of the learners. The model is a combination of two sub-models where the output of the first sub-model becomes the input to the second, and vice versa.

2.1.1 Learner progression

The first sub-model consists of two trains. Figure 2.1 contains these trains to show how the functional model units work together. Children enrol into the first grade with a predetermined level of school readiness. Their progression from one grade to the next up to the seventh grade is simulated as the progression of physical bodies through the school levels. The learning acquired during each phase of education is simulated and progresses along with the promoted learners. The quality of learning depends on the the level of each of the four learning outcomes as supported by the school system. Figure 2.2 contains the stock-and-flow diagram of one functional model unit from these two trains in a more detailed way.

The first train of this sub-model simulates the physical progression of learners from one grade to the next. Each grade consists of a number of learners distributed over four categories. These categories indicate the learners' initial aptitude and increased or decreased performance due to the impact of the system. Aptitude refers to the cumulative amount of learning a child has acquired by a certain age or grade. Let

$$\boldsymbol{G}_i = [G_{i1}, G_{i2}, G_{i3}, G_{i4}] \tag{2.1}$$

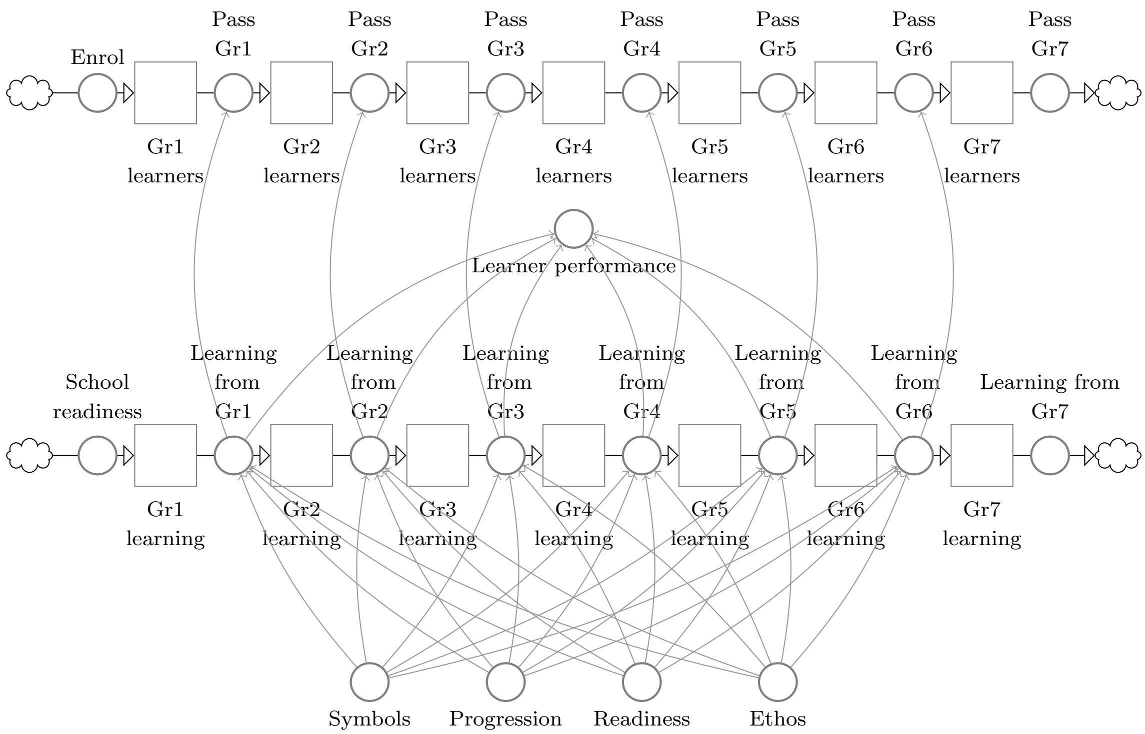

FIGURE 2.1: *The first sub-model of the School Effectiveness Model. Seven functional units as described in Figure 2.2 are linked to form two trains.*

be an arrayed stock of the number of learners in Grade i for $i \in [1, 2, 3, 4, 5, 6, 7]$ if the simulation is run for a primary school and $i \in [8, 9, 10, 11, 12]$ if the simulation is run for a secondary school, where

- G_{i1} indicates the number of learners who have the potential to achieve a high pass score, or who are currently achieving a high pass score, *i.e* they are scoring an average of 80% and above;
- G_{i2} indicates the number of learners who have the potential to achieve a standard pass score, or who are currently achieving a standard pass score, *i.e.* they are scoring an average between 60% and 80%;
- G_{i3} indicates the number of learners who have the potential to achieve a pass score, or who are currently achieving a pass score, *i.e.* they are scoring an average between 30% and 60%; and
- G_{i4} indicates the number of learners who have the potential to achieve a low pass score, or who are currently scoring a low score average of 30% and below.

Grades 1 and 8 have an input of enrolments for primary and secondary schools, respectively. The enrolments

$$\boldsymbol{E}_i = \begin{cases} [E_{i1}, E_{i2}, E_{i3}, E_{i4}] & \text{if } i \in [1, 8], \\ [0,\ 0,\ 0,\ 0] & \text{otherwise} \end{cases} \tag{2.2}$$

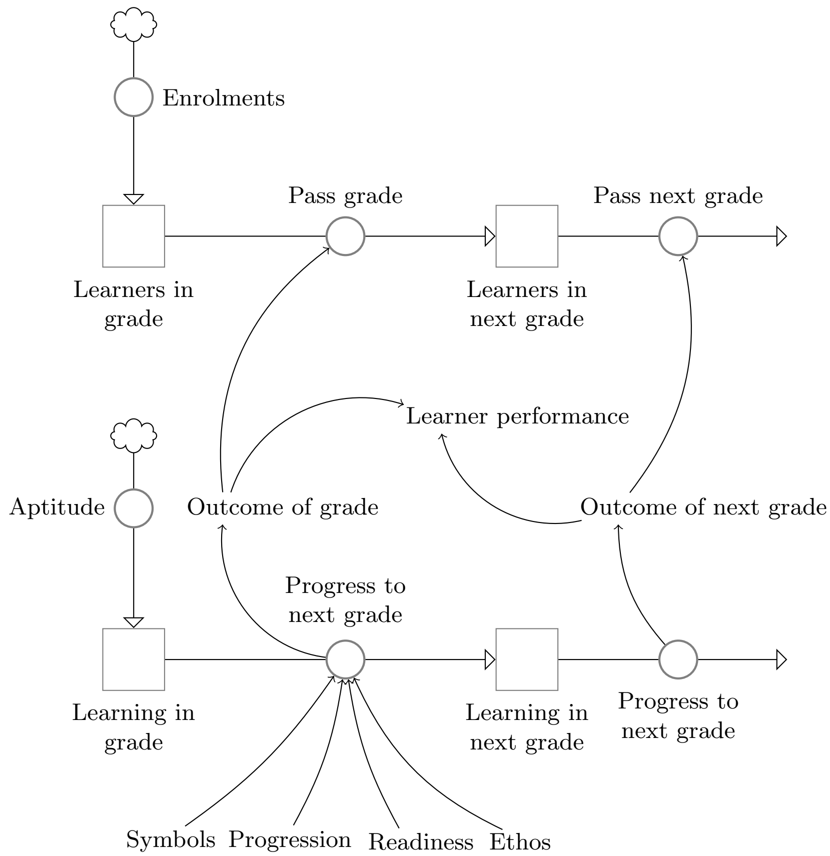

FIGURE 2.2: *The stock-and-flow diagram of one functional model unit modelling learner progression.*

are a set of learners distributed across the same performance categories of high, standard, pass, and low.

The second train simulates the progression of the learners' acquired learning from one grade to the next, where learning refers to the average of four elements.

Let

$$\begin{aligned}\boldsymbol{L}_i = & [L_{i11}, L_{i12}, L_{i13}, L_{i14}, \\ & L_{i21}, L_{i22}, L_{i23}, L_{i24}, \\ & L_{i31}, L_{i32}, L_{i33}, L_{i34}, \\ & L_{i41}, L_{i42}, L_{i43}, L_{i44}]\end{aligned} \tag{2.3}$$

be an arrayed stock of the learning acquired for each educational element for each learner performance category $j \in [1, 2, 3, 4]$ with $i \in [2, 3, 4, 5, 6, 7]$ if the simulation is run for a primary school, and $i \in [9, 10, 11, 12]$ if the simulation is run for a secondary school where

- L_{ij1} refers to the average symbols percentage that a learner scores on formal assessment (*e.g.* tests and exams) in Grade i and performance category j measured as a fraction between 0 and 1;
- L_{ij2} refers to the progression probability that a learner will pass to the next phase in Grade i and performance category j, measured as a fraction between 0 and 1;

- L_{ij3} refers to readiness, in other words, the learner's ability to adapt to the increased difficulty of the next phase in Grade i and performance category j, measured as a fraction between 0 and 1; and

- L_{ij4} refers to ethos, in other words the learner's level of social life skills obtained (*e.g.* leadership abilities, responsibility, *etc.*) in Grade i and performance category j, measured as a fraction between 0 and 1.

The learners enrolled in Grades 1 and 8 enter the system with a predetermined aptitude. Aptitudes are grouped according to potential performance categories across the four education elements. Let aptitude be represented by

$$\boldsymbol{A}_i = \begin{cases} [A_{i11}, A_{i12}, A_{i13}, A_{i14}, \\ A_{i21}, A_{i22}, A_{i23}, A_{i24}, \\ A_{i31}, A_{i32}, A_{i33}, A_{i34}, \\ A_{i41}, A_{i42}, A_{i43}, A_{i44}] & \text{if } i \in [1, 8] \\ \\ [0, 0, 0, 0, \\ 0, 0, 0, 0, \\ 0, 0, 0, 0, \\ 0, 0, 0, 0] & \text{otherwise.} \end{cases} \tag{2.4}$$

The first sub-model takes symbols, progression, readiness and ethos as input from a second sub-model where each converter is a $[1 \times 4]$ vector containing a score between 0 and 1 for each of the four performance categories of learners. These scores influence the progression of learning from one grade to the next. The existing learning level and the learning acquired during the learners' time within a grade are averaged and this average flows to the next phase.

Grade outcome is a $[1 \times 4]$ vector of averaged outcome scores for each performance category. The scores are averaged to determine the distribution of students passing from one grade to the next. If, for example, the averaged score for low scoring learners remains low, these learners progress to the next grade as low scoring learners. If, however, the averaged score for low scoring learners has increased above the threshold, these learners progress to the next grade as passing learners. The scoring process works similarly for all four performance categories.

The outcomes for all grades over all performance categories are further averaged within the *learner performance* converter to calculate one system score for the first sub-model. This score is passed to the second sub-model to form the feedback loop between the sub-models.

2.1.2 The school system

The second sub-model simulates the cumulative impact of seven components that influence a school system. These factors are the principal, the *school management team* (SMT), the school's capacity to support learning, the community, the school's sense of order, the strength of the educator pool, and the receptiveness of the learners. Figure 2.3 contains the stock diagram of one model unit simulating a factor.

Each factor's strength accumulates within stocks where strength is a score from 0 to 7. A strength of 0 indicates that a factor has no influence in the system and is not fulfilling its role. A strength of 7 indicates that a factor has a perfect influence in the system and is fulfilling its

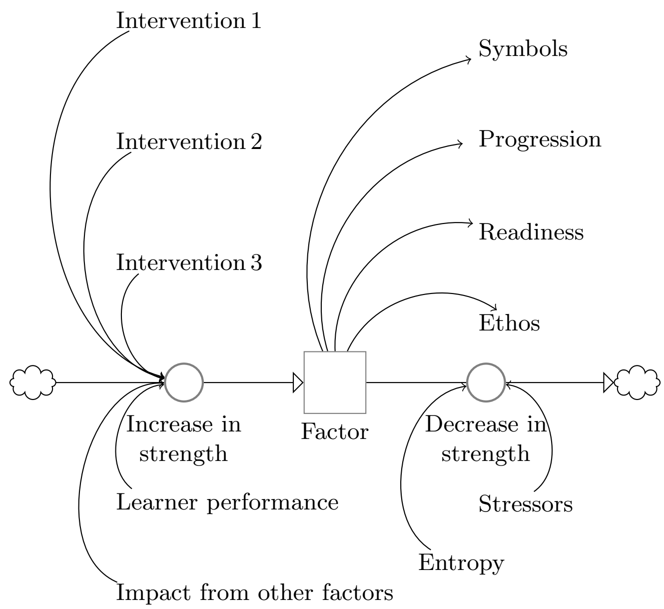

Figure 2.3: *Stock-and-flow diagram of one functional model unit modeling a system factor.*

role perfectly. Interventions and feedback from the system increase stock levels while stressors and entropy decrease them.

Interventions are decisions the principal can make to improve the system while stressors are any negative consequences resulting from these decisions. The second sub-model employs three types of interventions for each factor. The first intervention type causes only a small increase in strength, but its impact is felt with very little time delay. The second intervention type causes a moderate increase in strength, but its impact is subject to a reasonable time delay. The third causes a large increase in strength, but its impact is subject to a significant time delay. The decision-maker must therefore consider that there is a trade-off between the impact size of an intervention and the time until the impact manifests.

Strength is further increased or decreased by the cumulative impact of other relevant factors, as well as by the learner performance value from the first sub-model. Factor strength is further decreased by a constant entropy. Consequently, even a functional system cannot be left unmanaged for a long period without loss of strength. Factor strengths combine as a form of currency with which the education outcomes (symbols, progression, readiness and ethos) can be "bought". Strong factors combine to obtain many or all of the education outcomes, but weak factors obtain only a few or even no outcomes. These outcomes then return to the first sub-model as input values that influence learner achievement.

The change in each factor value is expressed as a differential equation. Let ζ be the stock value for each factor, ι be the cumulative increase in strength from the other factors and interventions, δ be the cumulative decrease in strength from entropy and the stressors. Then the change in each factor in general is expressed as

$$\frac{\mathrm{d}\zeta}{\mathrm{d}t} = \iota - \delta - \zeta. \tag{2.5}$$

2.2 Data and assumptions

Although simulation is a mathematical approach to understand systems and policies, it is recognised that the information available to the modeller is more often qualitative rather than numerical in nature. Forrester [38] recognised the actors' or stakeholders' mental database of intuition, experience and observations as the most important data source. This notion was shared by Randers [75], Robert *et al.* [82], Wolstenholme [117] and Sterman [101]. Coyle [16] believed that the uncertainty associated with quantifying qualitative variables causes fragile or even misleading results, but Luna-Reyes and Andersen [60] listed techniques from social science which prove to deliver useful and trustworthy transformed inputs. They supported the two techniques used to collect data for the School Effectiveness Model (*i.e.* focus groups and Delphi groups) in particular.

The Sasol Inzalo Foundation is a public benefit foundation driving excellence in *science*, *technology*, *engineering* and *maths* (STEM) education at all levels of the education value train [84]. It seeks to drive conversations among selected communities to better understand key issues, and how these influence the educator system.

The Foundation has been collecting baseline information from 104 participating schools since 2012. This longitudinal study focused on the impact of school leadership development programmes across the country and was conducted over a period of three years. It involved repeated narrative data collection, quantitative measures, school visits and observations, and school documentation analysis to study trends and changes in schools. The study was carried out in five of South Africa's nine provinces, was national in scope, and focused on the impact of different intervention programmes.

Ten leadership and management development programmes were invited to participate in the study. The selected programmes were chosen from different parts of the country. A sample group of school leaders from each of the programmes were invited to participate in the study. A total of 54 schools participated in the full scale data collection, and participant data was collected from an additional 81 schools in Gauteng, and 7 schools in the Western Cape.

While the principal was the key informant of the study, the views of other stakeholders were also solicited. This was done to gain additional perspectives on the role of the principal in the school. These stakeholders included members of the *School Management Team* (SMT), parent members of the *School Governing Body* (SBG), teachers, and others who work closely with the principal.

The baseline information from this study was transformed into rubrics for the initial input values. These rubric results become a score for each of the factors in the second sub-model. The score is a value from 0 to 7, where a score of 0 indicates a dysfunctional factor, a score of 4 indicates a functional factor, and a score of 7 indicates an exemplary (or transformational) factor.

The impact that each factor has on the other factors in the second sub-model emerge from the data collected by the Foundation through a drivers-and-driven exercise. The drivers-and-driven exercise is used for groups to understand causation and correlation linkages (and the magnitude thereof) between elements in a particular environment. Often, when people are faced with a challenge or complex problem, they are aware of the elements involved, but they may not have a clear idea of the nature or magnitude of their relationship. Representatives from ten different school leadership programmes where divided into three groups of five representatives per group. The groups were asked to identify every factor they believed affects the school system. A scribe captured each factor on post-it notes, and then placed the post-its on a wall. Once participants completed the initial generation of factors, a facilitator began the process of refining the list.

In each group, participants were asked to consider the frequency with which the factor was mentioned. Secondly, they were asked to clarify what each factor referred to. Only factors which all group members agreed were important remained. These were then ranked in order of importance, and magnitude. For example, if a factor was named four times, it would logically be ranked higher than a factor that was mentioned only once.

The facilitator then named each factor by rank and the participants decided whether it was driving or being driven by each one of the other factors. Once they agreed on the nature of the relationship, they could assign a magnitude to it based on their practical experience. Figure 2.4 contains one iteration of the drivers-and-driven exercise after participants agreed that Factor 1 was driving Factors 2, 3 and 5, and that it was being driven by Factors 4, 6, and 7. The weight of the influence indicates the influence magnitude. A heavy weight indicates a large influence, and a lighter weight indicates a smaller influence. The direct impacts emerging from the study are shown in the causal loop diagram of the system in Figure 2.5 and the stock-and-flow diagram in Figure 2.6. Finally, the facilitator guided participants to transform a qualitative expression of influence magnitude (or weight) from degrees of comparison (where factors have a "greater" or a "lesser" impact) to quantified values for the simulation model (where factors now had "half" or "twice" the impact or weight).

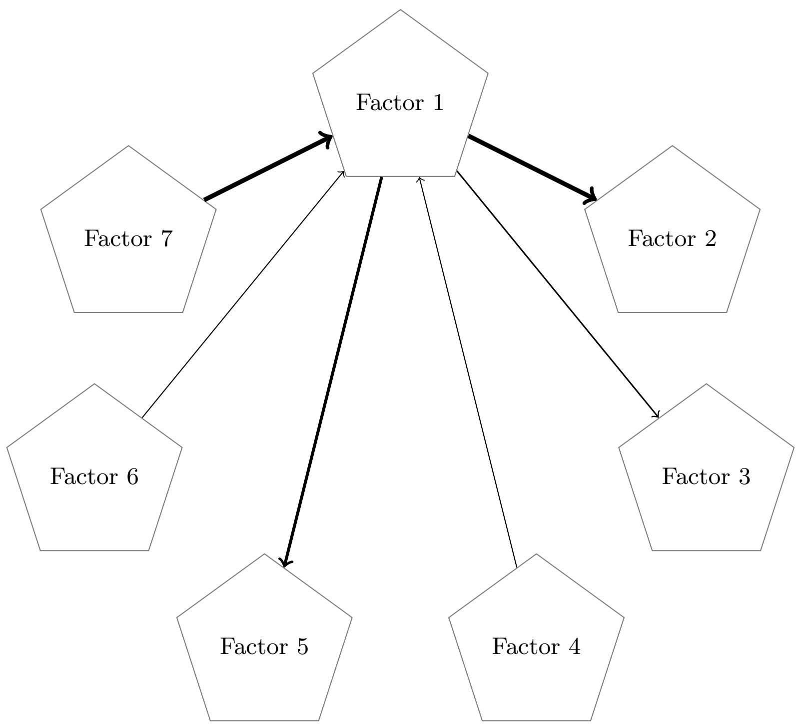

FIGURE 2.4: *One iteration of the drivers-and-driven exercise establishing the nature and magnitude of the relationship between Factor 1 and the other factors.*

Table 2.1 lists the weight of impact of each factor on the other factors as agreed upon by the focus group. A weight of 50% indicates that each level of strength change in the factor stock causes half a level of strength change in the influenced stock. A weight of 25% indicates that each level strength change in the factor stock causes a quarter of a level strength change in the influenced stock. An unfortunate phenomenon when using focus groups to collect data is their bias towards whole, half or quarter values. It is quite possible for an influence magnitude to be a third, fifth, eighth or any other fraction of impact. Therefore, sensitivity analysis must be performed to determine the robustness of results from these input values.

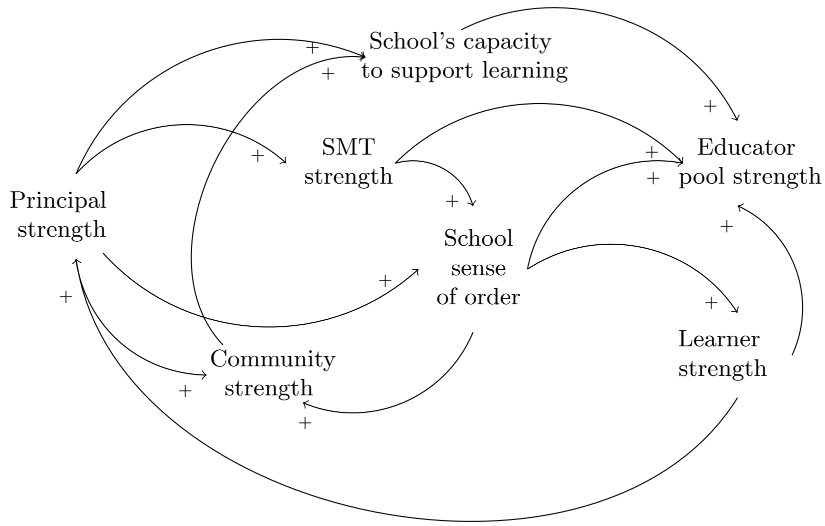

FIGURE 2.5: *The causal loop diagram for school effectiveness achievement.*

	Principal strength	SMT strength	Learning support	Sense of order	Community support	Educator pool strength	Learner strength
Principal strength	–	50%	50%	50%	50%	–	–
SMT strength	–	–	–	25%	–	25%	–
Learning support	–	–	–	–	–	50%	50%
Sense of order	–	–	–	–	25%	25%	25%
Community support	25%	–	25%	–	–	–	–
Educator pool strength	–	50%	–	–	–	–	50%
Learner strength	–	–	–	–	–	50%	–

TABLE 2.1: *The weight of each factor on the other factors of the second sub-model.*

The strength of a school's educator pool, learner receptiveness, capacity to support learning, and sense of order, determine which educational outcomes can be achieved. Table 2.2 lists the lowest value each factor can assume to achieve each of the four outcomes. For example, in order for learners to score well on assessments (*i.e.* achieve symbols), the stock value for the educator pool strength must be at least equal to 1, the stock value for learner strength must be at least equal to 3, the stock value for learning support must be at least 1, and the stock value for sense of order must be at least 3.

The minimum stock values to achieve these outcomes are however not enough to cause an achievement category change in the learners. Higher stock values are needed so that they not only achieve the outcomes, but achieve them so well that their achievement category is improved. For example, in order for learners to achieve a category improvement score on assessments (*i.e.* achieve symbols), the educator pool strength must be at least equal to 2, the stock value for learner strength must be at least equal to 4, the stock value for learning support must be at least 2, and the stock value for sense of order must be at least 4. Table 2.3 lists the required value each factor must assume to achieve one level improvement for learners in each of the four outcomes.

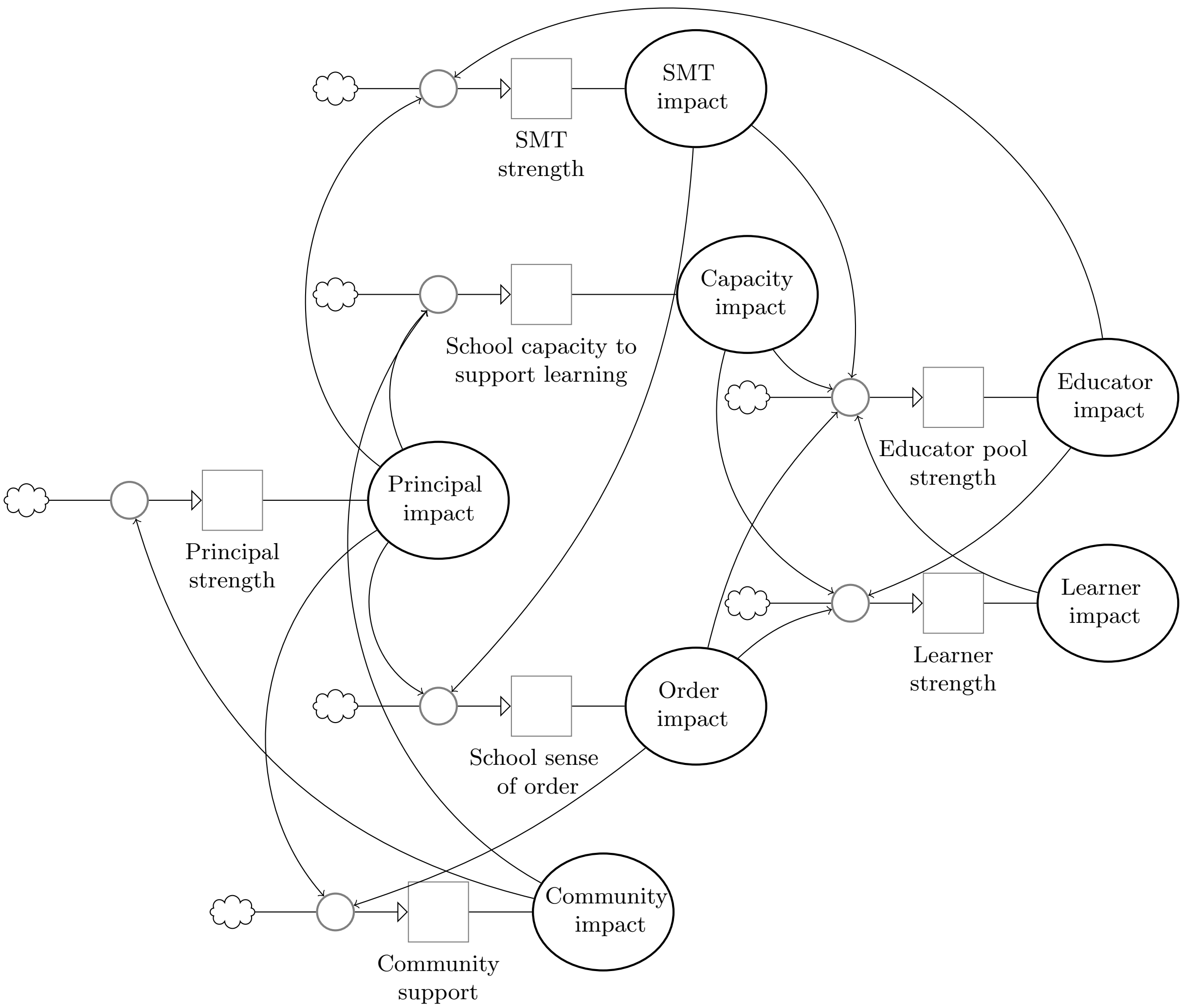

FIGURE 2.6: *The second sub-model of the School Effectiveness Model showing the relationship between each functional model unit as described in Figure 2.3.*

If these factor levels are reached, low achieving learners will improve to passing, passing learners will improve to standard learners, and standard learners will improve to high achieving learners. This assumption is needed to measure the impact of a growing learning deficit on learners as

	Factor			
	Educator pool strength	Learner strength	Learning support	Sense of order
Symbols	1	3	1	3
Progression	5	3	5	3
Readiness	5	3	3	3
Ethos	3	1	1	3

TABLE 2.2: *The minimum strength required to achieve each of the four education outcomes.*

they progress through the grades. In the model it is assumed that no learner will repeat a grade, but will instead be allowed to progress without the minimum requirement. In reality, however, the growing learning gap will extend to such a degree that a learner will eventually be forced to exit the system.

	Factor			
	Educator pool strength	Learner strength	Learning support	Sense of order
Symbols	2	4	2	4
Progression	6	4	6	4
Readiness	6	4	4	4
Ethos	4	2	2	4

TABLE 2.3: *The minimum strength required to achieve one level improvement for learners in each of the outcomes.*

The first sub-model contains the number of children per category per grade for the simulated school. For the base case, an average school is assumed. It implies all factors are initialised to functional (*i.e.* all strengths are at level 4). Table 2.4 contains the initial distribution of the learners in the base case. All grades following the first are initialised to be empty so that the effect of interventions on each cohort may be illustrated more clearly.

Phase	High	Standard	Pass	Low
Grade 1 or 8	20	30	30	20
Other grades	0	0	0	0

TABLE 2.4: *The aptitude distribution of annual learner enrolment in the base case school.*

Entropy grows linearly with a maximum impact of 2 over the forecast period. Stressors are set to 1 level loss per year for the forecast period. Interventions and losses are set to 0 so that the base case (*i.e.* the outcome when nothing in the system is manipulated) may be simulated. The simulation period is 15 years with a DT of 0.25 so that values update four times per year to coincide with the four assessed quarters of an academic year. Values are approximated using Euler's method.

2.3 Sensitivity analysis

The results of the interventions depend on the weight of each factor on the others in the school system. The magnitudes for the base case and interventions are shown in Table 2.1 and were collected by means of focus and Delphi groups.

Figures 2.7 to 2.10 contain the impact of change on the number of Grade 12 learners matriculating per performance category when the weights for principal strength, SMT strength, the school's capacity for learning, the school's sense of order, community strength, and educator strength are analysed between the lowerbound of 0 and upperbound of 1 in increments of 0.1. Each weight is analysed individually for each change while the others remain fixed at their initial value. The initial learner stock values are too low to maintain the initial populations of high and standard achieving learners. Therefore, there are no learners in these stocks upon which to observe the impact of change of factor weights. Pass and low performing learner distributions are most sensitive for an increase in principal, sense of order, and community strength influence weights and least sensitive for weight changes in SMT influence. Overall the model is stable. The results would change for an increase of 10% to 35% in these weights.

Figures 2.11 to 2.14 contain the impact of change on the number of Grade 12 learners matriculating per performance category for each initial value change for principal strength, SMT strength, the school's capacity for learning, the school's sense of order, community strength, and educator strength. The increase in the initial factor values causes a performance category upgrade for all learners from a principal strength and sense of order initial value of 5 and up. However, because the learner stocks for standard and pass achieving learners are initialised with the same value, this change is not observable.

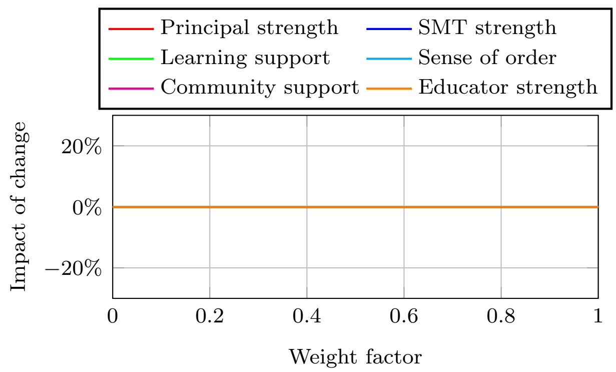

FIGURE 2.7: *The impact on the number of high achieving learners per change in factor weight size in the school system.*

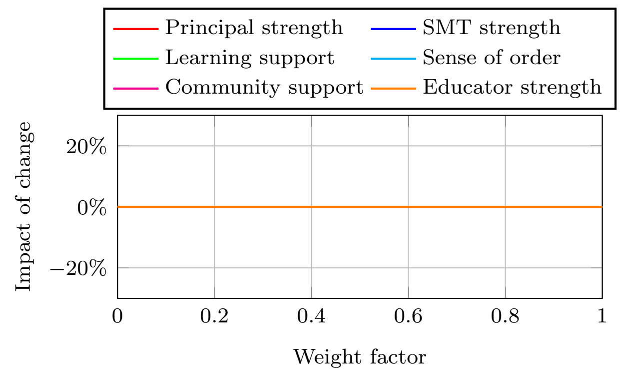

FIGURE 2.8: *The impact on the number of standard achieving learners per change in factor weight in the school system.*

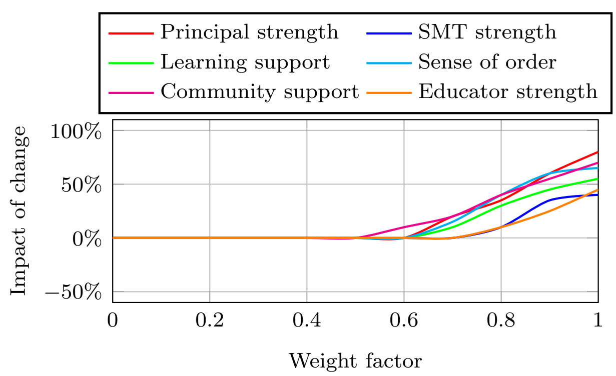

FIGURE 2.9: *The impact on the number of pass achieving learners per change in factor weight size in the school system.*

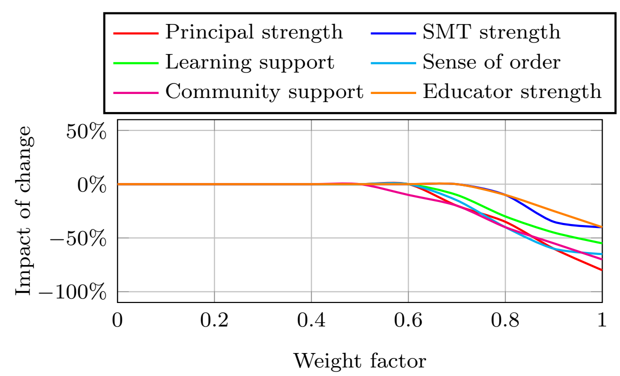

FIGURE 2.10: *The impact on the number of low achieving learners per change in factor weight size in the school system.*

2.4 Base case results

The simulation for the base case for a secondary school is run for a period of fifteen years with no active interventions. Figure 2.15 contains the changing factor strengths for the simulation period. There is an immediate strength decline in the system from the initialization and especially after the performance result of the first cohort feeds back into the principal's strength.

The reason for the weakening system is evident from Figures 2.16 and 2.17. In Figure 2.16 an outcome has a value of 1 if there were enough strengths to obtain this outcome. An outcome

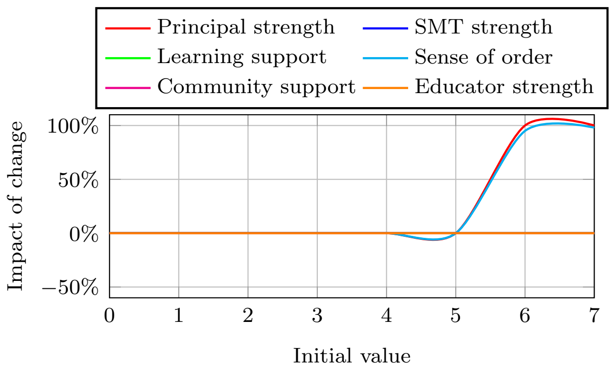

FIGURE 2.11: *The impact on the number of high achieving learners per change in factor initial value in the school system.*

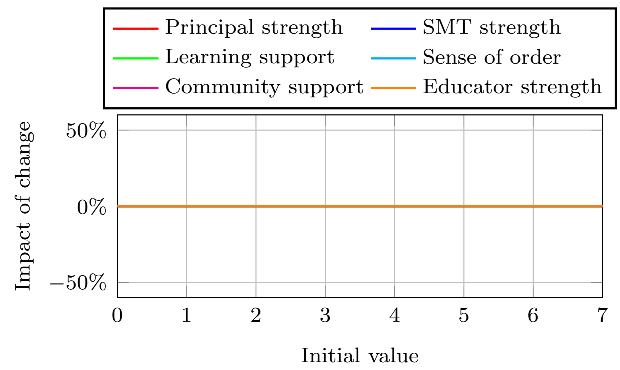

FIGURE 2.12: *The impact on the number of standard achieving learners per change in factor initial value in the school system.*

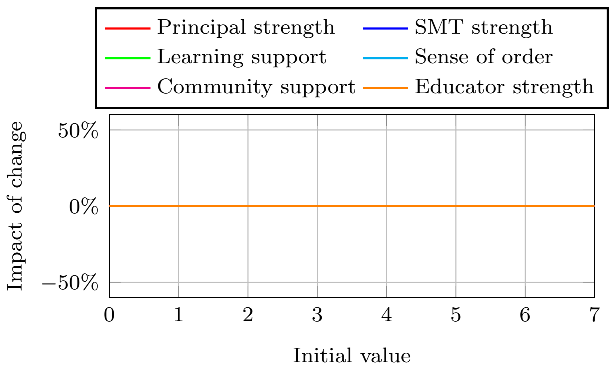

FIGURE 2.13: *The impact on the number of pass achieving learners per change in factor initial value in the school system.*

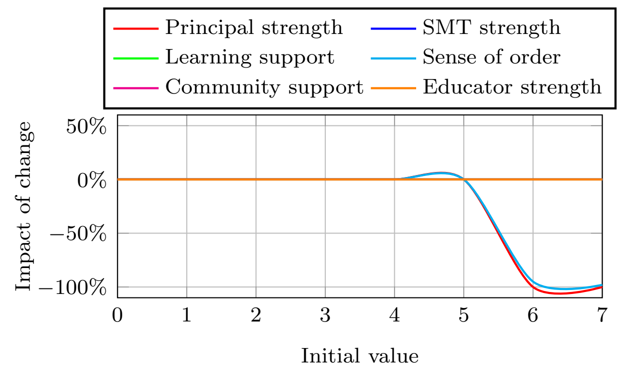

FIGURE 2.14: *The impact on the number of low achieving learners per change in factor initial value in the school system.*

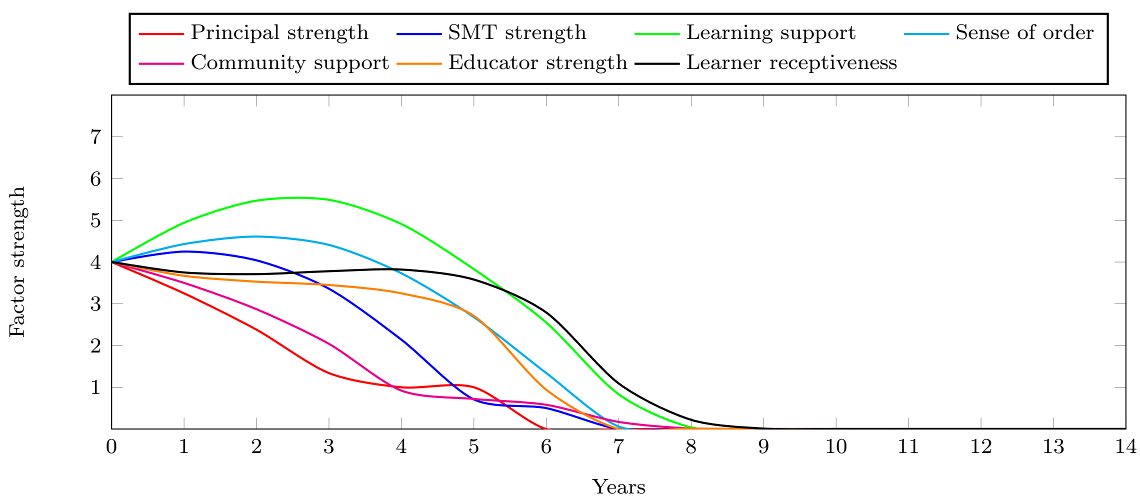

FIGURE 2.15: *Factor strengths during the fifteen year simulation period for the base case.*

has a value of 0 if the school system was not strong enough to obtain this outcome. In the base case, the school system has enough strength to secure symbols and ethos as outcomes during the first seven years of the simulation period. During the next year, only symbols could be achieved, but all outcomes are unobtainable from years eight to fifteen. The system is further weakened by entropy on the school's sense of order and capacity to support learning.

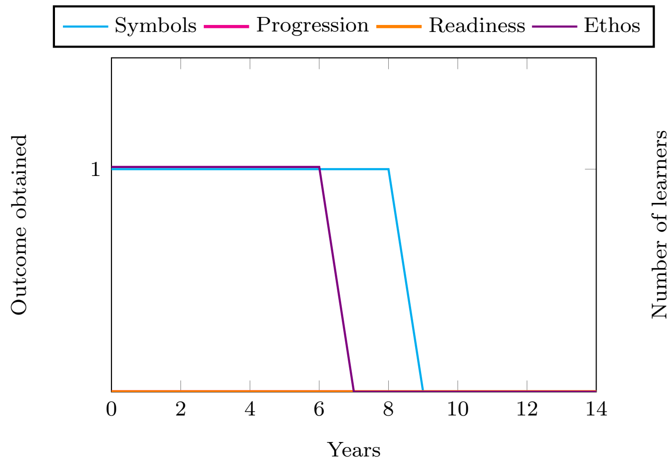

FIGURE 2.16: *Only symbols and ethos teaching outcomes are obtained during the fifteen year simulation period for the base case.*

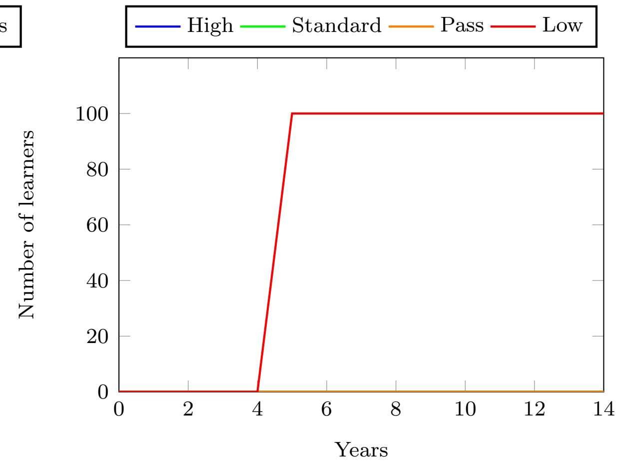

FIGURE 2.17: *Only low achieving Grade 12 learners are produced during the fifteen year simulation period for the base case.*

The limited number of outcomes achieved, reflect in the final results of the Grade 12 learners. The first Grade 12 results are visible from the fifth year. The entire population has decayed to achieving a low result, because only symbols and ethos could be obtained. New cohorts enter the system according to the initial distribution of 20 high potential students, 30 above average potential students, 30 passing potential students and 20 low potential students. However, they enter an ever-weakening system so this distribution cannot be maintained. In the base case, then, even a school that begins with a healthy distribution of learners' achievement and factor strength decays to low achievements if there are no interventions.

2.5 Interventions

Interventions may be applied to the factors in the second sub-model to change the direction of the feedback loop from propagating a declining result to propagating an improving result. Some interventions have a small impact (*i.e.* one level increase), but their impact is immediately visible (*i.e.* after one year). Some interventions have a medium impact (*i.e.* two levels increase), but their impact might only be observed after two years. Yet other interventions have a large impact (*i.e.* three levels increase), but their impact takes longer to be observed (*i.e.* after three years).

2.5.1 Reacting to emergencies

Principals often manage interventions by reacting to emergencies. Table 2.5 contains the time, magnitude and area of interventions applied each time a factor's strength falls below a value of 3. The principal reacts by applying the intervention with the largest possible impact, but the associated time delay causes slow improvement leading to more emergency reactions.

Figure 2.18 contains the changing factor strengths for the simulation period during the emergency reaction approach. Principal strength is the first to fall below a level of 3 by the second year. The principal reacts by implementing the largest intervention available, but this intervention can improve the factor only after a three year delay. The principal therefore implements a

Year	Factor	Impact size	Time to impact
2	Principal strength	Large	3 years
3	Principal strength	Medium	2 years
4	Principal strength	Small	1 years
4	SMT strength	Large	3 years
5	SMT strength	Medium	2 years
5	School's sense of order	Large	3 years
5	Educator strength	Large	3 years
6	Principal strength	Large	3 years
6	SMT strength	Small	1 years
6	School's sense of order	Medium	2 years
6	Learning support	Large	3 years
6	Educator strength	Medium	2 years
6	Learner strength	Large	3 years
7	Principal strength	Medium	2 years
7	School's sense of order	Small	1 years
7	Learning support	Medium	2 years
7	Educator strength	Small	1 years
7	Learner strength	Medium	2 years
8	Principal strength	Small	1 years
8	SMT strength	Large	3 years
8	Learning support	Small	1 years
8	Learner strength	Small	1 years
9	SMT strength	Medium	2 years
9	School's sense of order	Large	3 years
9	Educator strength	Large	3 years
10	Principal strength	Large	3 years
10	SMT strength	Small	1 years
10	School's sense of order	Medium	2 years
10	Learning support	Large	3 years
10	Educator strength	Medium	2 years
10	Learner strength	Large	3 years
11	Principal strength	Medium	2 years
11	School's sense of order	Small	1 years
11	Learning support	Medium	2 years
11	Educator strength	Small	1 years
11	Learner strength	Medium	2 years
12	Principal strength	Small	1 years
12	SMT strength	Large	3 years
12	Learning support	Small	1 years
12	Learner strength	Small	1 years
13	SMT strength	Medium	2 years
13	Educator strength	Large	3 years
14	Principal strength	Large	3 years
14	SMT strength	Small	1 years
14	School's sense of order	Large	3 years
14	Learning support	Large	3 years
14	Educator strength	Medium	2 years
14	Learner strength	Large	3 years

TABLE 2.5: *Interventions applied during the emergency reaction approach.*

medium intervention in the third year, but again the improvement is subject to a two year delay forcing the principal to implement a small intervention in the fourth year subject to a one year delay. The impact of the delays is evident as the strength is unable to restore to a value higher than one regardless of the number of interventions applied. A similar pattern emerges for the interventions on the other declining strengths.

Figure 2.19 contains the record of obtained outcomes based on the system's strength. The

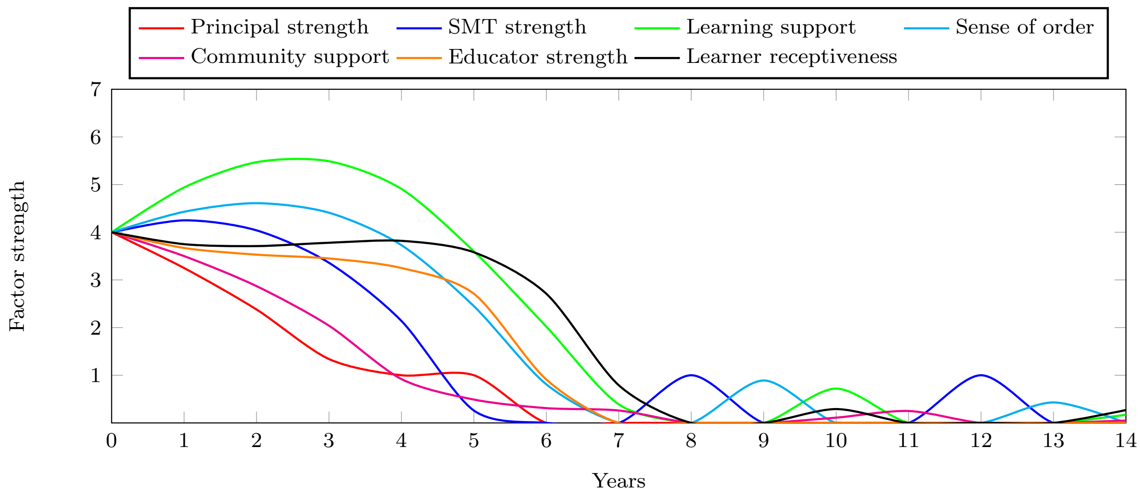

FIGURE 2.18: *Factor strengths during the fifteen year simulation period for the emergency reaction approach.*

emergency intervention produces the same profile of outcomes achieved as the base case for the first five years, and no outcomes are achieved until the weakening strengths are restored. The spike in factor strengths due to the cumulative effect of emergency interventions from the tenth year, however, makes it possible to achieve all symbols for only one cohort in the tenth year.

Figure 2.20 contains the distribution of Grade 12 learners in each achievement category after the emergency interventions were applied. Despite the number of interventions applied, the effort never translates into academic gain. Therefore all learners, regardless of their initial potential, decay to low performing learners.

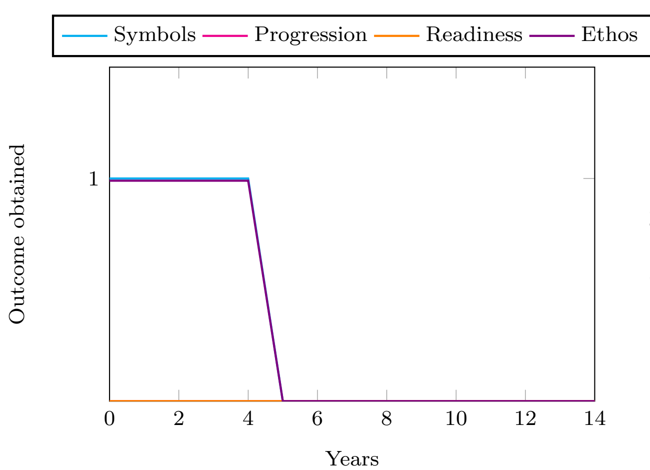

FIGURE 2.19: *Only symbols and ethos teaching outcomes are obtained during the 15 year simulation period for the emergency reaction approach.*

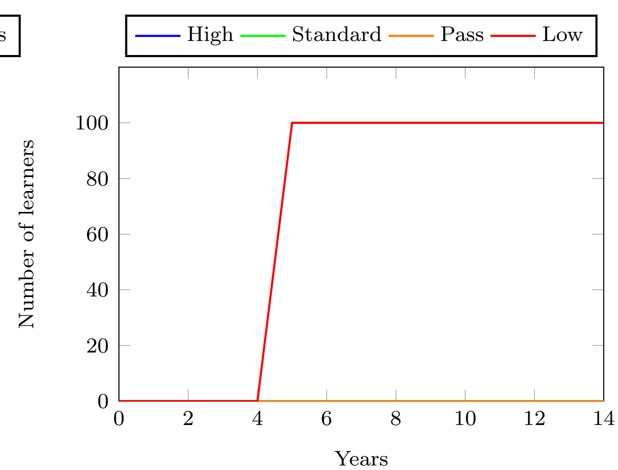

FIGURE 2.20: *Only low achieving Grade 12 learners are produced during the fifteen year simulation period for the emergency reaction approach.*

2.5.2 The silver bullet approach

An intuitive solution to achieving the desired academic outcome is to focus as many resources as possible in a single area. In the silver bullet approach, the focus is on what happens in the classroom. Table 2.6 contains the time and magnitude of the interventions applied only to educator and learner strength so that there is at least one intervention impact during each year of the simulation period.

Year	Factor	Intervention size	Time to impact
Every year	Educator strength	Large	3 years
Every year	Learner strength	Large	3 years

TABLE 2.6: *Interventions applied during the silver bullet approach.*

Figures 2.21 contains the changing factor strengths for the simulation period during the silver bullet approach. The focused interventions improve educator and learner strengths to the maximum level of seven by the sixth year. They are maintained at this level through continuous intervention. The lack of interventions on the other strengths is evident in their decline with the principal's strength falling most drastically to a value of zero by the fifth year.

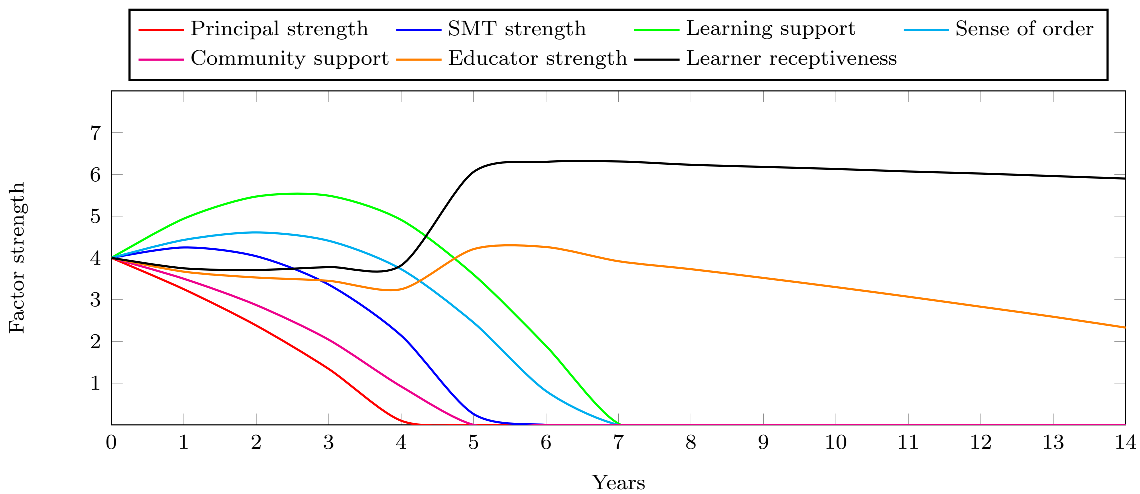

FIGURE 2.21: *Factor strengths during the fifteen year simulation period for the silver bullet approach.*

Figure 2.22 contains the record of obtained outcomes during the silver bullet approach. The initial system strength in combination with the maintained strength of the educators and learners is not enough to ensure that all four outcomes are achieved simultaneously at any time during the simulation period. The lack of maintenance on the other factors (especially the school's sense of order and capacity to support learning) causes all outcomes to be lost in the sixth year despite the good classroom situation.

Figure 2.23 contains the number of Grade 12 learners in each achievement category after the silver bullet interventions are applied. The loss of outcomes during the sixth year causes a complete deterioration of Grade 12 results so that all future cohorts achieve only a low result despite the maintained educator and learner strengths.

2.5.3 Improving the initial distribution

Good leadership seeks to improve the system so that the maximum number of learners graduate with a better achievement than their initial status during enrolment. Early and constant interventions are required to maintain initial achievement distributions. Table 2.7 contains the time and magnitude of the interventions applied to achieve this. The principal invests in large interventions to all factors from the first year of the simulation period. The principal's strength,

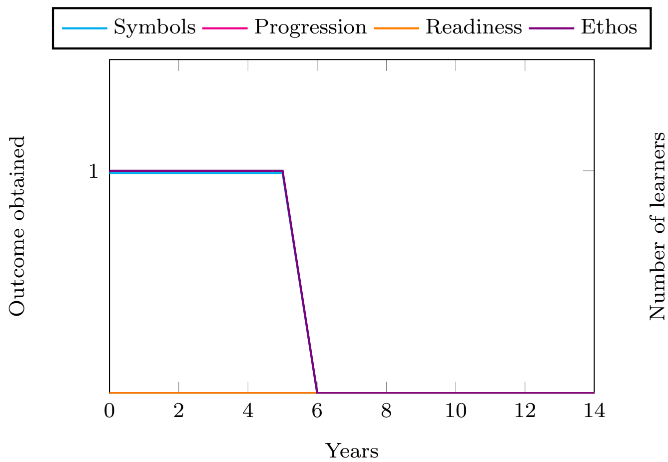

FIGURE 2.22: *Only symbols and ethos teaching outcomes are obtained during the fifteen year simulation period for the silver bullet approach.*

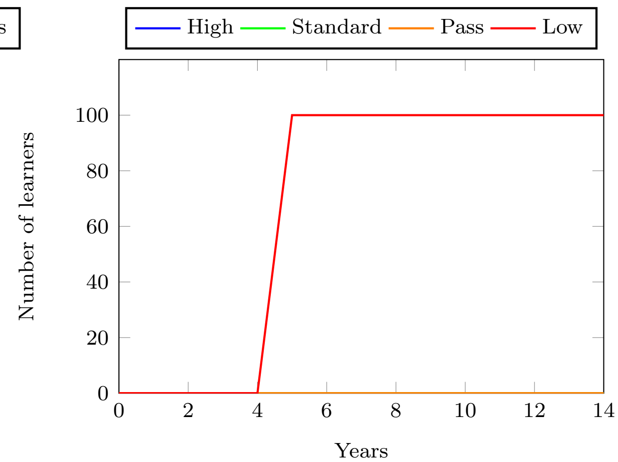

FIGURE 2.23: *Only low achieving Grade 12 learners are produced during the fifteen year simulation period for the silver bullet approach.*

school's sense of order and capacity to support learning are further strengthened during the first year by investing in medium and small interventions to minimise the impact of entropy. This significant boost so early in the period then allows the principal a rhythm of medium and large interventions to principal strength and all interventions to the school's sense of order and the school's capacity to support learning only once every four years. Direct intervention in the strength of these factors have an indirect maintenance impact on the others so that the system remains stable.

Figure 2.24 contains the changing factor strengths for the simulation period during the maintenance approach. Constant principal, order and capacity interventions keep all influencers stable. Figure 2.25 contains the record of obtained outcomes during the maintenance approach. All outcomes are achieved from the seventh year. Figure 2.26 contains the number of Grade 12 learners in each achievement category after the maintenance interventions are applied. The maintained outcomes enable an annual improvement in the final results of each new cohort. The system stabilises during the twelfth year so that the school is able to maintain the achievement of its high achieving learners and standard learners. The number of passing learners increase as the results of low achieving learners are improved.

2.6 Conclusion

An SD model is an appropriate methodology to simulate the systemic nature of school management. The School Effectiveness Model can be used to investigate the nature of the education environment, and school leaders are able to visualise the non-linearity, time dependence, and interdependence of the impact of their decisions.

The scenarios illustrate the impact of a principal's choice of timing, and magnitude when considering interventions. The least effective approach is one where interventions are applied only in response to a crisis. Late interventions are not able to restore the loss of strengths regardless of how many interventions are applied. Another ineffective approach to school management is where interventions are applied to only one area. Even when one or two areas can be maintained at maximum strength, the system as a whole suffers due to the weakening of other areas. The most effective approach is one where interventions are made early in order to build strengths, but

Year	Factor	Intervention size	Time to impact
1	Principal strength	Large	3 years
1	Principal strength	Medium	2 years
1	Principal strength	Small	1 years
1	SMT strength	Large	3 years
1	School's sense of order	Large	3 years
1	School's sense of order	Medium	2 years
1	School's sense of order	Small	1 years
1	Learning support	Large	3 years
1	Learning support	Medium	2 years
1	Learning support	Small	1 years
1	Educator strength	Large	3 years
1	Learner strength	Large	3 years
5	Principal strength	Large	3 years
5	Principal strength	Medium	2 years
5	School's sense of order	Large	3 years
5	School's sense of order	Medium	2 years
5	School's sense of order	Small	1 years
5	Learning support	Large	3 years
5	Learning support	Medium	2 years
5	Learning support	Small	1 years
9	Principal strength	Large	3 years
9	Principal strength	Medium	2 years
9	School's sense of order	Large	3 years
9	School's sense of order	Medium	2 years
9	School's sense of order	Small	1 years
9	Learning support	Large	3 years
9	Learning support	Medium	2 years
9	Learning support	Small	1 years
13	Principal strength	Medium	2 years
13	School's sense of order	Large	3 years
13	School's sense of order	Medium	2 years
13	School's sense of order	Small	1 years
13	Learning support	Large	3 years
13	Learning support	Medium	2 years
13	Learning support	Small	1 years

TABLE 2.7: *Interventions applied during the maintenance approach.*

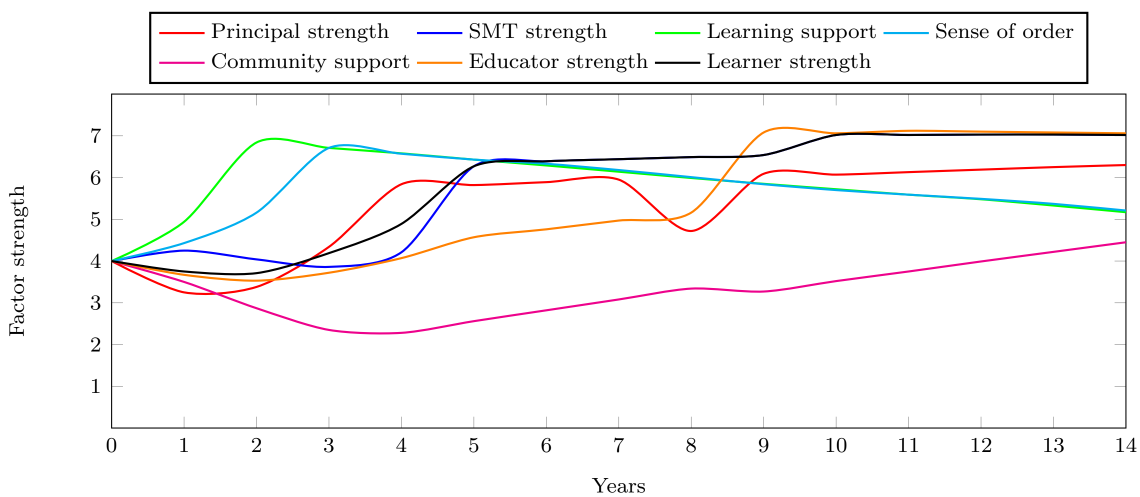

FIGURE 2.24: *Factor strengths during the fifteen year simulation period for the maintenance approach.*

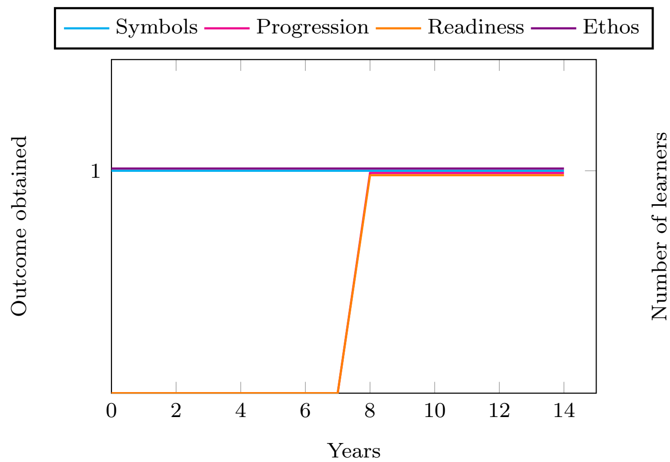

FIGURE 2.25: *All teaching outcomes obtained from the seventh year during the fifteen year simulation period with maintenance approach.*

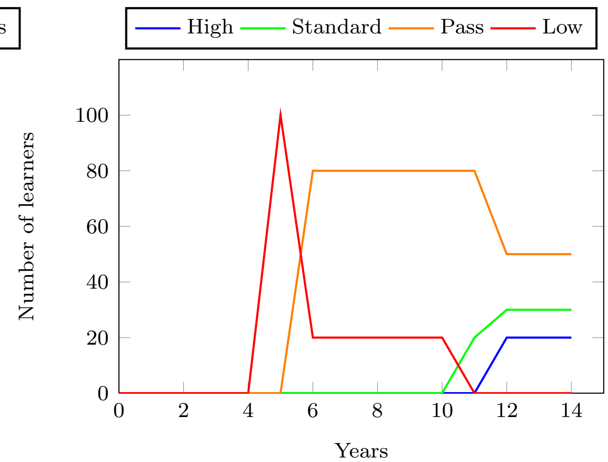

FIGURE 2.26: *High, standard and pass achieving Grade 12 learners are produced from the twelfth year during the fifteen year simulation period with maintenance approach.*

even then the principal must understand that it takes significant time for effective interventions to propagate through the system and secure the desired results.

The model is calibrated with the help of data collected through focus groups. A sensitivity analysis on the magnitude of influence that each element of the model has on the system contains that the model is stable. In other words, the results are not subject to much change considering alternative focus group calibration. In this model, successful application of simulation techniques (specifically SD) is shown. However, the model operates at the most abstract level and lacks the actual complexity found in the school system.

One area where greater complexity in modelling is required is at the level of decision and policy making. Currently, the model simulates a school under the influence of decisions from the principal, and the governing body only. In reality, schools are subject to an additional two levels of decision makers: Decisions made by the school's district and decisions made by the national education department. Decisions made by the national education department are implemented by the provincial department. These additional levels must be included to build a model that better reflects the South African education system.

Another area where greater model complexity in modelling is required is in the calibration and determination of parameters so that schools in different performance levels can be simulated realistically. Current calibration and parameters reflect an average school which is a broad, but necessary simplification in order to build a prototype.

CHAPTER 3

The impact of teacher effectiveness

Contents

In Chapter 2, a proof of concept model was created by which a basic education system can be simulated. The stocks are modelled at a high level of abstraction and can be expanded to analyse each of the priority goals set in the DBE Action Plan to 2030.

One of the priority goals of the Action Plan is the improvement of the professionalism, teaching skills, subject knowledge, and computer literacy of teachers throughout their entire careers. The SACMEQ is a quality control initiative that includes a test of teachers' literacy and numeracy. During 2007, 400 South African mathematics teachers and 415 language teachers for Grade 6 were tested. The results showed that 17% of Grade 6 students were taught by mathematics teachers who had a content knowledge below Grade 4 or 5 level, 62% of Grade 6 students were taught by mathematics teachers who had a content knowledge of Grade 4 or 5, 5% of Grade 6 students were taught by mathematics teachers who had a content knowledge of Grade 6 or 7, and 16% of grade 6 students were taught by mathematics teachers who had at least a Grade 8 or 9 level of content knowledge [112].

In the NSES of 2012, Grade 6 level mathematics items were given to Grade 4 and 5 teachers from eight South African provinces. The items tested estimation and rounding, fraction addition, pattern continuation, time, and perimeter of a composite shape. Only about half the teachers could complete the test items correctly [103].

In 2015 Deacon *et al.* [20] were commissioned by the Center for Development and Enterprise to investigate the number of students receiving initial teacher training from public and private institutions. They also modelled the supply and demand from 2013 to 2025. Using 2012 and 2013 data from public and independent schools, they determined that 19% of teachers were unqualified. Of the 81% qualified teachers 66%, had a three-year official qualification, and 15% had a four-year official qualification.

Holborn [49] focused on the challenges facing the South African education system and suggested possible solutions for these challenges. He found that in-classroom factors, especially teachers, have the greatest impact on the level of education received by the students and an improvement in the training of these teachers is the first step in improving the entire education system. He concluded that the majority of South African teachers who were currently teaching at various levels of education were trained under apartheid policies and therefore many had inadequate skills, leaving them unfit to give a quality education to current students. He suggested that teacher retraining was necessary to improve this issue.

The National Qualifications Framework Act 67 of 2008 describes two routes by which an individual can be trained as a teacher [27]. An individual can become qualified after a four-year *Bachelor of Education* (B.Ed) degree. Alternatively, an individual with a three year undergraduate degree can apply for a one-year *Post Graduate Certificate in Education* (PGCE) or *Advanced Diploma in Teaching* (ADT) at institutions offering *initial teacher education* (ITE) programmes. The current official requirement for a qualified teacher in South Africa is a Grade 12 (school-leaving) certificate plus four years of ITE. Until recently, however, only three years of ITE was the official requirement. The consequence is that a large portion of teachers in the country have the three-year qualification. *Continuing Professional Teacher Development* (CPTD) programmes therefore exist to qualify under-qualified (or unqualified) existing teachers as qualified teachers or to further enhance and refine the teaching capacity of teachers.

ITE graduates mainly come from three institutions: The *University of South Africa* (UNISA), the *University of KwaZulu-Natal* (UKZN) and *North-West University* (NWU). These universities produce about 60% of all ITE enrolments and nearly half of all graduates. From 2009 to 2012, ITE enrolments rose from 35 937 to 94 237 (a 160% increase). This was the result of the DBE's efforts to expand the provision of ITE programmes. Likewise the number of new teacher graduates grew from 6 978 in 2009 to 13 708 in 2012. The increase in DBE bursaries from R100 million in 2007 to over R900 million in 2014 has been a major contributing factor to this growth [20].

Teachers are known to be paid less than most other professionals and Armstrong [4] used an economic perspective on the career in 2015 to find that it did not make financial sense for teachers to remain in basic education for longer than twelve years. The consequence of this is that the education qualifications are unable to draw quality students since these students know they would be able to earn much better in other fields. When comparing the 2005, 2006 and 2007 Grade 12 results of first year students across different faculties, Armstrong found that students in the education faculty had the lowest level of academic ability.

Van Broekhuizen [106] used aggregate data from the *Higher Education Management Information System* (HEMIS) to analyse the trends of first-time enrolments and graduations in ITE programmes in the public higher education system between 2004 and 2013. He found that first-time enrolments in ITE programmes had grown rapidly since 2006, followed by a moderate rise in ITE programme graduations from 2008 onwards. Deacon *et al.* [20] found that the total number of ITE graduates grew from 6 980 in 2009 to 13 700 in 2012, but this number was far below their estimated required growth of 30 000 new teachers every year from 2013 to 2025 to meet their forecasted demand. Yet, even if the country managed to produce sufficient numbers of ITE graduates in the next ten years, it remains unlikely that the types of teachers that are produced would be the same as the types of teachers that are most needed in the schooling system.

About 66% of children in South Africa attend no-fee schools and are considered to come from poor communities, *i.e.* Quintiles 1 to 3. The next 20% attend low-fee schools (with fees ranging from R0 to R2 000 per annum). Approximately 9% attend mid-fee schools (with fees ranging from R2 000 to R12 000 per annum), while 5% attend high-fee schools (with fees being higher than R12 000 per annum). Of this 5%, 1.8% attend elite-fee schools where the annual fees exceed R20 000. These learners are considered to be from rich communities, *i.e.* Quintiles 4 to 5.

In this chapter the TEM is introduced to answer the research question whether it is the low teacher quality or low teacher quantity that contributes most to the education crisis. This question is asked within the context of Quintile 1 to 3 schools in the Western Cape province of South Africa to determine the reasons behind their lower academic performance when compared to Quintile 4 to 5 schools. It gives insight into the mechanics of the model's design, followed by a brief discussion on the input data, and the assumptions used to build the model. The base case results are shown, followed by interventions and a discussion of their results. This chapter has been accepted to appear in Systemic Practice and Action Research[1].

3.1 The Teacher Effectiveness Model

The TEM extends the complexity of the SEM presented in Chapter 2 by expanding the single educator pool strength stock to an entire system within which teachers find themselves. Figure 3.1 highlights the areas of the SEM expanded by the TEM. The TEM simulates the progression of teachers completing Grade 12 through their qualification route into their first year of employment up to retirement. Nine endogenous factors which impact upon teacher effectiveness are identified from literature: The effectiveness of the teachers, teacher quality, quantity, absenteeism, motivation, qualification, salary, the level of community unrest, and the class size [4, 30, 63, 110, 115].

3.1.1 The educator pool system

Figure 3.2 contains a diagram of the causal relationships between each of the elements within the educator pool system. Teacher quality describes a teacher's ability to personify virtue, their ability to transmit cultural and educational values, ability to teach the prescribed curricula, their commitment to their students' learning, their depth of understanding of the subject matter, their ability to manage and monitor learning, their level of self-reflection, and their involvement in the teaching community [65]. A teacher's quality can be measured by their level of experience, their qualifications and certifications, and the specific coursework they took in preparation for the profession [55].

[1] Venter L, Viljoen T, 2019. *A systems perspective on school improvement with a focus on teachers.* Accepted to appear in Systemic Practice and Action Research.

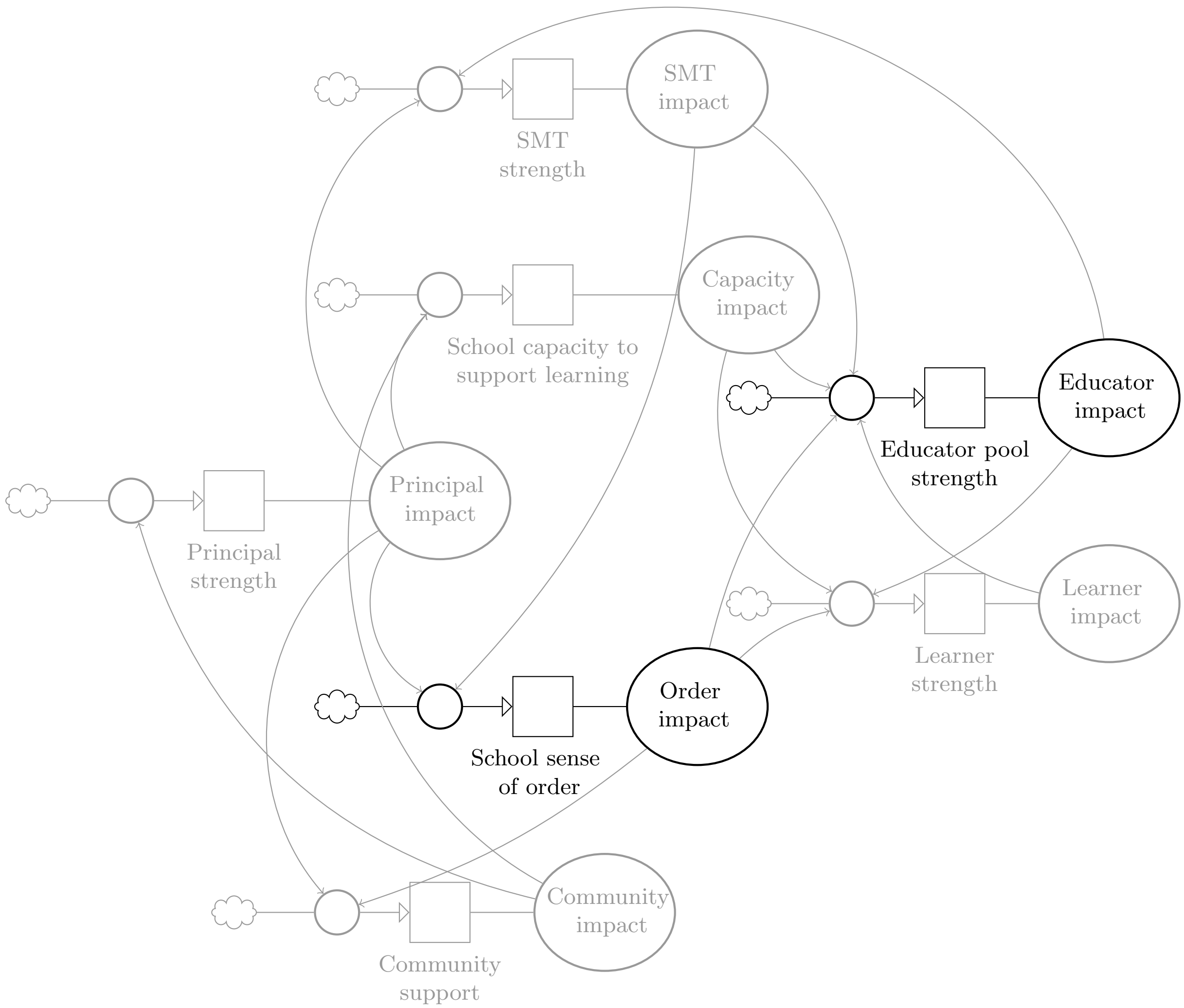

FIGURE 3.1: *The TEM expands the complexity of the SEM as a subsystem underlying the educator pool strength and influencing the school sense of order as highlighted in the stock-and-flow diagram.*

Motivation specifies the reason why teachers decide to teach, how long they are willing to sustain the activity and how hard they are going to pursue the activity. Sidebe [90] defined teacher motivation in terms of attraction, retention and concentration. Motivation is the measure of individuals' attraction to teaching, how long they remain in their initial teacher education courses and subsequently the teaching profession, and the extent to which they engage with their courses and the teaching profession. Poorly functioning educational delivery systems, poor working conditions, a lack of resources, limited human capacity, weak accountability, low salaries, and poor management, drain motivation. Consequently, low motivation is a characteristic of poorer communities [21, 53].

A high quality, highly motivated, educator pool will have few absent days as a characteristic [40]. Absenteeism is defined as periods of non-attendance (for reasons other than sick leave or maternity leave) as well as the number of days where teachers arrive late for school or class.

An unmotivated educator pool can cause community unrest in periods of protest. In South Africa, teacher unions and industrial action are defining features of the schooling landscape. Community unrest is defined as the number of days where no learning could take place, either

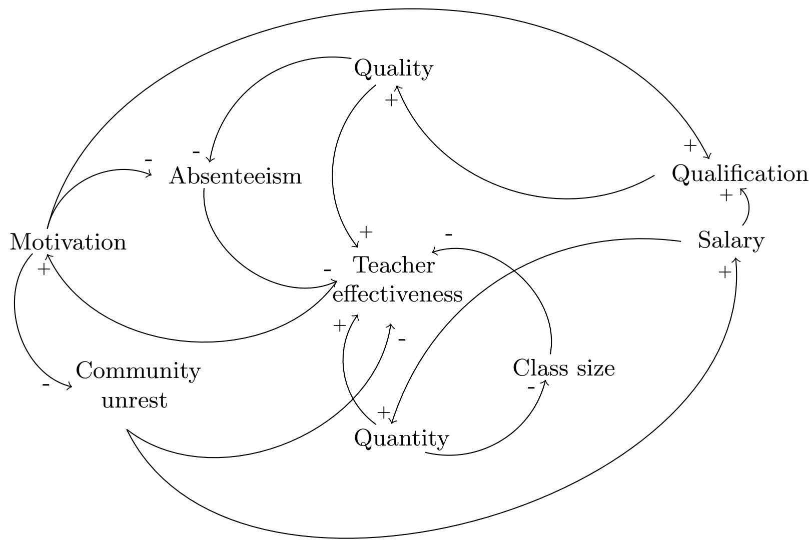

FIGURE 3.2: *The causal loop diagram for teacher effectiveness achievement.*

as result of absent protesting teachers, or as a result of the damage to school resources. Paglayan [72] showed that collective bargaining (especially by means of teacher strikes) usually leads to a raise in teacher pay. The resultant 2018 raise in South African state worker salaries after months of protest action would confirm this.

A teacher's salary is defined as the monthly remuneration amount as determined by the government and the school management team while a teacher's qualification is defined as the level of tertiary education they have obtained. An increased amount of disposable income through increased salary, in combination with a highly motivated educator pool, leads to an increase in self-enrolled teaching students which in turn leads to an increase in the quality of the teacher pool [111]. A high number of available teachers enable a school to keep the class sizes to the minimum. Class size refers to the teacher to learners ratio in the classroom.

The educator pool system is therefore driven by two main balancing loops and three main reinforcing loops. Balancing loops strive to bring a system to a desired state and to keep it constant. Reinforcing loops produce either growth or decay within the system. Figures 3.3 and 3.4 contain causal loops that illustrate how the quality, quantity, and motivation of teachers within the educator pool influence teacher effectiveness.

Figure 3.5 contains the stock-and-flow diagram for the educator pool system. Each factor increases or decreases the other by means of biflows to achieve a new teacher effectiveness score for each simulation time step. This teacher effectiveness score serves as input into teacher progression trains.

Scores are scaled to be values between 0 and 1. A value of 0 indicates a completely dysfunctional factor while a score of 1 indicates a functional, exemplary factor. A score of 0.5 indicates that a factor is operating at average achievement.

Let F^C be the score for teacher quality, F^Q be the score for teacher qualification, F^S be the score for teacher salary, F^M be the score for teacher motivation, F^E be the score for teacher effectiveness, F^U be the score for community unrest, F^A be the score for teacher absenteeism, F^Z be the score for class size, and F^K be the score for teacher quantity. The change in each

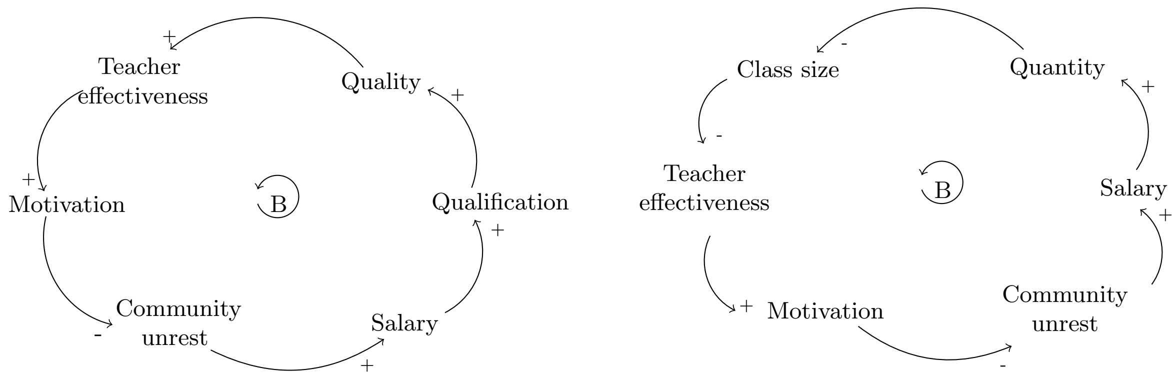

FIGURE 3.3: *There are two main balancing loops in the educator pool system.*

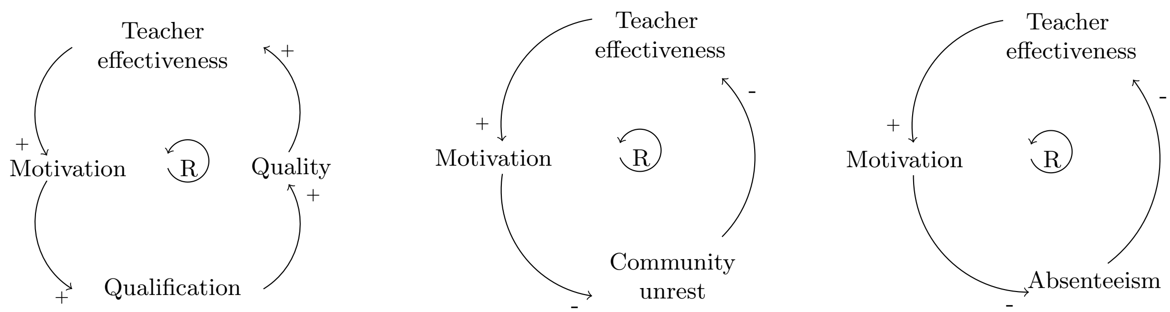

FIGURE 3.4: *There are three main reinforcing loops in the educator pool system.*

factor during the simulation period is described by

$$\frac{\mathrm{d}F^C}{\mathrm{d}t} = \frac{F^C + F^Q}{2} - F^C, \tag{3.1}$$

$$\frac{\mathrm{d}F^Q}{\mathrm{d}t} = \frac{F^Q + F^S + F^M}{3} - F^Q, \tag{3.2}$$

$$\frac{\mathrm{d}F^S}{\mathrm{d}t} = \frac{F^S + F^U}{2} - F^S, \tag{3.3}$$

$$\frac{\mathrm{d}F^M}{\mathrm{d}t} = \frac{F^M + F^E}{2} - F^M, \tag{3.4}$$

$$\frac{\mathrm{d}F^E}{\mathrm{d}t} = \frac{F^E + w^U F^U + w^K F^K + w^Z F^Z + w^C F^C + w^A F^A}{1 + w^U + w^K + w^Z + w^C + w^A} - F^E, \tag{3.5}$$

$$\frac{\mathrm{d}F^U}{\mathrm{d}t} = \frac{F^U + F^M}{2} - F^U, \tag{3.6}$$

$$\frac{\mathrm{d}F^A}{\mathrm{d}t} = \frac{F^A + F^M + F^C}{3} - F^A, \tag{3.7}$$

$$\frac{\mathrm{d}F^Z}{\mathrm{d}t} = \frac{F^Z + F^K}{2} - F^Z, \text{ and} \tag{3.8}$$

$$\frac{\mathrm{d}F^K}{\mathrm{d}t} = \frac{F^K + F^S}{2} - F^K \tag{3.9}$$

where w^U, w^K, w^Z, w^C, and w^A are the relative weights that each factor ultimately has on determining the effectiveness score for the system. The weight calibration for each parameter would result in 3 617 096 658 simulation runs for 10 samples between the values of 0 and 1. This large number is an infeasible execution requirement and only necessitates the weight calibration for the factors impacting teacher effectiveness directly.

The *General Household Survey* (GHS) is an annual household survey conducted by Statistics South Africa since 2002. The survey replaced the *October Household Survey* (OHS) introduced in 1993 and discontinued in 1999. The survey is a household-based measure to determine the progress of development in the country. It regularly measures the quality of service delivery in a number of key service sectors in the country. It covers six broad areas, namely, education, health and social development, housing, household access to services and facilities, food security, and agriculture.

Table 3.1 contains the percentage of learners reporting problems impacting teacher effectiveness within Western Cape public schools. A 1:1 relationship between teacher quality and teacher effectiveness is assumed so that the weights in the table scale the impact of the other elements on effectiveness. Table 3.2 contains the percentage learners reporting on these problems per socio-economic class (expressed as either a poor or a rich community). These values are suspiciously low. A closer inspection reveals that there is a technical error in the calculation methodology used by Statistics South Africa. The percentage is calculated as a ratio of all respondents instead of as a ratio of only the respondents per barrier. The percentages are therefore too low, but the relative relationships between the percentages are correct. The barriers can therefore be scaled against each other. Assume 0% as the absence of any barrier and 5% as the maximum presence of a barrier so that TEM initial values scale for each of the stocks as contained in Table 3.2, where a score of 0 indicates a completely disruptive factor and a score of 1 indicates a completely success-enabling factor.

Barrier	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**Average**
Large class size	5.2%	7.1%	6.6%	7.6%	6.2%	5.1%	9.8%	6.8%
Low teacher quantity	1.6%	2.4%	1.9%	2.5%	1.7%	2.5%	2.1%	2.1%
High teacher absenteeism	2.9%	3.4%	2.9%	2.4%	2.7%	2.6%	1.6%	2.6%
Low teacher quality	2.3%	2.9%	2.3%	2.5%	2.2%	3.2%	1.5%	2.4%
High community unrest	1.5%	1.0%	1.1%	1.8%	1.2%	1.8%	1.5%	1.4%

TABLE 3.1: *The average percentage of learners reporting barriers to learning in Western Cape public schools from 2010 to 2016 according to the GHS.*

Factor	**Total**	**Quintiles 1 to 3**	**TEM initial value**	**Quintiles 4 to 5**	**TEM initial value**
Class size and teacher quantity	6.8%	4.2%	0.2	2.6%	0.4
Absenteeism	2.6%	1.5%	0.6	1.3%	0.7
Teacher quality	2.4%	1.6%	0.6	1.0%	0.8
Community unrest	1.4%	0.8%	0.8	0.5%	0.9

TABLE 3.2: *The average percentage of learners reporting barriers to learning in Western Cape public schools by socio-economic quintile from 2010 to 2016 according to the GHS.*

Pon [74] finds that the average annual salary for teachers in Quintiles 1 to 3 is about 10% less than those for teachers in Quintiles 4 to 5. Instead of an equal scoring of 0.5, the teacher salary factor is therefore intialised with a score of 0.4 for the Quintiles 1 to 3 system and with 0.6 for the Quintiles 4 to 5 system to indicate this discrepancy. Teacher motivation is assumed to be equal (and average) and is therefore initialised to a score of 0.5 in both systems. The initial scores for the qualification and effectiveness factors are the number of effective teachers in each system as a percentage of the total number of teachers. The initial scores for the Quintiles 1 to 3 system are therefore 0.4 while the Quintile 4 to 5 system begins with scores of 0.6. The TEM initial values are used to initialise the educator pool system stock-and-flow diagram in Figure 3.5.

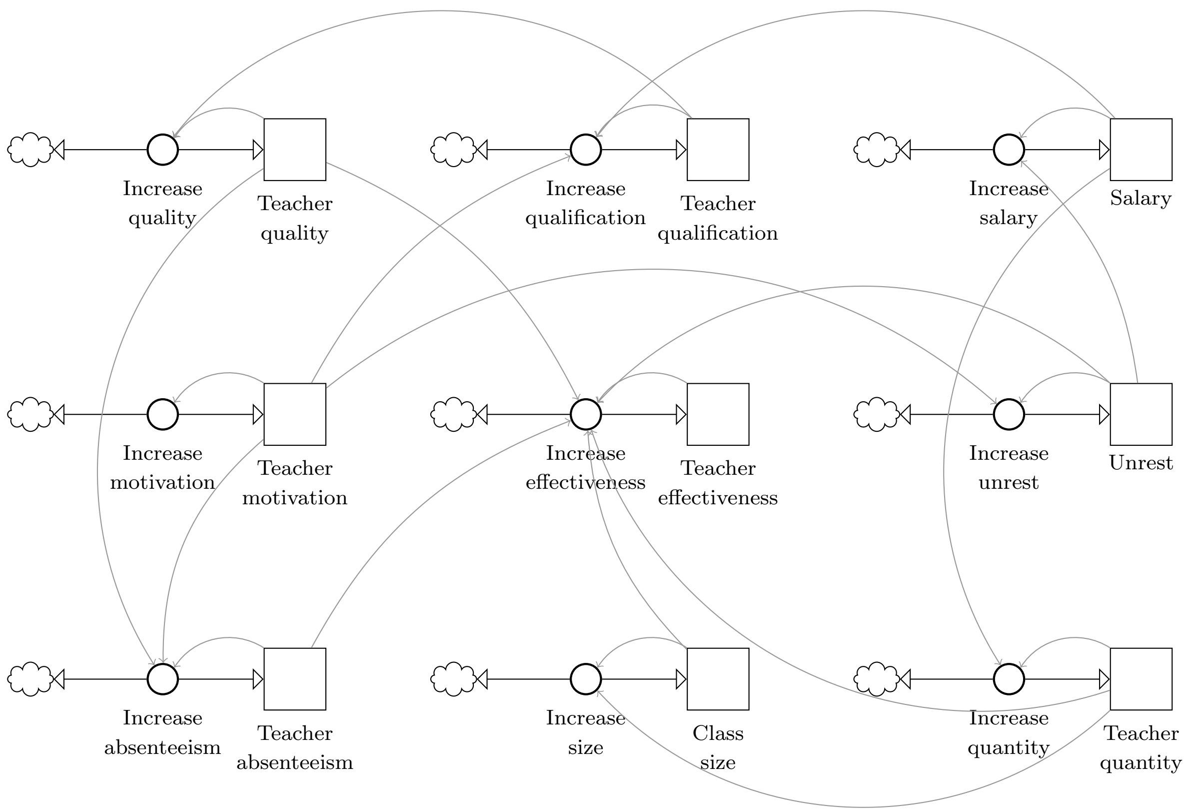

FIGURE 3.5: *The stock-and-flow diagram for the educator pool system in the TEM.*

3.1.2 Teacher progression

Table 3.3 lists the different qualifications by which teachers are trained within the South African higher education system, as well as the *National Qualifications Framework* (NQF) level of each. The NQF guideline sets out the boundaries of a standardised qualification system in order to recognise and categorise skills in South Africa. Level 6 indicates a diploma or certificate, level 7 indicates a bachelor's degree or post graduate certificate, while levels 8 to 10 indicate honours, masters or doctorate degrees [91].

Data collection about teachers in South Africa is difficult. Data sources are sometimes flawed, fragmented, and conflicting. This might be because data is entered incorrectly, or because it is unknown, or because it is out of date. None of the datasets used as input to the TEM agree on key issues like the number of teaching graduates or teachers employed. Deacon *et al.* [20] and Van Broekhuizen [106] acknowledge this problem and attempted to overcome it by making various assumptions.

All formal qualifications in the HEMIS are arranged according to *Classification of Educational Subject Matter* (CESM) codes. The exact numbers for students enrolled in the programs listed

Qualification	**Type**	**NQF level**
Bachelor of Education degree	ITE	7
Post Graduate Certificate in Education	ITE	7
Advanced Diploma in Teaching	ITE	7
Diploma in Grade R Teaching	Grade R	6
Advanced Certificate in Education	CPTD	6
Advanced Certificate in Teaching	CPTD	6
National Professional Diploma in Education	CPTD	6
Advanced Diploma in Education	CPTD	7
Postgraduate Diploma in Education	CPTD	8
Bachelor of Education Honours degree	CPTD	8
Master of Education Degree	CPTD	9
Doctor of Education Degree	CPTD	10

TABLE 3.3: *Higher education teacher qualifications in South Africa.*

in Table 3.3 cannot be accessed directly[2], but all programmes that are apportioned under the CESM1 category of "Education" can be grouped as indicated in Table 3.4 by *undergraduate* (UG) *Teacher Education Qualification* (TEQ), UG ITE, *postgraduate* (PG) ITE, and postgraduate CPTD [73]. Following the classification of Deacon *et al.* [20] and Van Broekhuizen [106], students graduating with UG TEQ are included in the TEM as unqualified teachers, while students graduating with UG ITE, PG ITE, or PG CPTD are considered qualified teachers.

Qualification	**Group**	**TEM classification**
Undergraduate Diploma or Certicate (3 years)	UG TEQ	Unqualified
National Certicate	UG TEQ	Unqualified
National Higher Certicate	UG TEQ	Unqualified
National Diploma	UG TEQ	Unqualified
Advanced Certificate	UG TEQ	Unqualified
Diploma	UG TEQ	Qualified
Professional First Bachelor's Degree (4 years or more)	UG ITE	Qualified
Post-graduate Bachelor's Degree	UG ITE	Qualified
Baccalaureus Technologiae Degree	UG ITE	Qualified
Bachelor's Degree (480 credits)	UG ITE	Qualified
Post-graduate Diploma or Certicate	PG ITE	Qualified
Post-diploma Diploma	PG ITE	Qualified
National Higher Diploma	PG ITE	Qualified
Postgraduate Diploma	PG ITE	Qualified
Honours Degree	PG CPTD	Qualified
Masters Degree	PG CPTD	Qualified
Doctoral Degree	PG CPTD	Qualified
Master's Diploma in Technology	PG CPTD	Qualified
Magister Technologiae Degree	PG CPTD	Qualified
Laureatus in Technology	PG CPTD	Qualified
Doctor Technologiae Degree	PG CPTD	Qualified

TABLE 3.4: *HEMIS classification of ITE qualifications for the CESM1 category, Education.*

Table 3.5 contains the total number of students enrolled in each group from 2010 to 2016, while Table 3.6 contains the total number of graduates as well as the average graduation rate per group. Therefore about 14 000 graduates are ready to enter the educator pool as effective teachers, and about 4 000 graduates are ready to enter the system as ineffective teachers [48].

South African employment is measured from an establishment based survey, the *Quarterly Em-*

[2]Only four director-level staff members within the Department of Higher Education have access to the full HEMIS database.

Group	2010	2011	2012	2013	2014	2015	2016	Average
UG TEQ	14 968	16 388	23 966	20 082	19 764	18 848	17 682	18 814
UG ITE	44 833	62 827	74 734	78 933	79 847	85 218	90 837	73 890
PG ITE	8 513	12 151	12 748	15 098	14 449	16 030	16 647	13 662
PG CPTD	28 685	30 358	28 050	27 436	24 189	19 586	22 259	25 795

TABLE 3.5: *The annual and average number of students enrolled in each of the teacher qualification groups from 2010 to 2016 according to the HEMIS.*

Group	2010	2011	2012	2013	2014	2015	2016	Average	Rate
UG TEQ	4 141	3 044	4 503	5 160	3 356	3 431	4 628	4 038	21%
UG ITE	4 759	5 697	7 421	8 617	10 319	11 518	14 206	8 934	12%
PG ITE	3 612	4 954	5 799	7 369	7 138	7 327	8 202	6 343	46%
PG CPTD	6 702	6 757	6 348	6 828	6 282	5 162	5 707	6 255	24%

TABLE 3.6: *The annual and average number of students graduating in each of the teacher qualification groups from 2010 to 2016 according to the HEMIS.*

ployment Survey (QES), and a household based survey, the *Quarterly Labour Force Survey* (QLFS). The two sources differ in coverage, scope, unit of measurement, and method of collection. Consequently, they yield different results. However, the two sources should be regarded as complementary rather than competitive [98]. The SNAP Survey of Ordinary Schools collects data from all schools in South Africa each year and the data forms part of the national *Education Management Information Systems* (EMIS) [34]. Data from these sources are used to populate the TEM.

All public schools in South Africa receive a ranking based on the level of poverty in the community in which the school is located. More specifically, this ranking is based on the average income, unemployment rate, and educational level, each of which is assigned a specific weighting determined by the DBE. Schools that fall in the lower 20% of this ranking (i.e. the poorest schools) are classified as being Quintile 1 schools. Schools that fall in the top 20% of this ranking are Quintile 5 schools.

A percentage of 66% of children in South Africa attend no-fee schools (Quintiles 1 to 3). A percentage of 20% attend low-fee schools with fees ranging from R0 to R2 000 per annum (Quintile 4). A percentage of 9% attend mid-fee schools with fees ranging from R2 000 to R12 000 per annum, while 5% attend high-fee schools with fees being higher than R12 000 per annum (Quintile 5). Of this 5%, a 1.8% attend elite-fee schools, where the annual fees exceed R20 000. These learners are considered to be from rich communities [99].

It is assumed that each quintile has the same ratio of qualified to unqualified teachers. Table 3.7 contains a summary of the number of teachers within the *Western Cape* (WC) public primary school system from 2010 to 2016 for socio-economic Quintiles 1 to 3. All permanent, substitute, and temporary teachers employed both full-time and part-time are assumed to make up this number. About 10% of all teachers work in the WC of which 90% are in the public school system, and a further 64% of these are in the primary school system.

Junior level teachers aged 20 to 29 years (17% of teachers) are assumed to have 0 to 10 years experience, middle level teachers aged 30 to 49 (47% of teachers) are assumed to have 11 to 20 years experience while senior level teachers aged 50 to 65 (36% of teachers) are assumed to work until they retire at age 65. Of these, an average of 55% are adequately qualified. An average of 3% of teachers become unemployed annually, while an average of 6% retire. An average of 2% of teachers are unemployed with no teachers finding employment once it is lost.

Salary is an indicator of an educator's educational background and years of experience, especially in countries like South Africa that has established a national pay scale. Therefore a higher salary indicates a higher level of qualification. Average annual salaries in the Western Cape increase from approximately R160 000 in Quintiles 1 to 3 to approximately R180 000 in Quintiles 4 to 5. Consequently the highest number of unqualified teachers (60% of all unqualified teachers) are concentrated in the lowest quintiles [74].

TEM qualified teachers for Quintiles 1 to 3							
Experience	**2010**	**2011**	**2012**	**2013**	**2014 - 2015**	**2016**	**Average**
Junior	289	267	259	256	377	469	320
Middle	800	737	716	709	1 042	1 296	883
Senior	613	565	549	543	798	992	676
Subtotal	1 702	1 568	1 524	1 508	2 217	2 756	1 879
TEM unqualified teachers for Quintiles 1 to 3							
Experience	**2010**	**2011**	**2012**	**2013**	**2014 - 2015**	**2016**	**Average**
Junior	434	400	289	385	565	703	463
Middle	1 200	1 106	1 075	1 063	1 563	1 943	1 325
Senior	919	847	823	814	1 197	1 448	1 008
Subtotal	2 552	2 353	2 287	2 262	3 325	4 135	2 796
Total	**4 254**	**3 921**	**3 811**	**3 770**	**5 542**	**6 891**	**4 675**

TABLE 3.7: *The annual and average number of teachers in Quintiles 1 to 3 by TEM qualification and years of experience in the Western Cape public primary school system from 2010 to 2016 according to the SNAP Survey of Ordinary Schools.*

TEM qualified teachers for Quintiles 4 to 5							
Experience	**2010**	**2011**	**2012**	**2013**	**2014 - 2015**	**2016**	**Average**
Junior	706	675	686	655	892	1 288	817
Middle	1 953	1 865	1 898	1 811	2 467	3 561	2 260
Senior	1 496	1 428	1 453	1 387	1 890	2 727	1 730
Subtotal	4 156	3968	4 037	3 853	5 249	7 576	4 807
TEM unqualified teachers for Quintiles 4 to 5							
Experience	**2010**	**2011**	**2012**	**2013**	**2014 - 2015**	**2016**	**Average**
Junior	471	450	458	437	595	859	545
Middle	1 302	1 243	1 265	1 207	1 645	2 374	1 506
Senior	997	952	969	925	1 260	1 818	1 153
Subtotal	2 270	2 645	2 692	2 569	3 499	5 051	3 204
Total	**6 926**	**6 613**	**6 729**	**6 422**	**8 748**	**12 627**	**8 011**

TABLE 3.8: *The annual and average number of teachers in Quintiles 4 to 5 by TEM qualification and years of experience in the Western Cape public primary school system from 2010 to 2016 according to the SNAP Survey of Ordinary Schools.*

Figure 3.6 contains the stock-and-flow diagram for teacher progression from the commencement of their studies, to graduation, to their eventual retirement. Along their careers teachers are lost through separation or retirement, while others are promoted and gain experience. It is assumed that a student must complete an UG ITE qualification before they can enrol for a PG CPTD qualification and that any student enrolling into the PG ITE qualification has the necessary undergraduate qualification from any appropriate field. It is also assumed that any UG ITE student cannot enrol for a PG ITE program should they wish to continue their postgraduate studies. The stocks are initialised with the values listed in Table 3.5 to 3.8.

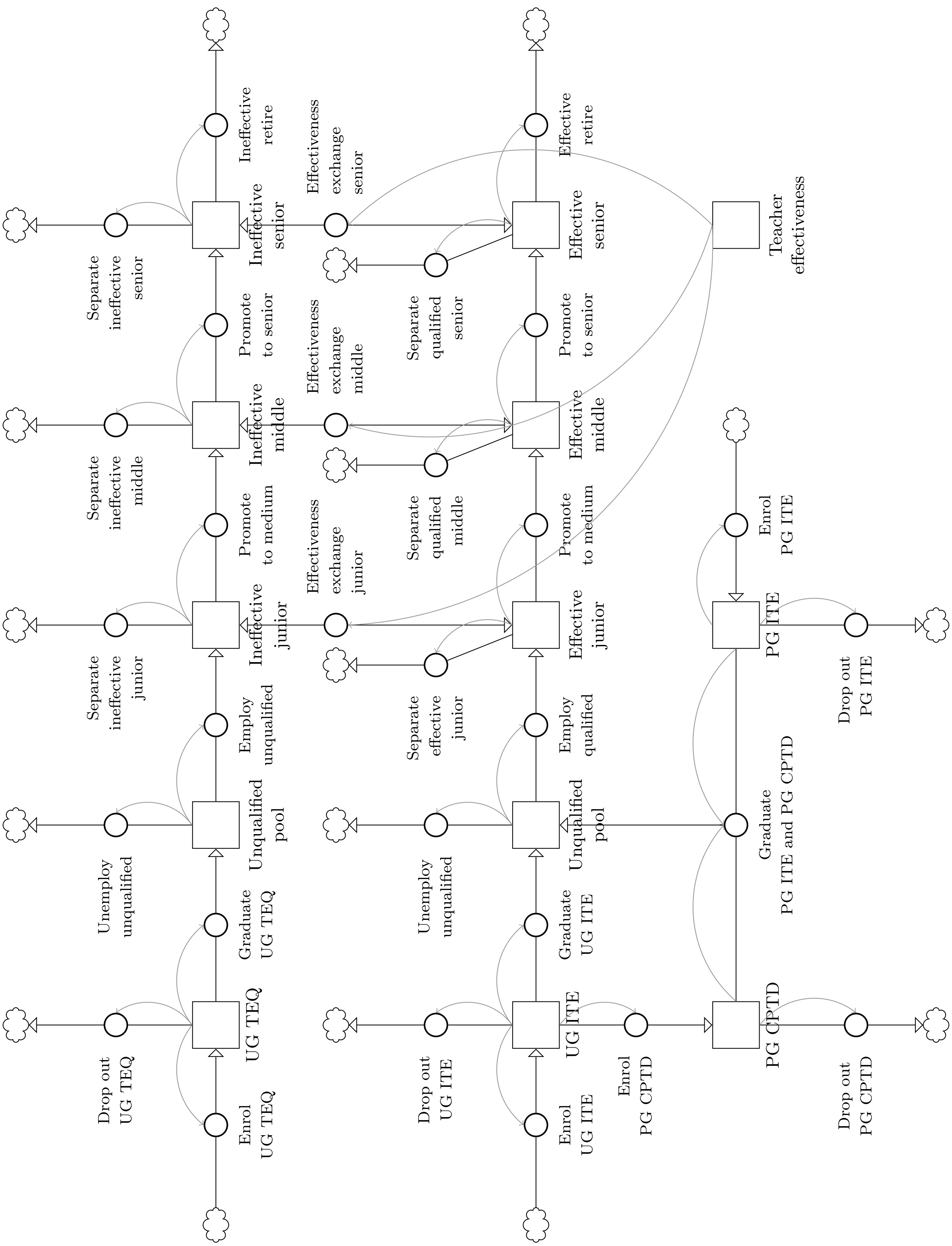

FIGURE 3.6: *The stock-and-flow diagram for teacher progression in the TEM.*

Let Q_k be the annual number of students enrolled for qualification k (*i.e.* these students are already active within the system), Q_k^E be the annual number of students enrolling for qualification k (*i.e.* these are new students that are entering the system for the first time), Q_k^G be the annual number of students graduating with qualification k, and Q_k^D be the annual number of students dropping out of qualification k, where $k = 1$ represents UQ TEQ, $k = 2$ represents UG ITE, $k = 3$ represents PG CPTD, and $k = 4$ represents PG ITE students. Therefore,

$$\frac{\mathrm{d}Q_k}{\mathrm{d}t} = \begin{cases} Q_{k-1}^G - Q_k^G - Q_k^D, & \text{for } k = 3\text{, and} \\ Q_k^E - Q_k^G - Q_k^D, & \text{otherwise.} \end{cases} \tag{3.10}$$

Similarly, let P be the annual number of newly qualified teachers while $\tilde{P}$ is the annual number of newly unqualified teachers. Let P^H be the annual number of these newly qualified teachers who are able to find employment while $P^{\tilde{H}}$ are not. Again let $\tilde{P}^H$ be the annual number of newly unqualified teachers who are able to find employment while $\tilde{P}^{\tilde{H}}$ represents those that cannot. Therefore,

$$\frac{\mathrm{d}P}{\mathrm{d}t} = Q_2^G + Q_3^G + Q_4^G - P^H - P^{\tilde{H}}, \text{ and} \tag{3.11}$$

$$\frac{\mathrm{d}\tilde{P}}{\mathrm{d}t} = Q_1^G - \tilde{P}^H - \tilde{P}^{\tilde{H}}. \tag{3.12}$$

Let T_x be the annual number of effective teachers and $\tilde{T}_x$ be the annual number of ineffective teachers with level x experience, where $x = 1$ represents the junior level, $x = 2$ represents the middle level, and $x = 3$ represents the senior level. Furthermore, let T_x^D and $\tilde{T}_x^D$ be the annual number of teachers dropping out of the profession from all experience levels, respectively for all number of experience years while T_x^P and $\tilde{T}_x^P$ are the number of teachers being promoted to the next experience class. Finally, let T_3^R and $\tilde{T}_3^R$ be the number of effective and ineffective retiring teachers. Therefore,

$$\frac{\mathrm{d}T_x}{\mathrm{d}t} = \begin{cases} \frac{1}{10}\left(P^H - T_x^P - T_x^D + F^E T_x - (1 - F^E)\tilde{T}_x\right) & \text{for } x = 1, \\ \frac{1}{20}\left(T_{x-1}^P - T_x^D + F^E T_x - (1 - F^E)\tilde{T}_x\right) & \text{for } x = 2, \text{ and} \\ \frac{1}{15}\left(T_{x-1}^P - T_x^D - T_x^R + F^E T_x - (1 - F^E)\tilde{T}_x\right) & \text{for } x = 3 \end{cases} \tag{3.13}$$

for the 10, 20, and 15 years, respectively, that a teacher remains in their experience level. Similarly,

$$\frac{\mathrm{d}\tilde{T}_x}{\mathrm{d}t} = \begin{cases} \frac{1}{10}\left(\tilde{P}^H - \tilde{T}_x^P - \tilde{T}_x^D + F^E T_x - (1 - F^E)\tilde{T}_x\right) & \text{for } x = 1, \\ \frac{1}{20}\left(\tilde{T}_{x-1}^P - \tilde{T}_x^D - (1 - F^E)\tilde{T}_x + F^E T_x\right) & \text{for } x = 2, \text{ and} \\ \frac{1}{15}\left(\tilde{T}_{x-1}^P - \tilde{T}_x^D - \tilde{T}_x^R - (1 - F^E)\tilde{T}_x + F^E T_x\right) & \text{for } x = 3. \end{cases} \tag{3.14}$$

The most important mechanism in the TEM is the transformation of effective teachers to ineffective teachers when the educator pool system is weak and the transformation of ineffective teachers to effective teachers when the educator system is strong. The transformation is dependent on the score of F^E and is described by the last two terms in equations (3.13) and (3.14).

3.2 Validation and sensitivity analysis

The factors of the educator pool system combine to produce F^E, the main factor supporting teacher progression. The weights for equation (3.5) are determined through parameter calibration so that the lowest average *root mean square error* (RMSE) for each teacher type and their simulated values are achieved. The weights are calibrated for every combination of weights between the values of 0 and 2 (or twice the initial weight). The lowest average RMSE of 18% is achieved when $w^U = 0.5$, $w_K = 1.33$, $w^Z = 1.17$, $w^C = 0.67$, and $W^A = 0.75$ for Quintiles 1 to 3 schools. The same lowest average RMSE of 18% is achieved when $w^U = 0.5$, $w^K = 1.00$, $w^Z = 0.92$, $w^C = 0.50$, and $W^A = 1.75$ for Quintiles 4 to 5 schools.

Figures 3.7 to 3.12 contain the TEM approximation of reality for 2010 to 2016 for all experience levels in both Quintiles 1 to 3 and Quintiles 4 to 5. In reality there is a significant increase in middle and senior level teachers that is not approximated by the simulation. This sharp increase was due to a recruitment intervention applied to the Western Cape system from approximately 2013 that is not built into the simulation model. The model's purpose, however, is to analyse the transformation of existing teachers from effective to ineffective within the existing pool. Therefore, external recruitment (or the absence thereof) does not affect the analysis.

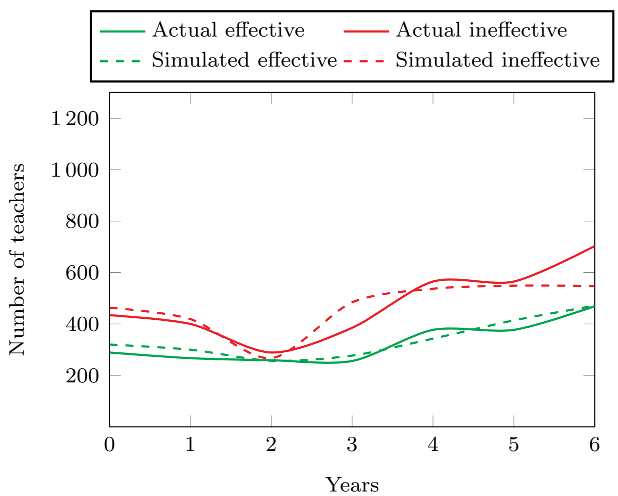

FIGURE 3.7: *Model approximation of reality for the calibrated weights for teacher effectiveness for junior level teachers in Quintiles 1 to 3.*

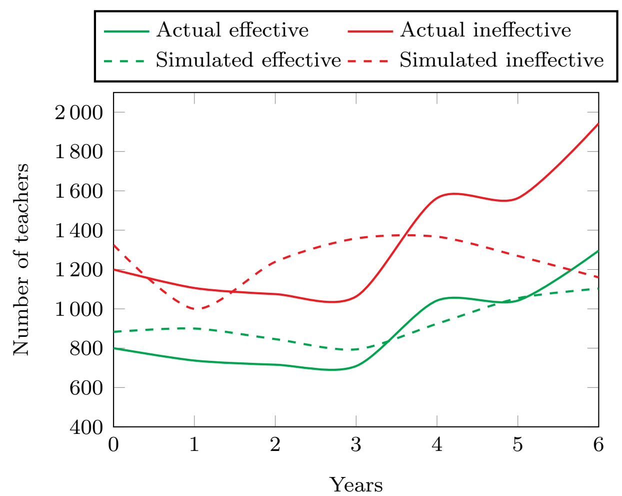

FIGURE 3.8: *Model approximation of reality for varying parameter values of teacher effectiveness for middle level teachers in Quintiles 1 to 3.*

The results of the TEM are subject to three major assumptions of estimated parameters. The first is the calibrated factor weights of the educator pool system depicted in Figure 3.5. The second is some of the initial values for each factor in this system. The third is the division of the number of teachers between the different quintiles. A sensitivity analysis on these values gives greater confidence with regards to their impact on the reported results. A sensitivity analysis is therefore only relevant for the Quintiles 1 to 3 system since interventions are only performed on these quintiles in order to compare their behaviour with that of Quintiles 4 to 5.

3.2.1 Factor weights within the educator pool system

Two indicators are used to measure the health of the system. The effectiveness score is the aggregate measure of the educator pool system's strength, and the success measure is the ratio of total effective to total ineffective teachers within the system. Figures 3.13 and 3.14 show

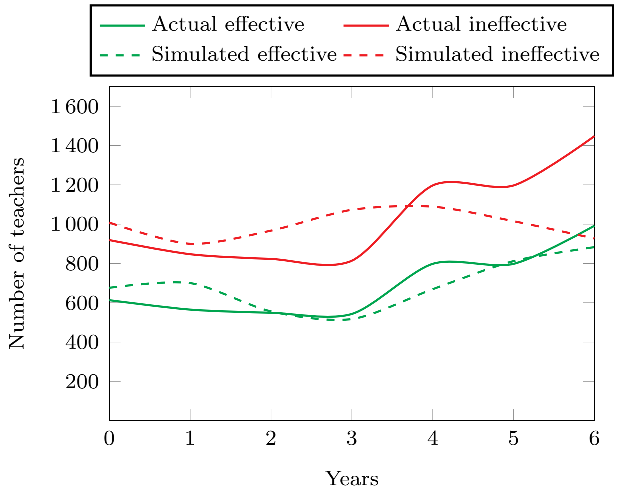

FIGURE 3.9: *Model approximation of reality for the calibrated weights for teacher effectiveness for senior level teachers in Quintiles 1 to 3.*

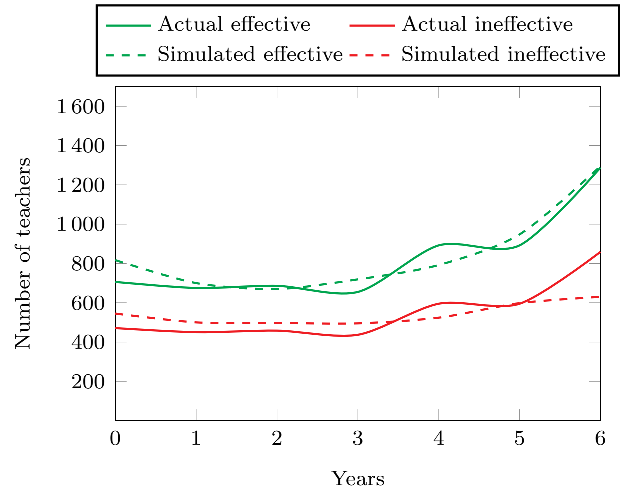

FIGURE 3.10: *Model approximation of reality for varying parameter values of teacher effectiveness for junior level teachers in Quintiles 4 to 5.*

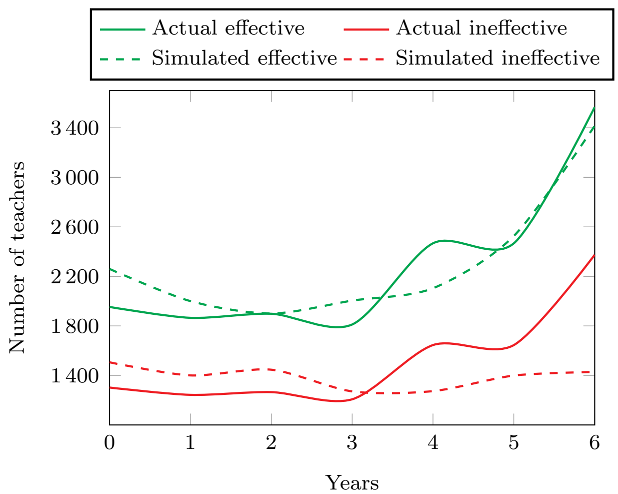

FIGURE 3.11: *Model approximation of reality for the calibrated weights for teacher effectiveness for middle level teachers in Quintiles 4 ot 5.*

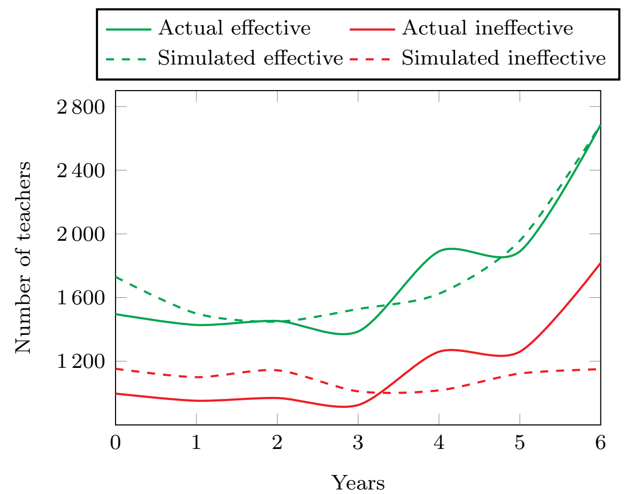

FIGURE 3.12: *Model approximation of reality for varying parameter values of teacher effectiveness for senior level teachers in Quintiles 4 to 5.*

the impact of change in these indicators when the weights for class size, teacher quality, and teacher quantity, respectively are increased or decreased by a factor of 0.5 to a minimum of 0 and a maximum of thrice the calibrated weight. Both the effectiveness score and success measure increase by approximately 2.5% when the weight of class size is halved, while both decrease by approximately 2.5% when the weight is doubled. Up to thrice the weight of class size causes a decrease of up to 5% in both measures. The effectiveness score remains the same when the weight of teacher quality is halved, while the success measure decreases slightly by approximately 2%. Both the effectiveness score and success measure increase by 5% when the weight is doubled. The model is least sensitive to weight changes of teacher quality. Consequently, the effectiveness score and the success measure both increase with approximately 2% when the weight is halved and the success measure decreases with about 2% when the weight is doubled. It is therefore reasonable to expect interventions pertaining to the quantity of teachers to have a greater impact on the results than interventions which focus on the quality of teachers.

3.2.2 Initial values within the educator pool system

Figures 3.15 and 3.16 contain the impact of change when the weights for class size, teacher qualification, teacher quality, and teacher quantity are changed. The model is most sensitive to initial value changes of class size and teacher quantity. This can be observed in both the effectiveness score and success measure. The effectiveness score increases by approximately 20% when the initial value of teacher quantity is at the maximum of 1 (from 0.2), while the effectiveness score increases by approximately 10% when class size is at its maximum (also from 0.2). The success measure increases in a similar fashion. It is again reasonable to expect interventions on teacher quantity to have a greater impact on the results than interventions on teacher quality.

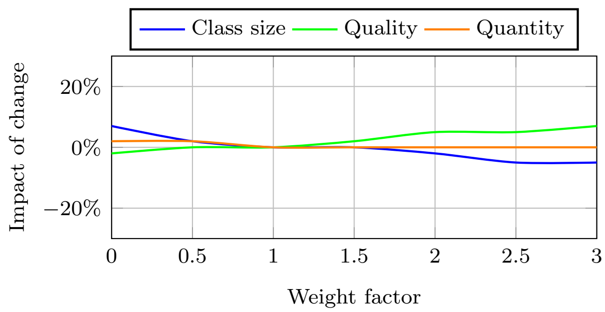

FIGURE 3.13: *The impact on the final teacher effectiveness score per change in the weight size of teacher quality, teacher quantity, and class size in the educator pool system.*

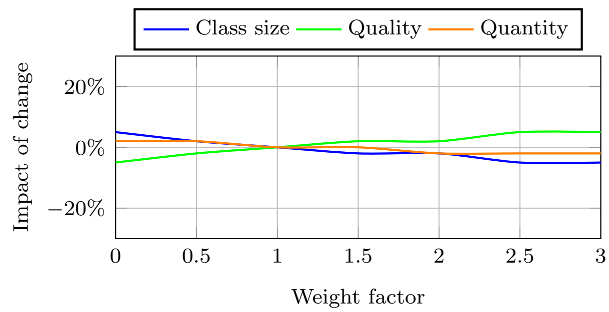

FIGURE 3.14: *The impact on the final success measure per change in the weight size of teacher quality, teacher quantity, and class size in the educator pool system.*

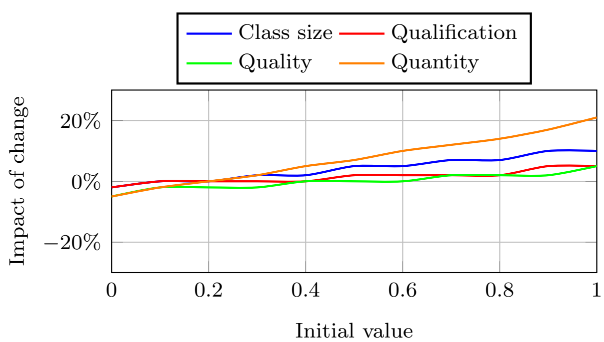

FIGURE 3.15: *The impact on the final teacher effectiveness score per change in the initial value of teacher quality, teacher qualification, teacher quantity, and class size, respectively, in the educator pool system.*

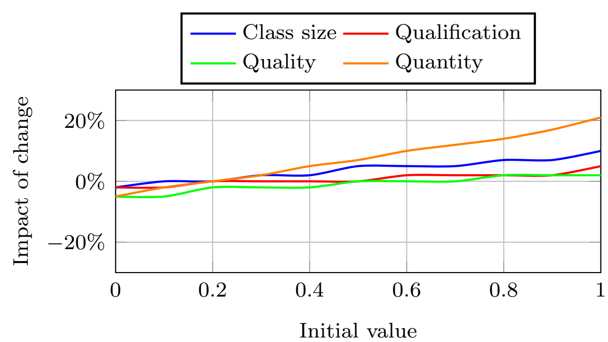

FIGURE 3.16: *The impact on the final success measure per change in the weight size of teacher quality, teacher qualification, teacher quantity, and class size in the educator pool system.*

3.2.3 Initial teacher populations

Figure 3.17 contains the impact of different initial distributions of effective to ineffective teachers in the Quintiles 1 to 3 system on the final teacher effectiveness score and success measure. Even when the model is initialised with only effective teachers, the system is not strong enough to support them. The effectiveness measure and success score both increase by only 5% after twelve months even with this drastic distribution change.

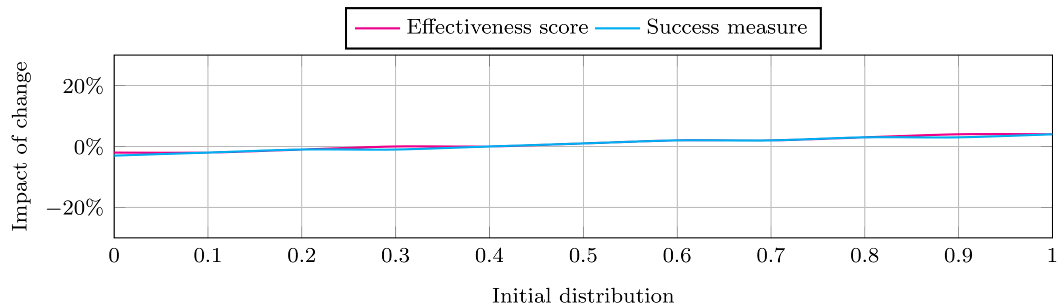

FIGURE 3.17: *The impact on the final teacher effectiveness score and success measure per change in the initial distribution of effective and ineffective teachers.*

3.3 Base case results

Figures 3.18 and 3.19 contain the resultant factor scores and teacher distributions during the twelve year simulation period for the Quintile 1 to 3 system. Despite four of the factors having an above average initial value, the goal seeking behaviour is balanced so that the system as a whole reaches a strength equilibrium at 0.50. The improvement of the class size score due to the increasing number of qualified teachers entering the profession causes teacher effectiveness to increase from the initial 0.40 to 0.50. A system stable at this low value is unable to support the transformation from ineffective teachers to effective teachers. The number of ineffective teachers remains higher than the number of effective teachers at every experience level for the duration of the simulation period. The success measure (*i.e.* the ratio of total effective teachers to total ineffective teachers) is 0.49.

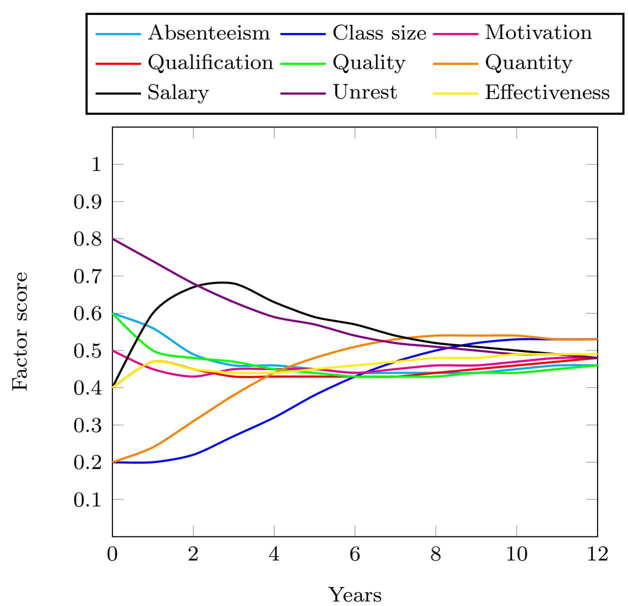

FIGURE 3.18: *Factor scores during the twelve year simulation period for the Quintile 1 to 3 base case.*

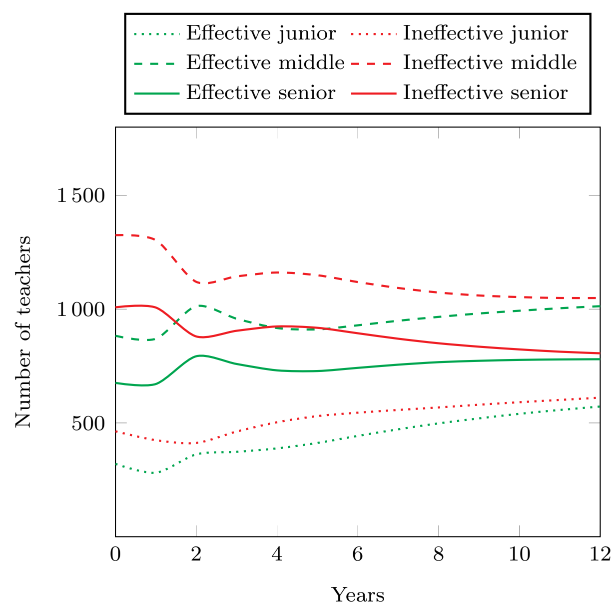

FIGURE 3.19: *The number of effective and ineffective teachers per experience level for the Quintile 1 to 3 base case.*

Figures 3.20 and 3.21 contain the resultant factor scores and teacher distributions during the twelve year simulation period for the Quintile 4 to 5 system. Despite two of the factors having a below average initial value, the goal seeking behaviour is balanced and teacher effectiveness remains at the initial score of 0.60. The strengthened system is able to maintain effective teachers for the simulation period. The reliable stream of well qualified teachers entering the profession as new graduates adds to the growth of effective junior level teachers and the Quintile 4 to 5 system continues to draw more teachers than the Quintile 1 to 3 system. The success measure is 0.63.

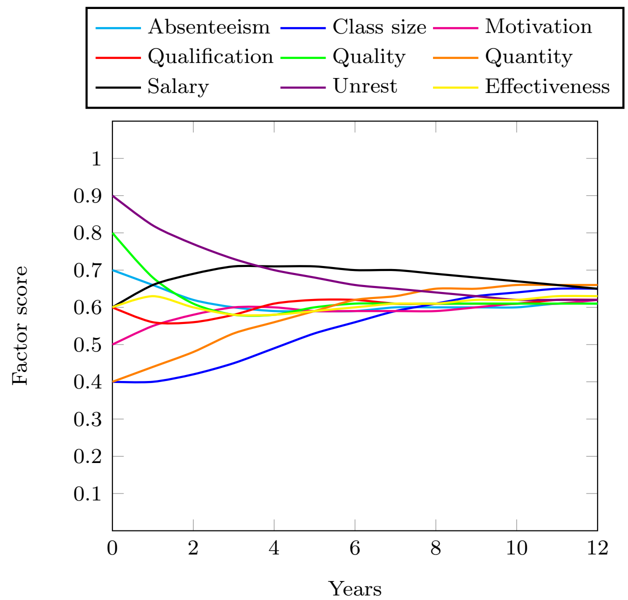

FIGURE 3.20: *Factor scores during the twelve year simulation period for the Quintile 4 to 5 base case.*

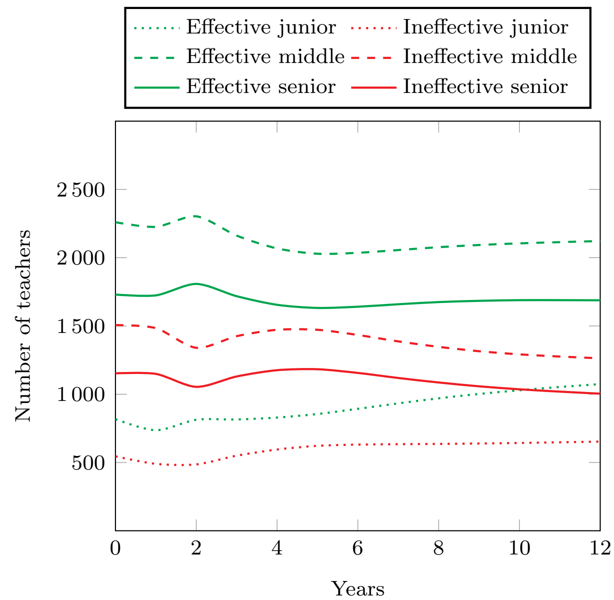

FIGURE 3.21: *The number of effective and ineffective teachers per experience level for the Quintile 4 to 5 base case.*

3.4 Interventions

Three interventions are tested to determine whether it is the low quantity of teachers or their low quality that is contributing to the education crisis. In Chapter 2 it was shown how late, once off interventions in only one area are incapable of improving the school system. Interventions are thus early, consistently and on multiple factors to examine their impact. To analyse the impact of interventions fairly, their magnitude must remain consistent. A standard large invention at an impact delay of three years is therefore selected and applied consistently so that only the area of intervention may be tested.

3.4.1 Increased teacher quantity

A large intervention, where the factor score is increased by the maximum, (*i.e.* a factor score increase of 1) is applied to teacher quantity, and class size for the Quintile 1 to 3 system. A large intervention is defined as in Chapter 2 and takes three years before its impact is experienced. This is the equivalent of setting the number of teachers, and resultant class size to the perfect ratio within a school. Figures 3.22 and 3.23 contain the resultant factor scores and teacher distributions for this intervention.

The constant increase in the number of teachers and the improvement in class size has a stabilising effect on the system as a whole from the ninth simulation year. This improvement is enough to increase the number of effective teachers so that their number exceeds the number of

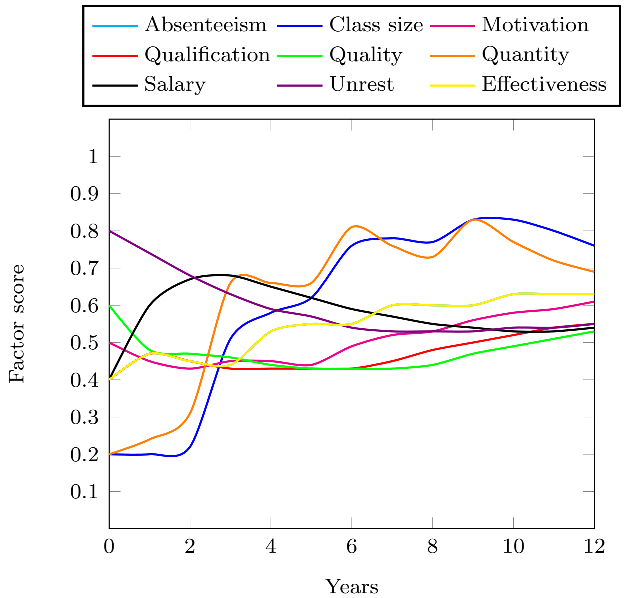

FIGURE 3.22: *Factor scores during the twelve year simulation period for Quintiles 1 to 3 for the quantity intervention.*

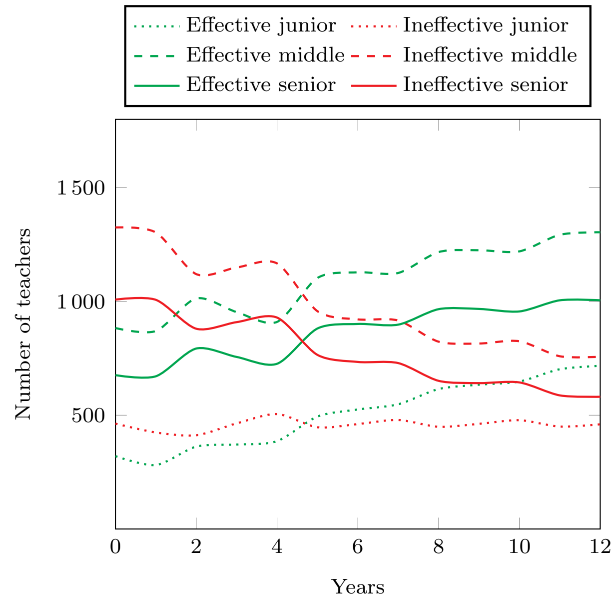

FIGURE 3.23: *The number of effective and ineffective teachers per experience level for Quintiles 1 to 3 for the quantity intervention.*

ineffective teachers at all experience levels from midway of the fourth simulation year. The overall teacher effectiveness score improves from the initial 0.4 to 0.6 during the simulation period and the success measure is 0.62.

3.4.2 Increased teacher quality

A large intervention where the factor score is increased periodically by the maximum is applied to teacher quality and qualification for Quintiles 1 to 3. Again, a large intervention takes three years before its impact is experienced. This is the equivalent of ensuring that all teachers are operating at maximum effectiveness with the perfect qualification type. Figures 3.24 and 3.25 contain the resultant factor scores and teacher distributions for this intervention. The regular increase in the quality of teachers and the improvement in their qualifications has a stabilising effect on the system as a whole from the eighth simulation year. The number of effective teachers exceeds the number of ineffective teachers for all experience levels from halfway through the fifth simulation year. The improvement occurs slightly slower than in the increased quantity intervention. The overall teacher effectiveness score improves in a similar fashion from the initial 0.4 to 0.6 during the simulation period and the final success measure is lower at 0.59.

3.4.3 Increased teacher quantity and quality

A large intervention is applied to teacher quantity, class size, teacher quality, and teacher qualification for Quintiles 1 to 3 system. Figures 3.26 and 3.27 contain the resultant factor scores and teacher distributions for this intervention.

All factors improve during the simulation period, and the strengthened system is able to support a majority of effective teachers at all experience levels within four and a half years. The overall teacher effectiveness score improves from the initial 0.4 to 0.7 during the simulation period and the success measure is the highest at 0.66.

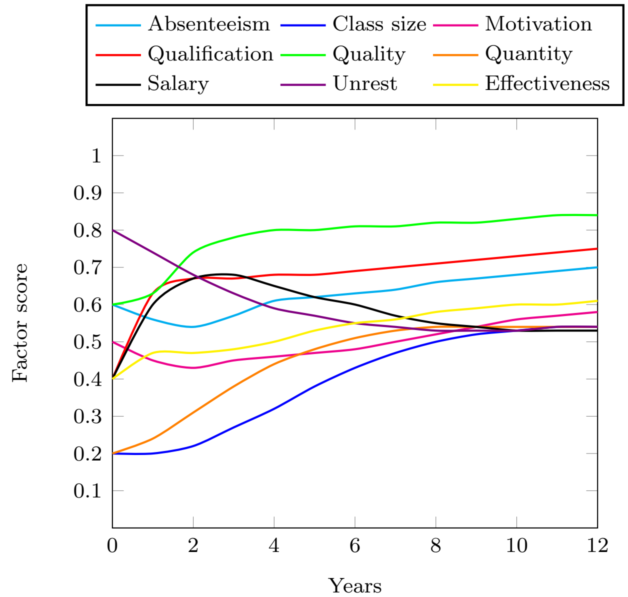

FIGURE 3.24: *Factor scores during the twelve year simulation period for Quintiles 1 to 3 for the quality intervention.*

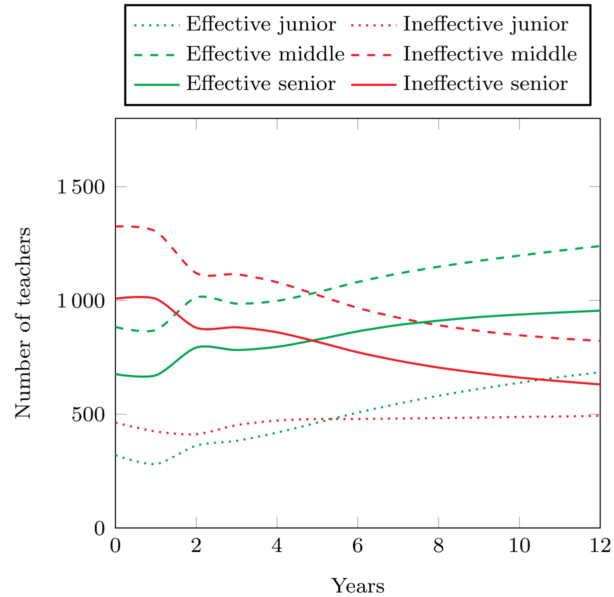

FIGURE 3.25: *The number of effective and ineffective teachers per experience level for Quintiles 1 to 3 for the quality intervention.*

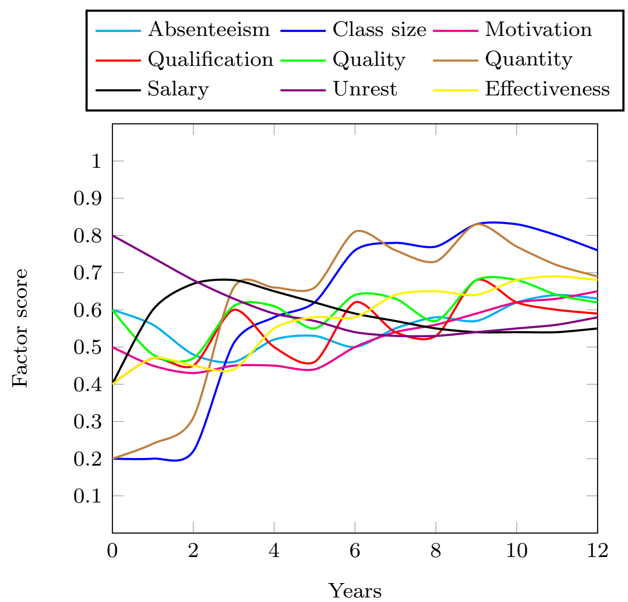

FIGURE 3.26: *Factor scores during the twelve year simulation period for Quintiles 1 to 3 for the combination intervention.*

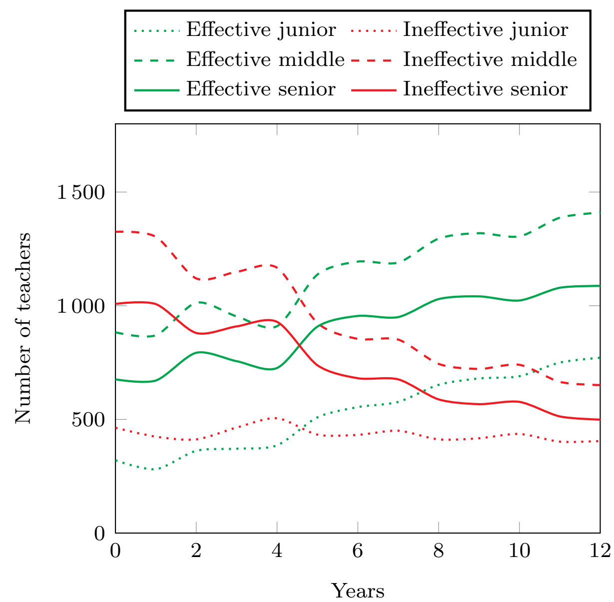

FIGURE 3.27: *The number of effective and ineffective teachers per experience level for Quintiles 1 to 3 for the combination intervention.*

3.5 Conclusion

The Teacher Effectiveness Model answers the research question as to whether it is low quantity of teachers, or low quality of teachers that contributes to the national basic education crisis. The model is populated with recent data from national datasets and the model is run for the twelve years leading up to 2030.

Initial weight values concerning teacher effectiveness are determined through parameter calibration. Validation of this calibration results in an average RMSE of 18% when the simulated number of teachers in each experience level is compared to the actual number. The worst fit occurs when additional teachers were recruited into the system in reality at middle experience level. This recruitment is not included in the mechanics of the simulation model and therefore causes discrepancies.

A sensitivity analysis is done on the initial weights of class size, teacher quality, and teacher quantity. A sensitivity analysis was also done on their initial scores and the initial teacher population distribution. The model is most sensitive to changes concerning teacher quality and class size, indicating that interventions in these areas should drive the greatest impact of change on the system.

The base case results show that schools in Quintiles 1 to 3 stabilise at a teacher effectiveness score leading to a greater number of ineffective teachers than effective teachers operating within them. In contrast to this schools in Quintiles 4 to 5 stabilise at a teacher effectiveness score leading to a greater number of effective teachers than ineffective teachers operating within them.

Three interventions address the research question. A timely, continuous, and large intervention in the quantity of teachers and class sizes of schools in Quintiles 1 to 3 system leads to a final effectiveness score increase of 0.10 and a success measure increase of 0.13. At those values both scores match the Quintiles 4 to 5 system. The system produces more effective than ineffective teachers from the fourth year of the simulation period during this intervention. A timely, continuous, and large intervention in the quality of teachers and their qualification in schools in Quintiles 1 to 3 system leads to a final effectiveness score increase of 0.10 and a success measure increase of 0.10. The system produces more effective than ineffective teachers from the fifth year of the simulation period during this intervention. A timely, continuous, and large intervention in all four of these factors leads to a final effectiveness score increase of 0.20 and a success measure increase of 0.17. The system produces more effective than ineffective teachers from the fourth year of the simulation period during this intervention. Table 3.9 contains a summary of the results.

	Effectiveness score	**Success measure**
Quintiles 1 to 3 base case	0.50	0.49
Quintiles 4 to 5 base case	0.60	0.63
Teacher quantity intervention	0.60	0.62
Teacher quality intervention	0.60	0.59
Combined intervention	0.70	0.66

Table 3.9: *The summary of the final success metric for each base case and intervention for the TEM.*

The research question is answered by showing that increasing the number of teachers has a greater positive impact on a school system than increasing the quality of the existing number of teachers, but that increasing both quantity and quality is the best approach. Practically this implies that funds should be directed towards making the profession more attractive to prospective students and increasing salaries. Enrolment into universities for teaching qualifications is good, but care must be taken to increase the graduation rate. The quickest success can be achieved by lowering the ratio of children to teachers in the classroom. It is recommended that the DBE's Action Plan for teachers in the Western Cape be changed to focus on increasing teacher populations.

The TEM adequately answers the research question in the context of the Western Cape education system. However, the model may be used with confidence to answer other research questions.

for example, would an increase in salary result in an increase in teacher effectiveness? The model may also be extended to investigate the remaining eight South African provinces. Similarly, the model can be used to analyse the entire South African education system by merely changing input data. Model accuracy may be improved by initialising teacher populations with values determined by means of formal forecasting methods instead of assuming an average.

CHAPTER 4

The impact of early childhood development

Contents

Goal 11 of the DBE Action Plan for 2030 is to improve the access of children under the age of six to quality ECD education below Grade 1. The early years of a child's life are the most sensitive to their cognitive, behavioural, social and physical development. During early childhood, key brain pathways are established which are required for lifelong skill development and learning. When the quality of ECD education is poor, it can have a detrimental impact on development and later learning [57].

The 2016 GHS shows that of the nearly 7.2 million South African children under the age of six, 46% were living in no- or low-income households [98]. This means that almost half of these children belong to a lower socio-economic class and cannot afford quality ECD education or Grade R programmes. These children will attend an informal form of education provided by a day-mother or a relative. These caregivers have often not received the training required to run quality ECD programmes. In fact, according to a 2013 audit, only 10% of early childhood educators had any qualification higher than Grade 12 [57].

Grade R, or reception year, is an optional year of instruction before enrolment into the compulsory Grade 1. During this grade, learners encounter structured learning for the first time with a formal curriculum focussed on language, mathematics, and life skills. Van der Berg *et al.* [109] looked at the DBE's ANA results from 2012 and found that children who had been exposed to Grade R had increased mathematics and home language scores in later school years. The increased scores were higher in the more affluent communities, but often not measurable in the poorer communities. From this they recognised that quality ECD education and Grade R learning is essential in preparing for foundation phase education.

Kotzé [57] analysed the likelihood of successful implementation of the DBE's National Development Plan. The plan proposes universal accessibility to two years of ECD education prior to Grade R. She found that participation rates in ECD programmes had increased significantly. She showed an increase in participation rates in all the age groups, with the largest increase of 38% among the four-year-olds. In 2013, 64% of four-year-olds, and 81% of five-year-olds in South Africa attended an education institution. However, a large majority of the facilities were inadequate, very few centres had adequate teaching materials, and barely any of the teachers at any of the centres were adequately trained. From this, Kotzé concluded that the potential impact of pre-Grade R on subsequent learning is high. However, the quality of many ECD programmes needed to be improved to reach this potential.

An ECD programme provides services to children and caregivers to promote school readiness. Programmes are structured within ECD facilities to provide learning and support appropriate for a child's development age and stage. Programmes are offered formally at ECD centres, and child-and-youth centres, or informally as non-centre based programmes.

Various forms of non-centre based programmes exist. Home based programmes at the household level are offered to primary caregivers, and young children to support early stimulation and development. Home-based programmes also promote referrals and linkages to support services. Community based programmes are provided at community structures like clinics, schools, traditional authority offices, municipal offices, community halls, or churches. These programmes are provided by trained community members and may operate two or three days per week. Mobile programmes are offered to children in rural and farming areas. Playgroups can be organised for young children to promote learning and play. Toy libraries provide children and families with access to developmentally appropriate educational play and learning materials. Finally, child minding is a programme for a maximum of six children in the care of a person during the day as arranged by the primary care-giver [50].

The Action Plan priority goal is set to increase the enrolment rate of children into ECDM programmes, whether formal or informal. The lack of consideration of the quality of these programmes, and especially of informal programmes, could cause the only outcome to simply be increased enrolments without increasing cognitive development and school readiness. A system dynamics model of the complexity of early life as a South African child enables analysis of the efficacy of a system with increase enrolment rates.

In this chapter the ECDM is presented to describe the causal linkages between improved ECD and Grade R learning practices on the education system as a whole. The chapter gives insight into the mechanics of the ECDM's design, followed by a brief discussion on the input data and assumptions used to populate the model. The system status quo is presented as base case results, followed by interventions and a discussion of results. The chapter finishes with some concluding observations on the results. The research question is answered as to whether it is the number of enrolments into ECD programmes that increases a cohort's readiness for primary school education, or whether it is the quality of the ECD programmes into which they were enrolled that increases readiness.

4.1 The Early Childhood Development Model

The ECDM extends the complexity of the SEM presented in Chapter 2 by expanding the single learner strength stock to an entire system within which children below the age of six find themselves. Figure 4.1 highlights the areas of the SEM expanded by the ECDM. The ECDM simulates the progression of children from birth to their enrolment into primary school at Grade R or Grade 1. It assumed that this progression is impacted upon by nine factors identified from literature: Poverty, the health of the children, their level of stunting, family support, infrastructure, programme quality, ECD practitioner quality, and the aptitude of the children. Aptitude is a measure of a child's school readiness and ultimately their academic success later in their school career [7, 8].

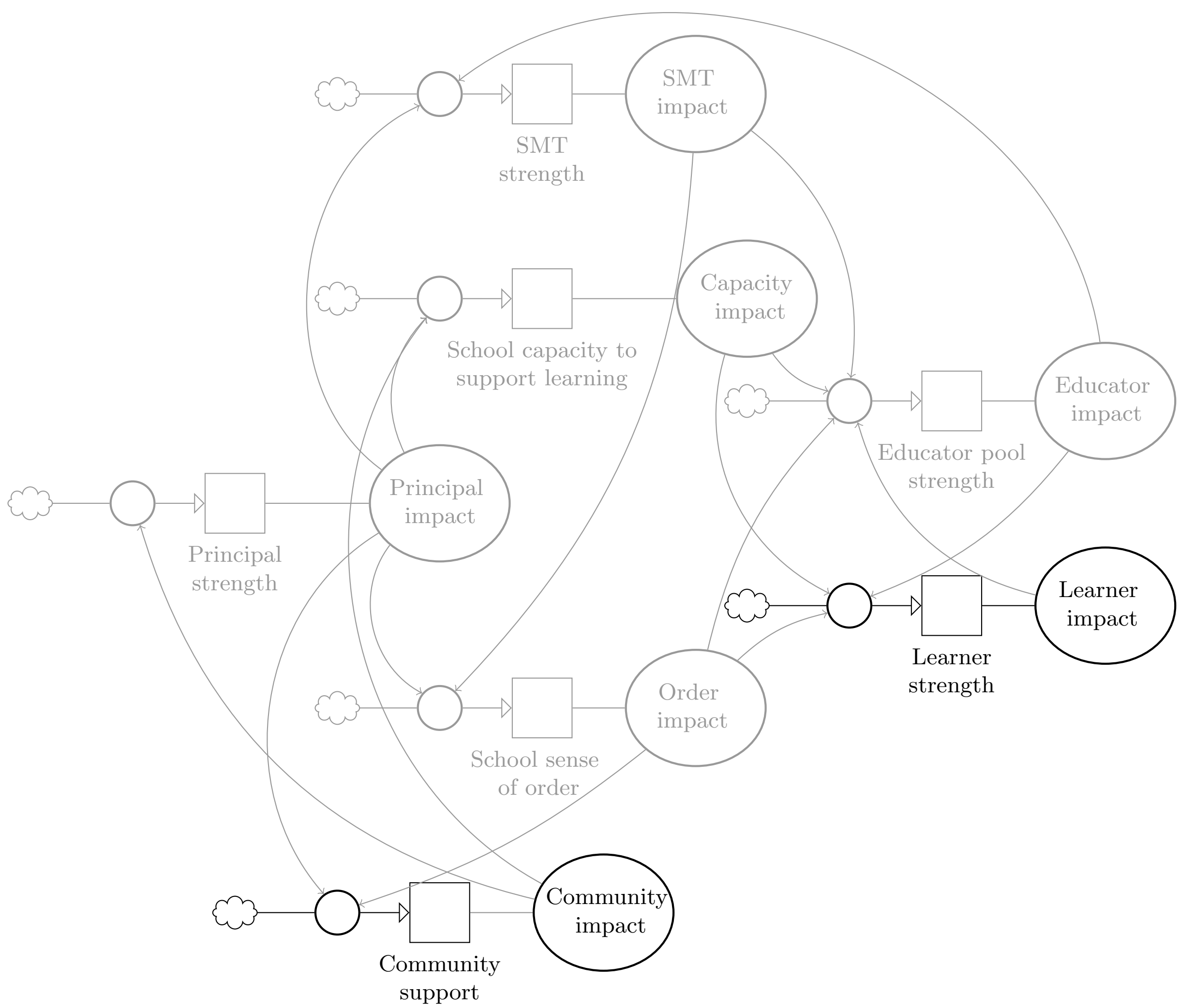

FIGURE 4.1: *The ECDM expands the complexity of the SEM as a subsystem underlying the learner strength highlighted in the stock-and-flow diagram.*

4.1.1 The early childhood system

Figure 4.2 contains the causal relationships between each of the factors within the early childhood system. The early childhood system is driven by four main reinforcing loops depicted in Figure 4.3. Poverty is determined by a person's access to income, employment, basic services, ownership of assets, social inclusion, and participation in decision-making. Absolute poverty describes an average monthly income that is less than absolute minimum required before the earner has to decide between procuring food and important non-food items. Relative poverty describes an income that is less than what others in a society are earning. Subjective poverty describes an income that is unable to meet the household's needs. Absolute poverty is the best measure for developing countries like South Africa as approximately 17 million people (or about a third of the country) live at this level [83]. South African households can be classified according to their socio-economic quintile by monthly income. The lowest three quintiles earn below R2 340 and fall under the 2018 living monthly wage level of R6 460 with 22% of the population falling under the food poverty line of R335 (*i.e.* their income is insufficient to purchase 2 100 calories per day, the minimum daily requirement in an emergency situation). The fourth quintile has an average monthly income between R2 341 and R5 956. In the richest quintile, 10% of all South Africans earn more than R7 313, 5% earn more than R11 091, and 2% earn more than R19 089 per month [100].

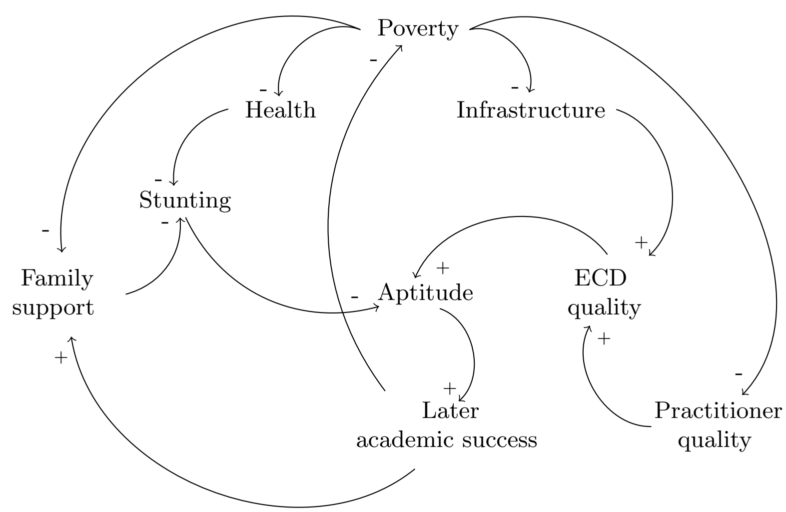

FIGURE 4.2: *The causal loop diagram for early childhood development.*

Increasing poverty has a decreasing effect on the quality of childhood health. Health is a measure of the physical well-being of the children in a community. Good health results from access to clean, warm homes with adequate ventilation, quality healthcare in the form of doctors, hospitals, clinics, and pharmacies, proper sanitation practices, food security, clean water, and regular refuse removal. Children from poor households suffer worse health and die younger than the rich. They have higher than average child and maternal mortality, higher levels of disease and limited access to quality health care and good nutrition [118].

Decreasing health increases stunting. Stunting occurs when a child is prevented from growing physically, or developing cognitively due to poor nutrition, repeated illness, and a lack of psychosocial interaction. As a result they fall behind their peers. A low height-for-age is the

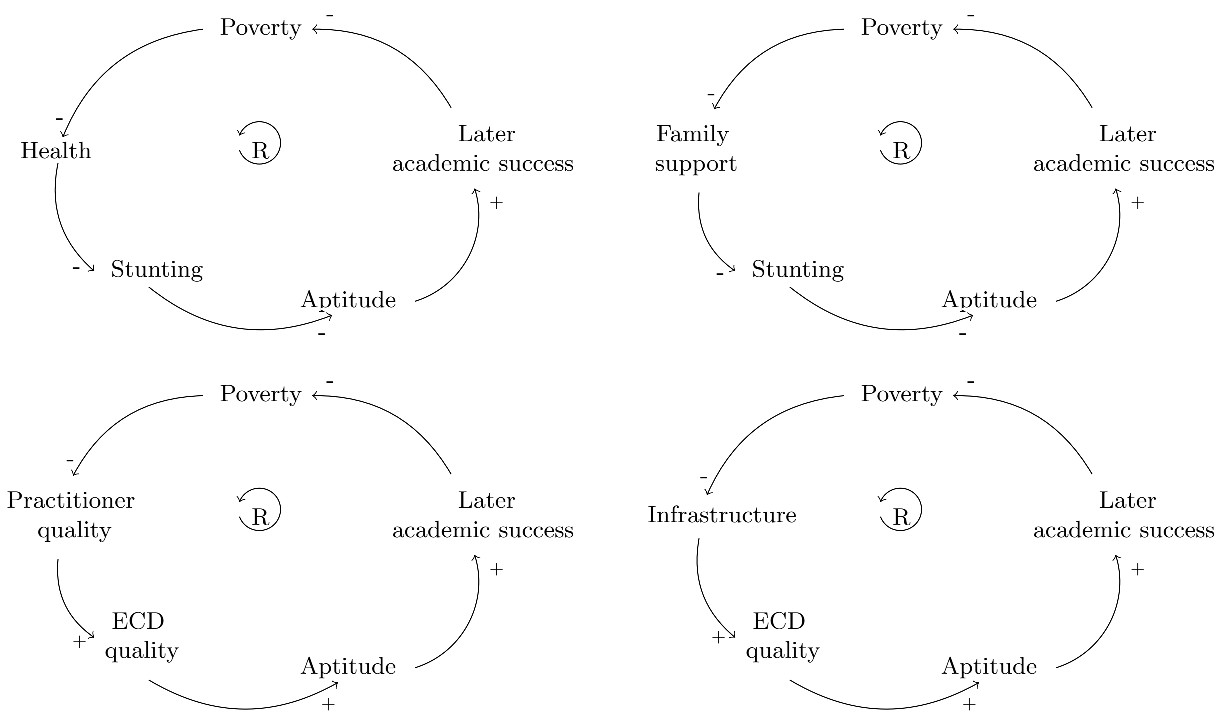

FIGURE 4.3: *There are four main reinforcing loops in the early childhood system.*

best indicator of the presence of childhood stunting [12]. Casale and Desmond [11] applied a multivariate regression analysis to a dataset of children born in urban South Africa in 1990 and found that poor child health, particularly poor nutrition, results in stunting. In previous work, Casale *et al.* [12] found a large and significant association between stunting of two-year-olds and their cognitive function at the age of five. Early childhood stunting is negatively associated with the cognitive development of children and therefore lowers their cognitive function, or aptitude [29, 113, 116].

Aptitude refers to a child's developmental progress at each stage between birth and the age of five according to the *Revised Denver Pre-screening Developmental Questionnaire* (R-DPDQ) [39]. The questionnaire evaluates a child's development in the areas of personal and social skills, fine and gross motor skills, language, and problem solving ability. Table 4.1 contains, for example, the physical, cognitive skills that a five-year-old should achieve. A child who has achieved these may be deemed ready for formal education.

Increasing the aptitude with which a child enrols into primary school increases their academic success in later grades. This is referred to as the cognitive advantage hypothesis and is widely accepted [6, 77]. Mendez and Adair [62] followed a cohort of children from the Philippines and found that even when they recover from stunting experienced at the age of two, they achieve lower grades at ages eight and eleven than children who were never stunted. Crookston *et al.* [17] found similar results in four developing countries (Ethiopia, India, Peru, and Vietnam), where school interventions were able to decrease (but not eliminate) the achievement deficit caused by stunting. Later academic success refers to the highest level of education the child will complete. This in turn increases the probability of the child growing up to find opportunities to generate a good income, thus reducing the impact of poverty upon that individual and their community.

Increasing poverty has a decreasing effect on family support. Family support refers to the level of financial, emotional, mental and physical support that children receive from family members.

Number	Description
1	The child is able to dress themselves without help.
2	The child can play any simple board or card game.
3	The child can brush their teeth without help or supervision.
4	The child can prepare a bowl of cereal without making too much of a mess.
5	The child can build a tower of blocks.
6	The child can count the number of blocks.
7	The child can imitate a vertical line.
8	The child can copy a circle.
9	The child can copy a cross.
10	The child can copy a square.
11	The child can identify which line is longer.
12	The child can draw a person using three parts.
13	The child can draw a person using six parts.
14	The child understands prepositions.
15	The child can name colours.
16	The child can define words.
17	The child knows adjectives.
18	The child knows opposites.
19	The child can wiggle their thumbs.
20	The child can balance on one foot.
21	The child can hop on one foot.
22	The child walks heel-to-toe.
23	The child's speech is understandable.

Table 4.1: *The required physical, communication and cognitive skills for five-year-old children according to the R-DPDQ [39].*

It can be measured by the number of parents present in the household, the level of parental education, the level of parental involvement, the number of learning related resources and the number of assets in the home [114]. Children may find themselves growing up in a nuclear family (where spouses or partners couple with their own children and no other members), a lone parent family (where a single parent has their children and no other members), an extended family (that is not a nuclear or lone parent family, but all members are related), or a composite family (that is not a nuclear or lone parent family, and some members are not related). A South African child qualifies for a governmental *Child Support Grant* (CSG) if their primary caregiver earns less than R3 300 per month. Approximately 12 million children qualified during 2017, and of these, only 25% of children came from families where both parents were present [28]. Parents from poorer communities are therefore less able to provide the presence and support necessary to stimulate early childhood development. The lack of stimulation and support from a struggling family increases a child's stunting [32, 44, 87, 88].

Poverty decreases the access of a community's ECD practitioners and the adequate training they require. A certificate in Early Childhood Education and Care is the absolute minimum childcare qualification that a practitioner requires in order to be considered a quality childcare provider or early childhood educator [86]. Practitioner quality describes the overall rating of the ECD practitioners in the community. The quality of a practitioner is determined by the level of education received by the practitioner, the tools achieved during ECD specific training, the level of practitioner absenteeism and the class size that a practitioner is assigned. Class size can either enable or prohibit practitioners from giving children individual attention [9]. Increasing practitioner quality increases the quality of the ECD programmes. A quality programme is one where children learn the correct skill at the correct time, in the correct way, so that an increase in quality has a positive effect on aptitude. The greatest gain in cognitive ability comes from participation in programmes for two years or more at a minimum of fifteen hours per week (preferably at thirty hours per week) where children are enrolled before the age of four [59].

Lastly, increasing poverty has a decreasing effect on infrastructure. Infrastructure refers to the presence of learning materials, sufficient facilities, and additional resources at each ECD centre. ECD centres in poorer communities are often without electricity, roads, water and an adequate supply of books and toys. The improvement of infrastructure has a positive effect on ECD quality.

Figure 4.4 contains the stock-and-flow diagram for the early childhood system. Each factor increases or decreases the other by means of biflows to achieve a new total aptitude score for each simulation time step. This aptitude score then serves as the input into child progression trains.

Let F^F be the score for family support, F^V be the score for family poverty, F^I be the score for ECD infrastructure quality, F^H be the score for child health, F^B be the score for child aptitude, F^Y be the score for practitioner quality, F^T be the score for child stunting, F^L be the score for later academic success, and F^D be the score for ECD programme quality. The change in each factor during the simulation period is described mathematically by

$$\frac{\mathrm{d}F^F}{\mathrm{d}t} = \frac{F^F + F^V + F^L}{3} - F^F, \tag{4.1}$$

$$\frac{\mathrm{d}F^V}{\mathrm{d}t} = \frac{F^V + F^L}{2} - F^V, \tag{4.2}$$

$$\frac{\mathrm{d}F^I}{\mathrm{d}t} = \frac{F^I + F^V}{2} - F^I, \tag{4.3}$$

$$\frac{\mathrm{d}F^H}{\mathrm{d}t} = \frac{F^H + F^V}{2} - F^H, \tag{4.4}$$

$$\frac{\mathrm{d}F^B}{\mathrm{d}t} = \frac{w^B F^B + w^T F^T + w^D F^D}{w^B + w^T + w^D} - F^B, \tag{4.5}$$

$$\frac{\mathrm{d}F^Y}{\mathrm{d}t} = \frac{F^Y + F^V}{2} - F^Y, \tag{4.6}$$

$$\frac{\mathrm{d}F^T}{\mathrm{d}t} = \frac{F^T + F^H + F^F}{3} - F^T, \tag{4.7}$$

$$\frac{\mathrm{d}F^L}{\mathrm{d}t} = \frac{F^L + F^B}{2} - F^L, \text{ and} \tag{4.8}$$

$$\frac{\mathrm{d}F^D}{\mathrm{d}t} = \frac{F^D + F^I + F^Y}{3} - F^D \tag{4.9}$$

where w^B, w^T, and w^D are the weighted influence of child aptitude, child stunting and ECD quality, respectively, on child aptitude, the factor which influences progression at each age. Calibrating weights for all the terms in equations (4.1) to (4.9) would result in an infeasible 10^{22} number of simulation runs for each 0.1 increment between 0 and 1. Simplified weight calibration for each term at values of 0, 0.5, and 1 each would not only be too blunt, but still result in an infeasible number of 3^{22} simulation runs. Therefore, a feasible 10^3 simulation runs are used to calibrate the three weights directly impacting on the output variable, F^B. This output variable is received by the child progression trains.

Initial values for the factors are obtained from surveys and test results. The GHS remains the main dataset for quantifying the various factors of the early childhood system by socio-economic class. Each year in the Western Cape, the parents of about 700 children below the age of six are surveyed about multiple aspects of their children's development and living situation. This

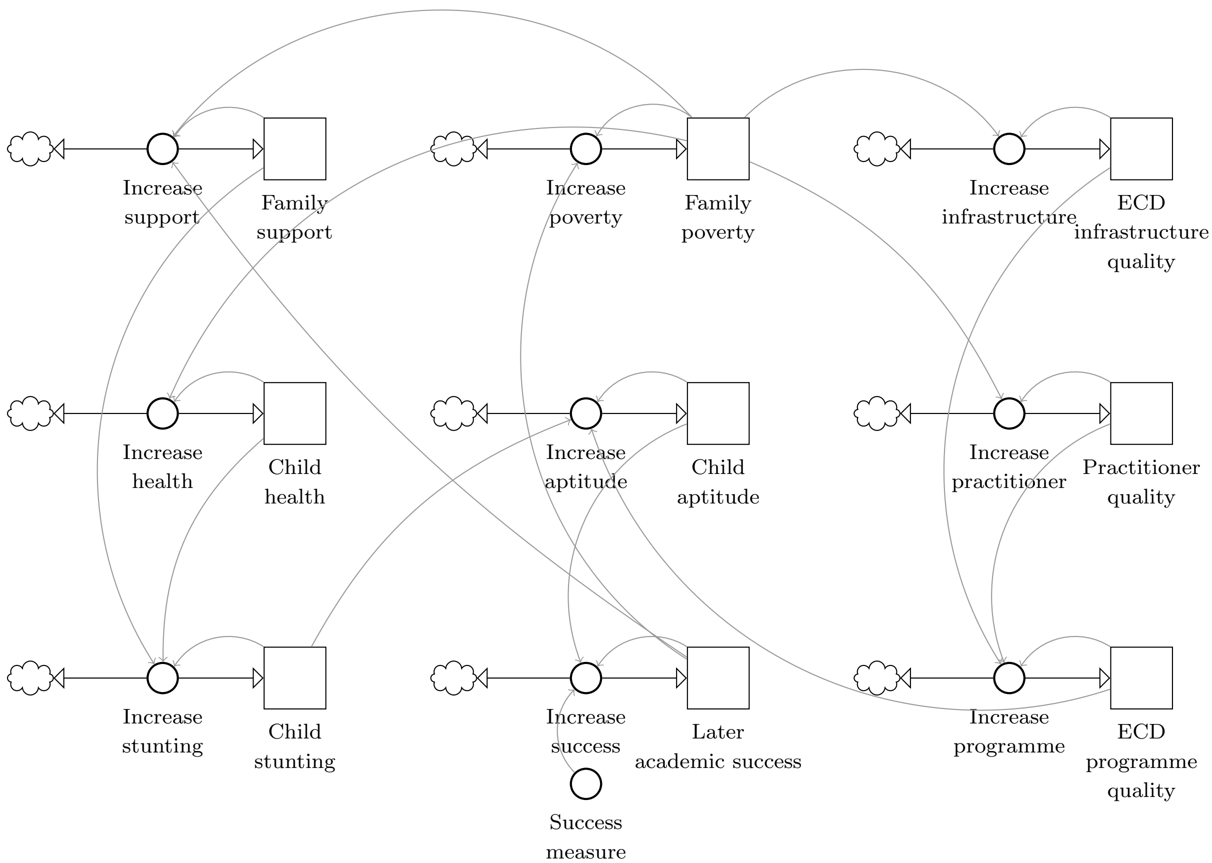

FIGURE 4.4: *The stock-and-flow diagram for the early childhood system in the ECDM.*

data is supported by data from the five waves of the *National Income Dynamics Survey* (NIDS) where about 500 children are surveyed each year [92]. Normalisation of survey responses and test results ensures that factor scores can be brought into proportion with each other without unit discrepancies. Response options for survey questions are ranked from most to least desirable state and goodness scores are assigned to each response option in ascending order. The least desirable state is assigned a goodness score of 0 and the most desirable state is assigned a goodness score of 1. Intermediary states are assigned goodness scores linearly between these two extremes. The sum-product of the number of responses per response option and its goodness score provides the initial value for each factor.

Table 4.2 contains the average number of newborns to five-year-olds per quintile and per family type from 2010 to 2017. The nuclear family is the ideal structure to provide family support [2, 35, 68] and it is therefore assigned a score of 1. Children from lone families experience greater support as at least one of their biological parents are present within the household and the family type is assigned a higher score of 0.6 when compared to the score of 0.3 for extended families. Children from composite families are the worst off and the family type is therefore assigned a score of 0.

Table 4.3 contains the average household monthly income for children under the age of six per quintile from 2010 to 2017. The lowest income bracket describes utmost poverty and is therefore assigned a goodness score of 0. The highest income bracket is assigned a goodness score of 1 and the remaining brackets are scored evenly between these extremes. The large difference between

Family type	Goodness score	Quintiles 1 to 3	Quintiles 4 and 5
Composite	0.0	3%	1%
Extended	0.3	13%	12%
Lone	0.6	48%	29%
Nuclear	1.0	36%	58%
F^F initial value		0.69	0.79

Table 4.2: *The average percentage of children below the age of six living in each of the four family types per quintile within the Western Cape from 2010 to 2017 according to the NIDS.*

the scores for each quintiles is an accurate mirror of South Africa's high Gini coefficient.

Household income	Goodness score	Quintiles 1 to 3	Quintiles 4 and 5
R0 to R540	0.0	28%	0%
R540 to R1 151	0.3	19%	0%
R1 151 to R2 340	0.5	53%	0%
R2 340 to R5 956	0.8	0%	51%
More than R5 956	1.0	0%	49%
F^V initial value		0.32	0.90

Table 4.3: *The percentage of children below the age of six per household income level per quintile within the Western Cape from 2010 to 2017 according to the NIDS.*

The GHS of 2016 is the first version to survey the quality of ECD facilities and infrastructure. Table 4.4 contains the percentage of children below the age of six who attend facilities where the listed infrastructure was present. There is little difference between the facilities in each quintile and the averages of these percentages become the ECDM score.

Infrastructure element	Quintiles 1 to 3	Quintiles 4 and 5
Pictures on the walls	92%	92%
Tapped or piped water	94%	95%
Electricity	96%	97%
Flushing toilets	89%	95%
Educational toys	88%	90%
Fenced facility	84%	90%
Outside play area	92%	92%
Outside play equipment	76%	87%
F^I initial value	0.89	0.92

Table 4.4: *The percentage of children below the age of six per quintile during 2016 within the Western Cape where the necessary infrastructure is present according to the GHS.*

Table 4.5 contains the percentage of children below the age of six per health category [92]. There is surprisingly little difference between the general health of children in each quintile. This similarity may be due to the subjective nature of classifying health, where richer communities might have a higher expectation of what constitutes good health.

Health category	**Goodness score**	**Quintiles 1 to 3**	**Quintiles 4 and 5**
Poor	0.0	0%	0%
Fair	0.3	1%	0%
Good	0.5	12%	14%
Very good	0.8	44%	36%
Excellent	1.0	43%	49%
F^H initial value		0.85	0.85

TABLE 4.5: *The percentage of children below the age of six per health level per quintile within the Western Cape from 2010 to 2017 according to the NIDS.*

Again, the GHS of 2016 is the first version to survey the level of stimulation children receive from their ECD practitioner. Tables 4.6 and 4.7 contain the percentage of children below the age of six who receive different forms of cognitive stimulation. It is assumed that these three stimulation techniques play an equal role in the cognitive development of a child. Consequently, the averages of these percentages become the initial value for practitioner quality.

Activity	**Goodness**	**Quintiles 1 to 3**			
frequency	**score**	Talking	Story telling	Singing	Average
Never	0.0	8%	28%	12%	16%
Sometimes	0.3	19%	27%	32%	26%
Often	0.6	19%	18%	21%	19%
Always	1.0	54%	28%	35%	39%
F^Y initial value	0.58				

TABLE 4.6: *The percentage of children below the age of six receiving cognitive stimulation in Quintiles 1 to 3 within the Western Cape during 2016 according to the GHS.*

Activity	**Goodness**	**Quintiles 4 to 5**			
frequency	**score**	Talking	Story telling	Singing	Average
Never	0.0	15%	21%	9%	15%
Sometimes	0.3	7%	17%	24%	14%
Often	0.6	16%	17%	24%	19%
Always	1.0	62%	46%	49%	53%
F^Y initial value	0.68				

TABLE 4.7: *The percentage of children below the age of six receiving cognitive stimulation in Quintiles 4 and 5 within the Western Cape during 2016 according to the GHS.*

Table 4.8 contains the average parental educational level for children under the age of six per quintile from 2010 to 2016. Parental educational level is an important predictor of children's later academic success as it determines the level of academic support parents can provide and the level of future academic aspirations they set for their children [18, 31]. The highest level of parental education is a qualification from a tertiary education institution and we assign a goodness score of 1 to this category. Parents who completed only high school is not ideal, but still able to provide better support than parents who completed only primary school. A goodness score of 0.6 and 0.3 is assigned to these, respectively. Parents with no formal education provide the least support and have a goodness score of 0.

The NIDS surveys the height of children below the age of six. A child is considered severely

Parental educational level	**Goodness score**	**Quintiles 1 to 3**	**Quintiles 4 and 5**
None or informal	0.0	1%	1%
Primary	0.3	20%	6%
Secondary	0.6	67%	54%
Tertiary	1.0	12%	39%
F^L initial value		0.58	0.73

TABLE 4.8: *The percentage of children below the age of six with household heads from one of the four education levels per quintile within the Western Cape from 2010 to 2017 according to the NIDS.*

stunted if their height-for-age is three standard deviations below the mean of a healthy reference population set by the World Health Organization. A child is considered stunted if their height is two standard deviations below this reference. Table 4.9 contains the average percentage of children under the age of six per quintile at each level of stunting from 2010 to 2017. Severly stunted children are at the greatest disadvantage and we assign a goodness score of 0 to this state. Children who experience no stunting are best off and are assigned a goodness score of 1 with stunted children having a goodness score of 0.5.

Level of stunting	**Goodness score**	**Quintiles 1 to 3**	**Quintiles 4 and 5**
Severely stunted	0.0	22%	22%
Stunted	0.5	17%	11%
Not stunted	1.0	52%	67%
F^T initial value		0.60	0.73

TABLE 4.9: *The percentage of children below the age of six at each level of stunting per quintile within the Western Cape from 2014 to 2017 according to the NIDS.*

The GHS does not contain a survey to record the cognitive skills for children below the age of five. The *Early Learning Outcomes Measure* (ELOM) is the first programme to measure the performance of South African children aged 50 to 59 months and 60 to 69 months, respectively. It includes 23 items measuring indicators of a child's early development in five domains: gross motor development, fine motor coordination and visual motor integration, emergent numeracy and mathematics, cognition and executive functioning, and emergent literacy and language as listed in Table 4.1 [19]. Because no dataset yet exists for children below this age, the level of aptitude at age five is used as a continuation of the level of aptitude of all ages below and assigned the same score to all children aged five and younger. Table 4.10 contains the percentage of children aged 50 to 69 months at each achievement level during 2016.

Level of performance	**Goodness score**	**Quintiles 1 to 3**	**Quintiles 4 and 5**
At risk	0.0	29%	16%
Falling behind	0.5	24%	34%
Achieving the standard	1.0	46%	49%
F^B initial value		0.58	0.66

TABLE 4.10: *The percentage of children below the age of six at each level of aptitude per quintile within the Western Cape during 2016 according to the ELOM.*

As an ECD programme consists of practitioners enabled by their infrastructure, the initial value for ECD quality may be taken as the average initial values of infrastructure and practitioner quality. Table 4.11 contains a summary of the initial values for the ECDM factor scores.

ECDM factor	Symbol	Quintiles 1 to 3	Quintiles 4 and 5
Child aptitude	F^B	0.58	0.66
ECD programme quality	F^D	0.74	0.80
Family support	F^F	0.75	0.79
Practitioner quality	F^Y	0.58	0.68
Child health	F^H	0.85	0.85
ECD infrastructure quality	F^I	0.89	0.92
Later academic success	F^L	0.58	0.73
Family poverty	F^V	0.32	0.90
Child stunting	F^T	0.60	0.73

TABLE 4.11: *The initial values for the factor scores of the ECDM.*

4.1.2 Early childhood progression

An average of 60% of children under the age of two in the Western Cape are reported to have been enrolled into ECD programmes[1] from 2010 to 2016 [92]. It is difficult to interpret this data for meaning because it is impossible to determine what the respondents to the survey regard as appropriate education for children of this age. Better data are needed for this age group. However, Table 4.12 contains the average percentage of children enrolled into formal programmes. Table 4.13 contains the average percentage of stunted children by age in years, socio-economic quintile and ECD enrolment status in the Western Cape from 2014 to 2017 [92]. These values are used to initialize the stocks simulating early childhood progression. The stock-and-flow diagram in Figure 4.4 depicts this process.

	Quintiles 1 to 3		Quintiles 4 to 5	
Age	Enrolled	Not enrolled	Enrolled	Not enrolled
0	56%	44%	60%	40%
1	68%	32%	69%	31%
2	65%	35%	70%	30%
3	71%	29%	77%	23%
4	77%	23%	82%	18%
5	97%	3%	98%	2%

TABLE 4.12: *The average percentage of children enrolled into ECD programmes by age in years and by socio-economic quintile from 2010 to 2016 according to the GHS.*

Some children spend the first five years of their lives enrolled into ECD education. Those who don't, may enrol at a later stage as they grow older, or remain outside of the system until they have to enrol into primary school for Grade 1 at the age of six. It is assumed that children never leave the ECD system once they've entered into it. The children exhibit a level of age appropriate cognitive readiness assumed to be equal to their level of stunting. Stunted or severely stunted children are assumed to not be ready to perform the tasks expected of them at each age. For children outside of the system, their readiness remains unchanged from its initial formation. For children within the system, their readiness can be improved upon or lost depending on the strength of the system. This strength is quantified as the resultant support for child aptitude from the interaction between the elements in Figure 4.4.

[1]The GHS lists creches, play schools, edu-care centres, day mothers, and pre-schools as ECD programmes.

		Quintiles 1 to 3		Quintiles 4 to 5	
Age	**Stunting**	**Enrolled**	**Not enrolled**	**Enrolled**	**Not enrolled**
0	Severely stunted	0%	47%	0%	54%
	Stunted	0%	0%	0%	3%
	Not stunted	100%	53%	100%	43%
1	Severely stunted	15%	47%	17%	49%
	Stunted	5%	15%	20%	15%
	Not stunted	80%	37%	63%	36%
2	Severely stunted	25%	45%	8%	13%
	Stunted	25%	11%	0%	17%
	Not stunted	50%	44%	92%	71%
3	Severely stunted	14%	26%	14%	14%
	Stunted	12%	20%	13%	47%
	Not stunted	74%	55%	72%	39%
4	Severely stunted	10%	8%	8%	2%
	Stunted	24%	34%	8%	6%
	Not stunted	67%	58%	84%	92%
5	Severely stunted	4%	5%	2%	7%
	Stunted	26%	36%	2%	7%
	Not stunted	70%	59%	96%	86%

Table 4.13: *The average percentage of children who are classified as stunted by age in years, socio-economic quintile and ECD enrolment status in the Western Cape from 2014 to 2017 according to the NIDS.*

Let F_j^b be the child aptitude or readiness for children of age (in years) $j \in [0,1,2,3,4,5]$ already enrolled in formal ECD programmes. During each iteration the change in readiness depends on the strength of the early childhood system so that

$$\frac{\mathrm{d}F_j^b}{\mathrm{d}t} = \frac{F_j^b + F^B}{2} \tag{4.10}$$

for all j. Similarly let $\tilde{F}_j^b$ be the child aptitude or readiness for children of age (in years) $j \in [0,1,2,3,4,5]$ not enrolled in formal ECD programmes.

Let the entries in $\boldsymbol{C}_j$ be the percentage of children of age (in years) j who are enrolled into formal ECD programmes and who are either cognitively ready (r) for that age, or not ready ($\tilde{r}$), respectively so that

$$\boldsymbol{C}_j = [C_j^r, C_j^{\tilde{r}}] \tag{4.11}$$

where $j \in [0,1,2,3,4,5]$. Similarly let the entries in $\tilde{\boldsymbol{C}}_j$ be the percentage of children who are not enrolled into formal ECD programmes so that

$$\tilde{\boldsymbol{C}}_j = [\tilde{C}_j^r, \tilde{C}_j^{\tilde{r}}] \tag{4.12}$$

for all j. Let β be the percentage of babies enrolled into formal ECD programmes, let λ_j be the percentage of children of age $j \in [0,1,2,3,4]$ that enrol for ECD education and recall $\boldsymbol{E}_1$ as the enrolment into Grade 1 from Chapter 2 so that

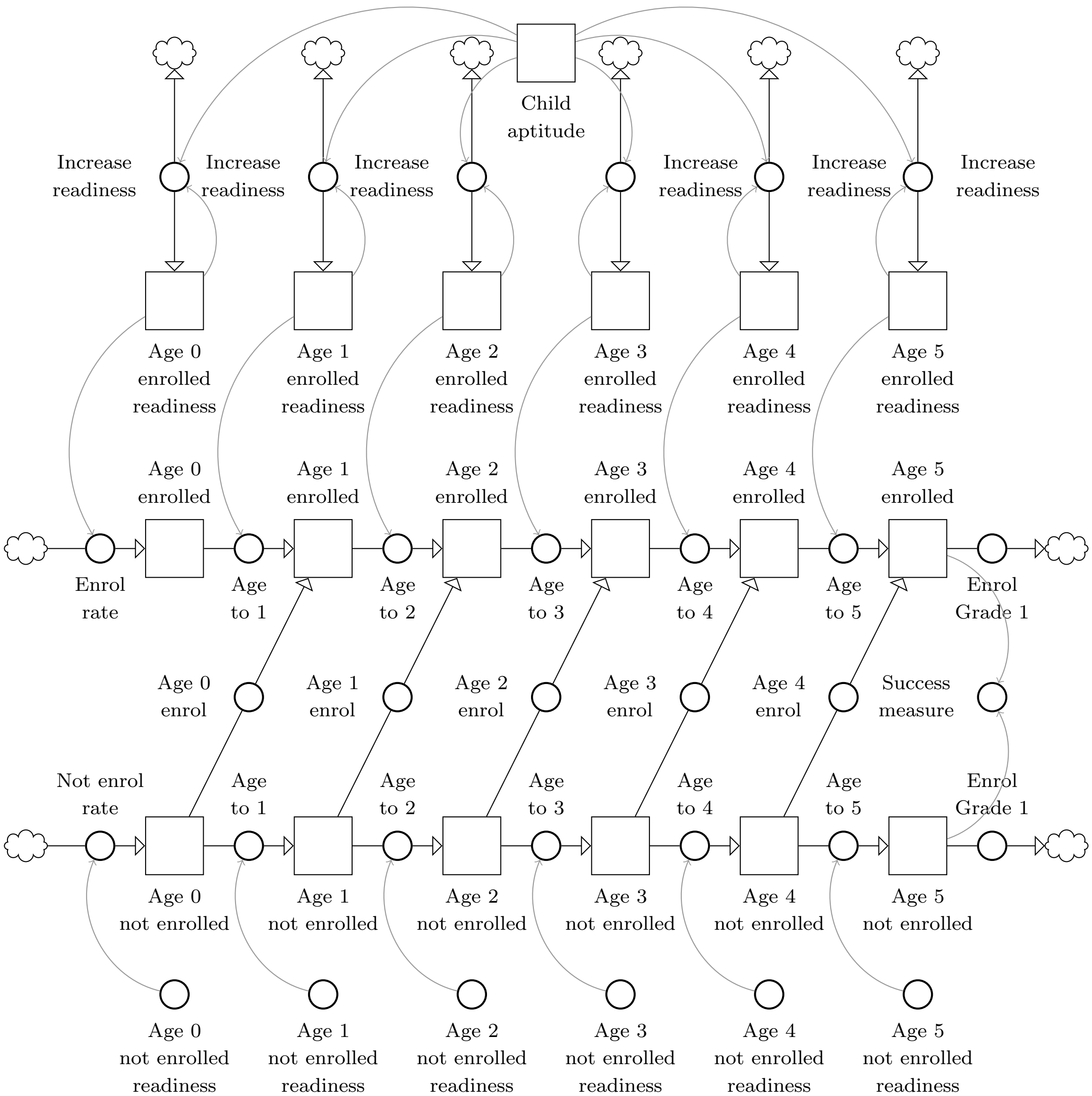

Figure 4.5: *The stock-and-flow diagram for child progression in the ECDM.*

$$\frac{\mathrm{d}\boldsymbol{C}_j}{\mathrm{d}t} = \begin{cases} [\beta F_0^b - C_1^r, \beta(1-F_0^b) - C_1^{\tilde{r}}] & \text{for } j=0, \\ [F_j^b C_{j-1}^r + \lambda_{j-1}^r - F_{j+1}^b C_j^r, (1-F_j^b) C_{j-1}^{\tilde{r}} + \lambda_{j-1}^{\tilde{r}} - (1-F_{j+1}^b) C_j^{\tilde{r}}] & \text{for } j \in [1,2,3,4], \text{ and} \\ [F_j^b C_{j-1}^r + \lambda_{j-1}^r, (1-F_j^b) C_{j-1}^{\tilde{r}} + \lambda_{j-1}^{\tilde{r}}] - \boldsymbol{E}_1 & \text{for } j=5 \text{ and} \end{cases} \tag{4.13}$$

$$\frac{\mathrm{d}\tilde{\boldsymbol{C}}_j}{\mathrm{d}t} = \begin{cases} [(1-\beta)\tilde{F}_0^b - \tilde{C}_1^r, (1-\beta)(1-\tilde{F}_0^b) - \tilde{C}_1^{\tilde{r}}] & \text{for } j=0, \\ [\tilde{F}_j^b \tilde{C}_{j-1}^r - \lambda_{j-1}^r - \tilde{F}_{j+1}^b \tilde{C}_j^r, (1-\tilde{F}_j^b) C_{j-1}^{\tilde{r}} - \lambda_{j-1}^{\tilde{r}} - (1-\tilde{F}_{j+1}^b) \tilde{C}_j^{\tilde{r}}] & \text{for } j \in [1,2,3,4], \text{ and} \\ [\tilde{F}_j^b \tilde{C}_{j-1}^r - \lambda_{j-1}^r, (1-\tilde{F}_j^b) \tilde{C}_{j-1}^{\tilde{r}} + \lambda_{j-1}^{\tilde{r}}] - \boldsymbol{E}_1 & \text{for } j=5. \end{cases} \tag{4.14}$$

4.2 Validation and sensitivity analysis

The factors of the early childhood system combine to produce F^B, the main factor supporting child aptitude. The weights for equation (4.5) are determined through parameter calibration so that the lowest average *root mean square error* (RMSE) for each childhood age and its simulated values are achieved. The lowest average RMSE of 14% and 15%, is achieved when $w^B = w^T = w^D = 1$, for both Quintiles 1 to 3 and Quintiles 4 to 5 schools, respectively. Figures 4.6 and 4.7 contain the ECDM approximation of reality for 2010 to 2016 for all enrolled children in both Quintiles 1 to 3 and Quintiles 4 to 5.

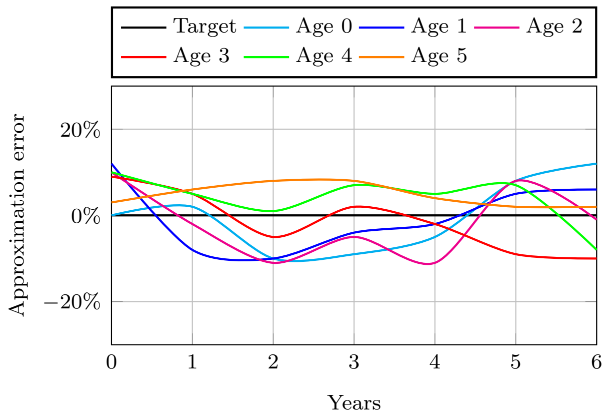

FIGURE 4.6: *Model approximation of reality for the calibrated weights for the number of ECD enrolled children per age group in Quintiles 1 to 3.*

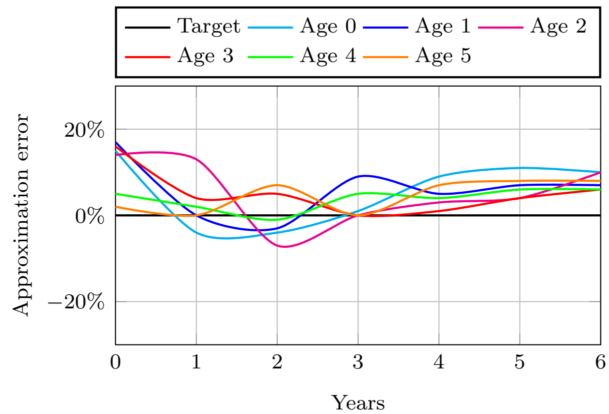

FIGURE 4.7: *Model approximation of reality for the calibrated weights for the number of ECD enrolled children per age group in Quintiles 4 to 5.*

The results of the ECDM are subject to three major assumptions of estimated parameters. The first is the calibrated factor weights of the early childhood system depicted in Figure 4.4 and the second is some of the initial values for each factor in this system.

The third is the division of the number of children enrolled into the different quintiles. Sensitivity analysis on these values gives greater confidence in the reported results. Sensitivity analysis is therefore only relevant for the Quintiles 1 to 3 system as interventions are only performed on these quintiles in order to compare their behaviour with that of Quintiles 4 to 5.

4.2.1 Factor weights within the early childhood system

Two indicators are used to measure the health of the system. The child aptitude score is the aggregate measure of the early childhood system's ability to increase or decrease children's school readiness and the success measure is the ratio of total school ready five-year-olds to the total number of five-year-olds within the system. Figures 4.8 and 4.9 show the impact of change in these indicators when the weights for ECD quality and child stunting, respectively are increased or decreased by a factor of 0.5 to a minimum of 0 and a maximum of five times the calibrated weight. Model results are effected less by changes to the weight of child stunting than by changes to the weight of the ECD quality score, but the impact of weight changes to both is small, *i.e.* less than a 1% increase or decrease.

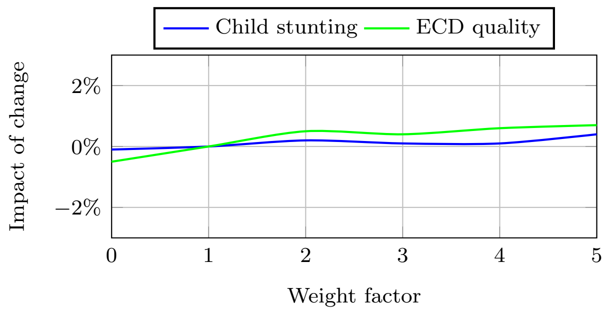

FIGURE 4.8: *The impact on the final child aptitude score per change in the weight size of ECD quality and child stunting, respectively in the early childhood system.*

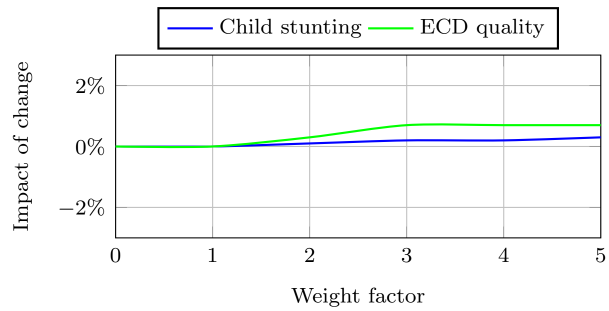

FIGURE 4.9: *The impact on the final success measure per change in the weight size of ECD quality and child stunting, respectively in the early childhood system.*

4.2.2 Initial stock values within the early childhood system

Figures 4.10 and 4.11 contain the impact of change in these indicators when the weights for child stunting, ECD quality, practitioner quality, and infrastructure quality respectively are changed. Predictably from the structure of Figure 4.4, changes to the initial values of child stunting and ECD quality have a greater impact on the final child aptitude score than changes to the practitioner and infrastructure quality, albeit to a small maximum change of approximately 5%. The child progression trains are much less sensitive to changes in these initial values with changes of less than 2% observable when the values are increased to values higher than 0.6. The relatively high values (*i.e.* the values greater than 0.7 in Table 4.11) of the factors within the early childhood system absorb large decreases in the factors tested for sensitivity so that the success measure is not affected.

4.2.3 Initial enrolment distribution

The model's sensitivity to changes in the initial distribution of enrolled to not-enrolled children is decreased to a minimum enrolment of 0% to a maximum of 100%. Figure 4.12 show the impact of change on the child aptitude and success measure for each change to the initial population distribution. The best success measure is achieved for when more than 60% of children are enrolled into ECD programmes, but this increased enrolment has no impact on the system's ability to increase or decrease child aptitude.

4.3 Base case results

Figures 4.13 and 4.14 contain the resultant factor scores and child distributions during the twelve year simulation period for the Quintile 1 to 3 system. The lack of exogenous variables to the system causes the convergence of the factors to an equal score over time. The impact of the low poverty score visibly draws the initially high infrastructure and health scores downwards so that the system achieves a final aptitude goodness score of 0.62. This score ultimately produces a final percentage of school ready five-year-olds at 60% of all children. Therefore, the success measure (*i.e.* the ratio of total school ready five-year-olds to total number of five-year-olds) is 0.60.

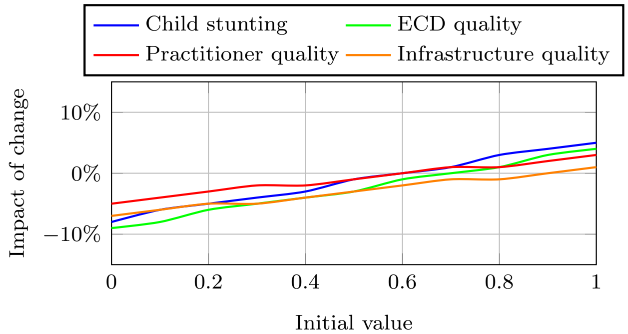

FIGURE 4.10: *The impact on the final child aptitude score per change in the initial value of child stunting, ECD quality, practitioner quality, and infrastructure quality, respectively, in the early childhood system.*

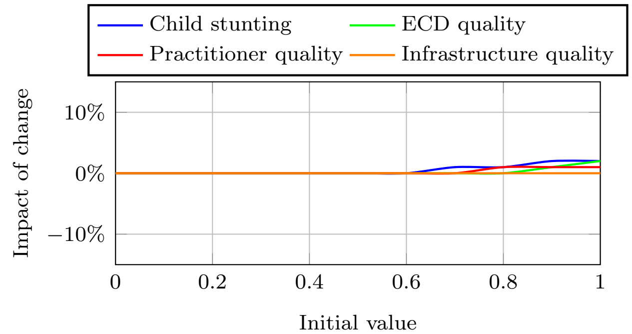

FIGURE 4.11: *The impact on the final success measure per change in the initial value of child stunting, ECD quality, practitioner quality, and infrastructure quality, respectively, in the early childhood system.*

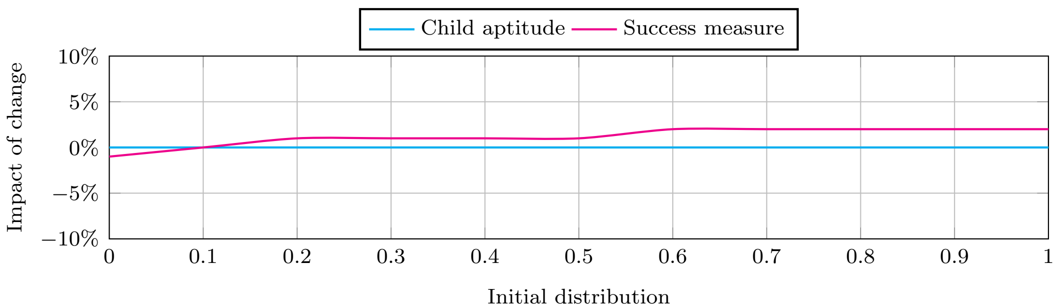

FIGURE 4.12: *The impact on the final child aptitude and success measure per change in the initial distribution of enrolled and not-enrolled children.*

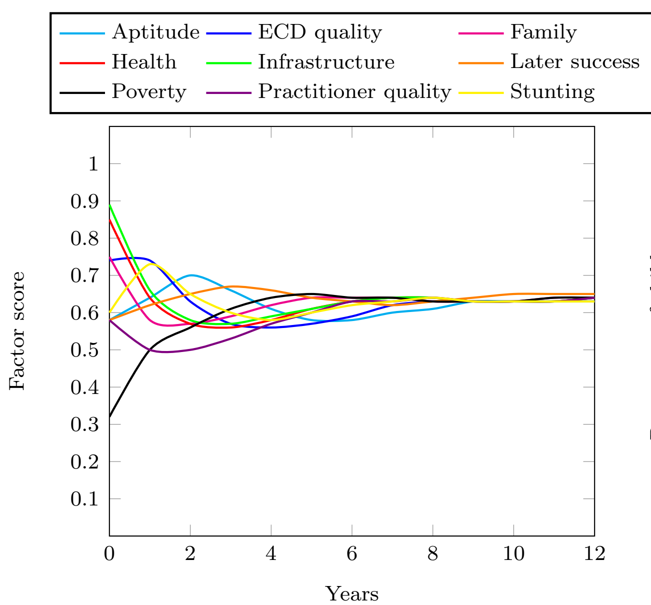

FIGURE 4.13: *Factor scores during the twelve year simulation period for the Quintile 1 to 3 base case.*

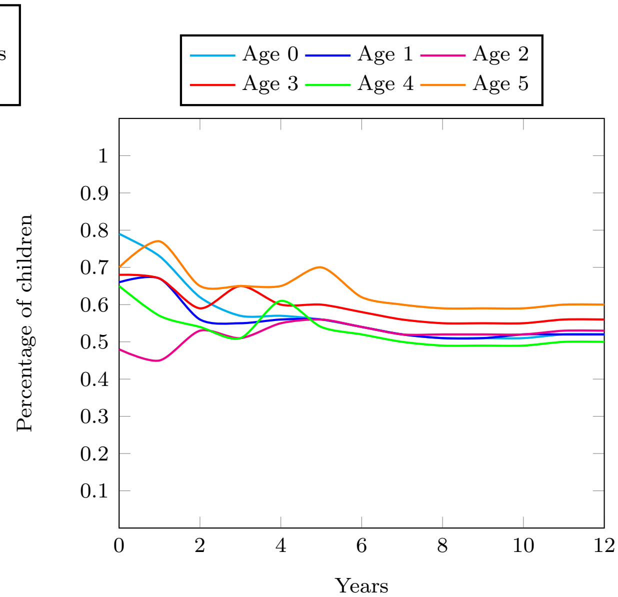

FIGURE 4.14: *The percentage of children with adequate development for their age for the Quintile 1 to 3 base case.*

Figures 4.15 and 4.16 contain the resultant factor scores and child distributions during the twelve year simulation period for the Quintile 4 to 5 system. The high initial values for the system factors remain high throughout the simulation period so that a final aptitude goodness score of 0.80 is achieved. This high score produces a final percentage of school ready five-year-olds at 81% of all children. The success measure therefore is 0.81.

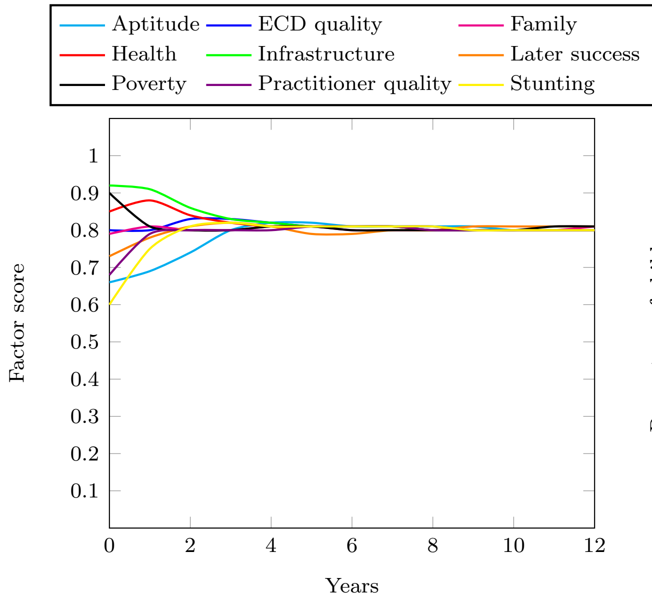

FIGURE 4.15: *Factor scores during the twelve year simulation period for the Quintile 4 to 5 base case.*

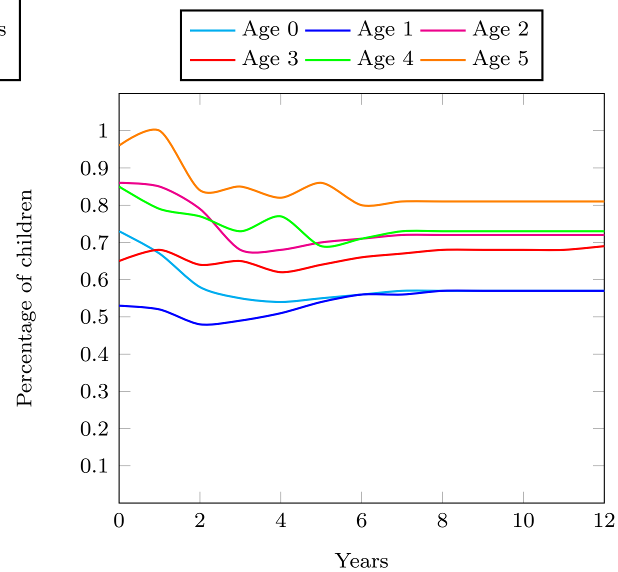

FIGURE 4.16: *The percentage of children with adequate development for their age for the Quintile 4 to 5 base case.*

4.4 Interventions

Three interventions are run to determine whether it is the number of children enrolled into EDC programmes or the quality of the programmes that is contributing to the low percentage of school ready five-year-olds in Quintiles 1 to 3 communities. As shown in Chapter 2, late, once-off and singular interventions are incapable of improving a system. Therefore interventions are applied early, consistently and on multiple factors to examine their impact.

4.4.1 Increased ECD programme quality

A large intervention where the factor score is increased by the maximum is applied to ECD quality, practitioner quality, and infrastructure quality for the Quintile 1 to 3 system. A large intervention takes three years before its impact is experienced and this is the equivalent of ensuring that all ECD programmes are operating at maximum effectiveness. Figures 4.17 and 4.18 contain the resultant factor scores and distribution of children for this intervention. Increasing practitioner quality is effective in particular as the other two factors are initially strong and need only to be maintained. The regular increase in ECD education quality has an improvement effect on the system as a whole so that a final aptitude goodness score of 0.78 is achieved. The percentage of school ready five-year-olds increases to 70% of all children so that the final success measure is 0.70.

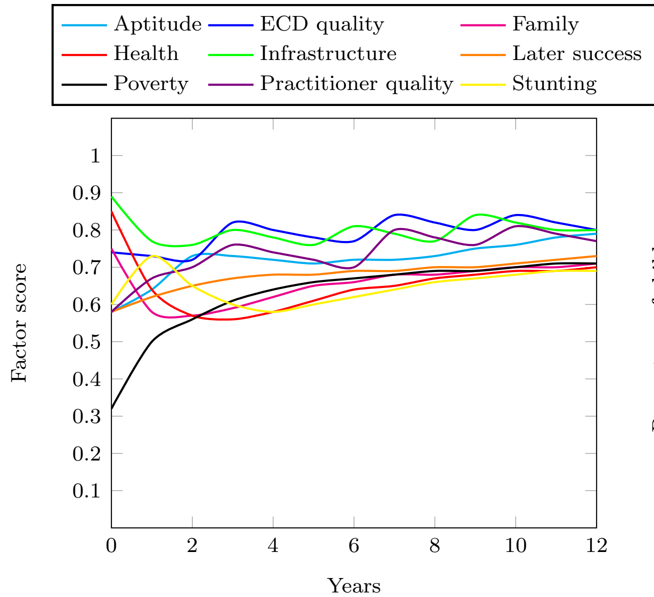

FIGURE 4.17: *Factor scores during the twelve year simulation period for Quintiles 1 to 3 for the quality intervention.*

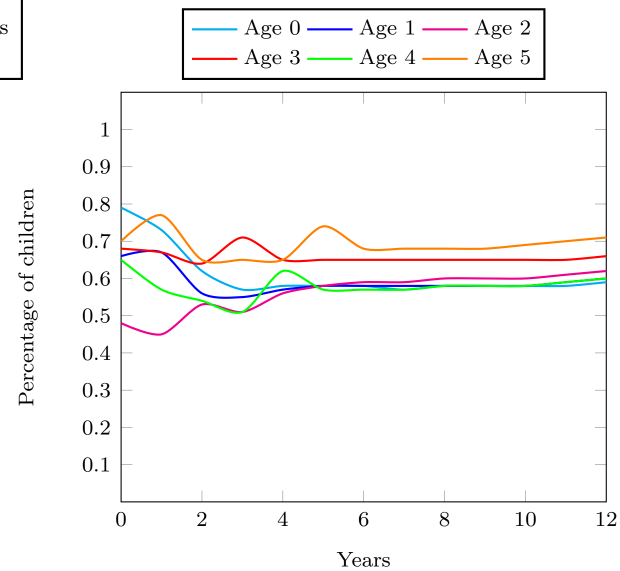

FIGURE 4.18: *The percentage of children with adequate development for their age for Quintiles 1 to 3 for the quality intervention.*

4.4.2 Increased ECD enrolment

The ECDM is initialised so that all children are enrolled into ECD education. This means that no children grow to the age of five having been exposed to only informal or no education. Figures 4.19 and 4.20 contain the resultant factor scores and children distributions for this intervention. Exposing all children to early childhood development at its base case quality improves their cognitive development for only two- and four-year-olds. It cannot improve the percentage for children of other ages, but it is strong enough to maintain a number of school ready five-year-olds at 65% of all five-year-olds. A final aptitude goodness score of 0.66 is achieved and the final success measure is 0.66.

4.4.3 Decreased poverty

All four of the system's reinforcing loops depicted in Figure 4.3 include poverty as a factor. Family poverty also has the greatest difference between the initial values of the Quintiles 1 to 3 and Quintiles 4 to 5. It is therefore necessary to analyse the impact of an intervention in this area on the resultant performance measures. A large intervention is applied to poverty for the Quintile 1 to 3 system where a large intervention takes three years before its impact is experienced and is equivalent of providing an extreme form of regular poverty relief. Figures 4.21 and 4.22 contain the resultant factor scores and distribution of children for this intervention. The regular decrease in the poverty score has an improvement effect on the system as a whole so that a final aptitude goodness score of 0.80 is achieved. The percentage school ready five-year-olds increases to 71% of all children so that the final success measure is 0.70.

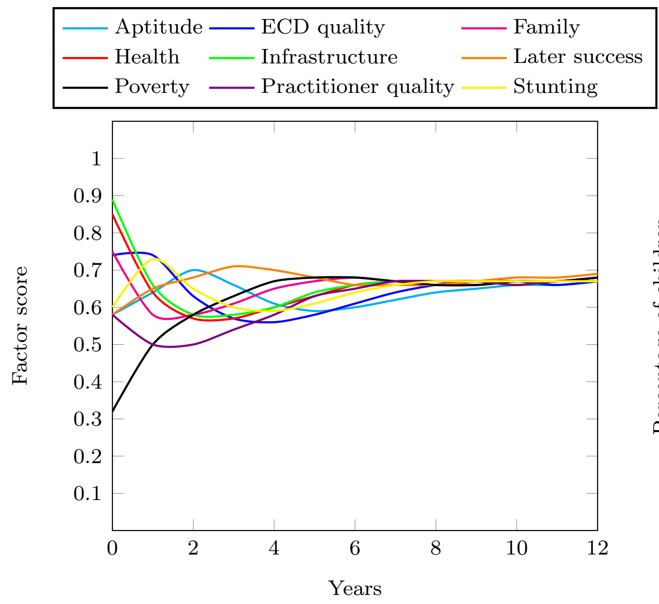

FIGURE 4.19: *Factor scores during the twelve year simulation period for Quintiles 1 to 3 for the increased enrolment intervention.*

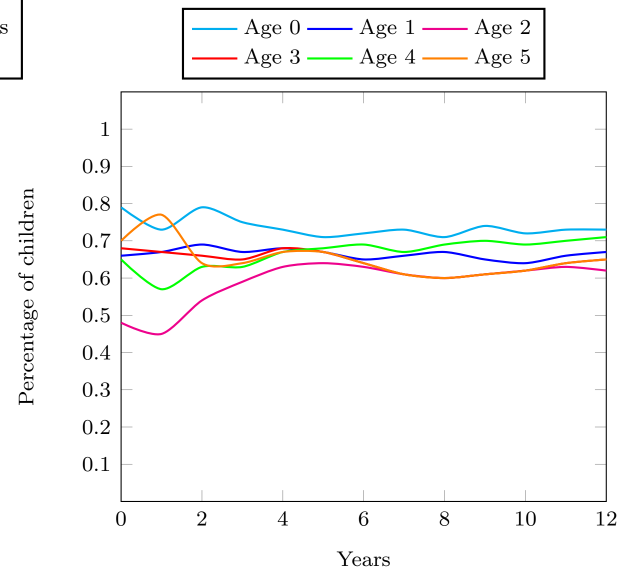

FIGURE 4.20: *The percentage of children with adequate development for their age for Quintiles 1 to 3 for the increased enrolment intervention.*

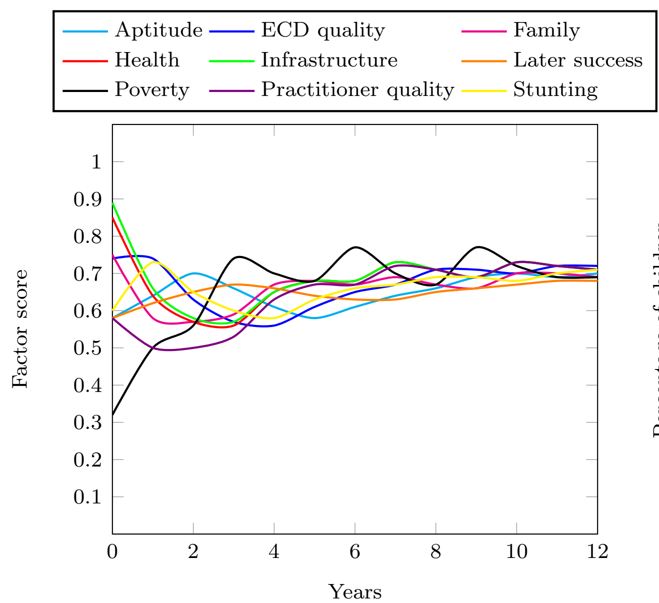

FIGURE 4.21: *Factor scores during the twelve year simulation period for Quintiles 1 to 3 for the decreased poverty intervention.*

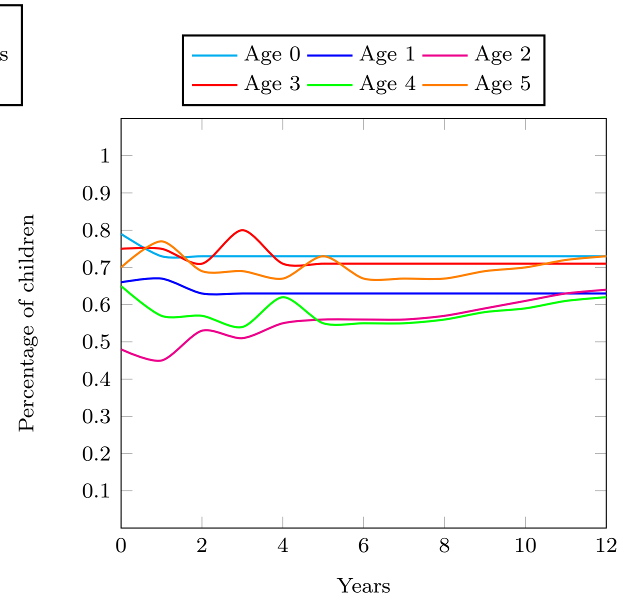

FIGURE 4.22: *The percentage of children with adequate development for their age for Quintiles 1 to 3 for the decreased poverty intervention.*

4.5 Conclusion

The Early Childhood Development Model can be used to answer the research question whether it is the number of children enrolled into formal ECD programmes in the Western Cape or the quality of these programs that contributes most towards the number of school ready five-year-olds in a community. The model is populated with data from national datasets and the model is run for the twelve years leading up to 2030.

Initial values for the weights of the factors impacting childhood aptitude are determined through parameter calibration. Validation of this calibration results in an average RMSE of 14% and 15% for each system, respectively, when the simulated percentage children per age group is fitted to the actual number.

A sensitivity analysis is done on the initial weights of child stunting and ECD programme quality, respectively. The model is more sensitive to changes in the weight of child stunting although the resultant changes to child aptitude and the success measure are very small (*i.e.* smaller than 2%). Further sensitivity analysis is done on the initial stock values of child stunting, ECD programme quality, practitioner quality, and infrastructure quality, respectively. Again the model is more sensitive to changes in the initial stock values of child stunting and ECD quality indicating that interventions in these areas are expected to cause the greatest impact of change on the system.

The base case results show that schools in socio-economic Quintile 1 to 3 communities stabilise at a childhood aptitude score so that up to 60% of all five-year-olds in these communities are adequately prepared to enter Grade 1. In contrast to this children in socio-economic Quintile 4 to 5 communities stabilise at a childhood aptitude score so that up to 81% of all five-year-olds in these communities are adequately prepared.

Three interventions explore the research question of whether it is the number of enrolments into ECD programmes that increases a cohort's school readiness, or rather the quality of the ECD programmes into which they were enrolled. A timely, continuous, and large intervention in the quality of the ECD system for the Quintiles 1 to 3 system leads to a final child aptitude score increase of 0.16 and a success measure increase of 0.10. A timely, continuous, and large intervention in the percentage of children enrolled into formal ECD programmes in the Quintiles 1 to 3 system leads to a final child aptitude increase of 0.04 and a success measure increase of 0.06. A timely, continuous, and large intervention to decrease family poverty in the Quintiles 1 to 3 system leads to a final child aptitude increase of 0.18 and a success measure increase of 0.10. None of the interventions enable the Quintiles 1 to 3 system to match the success measure of the Quintiles 4 to 5 system. Table 4.14 contains a summary of the results.

The research question is answered for the Western Cape by showing that increasing the quality of the formal ECD programmes leads to a greater percentage of school ready five-year-olds than increasing the percentage of enrolled children, but that decreasing community poverty leads to better results than either intervention. Practically this implies that interventions should focus on decreasing the unemployment rate of parents, and allocating more funds to training practitioners and procuring resources for ECD facilities.

	Aptitude score	**Success measure**
Quintiles 1 to 3 base case	0.62	0.60
Quintiles 4 to 5 base case	0.80	0.81
Programme quality intervention	0.78	0.70
Enrolment intervention	0.66	0.66
Poverty intervention	0.80	0.70

Table 4.14: *The summary of the final success metric for each base case and intervention for the ECDM.*

It is again important to remember that the Western Cape province is one of the richest and most functional provinces in the country. These conclusions cannot be assumed to be true for the country as a whole. The model can be populated with province specific data to test the research question in the context of the remaining eight provinces to get specific recommendations for the South African system. The ECDM can also be expanded to include the developmental stage before birth as it currently excludes differentiation of children based on their prenatal circumstances. Lack of adequate nutrition, fetal alcohol syndrome, and other factors during pregnancy can influence cognitive development and should be considered for even more accurate analysis.

CHAPTER 5

The impact of primary school management

Contents

Goals 1 and 2 of the DBE's Action Plan for 2030 is to increase the number of learners in Grade 3 and 6 who, by the end of the year, have mastered the minimum language and numeracy competencies for these grades. The SAQMEC survey is an extensive dataset for assessing the numeracy of South African learners. It defines numeracy as the ability to calculate numbers correctly (operations and number line, square roots, rounding and place value, significant figures, fractions, percentages, and ratios), measurements (related to distance, length, area, capacity, money, and time), and space-data (geometric shapes, charts such as bar, pie, and line, and tables of data) [105].

Kotzé and Strauss [56] analysed the SAQMEC II of 2006 for Grade 6 learners by means of Rasch analysis. Rasch analyses calculate difficulty values for each test item and then use these difficulty values in conjunction with student and teacher responses to each question to create a composite score with a particular mean (*i.e.* 500) and standard deviation (*i.e.* 100). The main benefit of using Rasch analysis is that items are weighted differently based on their difficulty and a student's performance on those items. This differs from simpler measures such as "percentage correct" which weights all answers equally. This model is regarded as ideal for assessing performance [3]. The overall Rasch score of 486.2 was below the required score of 500 with three provinces (Gauteng, Kwazulu-Natal and the Western Cape) achieving above 500. A total of 44% of learners achieved level 2 (emergent) numeracy while 8% achieved level 1 (introductory) numeracy. Only 24% achieved above level 3, and a mere 1.3% achieved competency at level 8. Their *socio-economic status* (SES) difference and learner achievement analysis revealed again the bimodal distribution: 54.9% of all low SES sub-group learners achieved level 2 numeracy, while only 34.2% of all high SES sub-group learners achieved a high level of numeracy.

Spaull [93] analysed the SAQMEC III of 2011 and continued to find that a large proportion of Grade 6 learners were functionally illiterate and functionally innumerate. The extent of these worrying findings remain largely regional. Only one in twenty Western Cape learners were found to be illiterate while ten in twenty in the Limpopo province were found to be illiterate. Nationally, 59% of learners from the poorest socio-economic quintiles were found to be innumerate, while this was true of only 5% of learners in the richest quintile. He recommended interventions to increase homework frequency, access to textbooks, and access to quality pre-school education; improvement in teacher quality, their knowledge bases, and quality while decreasing teacher absenteeism.

The ANA were introduced in 2011 and tested almost six million learners from Grade 2 to 7. A universal ANA was used to test both literacy and numeracy while a verification ANA applied more rigorous procedures to a sample of 1 800 primary schools to verify the results from the universal ANA. ANA 2011 showed that in Grade 3 numeracy, 34% of learners achieved a partial performance level. In Grade 3 literacy, this statistic was 47% at the national level. The Grade 6 language results indicated that 30% of learners partially reached the performance level and in Grade 6 numeracy this statistic was 31% [22]. Van der Berg [108] used ANA 2012 to show the performance discrepancies across SES by sectioning it into quintiles where the first quintile represented learners from the lowest SES and the fifth represented learners from the highest SES. Table 5.1 contains the distribution of learners from each quintile for the top 20% of performers in each grade. The population share of the top two quintiles (Quintiles 4 to 5) was around 30%, yet their share of the best primary school results was an average of 46%, showing how skewed the distribution of learning outcomes were across the socio-economic spectrum.

Quintile	**1**	**2**	**3**	**4**	**5**	**4 and 5**
Share of the top 20%						
Grade 1	20%	17%	24%	18%	22%	40%
Grade 2	19%	15%	23%	18%	25%	43%
Grade 3	18%	15%	22%	18%	27%	45%
Grade 4	16%	12%	20%	19%	32%	51%
Grade 5	16%	13%	19%	18%	34%	52%
Grade 6	20%	16%	20%	16%	29%	45%
Share of the population						
Grade 1	25%	20%	25%	16%	13%	29%

Table 5.1: *Share of learners from different quintiles in the top 20% of learner performance in each grade according to ANA 2012.*

PIRLS 2016 is an international comparative evaluation of reading literacy of Grade 4 learners. PIRLS is a trend study and the methods have been developed to measure changes over time. South Africa has participated in three rounds, namely 2006, 2011 and 2016. The 2016 PIRLS tested 12 810 fourth graders from 293 schools and found that 78% of those who could read could not read with comprehension. This means that learners can identify individual words, but that they are reading at a speed too slow for their short-term memory to record the decoded information. No significant difference in achievement for South African learners was noted between 2011 and 2016 despite the lower score in 2016. Again, only the Western Cape learners' achievement was significantly higher than any other province, with the exception of the Gauteng province [51].

Most interventions by the South African government to improve the situation has been to allocate more financial resources to the problem. The overall 2019 to 2020 national budget allocation for the DBE is R24.5 billion, an increase of 3.4% from the previous year's allocation [67]. Financial resources may be used to employ and train teachers, provide resources such as stationary and textbooks, and procure food for feeding schemes. Only about half of learners' days are spent in the classroom. The remaining part of their world consists of interaction with family, home resources, and their community. Social interventions may prove to be effective in changing undesirable system behaviour and low academic output.

Adequate performance at Grade 3 and 6 level is of the utmost importance as these grades are gateways into the next phase of education. A learner's Grade 3 performance greatly determines how they will fare in the intermediate phase while a learner's Grade 6 performance greatly determines how they will fare in the lower secondary phase. In this chapter the PSM is presented and the causal linkages between improved primary school management and primary school achievement on the whole education system are described. It gives insight into the mechanics of the model's design, followed by a brief discussion on the input data and assumptions used to populate the model. The base case results are shown, followed by interventions and a discussion of their results. The chapter finishes with some concluding observations on the results. Improved academic performance can be achieved by increasing classroom resources through greater financial budget allocation. It can also be achieved by improving learners' social and home circumstances. The research presented in this chapter answers the question of which of these approaches is most effective to increase the average literacy and numeracy scores of learners within the Western Cape education system.

5.1 The Primary School Model

The PSM extends the complexity of the SEM presented in Chapter 2 by expanding the single learner strength stock to an entire system within which primary school learners find themselves. Figure 5.1 highlights the areas of the SEM expanded by the PSM. The PSM simulates the progression of learners from Grade 1 to 7 in a public primary school. This progression is impacted by seven factors: The effectiveness of the teachers, the classroom resources, the amount of engaged time, the learner's motivation, their level of family support, their initial aptitude, and the extent to which learning is disrupted through community unrest. The model is a combination of two sub-models, where the output of the first sub-model becomes the input to the second, and vice versa.

5.1.1 The primary school learner system

Figure 5.2 contains the causal relationships between each of the seven endogenous and one exogenous factors within the primary school learner system. It is driven by these four reinforcing loops depicted in Figure 5.3.

School resources may be defined as the number of computers and software licenses available for instruction, the state of the school buildings, the availability of textbooks, the availability of

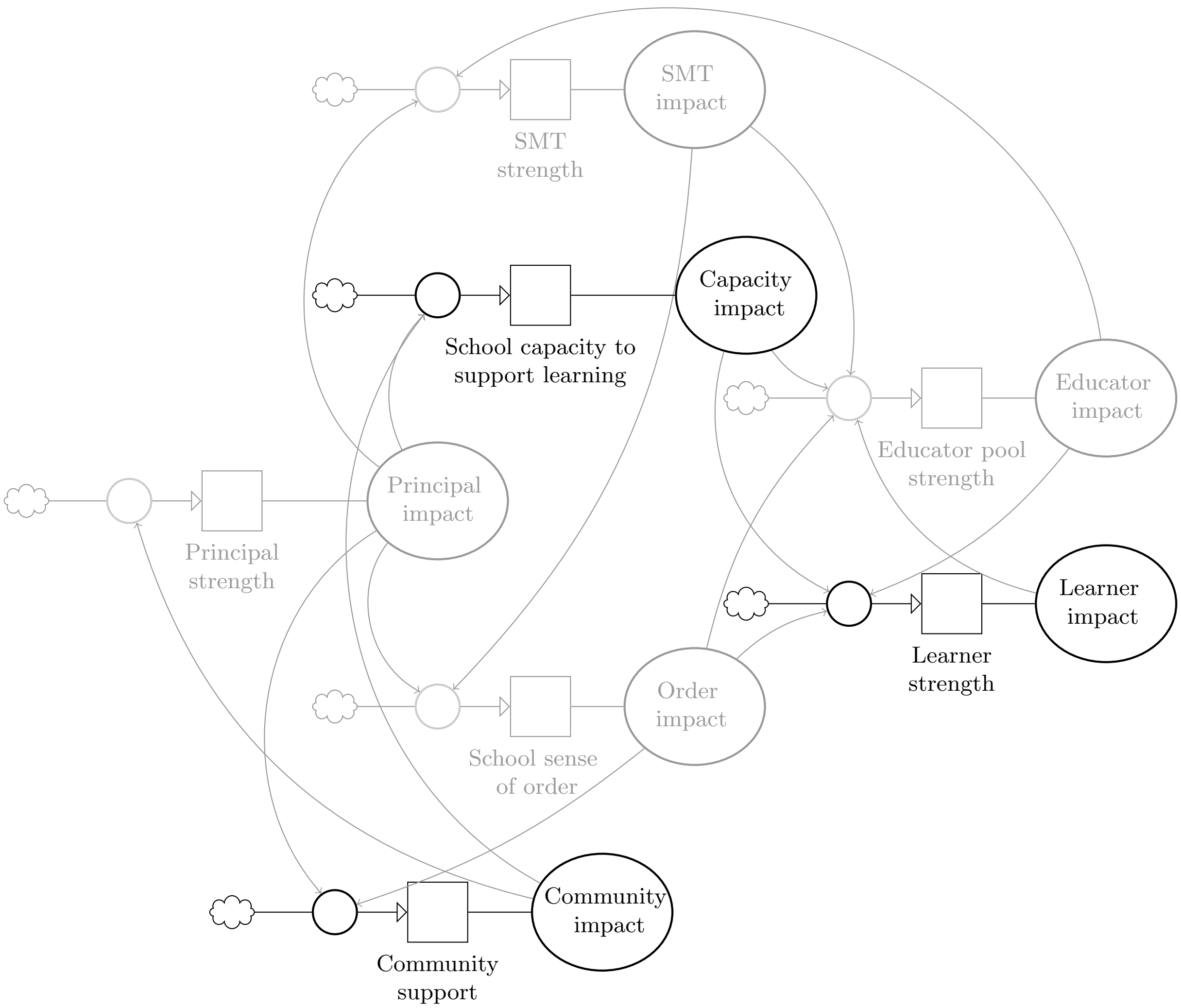

FIGURE 5.1: *The PSM expands the complexity of the SEM as a subsystem underlying community support, school capacity to support learning, and learner strength highlighted in the stock-and-flow diagram.*

workbooks, and the availability of stationary and other concrete classroom objects. Sidebe [90] added to this the presence of safe and clean toilet facilities. Visser and Juan [114] found that an increase in the quality of resources attract teachers of higher effectiveness and is positively correlated with learner achievement. Ye [119] used the Teacher Working Condition Survey and Student Perception Survey in Measures of Effective Teaching and found that classroom related working conditions at school played a significant role in effective teaching.

Teacher effectiveness may be described by a score that includes a teacher's involvement with learners' activities, their enthusiasm, their subject knowledge, their engagement in elaborate conversation with learners, their facilitation of learning activities, their attention to requests for help, their reflection on their own practice, their encouragement of learners, and their assistance to learners to reach their intellectual potential [45, 79], the dimensions of the number of days that they are physically present, the number of teachers in the educator pool, and their active

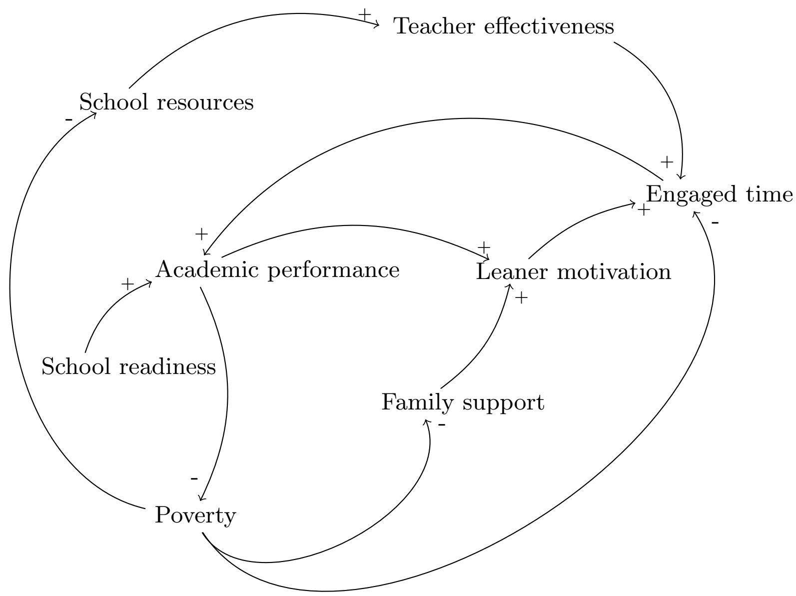

FIGURE 5.2: *The causal loop diagram for learner achievement at primary school level.*

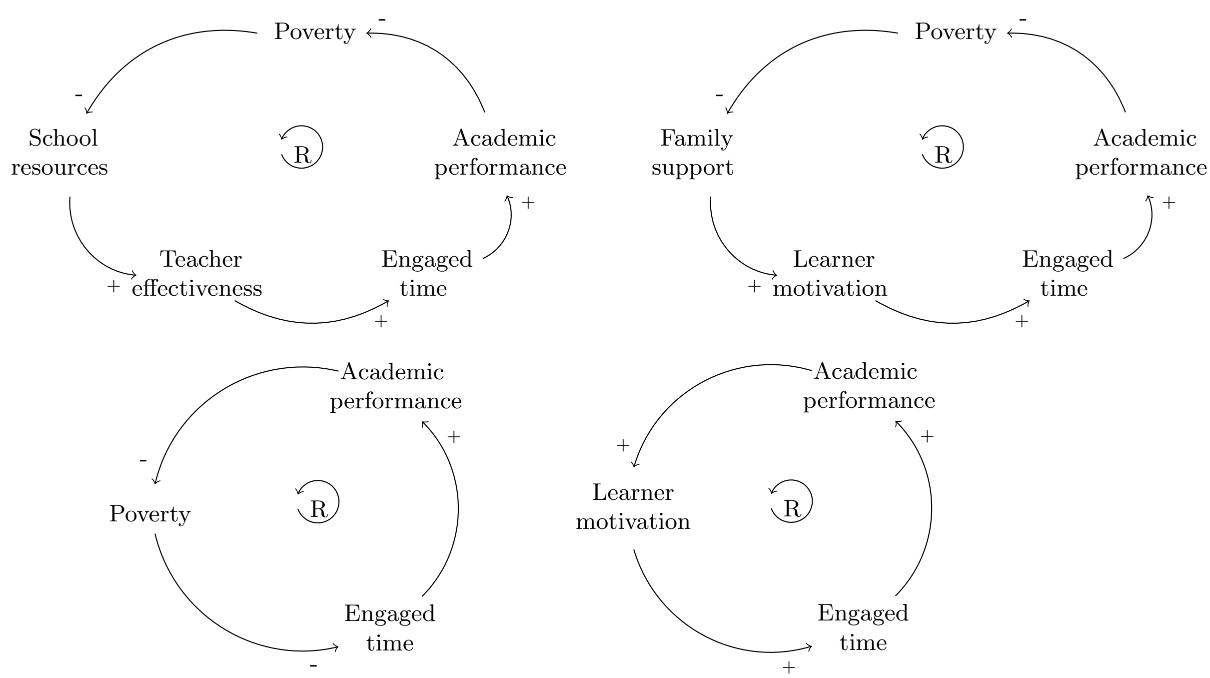

FIGURE 5.3: *There are four reinforcing loops in the primary school learner system.*

participation in extra-mural activities.

The engaged time in the classroom increases as the teacher effectiveness increases [46, 69]. Engaged time may be defined as the amount of curriculum content covered in combination with the learners' attention and engagement. Carroll [10] defined content studied as the amount of content from the prescribed textbooks covered, the number of pages of the textbook read during the year, the measure to which the material was presented relevant to the assessment, and the number of completed workbook pages by learners before they were assessed. Stallings and

Kaskowitz [96] defined learners as engaged only when they are obviously working on reading or mathematics activities and not when they were engaged in group work or play. In other words, only alone-time with textbooks and workbooks was correlated with learner achievement. An increase in engaged time leads to an increase in learner achievement [37, 69, 76, 79]. Learner achievement may be quantified in terms of examination scores, or as Aftab and Riaz [1] puts it, "the measurement in differentiating a learner's level of knowledge for them to go further in their studies, gain scholarship and obtain better entry level at top universities".

School readiness may be defined as the combination of learners' task knowledge (knowing what to do) and task skill (knowing how to do it) [64]. This ability is nurtured during pre-school development and acquired during early childhood education. Learners who rank higher in ability have greater capacity for insight, formation processing, attending to important stimuli and excluding unimportant stimuli, and using knowledge than those who rank lower in ability. They perform better because they learn more efficiently and effectively [6, 17, 62, 77].

Motivation to learn is measured by the learners' attention and effort in classroom activities [89]. Elliot *et al.* [36] found that in particular younger pupils are motivated by positive feedback from their parents. They also found that motivation was higher in classes where learners did not feel hostility, respected the teacher, and where tasks were not overly demanding. Furthermore, learners at primary school level, in particular, were mostly motivated by the attainment of good grades. This positive impact of increased academic performance on learner motivation was further reiterated by Aftab and Riaz [1], while the positive of impact of increased family support on learner motivation was also shown by Gonzalez-Pienda *et al.* [43].

Family support can be measured by the availability of resources at home, parental involvement in the learner's academic activities, the parents' own level of education, and home culture. Banovcinova *et al.* [5] showed an association between poverty and disrupted home life. They found that a dysfunctional family was weak in communication and behaviour control and that family stress due to poor economic circumstances negatively affected the way parents fulfilled their parental role.

According to the Living Conditions Survey of 2014 and 2015, approximately half (49.2%) of the South African adult population were living below the upper-bound poverty line. Gauteng and the Western Cape had the lowest proportion of adults living in poverty. Female-headed households mostly felt the experience of poverty since they had better access to housing and electricity, but not to water, sanitation and refuse removal services [99]. Some of the factors that impact a child's engaged time include the following: very young, single or low educational level parents, their unemployment, their abuse and neglect, substance abuse, location in dangerous neighbourhoods, homelessness, mobility, and a child's exposure to inadequate or inappropriate educational experiences.

Education offers a basis for poverty eradication and the improvement of economic development. It is the foundation on which a great deal of citizens' financial and social well-being is constructed. Education is the key to enhancing economic efficiency and social consistency by enhancing the labour force's value and effectiveness and so raising the poor out of poverty. It improves general labour productivity and intellectual flexibility and guarantees that a nation is competitive in the world market, which is now defined by altering technologies and manufacturing techniques [70]. The effect of inferior academic achievement on poverty is therefore significant.

Figure 5.4 contains the stock-and-flow diagram for the primary school learner system. Each factor increases or decreases the other by means of biflows to achieve a new total academic achievement score for each simulation time step. This academic achievement score serves as input into learner progression trains. Scores are again scaled to be values between 0 and 1.

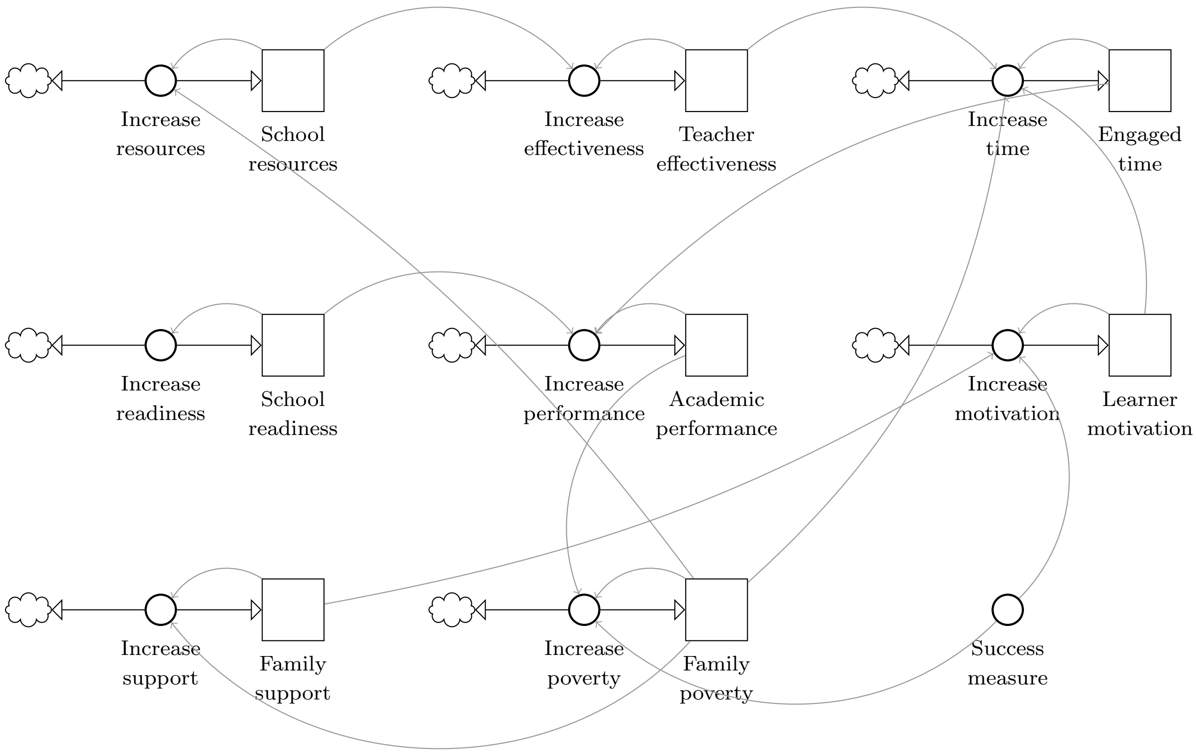

FIGURE 5.4: *The stock-and-flow diagram for the primary school learner system in the PSM.*

Let F^R be the score for school resources, F^T be the score for engaged time, F^P be the score for academic performance, F^N be the score for learner motivation, and F^F be the score for family support. The score for teacher effectiveness is F^E, and the score for family poverty is F^V as defined in Chapter 3 and the score for school readiness is F^B, an exogenous variable as defined in Chapter 4. The change in each factor during the simulation period is described by

$$\frac{\mathrm{d}F^R}{\mathrm{d}t} = \frac{F^R + F^V}{2} - F^R, \tag{5.1}$$

$$\frac{\mathrm{d}F^E}{\mathrm{d}t} = \frac{F^E + F^R}{2} - F^E, \tag{5.2}$$

$$\frac{\mathrm{d}F^T}{\mathrm{d}t} = \frac{F^T + F^E + F^N + F^V}{4} - F^T, \tag{5.3}$$

$$\frac{\mathrm{d}F^P}{\mathrm{d}t} = \frac{w^P F^P + w^B F^B + w^T F^T}{w^P + w^B + w^T} - F^P, \tag{5.4}$$

$$\frac{\mathrm{d}F^N}{\mathrm{d}t} = \frac{F^N + F^F}{2} - F^N, \tag{5.5}$$

$$\frac{\mathrm{d}F^F}{\mathrm{d}t} = \frac{F^F + F^V}{2} - F^F, \text{ and} \tag{5.6}$$

$$\frac{\mathrm{d}F^V}{\mathrm{d}t} = \frac{F^V + F^P}{2} - F^V, \tag{5.7}$$

where w^P, w^B, and w^T are the weighted influence of academic performance, school readiness and engaged time, respectively. These factors influence academic performance and learner progression at each primary school grade.

The NSES [54] investigated school outcomes in South Africa with a sample of 268 schools representative of all South African provinces except Gauteng. The study followed a cohort of children for three years, commencing with Grade 3 in 2007 and ending with Grade 5 in 2009. Around 16 000 children participated in each year of data gathering, within which a cohort of 8 383 was successfully tracked over all three years. School-level and classroom data was collected by means of interviews and direct observations. Learner performance was assessed by means of literacy and mathematics tests administered to learners. Teacher practices were assessed through an analysis of planning and assessment records and a test administered to mathematics and language teachers. The study covered a wide range of outcomes and was intended to generate information on what is important in improving student performance in the context of South African education.

Taylor [104] analised the NSES and found that learners who were exposed to English through broadcast media achieved higher scores when home language and poverty was taken into account, as did children who read frequently on their own at home. African language students in historically white schools enjoyed a considerable performance advantage over those in historically black schools. A positive effect in both literacy and mathematics was obtained in his regression models for schools in which the principal was present on the day of the survey and no teachers were absent. In schools which covered more than 25 curriculum mathematics topics a significant effect could be seen. A large and statistically significant negative impact on literacy scores occurred when no paragraph length writing had been undertaken over the year. On the other hand a positive effect was found for schools in which more than 27 writing exercises of all types were encountered in students' English workbooks.

Table 5.2 contains the percentage of school principals reporting no problems impacting academic performance within Western Cape public primary schools per socio-economic group (expressed as either a poor or a rich community). The NSES defines adequate school resources as proper supply materials and classrooms. In other words, school resources must support teaching and learning. It defines effective teachers as teachers who are punctual, present, policy compliant, and able to understand the curriculum that they are teaching. The percentage of schools with adequate engaged time are those schools where more than fifteen hours per week are spent on teaching literacy and numeracy proficiencies. The NSES defines motivated learners as those who do not display bad discipline or tardiness. It defines adequate family support as a school's relationship with the community so that parental interference in school management is low but their educational assistance to learners at home is high.

Table 5.3 contains the average household monthly income for learners in Western Cape public primary schools per quintile from 2007 to 2009. The lowest income bracket describes utmost poverty and is therefore assigned a goodness score of 0. The highest income bracket is assigned a goodness score of 1 and the remaining brackets are scored evenly between these extremes. The large difference between the scores for each quintile is an accurate mirror of South Africa's high Gini coefficient.

Table 5.4 contains the average academic performance for literacy and numeracy for Grade 1 to Grade 6 learners in Western Cape public schools per quintile group from 2007 to 2009. The literacy score is the average percentage of correct answers to a test comprising 40 questions. These questions test learners' proficiency in word recognition, interpretation, grammar, comprehension, writing, and reasoning. The numeracy score is the average percentage of correct answers to a test comprising 53 questions. These questions test learners' proficiency in counting, number ordering, shape recognition, number patterning, addition, subtraction, multiplication, division, fractions, and their ability to calculate mass, length, and time. Table 5.5 contains a summary of the initial values for the PSM factor scores.

Barrier	2007	2008	2009	Average	PSM score
			Quintile 1 to 3 schools		
Adequate school resources	56%	59%	70%	62%	0.62
Effective teachers	54%	76%	89%	73%	0.73
Adequate engaged time	-	53%	70%	62%	0.62
Adequate learner motivation	71%	41%	80%	64%	0.64
Adequate family support	29%	24%	20%	24%	0.24
			Quintile 4 to 5 schools		
Barrier	**2007**	**2008**	**2009**	**Average**	**PSM score**
Adequate school resources	70%	50%	65%	62%	0.62
Effective teachers	80%	83%	100%	88%	0.88
Adequate engaged time	-	75%	90%	83%	0.83
Adequate learner motivation	70%	75%	70%	72%	0.72
Adequate family support	60%	75%	100%	78%	0.78

TABLE 5.2: *The average percentage of learners reporting no barriers to learning in Western Cape public schools from 2007 to 2009 according to the NSES.*

Household income	Goodness score	Quintiles 1 to 3	Quintiles 4 and 5
R0 to R540	0.0	33%	0%
R540 to R1 151	0.3	20%	0%
R1 151 to R2 340	0.5	46%	0%
R2 340 to R5 956	0.8	0%	68%
More than R5 956	1.0	0%	32%
PSM score		0.29	0.86

TABLE 5.3: *The percentage of learners in Western Cape public schools per household income level per quintile group within the Western Cape from 2007 to 2009 according to the NSES.*

Area	2007	2008	2009	Average	TEM Score
			Quintile 1 to 3 schools		
Literacy score	25%	43%	45%	38%	0.38
Numeracy score	27%	39%	58%	41%	0.41
			Quintile 4 to 5 schools		
Area	**2007**	**2008**	**2009**	**Average**	**TEM Score**
Literacy score	38%	48%	60%	49%	0.49
Numeracy score	50%	58%	73%	60%	0.60

TABLE 5.4: *The average academic achievement of learners per quintile group in Western Cape public schools from 2007 to 2009 according to the NSES.*

5.1.2 Learner progression

Table 5.7 contains the average number of primary school learners in the Western Cape primary school system per grade and socio-economic quintile for 2010 to 2016 [34]. South Africa implemented the *Outcomes Based Education* (OBE) academic grading in 2008. The OBE system, when it was in its experimental stage, originally used a scale from 1 - 4 (a pass being a score of 3), but this system was considered too coarse and was replaced by a scale from 1 to 7. Table 5.6 lists the scale of achievement for the national curriculum [23]. In order to pass a grade, learners have to achieve 50% or more in one language (at home language level), 40% or more in the second required official language (at first additional language level), 40% or more in mathemat-

PSM factor	**Symbol**	**Quintiles 1 to 3**	**Quintiles 4 and 5**
Teacher effectiveness	F^E	0.73	0.88
Engaged time	F^T	0.62	0.83
Learner motivation	F^N	0.64	0.72
Poverty	F^V	0.29	0.86
School resources	F^R	0.62	0.62
Academic performance	F^P	0.40	0.55
Family support	F^F	0.24	0.78

TABLE 5.5: *The initial values for the factor scores of the PSM.*

ics, and 40% or more in any three of the other required subjects (including natural sciences, life orientation, social sciences, arts and culture, and economic management sciences). In South Africa's current grading system, a fail at 29% is one of the lowest in the world. A learner who does not meet the requirements for promotion can progress to the next grade to prevent them from being retained for more than four years.

Score	**Description**	**Percentage**
7	Outstanding achievement	80% - 100%
6	Meritorious achievement	70% - 79%
5	Substantial achievement	60% - 69%
4	Adequate achievement	50% - 59%
3	Moderate achievement	40% - 49%
2	Elementary achievement	30% - 39%
1	Not achieved	0% - 29%

TABLE 5.6: *The scale of achievement for the basic education OBE curriculum.*

Tables 5.8 and 5.9 contain the distribution of learners by average academic achievement score per grade and socio-economic group in the Western Cape public primary school system from 2007 to 2009. These values are used to initialise the stocks simulating primary school learner progression. Both systems begin with a majority of high achievers in Grade 1 which quickly deteriorate to a majority of above average achievers. By Grade 7 the majority of learners are low achievers in the Quintiles 1 to 3 system, while the Quintiles 4 to 5 system is able to maintain a majority of at least passing learners. The stock-and-flow diagram in Figure 5.5 depicts this process.

As in Chapter 2, each grade consists of a number of learners distributed over four achievement categories. Learners' performance increases or decreases based on the strength of the system. Recall from equation (2.1) that the arrayed stock of the number of learners in Grade i is given by

$$\boldsymbol{G}_i = [G_{i1}, G_{i2}, G_{i3}, G_{i4}] \tag{5.8}$$

for $i \in [1, 2, 3, 4, 5, 6, 7]$ for a primary school.

				Quintliles 1 to 3				
Grade	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**Average**
1	28 864	25 489	25 635	25 814	29 600	26 257	23 013	26 382
2	36 142	31 416	31 655	34 861	35 043	34 315	38 641	34 582
3	30 604	26 705	27 407	31 240	31 174	31 645	38 333	31 015
4	29 983	24 992	24 955	27 947	28 791	29 599	35 633	28 843
5	30 515	25 541	24 083	26 291	26 060	27 753	35 920	28 023
6	29 190	24 796	24 104	23 620	23 264	23 977	32 102	25 865
7	28 406	24 227	23 938	23 317	21 019	21 583	28 872	24 480
				Quintliles 4 to 5				
Grade	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**Average**
1	17 773	21 540	22 505	24 595	37 485	34 298	24 502	26100
2	39 539	43 919	46 276	45 011	55 842	56 140	47 617	47763
3	36 884	39 924	42 133	41 866	49 249	50 427	47 561	44006
4	35 851	38 111	39 938	39 676	44 903	47 012	43 764	41322
5	37 180	37 832	40 088	38 127	41 788	45 203	43 868	40584
6	36 954	37 299	37 933	36 610	35 311	39 057	38 968	37447
7	37 418	36 497	38 022	36 087	33 946	34 439	36 107	36074

TABLE 5.7: *The annual and average number of learners per socio-economic group per grade in the Western Cape public primary school system from 2010 to 2016 according to the SNAP Survey of Ordinary Schools.*

	Total score			
Grade	**7**	**6 - 5**	**4 - 2**	**1**
1	52%	24%	20%	4%
2	19%	32%	31%	18%
3	18%	18%	35%	29%
4	13%	24%	48%	14%
5	14%	27%	47%	12%
6	14%	17%	46%	23%
7	13%	16%	37%	30%

TABLE 5.8: *The distribution of learners by average achievement score per grade in Quintiles 1 to 3 schools in the Western Cape public primary school system from 2007 to 2009 according to the NSES.*

	Total score			
Grade	**7**	**6 - 5**	**4 - 2**	**1**
1	63%	24%	9%	4%
2	23%	45%	21%	11%
3	20%	25%	36%	19%
4	18%	31%	35%	16%
5	16%	35%	40%	9%
6	14%	27%	47%	12%
7	16%	24%	36%	24%

TABLE 5.9: *The distribution of learners by average achievement score per grade in Quintiles 4 to 5 schools in the Western Cape public primary school system from 2007 to 2009 according to the NSES.*

In equation (5.8)

- G_{i1} indicates the number of learners who achieve a high pass score, *i.e* they are achieving an average numeracy and literacy score of 7;
- G_{i2} indicates the number of learners who achieve a standard pass score, *i.e.* they are achieving an average numeracy and literacy score of 5 to 6;
- G_{i3} indicates the number of learners who achieve a pass score, *i.e.* they are achieving an average numeracy and literacy score of 2 to 4; and
- G_{i4} indicates the number of learners who achieve a low score , *i.e.* they are achieving an average numeracy and literacy score of 1.

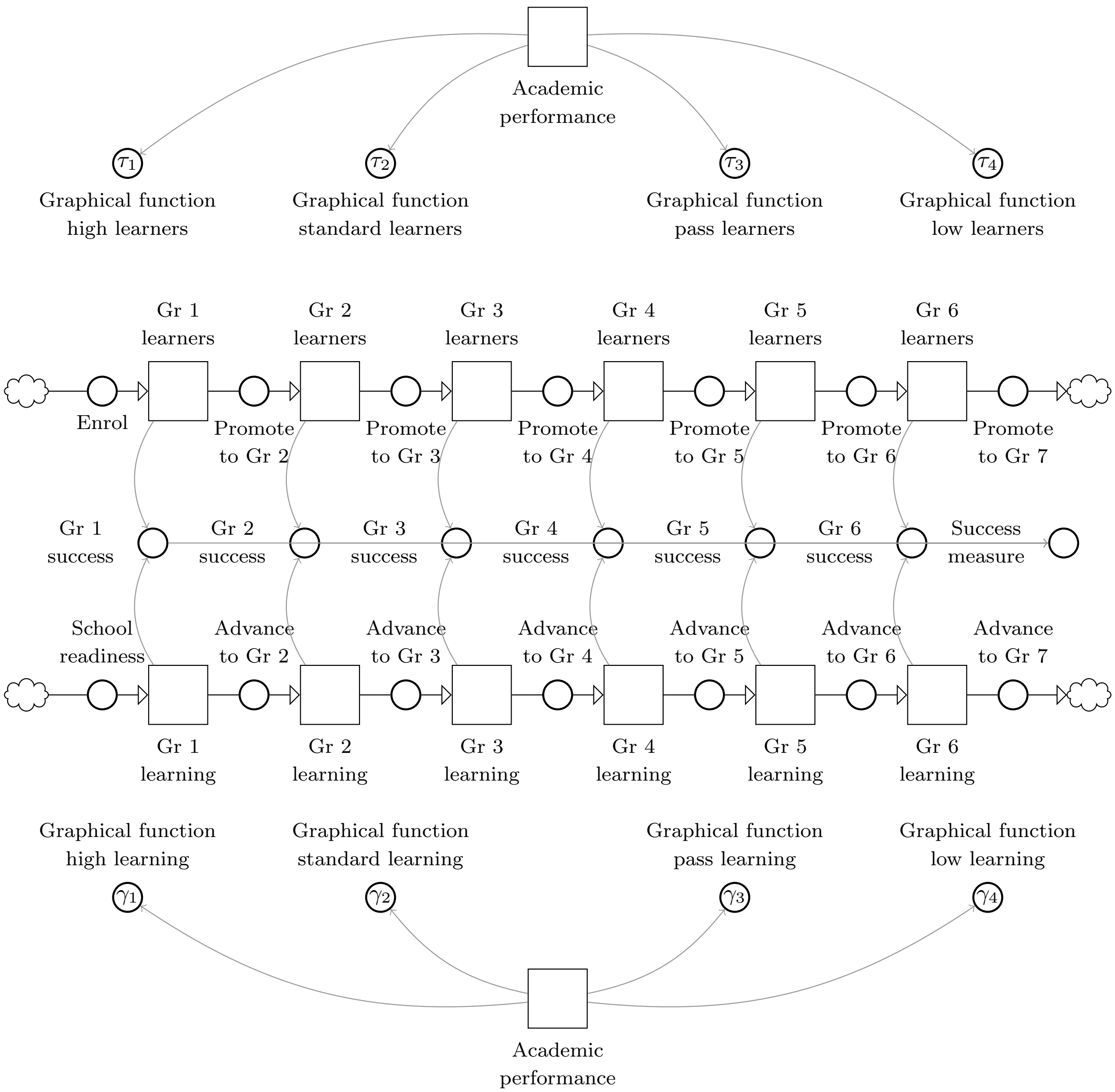

FIGURE 5.5: *The stock-and-flow diagram for learner progression in the PSM.*

The enrolments

$$\boldsymbol{E} = [E_1, E_2, E_3, E_4] \tag{5.9}$$

are a set of learners distributed across the same four performance categories and it is assumed that no learners enter the system at any other grade. It is further assumed that no learners leave the system by dropping out at primary school level.

For each of the performance categories $j \in [1, 2, 3, 4]$, the progression of primary school learners is described by

$$\frac{\mathrm{d}\boldsymbol{G}_i}{\mathrm{d}t} = \begin{cases} \boldsymbol{E} - \boldsymbol{G}_{i+1} & \text{for } i = 1, \text{and} \\ \left[\tau_1 \sum_{j=1}^{4} G_{(i-1)j}, \tau_2 \sum_{j=1}^{4} G_{(i-1)j}, \tau_3 \sum_{j=1}^{4} G_{(i-1)j}, \tau_4 \sum_{j=1}^{4} G_{(i-1)j}\right] - \boldsymbol{G}_{i+1} & \text{otherwise,} \end{cases} \tag{5.10}$$

where τ_j is the performance category learner converter and the result of the graphical function $f_j(F_P)$ described in Figure 5.6 for all $j \in [1, 2, 3, 4]$. The graphical functions were determined by means of parameter calibration for the number of learners in each primary school grade and the simulated values are achieved. The higher the academic performance, the more learners achieve a high pass score, and vice versa. Average academic performance produces more learners achieving a standard and pass score.

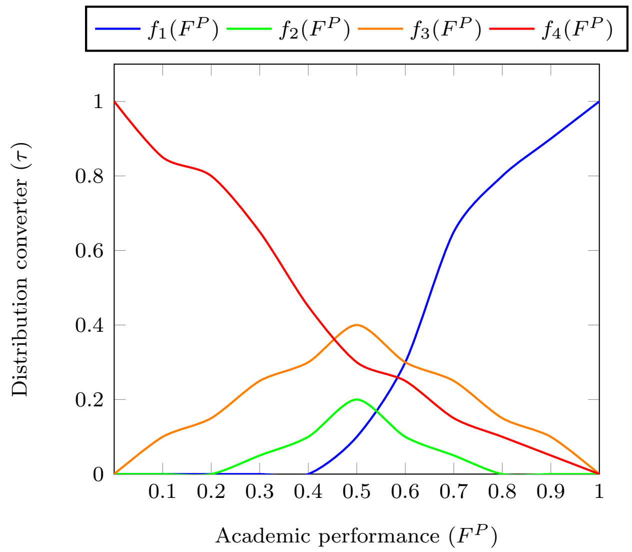

FIGURE 5.6: *The graphical functions for argument F^P used to determine the distribution of learners in each performance category for each grade for PSM learner progression.*

The PSM measures academic performance in two areas (literacy and numeracy) while the SEM presented in Chapter 2 measures it in four areas. Therefore, redefine Equation (2.3) for $\boldsymbol{L}_i$ so that

$$\boldsymbol{L}_i = [L_{i11}, L_{i12}, L_{i21}, L_{i22}, L_{i31}, L_{i32}, L_{i41}, L_{i42}] \tag{5.11}$$

is an arrayed stock of the learning acquired for each learner performance category for $i \in [2, 3, 4, 5, 6]$ where

- L_{ij1} refers to the average numeracy percentage that a learner scores on formal assessments (*e.g.* tests and exams) in Grade i and performance category j; and
- L_{ij2} refers to the average literacy percentage that a learner scores on formal assessments (*e.g.* tests and exams) in Grade i and performance category j.

The learners enrolled in Grade 1 enter the system with a predetermined school readiness grouped according to the performance categories across the two performance metrics. Redefined Equation (2.4) from Chapter 2 describing school readiness becomes

$$\boldsymbol{A} = [A_{11}, A_{12}, A_{21}, A_{22}, A_{31}, A_{32}, A_{41}, A_{42}]. \tag{5.12}$$

The progression of primary school learners' knowledge is described by

$$\frac{\mathrm{d}\boldsymbol{L}_i}{\mathrm{d}t} = \begin{cases} \boldsymbol{A} - \boldsymbol{L}_{i+1} & \text{for } i = 1, \text{and} \\ \Big[\frac{\gamma_1+L_{i11}}{2}, \frac{\gamma_1+L_{i12}}{2}, \\ \quad \frac{\gamma_2+L_{i21}}{2}, \frac{\gamma_2+L_{i22}}{2}, \\ \quad \frac{\gamma_3+L_{i31}}{2}, \frac{\gamma_3+L_{i32}}{2}, \\ \quad \frac{\gamma_4+L_{i41}}{2}, \frac{\gamma_4+L_{i42}}{2}\Big] - \boldsymbol{L}_{i+1} & \text{otherwise} \end{cases} \tag{5.13}$$

where γ_j is the performance category learning converter and the result of the graphical function $g_j(F^V)$ described in Figure 5.7 for all $j \in [1, 2, 3, 4]$. The lowest academic performance for a high scoring learner is an average of 80% on a numeracy and literacy assessment. The highest academic performance for a high scoring learner is an average of 100% on the assessment. Similarly the minimum and maximum achievement for standard scoring learner is 60% and 80%, respectively. For a pass scoring learner it is 30% and 60%, respectively. For a low scoring learner it is 0% and 30%, respectively. A linear increase in achievement is assumed between these performance extremes for all achievement categories.

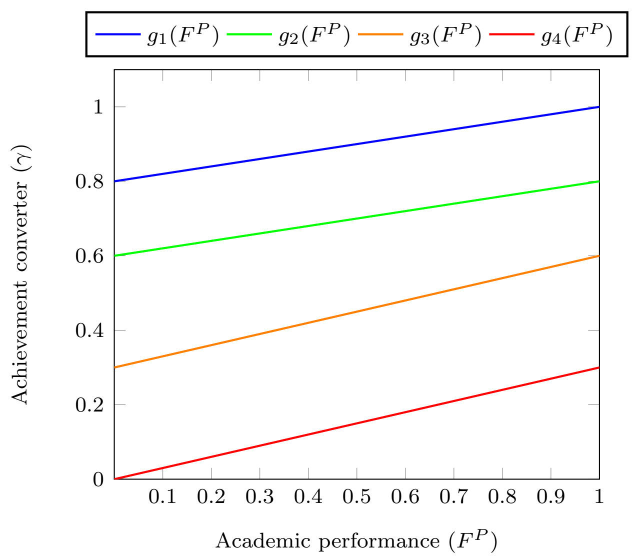

FIGURE 5.7: *The graphical functions for argument F^P used to determine the accumulation of knowledge in each performance category for each grade for PSM learning progression.*

Finally, let

$$s_i = \sum_{j=1}^{4} \frac{L_{ij1} + L_{ij2}}{2} G_{ij} \tag{5.14}$$

be the success measure for each Grade i and performance category j and let

$$S = \frac{1}{6} \sum_{i=1}^{6} s_i \tag{5.15}$$

be the average success measure and final success metric for the system.

5.2 Validation and sensitivity analysis

The factors of the primary school system are combined to determine F^P, the main metric for academic performance. The weights for equation (5.4) are determined through parameter calibration so that the lowest average RMSE for each primary school grade and its simulated values are achieved. The lowest average RMSE of 16% is achieved when $w^P = 0.5$, $w^T = 0.3$, and $w^D = 0.3$ for the Quintiles 1 to 3 system. When $w^P = 0.3$, $w^T = 0.25$, and $w^D = 0.2$ for the Quintiles 4 to 5 system, the lowest average RMSE of 14% is achieved. Figures 5.12 to 5.19 contain the PSM approximation of reality for 2010 to 2016 for primary school learners in each performance category in both Quintiles 1 to 3 and Quintiles 4 to 5. Figures 5.12, 5.14, and 5.18 in particular contain an anomalous increase in the actual numbers from year 5. These spikes may be due to an error in data capturing, or the result of some new policy or experiment. System dynamics modelling is not the appropriate methodology with which to replicate spikes, pulses, or shocks to a system, and the resultant simulation output is therefore unable to replicate these.

The results of the PSM is influenced by assuming certain initial value inputs such as the calibrated factor weights of the primary school system (depicted in Figure 5.4) and the initial values for each factor in the system. A sensitivity analysis on these values gives greater confidence in the reported results. The sensitivity analysis is therefore only relevant for the Quintiles 1 to 3 system as interventions are only performed on these quintiles in order to compare their behaviour with that of Quintiles 4 to 5.

5.2.1 Factor weights within the primary school system

The academic performance score and the success measure are two indicators which are used to measure the strength of the system. The academic performance score is the aggregate measure of the primary school system's ability to increase or decrease learners' achievement. The success measure is the sum-product of the number of learners per achievement category and their average achievement within that category for all grades. Figures 5.8 and 5.9 show the impact of change in these indicators when the weights for school readiness and the engaged time are increased or decreased. Factors run from a minimum of zero to a maximum of five (five times the calibrated weight). Model results are affected equally but proportionally by changes to these weights, with the magnitude of impact of both being less than 10%.

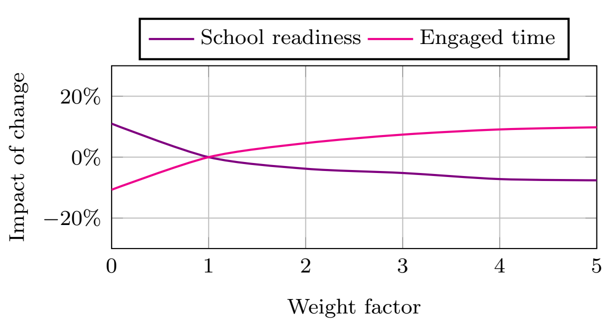

FIGURE 5.8: *The impact on the final academic performance score per change in the weight size of school readiness and engaged time in the primary school system.*

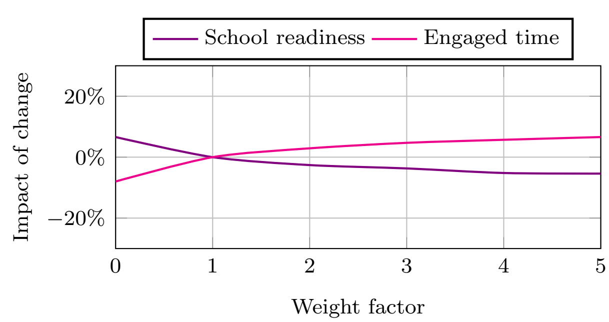

FIGURE 5.9: *The impact on the final success measure score per change in the weight size of school readiness and engaged time in the primary school system.*

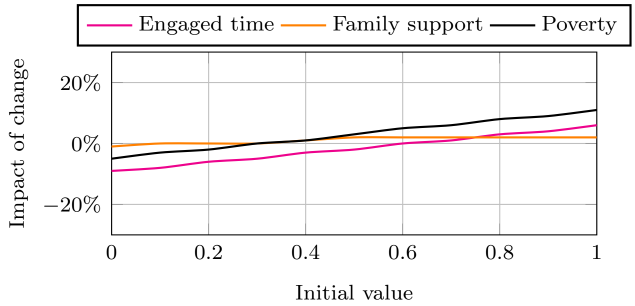

FIGURE 5.10: *The impact on the final academic performance score per change in the initial value of engaged time, poverty, and family support, respectively, in the primary school system.*

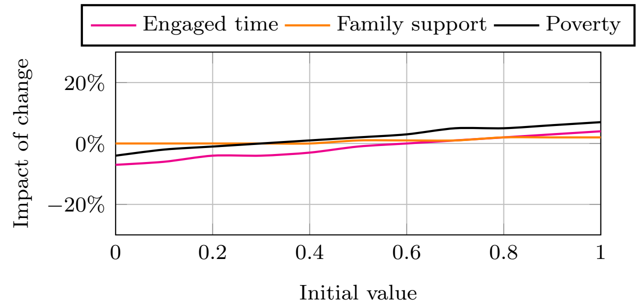

FIGURE 5.11: *The impact on the final success measure per change in the initial value of engaged time, poverty, and family support, respectively, in the primary school system.*

5.2.2 Initial stock values within the early childhood system

Figures 5.10 and 5.11 show the impact of change in these indicators when the weights for engaged time, family support, and poverty are changed. Changes to the initial values of engaged time and poverty have a greater impact on the final academic performance score than the family support. Changes to the former can be up to 10%. The learner progression trains are similarly sensitive to these changes.

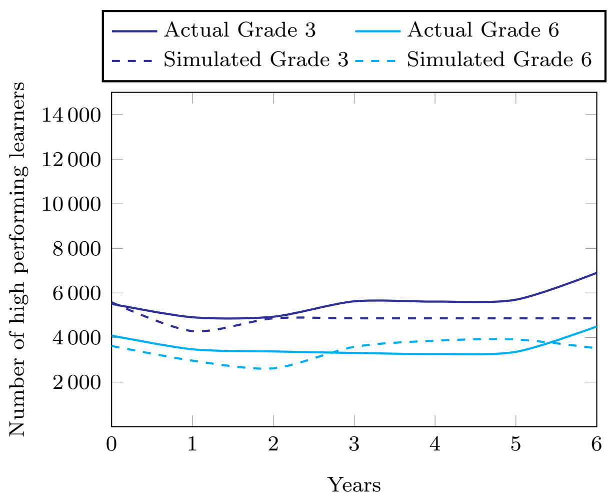

FIGURE 5.12: *Model approximation of reality for the calibrated weights for the number of high performing learners per achievement category in Quintiles 1 to 3.*

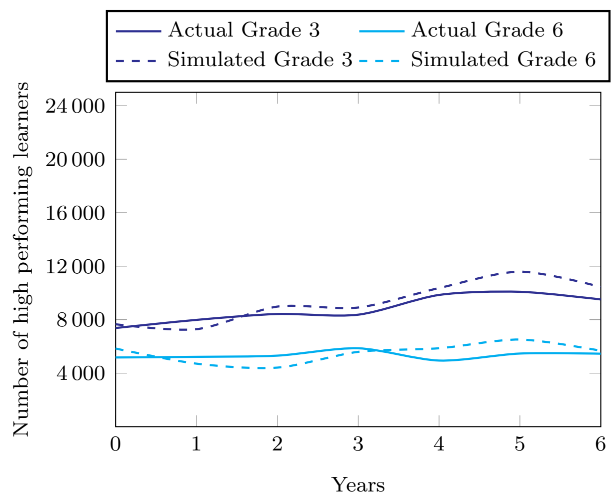

FIGURE 5.13: *Model approximation of reality for the calibrated weights for the number of high performing learners per achievement category in Quintiles 4 to 5.*

5.3 Base case results

Figures 5.20, 5.22, and 5.24 contain the resulting factor scores and learner distributions during the twelve year simulation period for the Quintiles 1 to 3 system. The impact of the low poverty and family support scores draws the teacher effectiveness and engaged time scores (which were initially high) down so that the system achieves a final academic performance score of 0.45. This score ultimately produces a final distribution of 18% high performing, 18% standard performing,

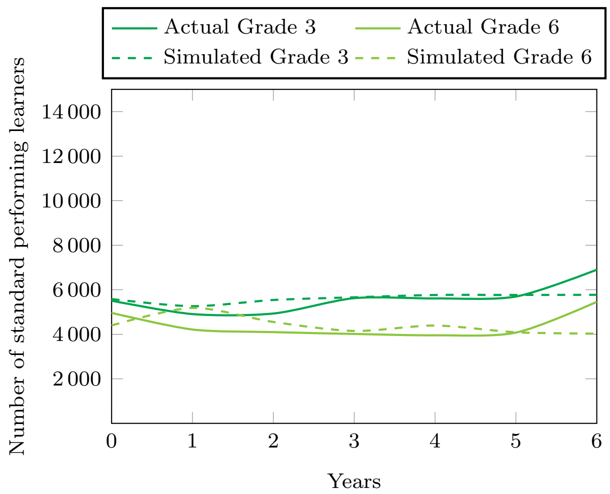

FIGURE 5.14: *Model approximation of reality for the calibrated weights for the number of standard performing learners per achievement category in Quintiles 1 to 3.*

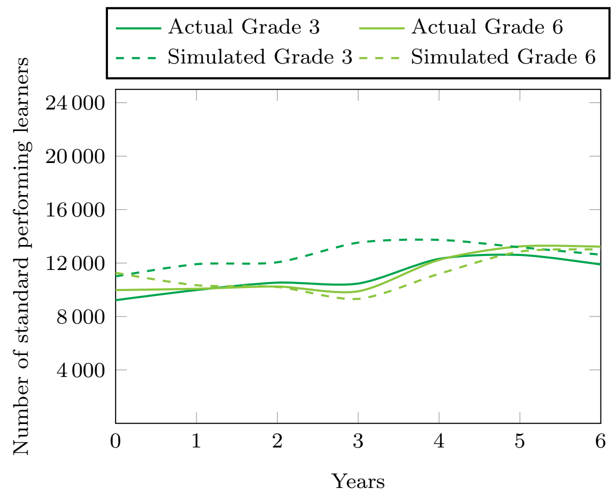

FIGURE 5.15: *Model approximation of reality for the calibrated weights for the number of standard performing learners per achievement category in Quintiles 4 to 5.*

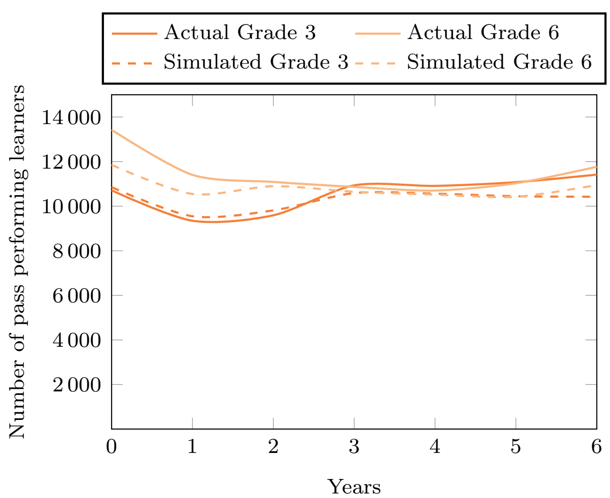

FIGURE 5.16: *Model approximation of reality for the calibrated weights for the number of pass performing learners per achievement category in Quintiles 1 to 3.*

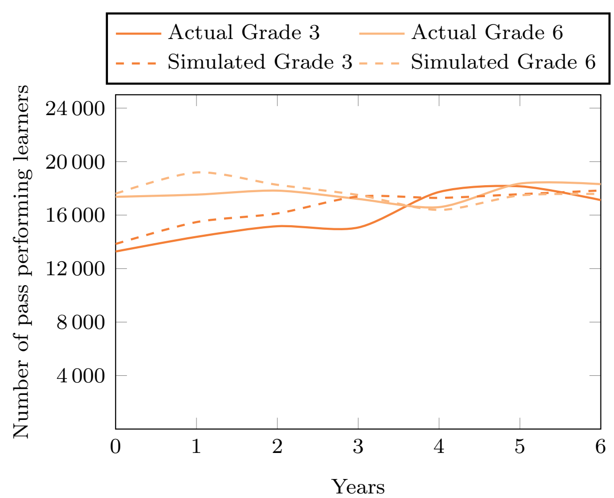

FIGURE 5.17: *Model approximation of reality for the calibrated weights for the number of pass performing learners per achievement category in Quintiles 4 to 5.*

33% pass performing, and 31% low performing Grade 3 learners. This score further produces a final distribution of 7% high performing, 16% standard performing, 38% pass performing, and 39% low performing Grade 6 learners. A success measure of 0.49 is achieved.

Figures 5.21, 5.23, and 5.25 contain the resultant factor scores and learner distributions during the twelve year simulation period for the Quintiles 4 to 5 system. The impact of the low initial academic performance draws the initially high teacher effectiveness and poverty scores down so that the system achieves a final academic performance score of 0.60. This score produces a final distribution of 23% high performing, 21% standard performing, 40% pass performing, and 16% low performing Grade 3 learners. This score further produces a final distribution of 11% high performing, 20% standard performing, 48% pass performing, and 21% low performing Grade 6 learners. A success measure of 0.59 is achieved.

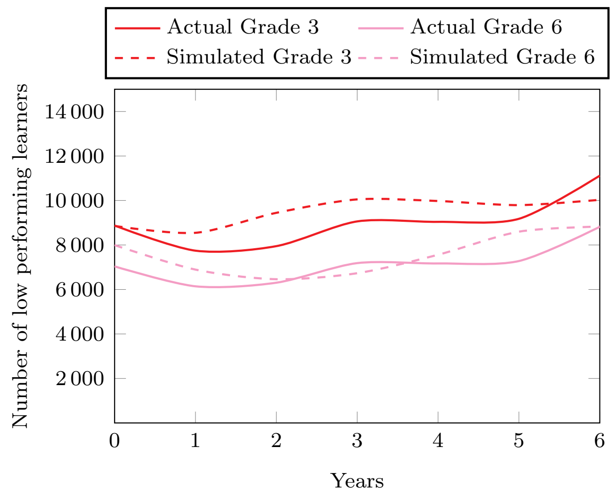

FIGURE 5.18: *Model approximation of reality for the calibrated weights for the number of low performing learners per achievement category in Quintiles 1 to 3.*

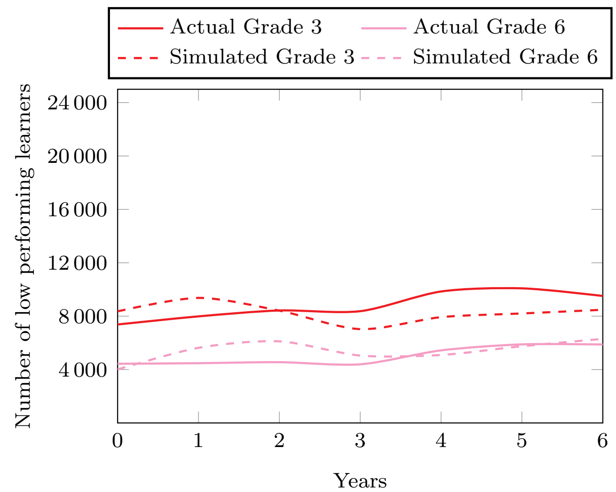

FIGURE 5.19: *Model approximation of reality for the calibrated weights for the number of low performing learners per achievement category in Quintiles 4 to 5.*

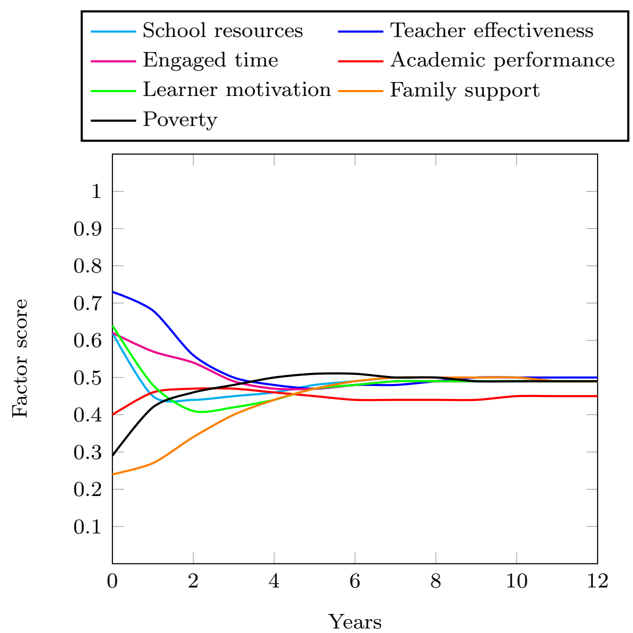

FIGURE 5.20: *Factor scores during the twelve year simulation period for the Quintile 1 to 3 base case.*

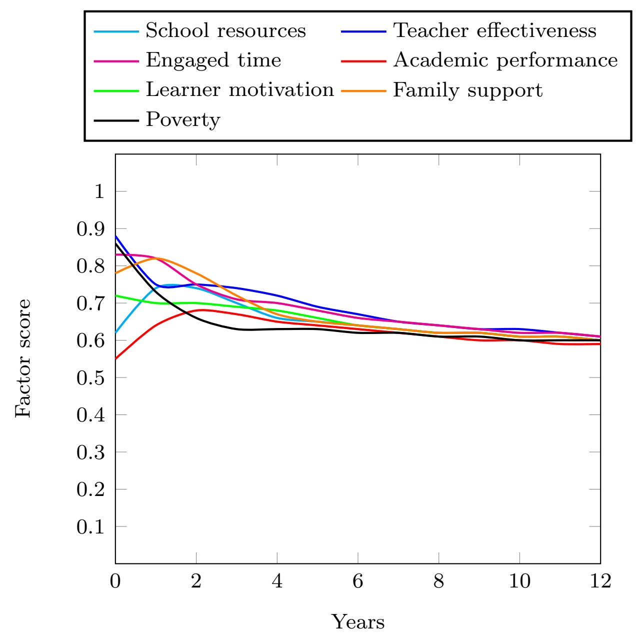

FIGURE 5.21: *Factor scores during the twelve year simulation period for the Quintile 4 to 5 base case.*

5.4 Interventions

Three interventions determine whether interventions in the classroom or interventions at home are required to increase the average literacy and numeracy scores of learners in schools within the Quintiles 1 to 3 education system of the Western Cape. From Chapter 2 it is clear that late, once-off and singular interventions are incapable of improving a system. Therefore interventions are applied early, consistently and on multiple factors to examine the impact of each.

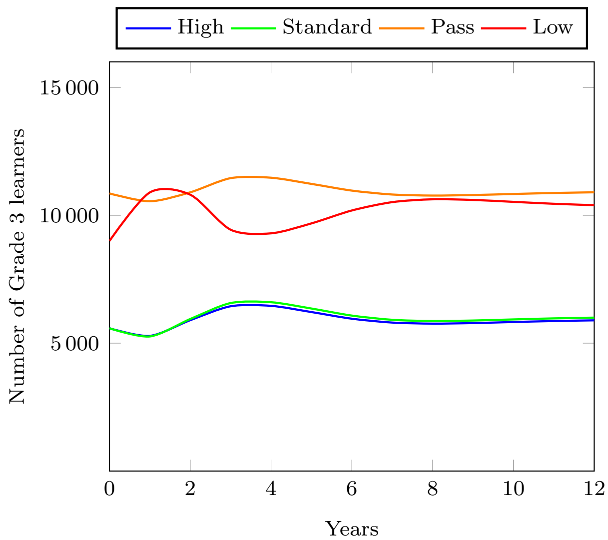

FIGURE 5.22: *The number of Grade 3 learners per achievement category for the Quintile 1 to 3 base case.*

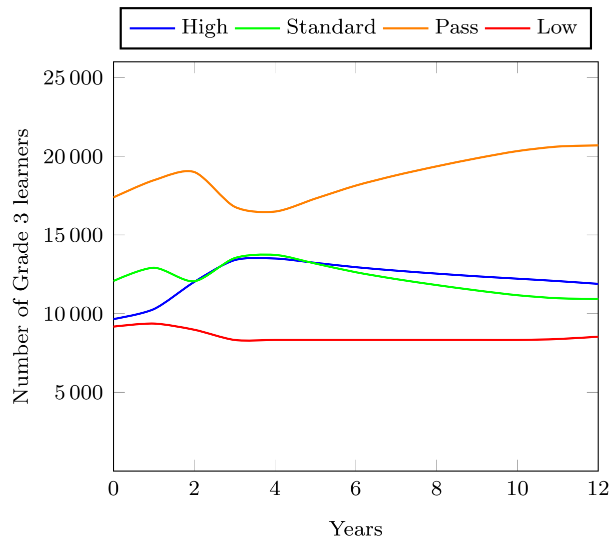

FIGURE 5.23: *The number of Grade 3 learners per achievement category for the Quintile 4 to 5 base case.*

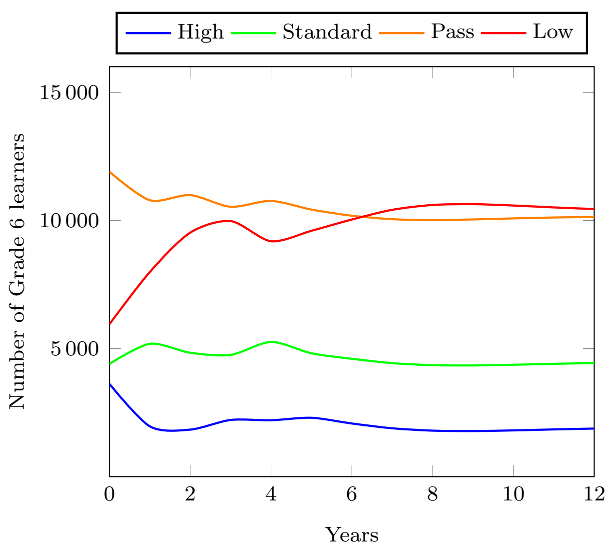

FIGURE 5.24: *The number of Grade 6 learners per achievement category for the Quintile 1 to 3 base case.*

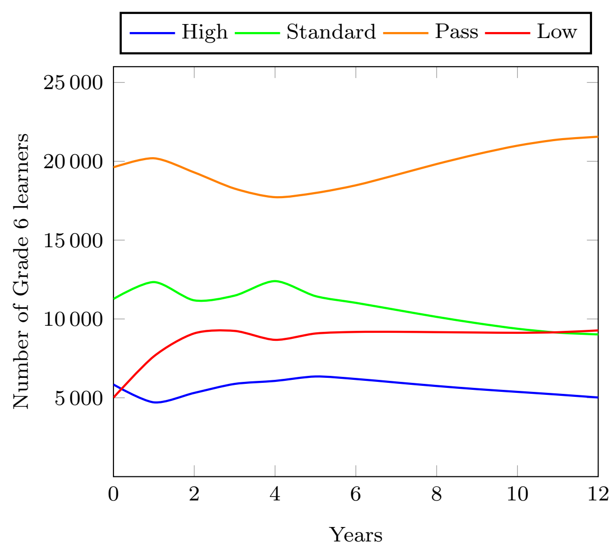

FIGURE 5.25: *The number of Grade 6 learners per achievement category for the Quintile 4 to 5 base case.*

5.4.1 Improved classroom strength

Intervening financially to increase the effectiveness of time spent in the classroom is a practical solution. It is reasonable to turn to policy driven improvements to, for example, procure learning material, equip and remunerate teachers, improve infrastructure, or offer feeding schemes. To test the impact of this solution, a large intervention where the factor score is increased by the maximum is applied to engaged time for the Quintile 1 to 3 system. A large intervention takes three years before its impact is experienced and this is the equivalent a classroom operating at maximum effectiveness. Figures 5.26 to 5.28 contain the resultant factor scores and distribution of learners for this intervention. The regular increase in engaged time has a beneficial effect on the system as a whole so that a final academic performance score of 0.46 is achieved. The success measure increases to 0.52 with a final distribution of 19% high performing, 20% standard performing, 34% pass performing, and 27% low performing Grade 3 learners. This score further produces a final distribution of 9% high performing, 18% standard performing, 39% pass performing, and 34% low performing Grade 6 learners. The only significant improvement of this intervention is a lower number of low performing learners and an increased number of pass performing learners.

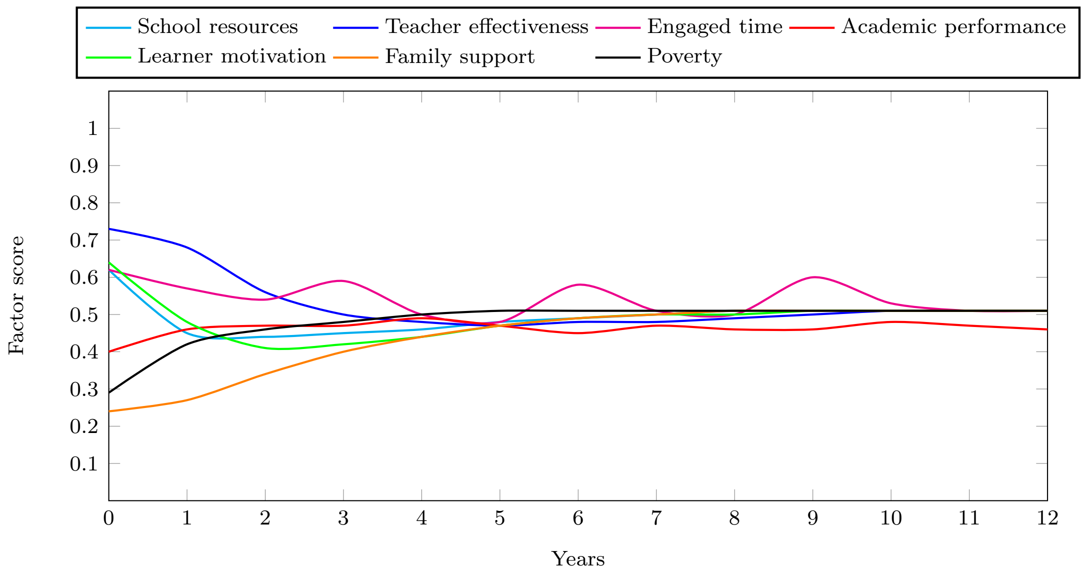

FIGURE 5.26: *Factor scores during the twelve year simulation period for the Quintile 1 to 3 classroom intervention.*

5.4.2 Improved home strength

Most of learners' lives are spent outside of the classroom and their success depends to a large extent also on their social and familial circumstances. Interventions in these areas are more difficult to implement as they would depend on changing a community's social culture. As such they are often disregarded as real solutions. The impact of interventions in a learner's social sphere is tested by applying a large intervention, where the factor score is increased by the maximum. It is applied to family support and poverty for the Quintile 1 to 3 system. A large intervention takes three years before its impact is experienced and this is the equivalent of providing an extreme form of regular poverty relief as well as regular social and psychological support for guardians. Figures 5.29 to 5.31 contain the resultant factor scores and distribution of learners for this intervention. The regular decrease in poverty and increase in family support has an improvement effect on the system as a whole so that a final academic performance score of 0.50 is achieved. The success measure increases to 0.53 with a final distribution of 20% high performing, 21% standard performing, 35% pass performing, and 24% low performing Grade 3 learners. This score further produces a final distribution of 11% high performing, 20% standard performing, 39% pass performing, and 30% low performing Grade 6 learners. The smaller

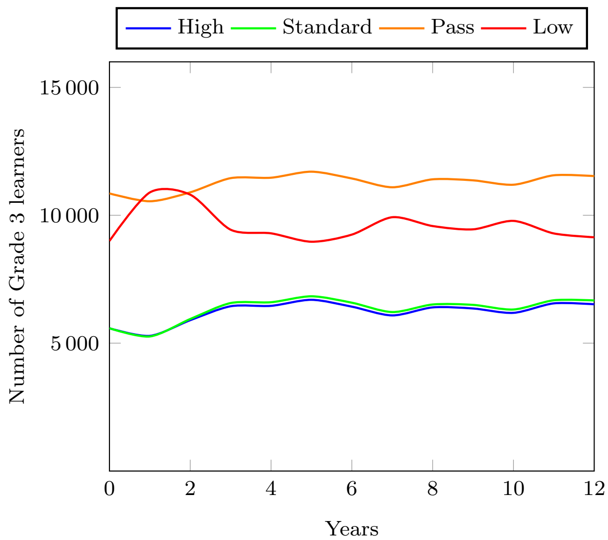

FIGURE 5.27: *The number of Grade 3 learners per achievement category for the Quintile 1 to 3 classroom intervention.*

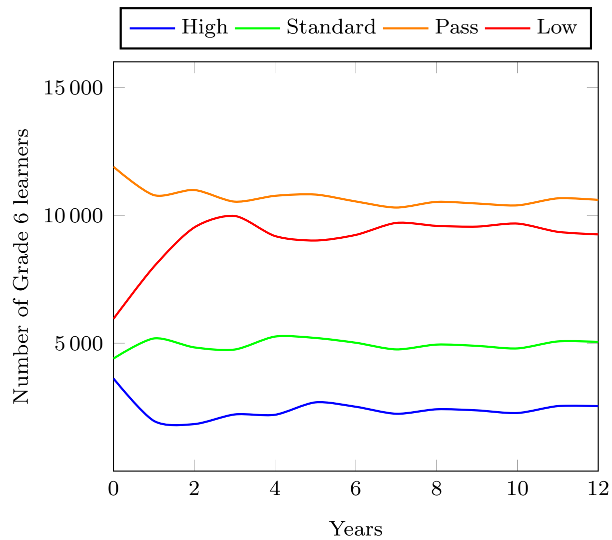

FIGURE 5.28: *The number of Grade 6 learners per achievement category for the Quintile 1 to 3 classroom intervention.*

number of low performing learners allows for an increased number of learners from all other achievement categories.

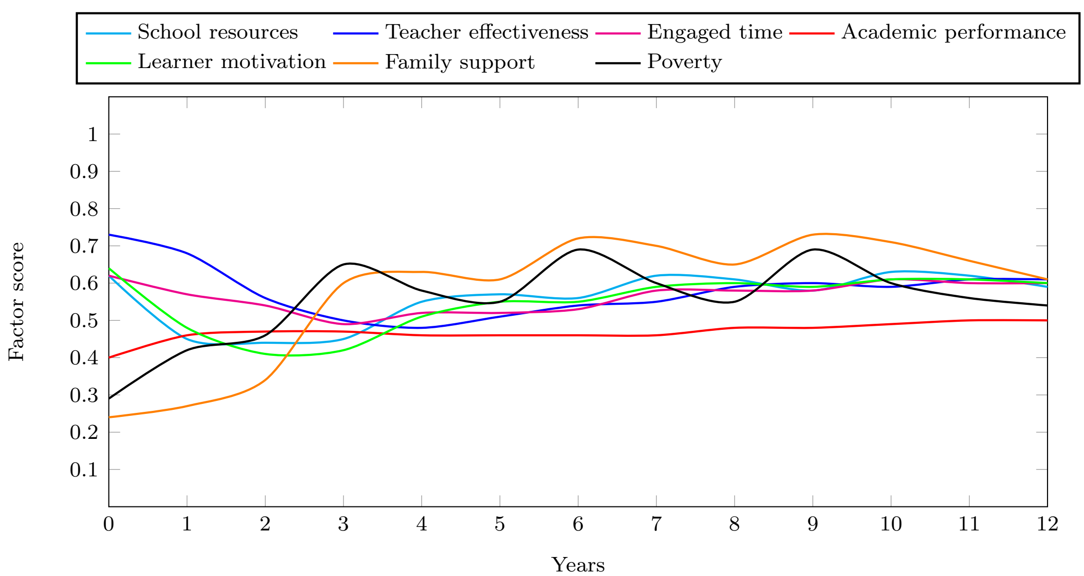

FIGURE 5.29: *Factor scores during the twelve year simulation period for the Quintile 1 to 3 home intervention.*

5.4.3 Improved classroom and home strength

In a perfect world it would be possible to intervene at a policy level within the learners' school environment as well as socially within the learners' home environment. The impact of this combined approach is analysded by a large intervention. It is applied to engaged time, family support and poverty for the Quintile 1 to 3 system. Figures 5.32 to 5.34 contain the resulting factor scores and distribution of learners for this intervention. The regular decrease in poverty

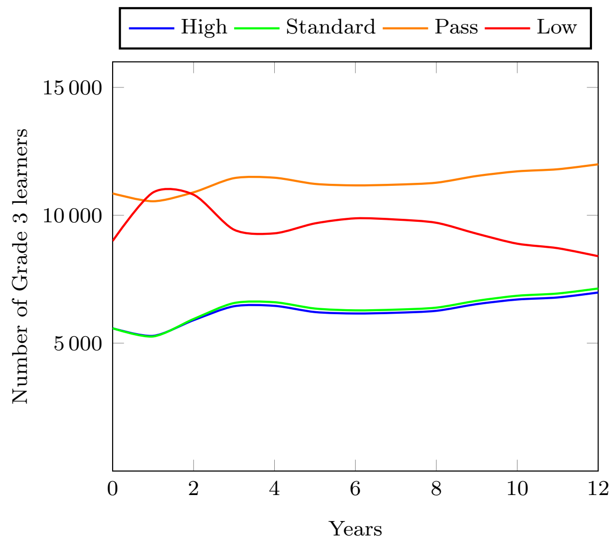

FIGURE 5.30: *The number of Grade 3 learners per achievement category for the Quintile 1 to 3 home intervention.*

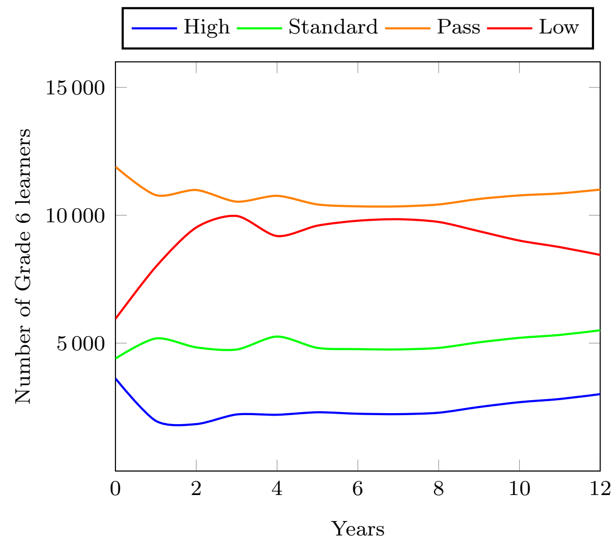

FIGURE 5.31: *The number of Grade 6 learners per achievement category for the Quintile 1 to 3 home intervention.*

and increase in family support has a beneficial effect on the system as a whole so that a final academic performance score of 0.51 is achieved. The success measure increases to 0.55 with a final distribution of 23% high performing, 20% standard performing, 34% pass performing, and 23% low performing Grade 3 learners. This score further produces a final distribution of 14% high performing, 19% standard performing, 38% pass performing, and 28% low performing Grade 6 learners. Despite these large interventions, the Quintile 1 to 3 system is unable to match the performance of the Quintile 4 to 5 system as the significant difference in the initial poverty values cannot be overcome within the simulation period.

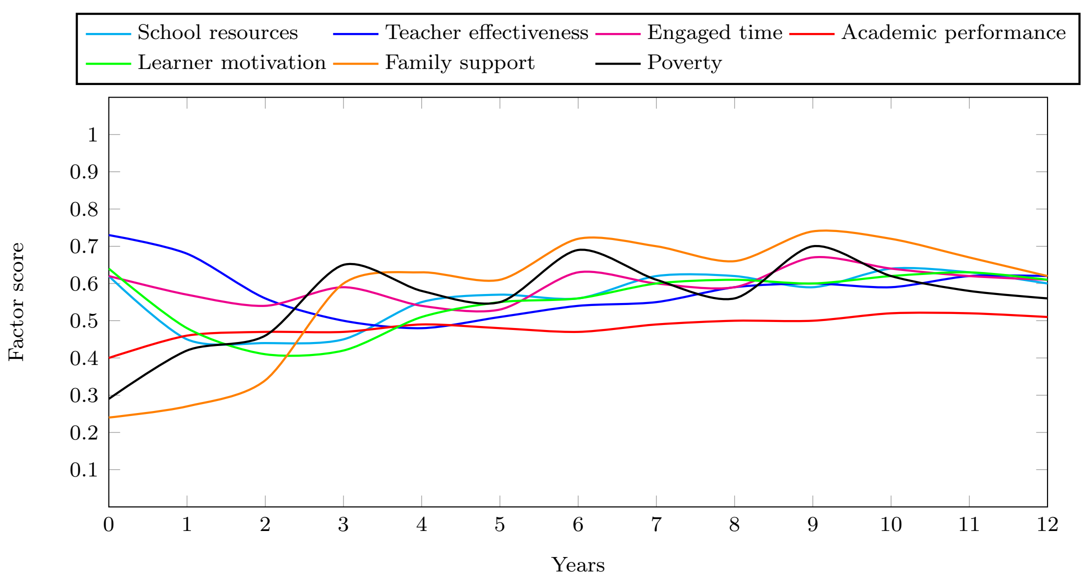

FIGURE 5.32: *Factor scores during the twelve year simulation period for the Quintile 1 to 3 combined intervention.*

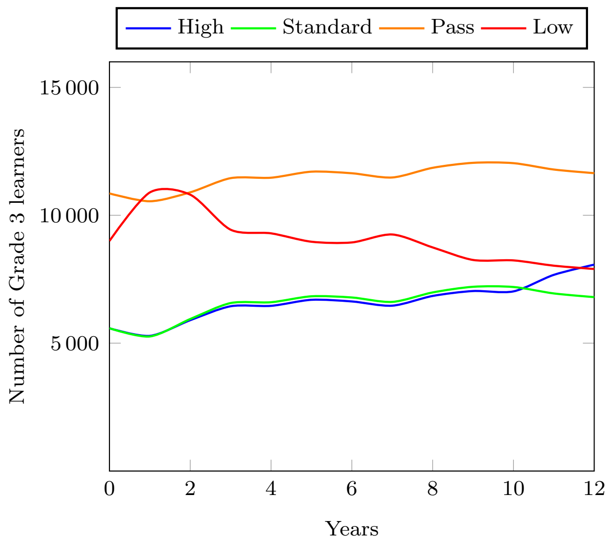

FIGURE 5.33: *The number of Grade 3 learners per achievement category for the Quintile 1 to 3 combined intervention.*

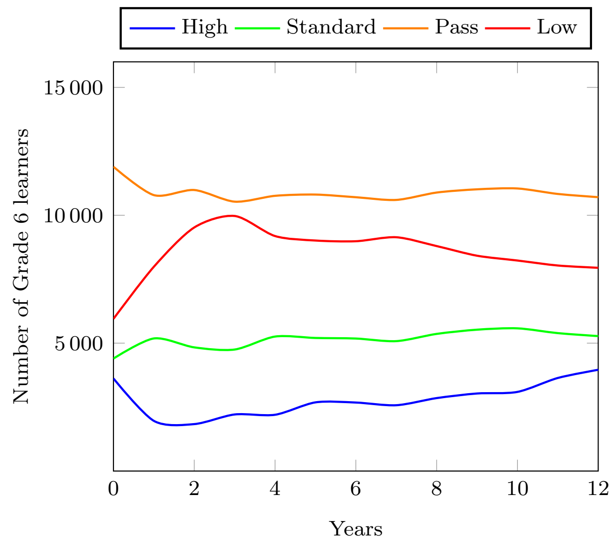

FIGURE 5.34: *The number of Grade 6 learners per achievement category for the Quintile 1 to 3 combined intervention.*

5.5 Conclusions

The Primary School Model can be used to answer the research question whether interventions in classroom support or interventions in household support should be applied to increase the average academic performance of Grade 3 and Grade 6 learners in the Western Cape. The model is populated with data from national datasets, and run for twelve years leading up to 2030.

Initial values for the weights of the factors impacting childhood aptitude are determined through parameter calibration. Validation of this calibration results in an average RMSE 16% for the Quintile 1 to 3 system and 14% for the Quintile 4 to 5 system when the simulated number of learners per performance category is fit to the actual number.

A sensitivity analysis on the initial weights of school readiness and engaged time shows that the model is sensitive to changes for both weights and the resulting change to the success measure is smaller than 10%. Additional sensitivity analysis on the initial stock values of engaged time, family support, and poverty shows that the model is more sensitive to changes in the initial stock values of poverty and engaged time, indicating that interventions in these areas should cause the greatest change on the system.

The base case results show that learners in Quintiles 1 to 3 stabilise at an academic performance score of 0.45 so that a success measure of 0.49 is achieved. In contrast to this, learners in Quintiles 4 to 5 stabilise at an academic performance score of 0.6 so that a success measure of 0.59 is achieved.

Three interventions explore the research question. A timely, continuous, and large intervention in engaged time for the Quintiles 1 to 3 system leads to a final academic performance score increase of 0.01 and a success measure increase of 0.03. A timely, continuous, and large intervention on poverty and family support leads to a final academic performance increase of 0.01 and a success measure increase of 0.04. Combining these two interventions leads to a final academic performance score increase of 0.02 and a success measure increase of 0.06. None of the interventions enable the Quintiles 1 to 3 system to match the performance of the Quintiles 4 to 5 system. Tables 5.10 to 5.11 contains a summary of the results for the base case and after interventions were implemented for the PSM.

	Gr 3 achievement			
	High	**Standard**	**Pass**	**Low**
Quintiles 1 to 3 base case	18%	18%	33%	31%
Quintiles 4 to 5 base case	23%	21%	40%	16%
Classroom intervention	19%	20%	34%	27%
Home intervention	20%	21%	35%	24%
Combined intervention	23%	20%	34%	23%
	Gr 6 achievement			
	High	**Standard**	**Pass**	**Low**
Quintiles 1 to 3 base case	7%	16%	38%	39%
Quintiles 4 to 5 base case	11%	20%	48%	21%
Classroom intervention	9%	18%	39%	34%
Home intervention	11%	20%	39%	30%
Combined intervention	14%	19%	38%	29%

Table 5.10: *The summary of the final learner distributions per achievement category for each base case and intervention for the PSM.*

	Academic performance score	**Success measure**
Quintiles 1 to 3 base case	0.45	0.49
Quintiles 4 to 5 base case	0.60	0.59
Classroom intervention	0.46	0.52
Home intervention	0.50	0.53
Combined intervention	0.51	0.55

Table 5.11: *The summary of the final success metric for each base case and intervention for the PSM.*

The research showed that in the Western Cape an intervention concerning the home circumstances of learners is more effective than a classroom intervention. However, an intervention in strengthening both environments lends to the best results. Practically this implies that interventions should focus on decreasing the unemployment rate of parents, increasing access to social and psychological support for families, and increasing focused, engaged time in the classroom.

As always, it is important to note that the Western Cape province is one of the richest and least dysfunctional provinces in South Africa. These conclusions may thus not hold for the country as a whole. The model can be populated with province specific data to test the research question in the context of the remaining eight provinces to get better recommendations for the South African system.

CHAPTER 6

The expanded School Effectiveness Model

Contents

In Chapter 2, the SEM was introduced to illustrate that SD is an appropriate methodology with which to simulate basic education systems. The high level of abstraction inherent in the model provided the necessary proof of concept and a broader understanding of the impact of interventions. However, it required more granular modelling to be useful in the South African context. This granularity is achieved when the SEM is expanded by means of the TEM, ECDM, and PSM in Chapters 3 to 5 to finally form the eSEM.

Figure 6.1 contains the SEM system diagram that is used as a base for expansion by the three sub-models. The TEM expands the two abstracted factors of educator pool strength and school sense of order of the SEM to a detailed system of nine factors depicted in Figure 3.2. The ECDM expands the two abstracted factors of learner strength and community support of the SEM to a detailed system of nine factors depicted in Figure 4.2. The PSM expands three abstracted factors of learner strength, a school's capacity to support learning, and community support in the SEM to a detailed system of eight factors depicted in Figure 5.2.

Figure 6.2 contains the resultant causal loop diagram for the eSEM when the SEM, TEM, ECDM, and PSM are brought together. The school, teacher, early childhood, and primary school systems combine to give an extended systems perspective of basic education. Figure 6.3 contains the stock-and-flow diagram for the extended school system with the additional stocks for principal strength, SMT strength and the measure of a sense of order present in the school. All factors remain initialised with the values described in Chapters 3, 4, and 5. Initial values for the three remaining factors (principal strength, SMT strength, and school sense of order) are obtained from the NSES.

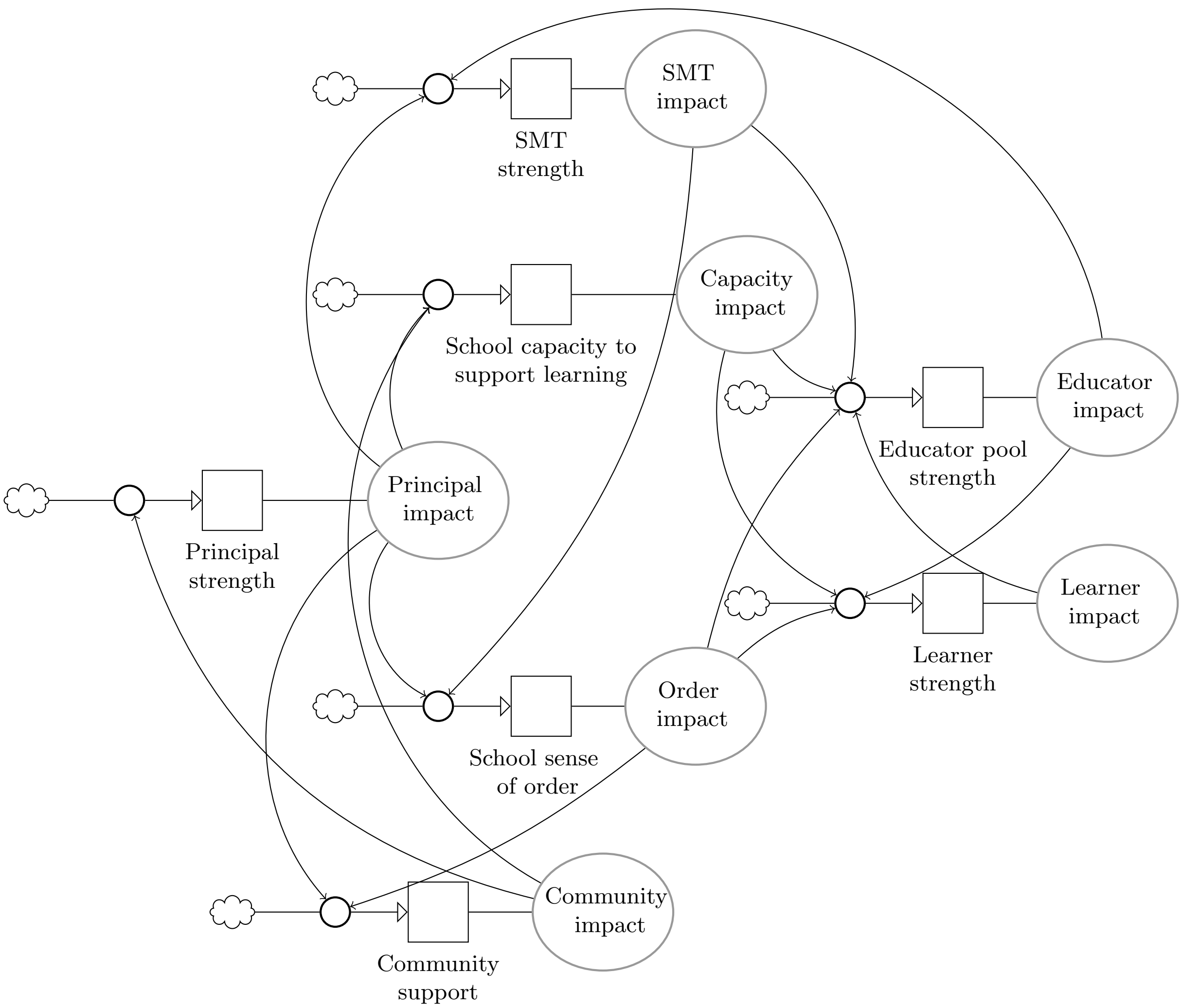

FIGURE 6.1: *The SEM system diagram at a high level of abstraction.*

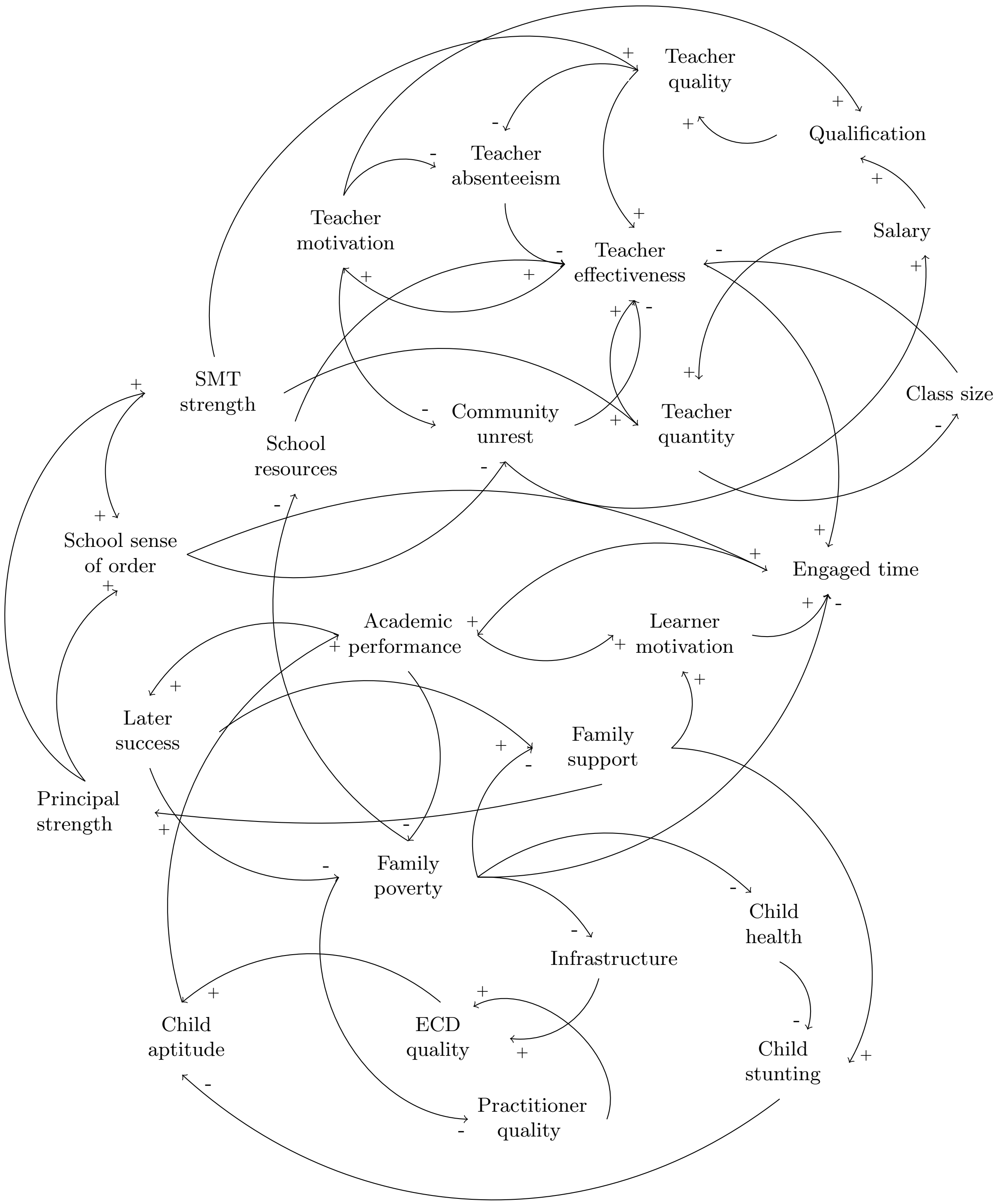

FIGURE 6.2: *The causal loop diagram for the extended School Effectiveness Model.*

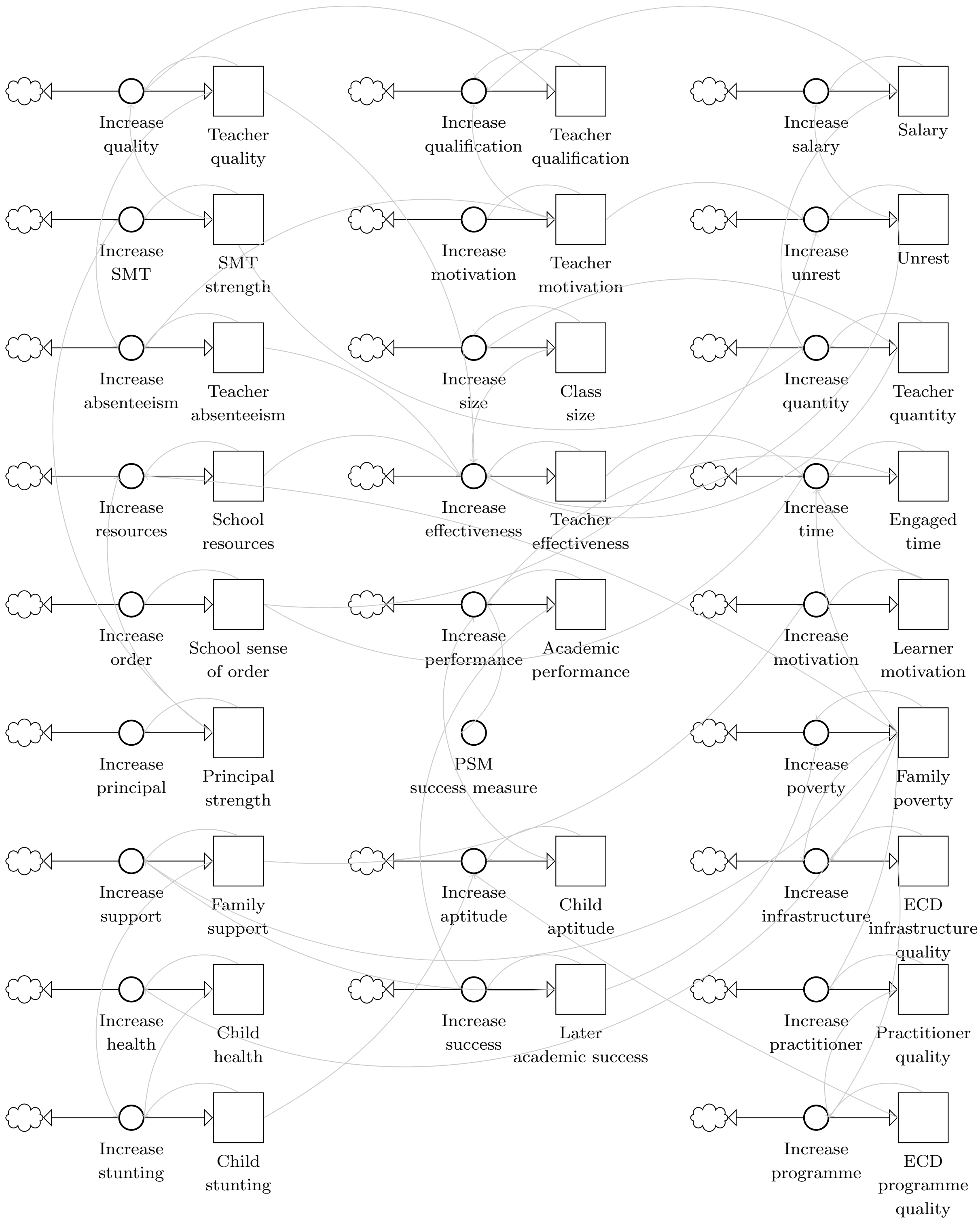

Figure 6.3: *The stock-and-flow diagram for the eSEM system.*

The official policy on the South African standards for principalship details the requirements for school leadership in the South African education system [25]. A strong principal is one who holds a university qualification and professional experience in education, has sufficient knowledge in management and accountancy, is intelligent, and is rational and consistent with their ideas. They have experience in teaching and management, practical knowledge in computer literacy, and communication skills. They know how to delegate, plan, organise and assess, motivate, lead and conduct a team while making good use of educational materials and equipment. They are aware of contemporary issues (such as HIV and AIDS, gender identity, sexual and substance abuse). They exhibit patience, openness, justice and equity, impartiality, understanding, compassion, democracy, energy, enthusiasm, discipline, responsibility and are good advisors. The school management team consists of the principal, deputy principal, and subject heads and serves to ensure efficient school administration (for example, setting school calendars, timetables, arranging substitutes for absent staff, admission of new learners, organisation of meetings and ceremonies), guiding and supervising teacher performance.

The NSES [54] includes three questions to survey the measure of leadership quality. The first question determines whether chronic principal absenteeism disrupts school functioning, the second determines whether the SMT and teachers appear uncooperative on the day of the survey recording, and the third determines whether the school day was disrupted for any reason. The responses to these questions may be used to quantify the overall quality of school leadership overall, and it is best to take the data from this dataset to ensure coherence with the PSM initialisation. However, it is obvious that school leadership is complex and needs far more detailed and expansive data collection for more accurate results.

Regardless, Tables 6.1 and 6.2 include the percentage of teachers reporting these barriers to quality leadership for each socio-economic group in Western Cape public schools from 2007 to 2009. The percentage of complaints is very low in the lower socio-economic group and no problems in this regard are reported in the higher group. The eSEM is therefore initialised with a score of 1 for principal strength, SMT strength and school sense of order in both systems, where a value between 0 and 1 is used once more. A sensitivity analysis on these initial values will indicate the impact of this assumption.

Barrier	**2007**	**2008**	**2009**	**Average**	**Goodness score**
Absent principal	0%	6%	0%	2%	1.00
Uncooperative SMT	9%	12%	0%	11%	0.89
Disrupted school days	9%	12%	0%	11%	0.89

Table 6.1: *The average percentage of teachers reporting barriers to quality leadership in Quintiles 1 to 3 Western Cape public schools from 2007 to 2009 according to the NSES.*

Barrier	**2007**	**2008**	**2009**	**Average**	**Goodness score**
Absent principal	0%	0%	0%	0%	1.00
Uncooperative SMT	0%	0%	0%	0%	1.00
Disrupted school days	0%	0%	0%	0%	1.00

Table 6.2: *The average percentage of teachers reporting barriers to quality leadership in Quintiles 4 to 5 Western Cape public schools from 2007 to 2009 according to the NSES.*

Recall from Chapters 3 to 5 the variables which make up the expanded education system listed in Table 6.3. The ECDM and the PSM share the factors of family support and family poverty. The PSM and TEM share the teacher effectiveness factor. Where a factor is shared, its new initial value becomes the average of the two original intial values. The PSM receives scores for

ECDM factor	**Symbol**	**Quintiles 1 to 3**	**Quintiles 4 and 5**
Teacher absenteeism	F^A	0.60	0.70
Child aptitude	F^B	0.58	0.66
Teacher quality	F^C	0.60	0.80
ECD programme quality	F^D	0.74	0.80
Teacher effectiveness	F^E	0.57	0.65
Family support	F^F	0.50	0.80
Engaged time	F^G	0.62	0.83
Child health	F^H	0.85	0.85
ECD infrastructure quality	F^I	0.89	0.92
Principal strength	F^J	1.00	1.00
Teacher quantity	F^K	0.20	0.40
Later academic success	F^L	0.58	0.73
Teacher motivation	F^M	0.50	0.50
Learner motivation	F^N	0.64	0.72
School sense of order	F^O	0.89	1.00
Academic performance	F^P	0.40	0.55
Teacher qualification	F^Q	0.40	0.60
School resources	F^R	0.62	0.62
Teacher salary	F^S	0.40	0.60
Child stunting	F^T	0.60	0.73
Community unrest	F^U	0.80	0.90
Family poverty	F^V	0.36	0.88
SMT strength	F^W	0.89	1.00
Practitioner quality	F^Y	0.58	0.68
Class size	F^Z	0.20	0.40

TABLE 6.3: *The initial values for the factor scores of the eSEM.*

child aptitude from the ECDM to replace the exogenous variable for school readiness. Let F^J be the score for principal strength, F^W be the score for SMT strength, and F^O be the score for the school's sense of order, so that

$$\frac{\mathrm{d}F^J}{\mathrm{d}t} = \frac{F^J + F^F}{3} - F^J, \tag{6.1}$$

$$\frac{\mathrm{d}F^W}{\mathrm{d}t} = \frac{F^W + F^J + F^E}{3} - F^W, \text{ and} \tag{6.2}$$

$$\frac{\mathrm{d}F^O}{\mathrm{d}t} = \frac{F^O + F^J + F^W}{3} - F^O. \tag{6.3}$$

Equations (3.1) and (3.9) are updated to include the impact of SMT strength, equations (3.6) and (5.3) are updated to include the impact of the school's sense of order, and equation (5.1) is updated to included the impact of principal strength so that

$$\frac{\mathrm{d}F^C}{\mathrm{d}t} = \frac{F^C + F^Q + F^W}{2} - F^C, \tag{6.4}$$

$$\frac{\mathrm{d}F^U}{\mathrm{d}t} = \frac{F^U + F^M + F^O}{3} - F^U, \tag{6.5}$$

$$\frac{\mathrm{d}F^K}{\mathrm{d}t} = \frac{F^K + F^S + F^W}{3} - F^K, \tag{6.6}$$

$$\frac{\mathrm{d}F^R}{\mathrm{d}t} = \frac{F^R + F^V + F^J}{3} - F^R, \text{ and} \tag{6.7}$$

$$\frac{\mathrm{d}F^T}{\mathrm{d}t} = \frac{F^T + F^E + F^N + F^V + F^O}{5} - F^T. \tag{6.8}$$

Equation (3.5) is updated to include the impact of school resources and replaces equation (5.2) so that

$$\frac{\mathrm{d}F^E}{\mathrm{d}t} = \frac{F^E + w^U F^U + w^K F^K + w^Z F^Z + w^C F^C + w^A F^A + w^R F^R}{1 + w^U + w^K + w^Z + w^C + w^A + w^R} - F^E, \qquad (6.9)$$

where w^R is the additional relative weight of this impact. Finally, let F^X be the average success measure and final success metric for the system as calculated in equation (5.15).

6.1 Validation and sensitivity analysis

Figures 6.4 to 6.11 contain the eSEM approximation of reality for 2010 to 2016 for primary school learners in each performance category in both Quintiles 1 to 3 and Quintiles 4 to 5. An average RMSE of 12% is achieved for both systems (a 2% and 4% improvement to the fit of the PSM for each system).In each instance the model approximation of historical reality is acceptable and facilitates trust in the forecasted results over the twelve year forecast period.

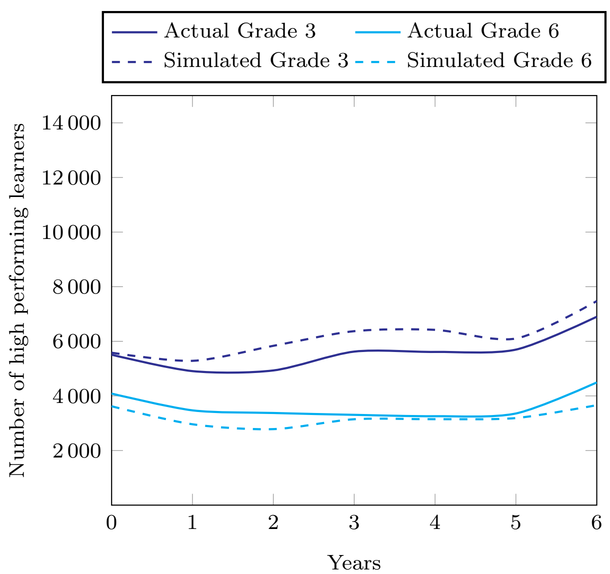

FIGURE 6.4: *Model approximation of reality for the calibrated weights for the number of high performing learners per achievement category in Quintiles 1 to 3.*

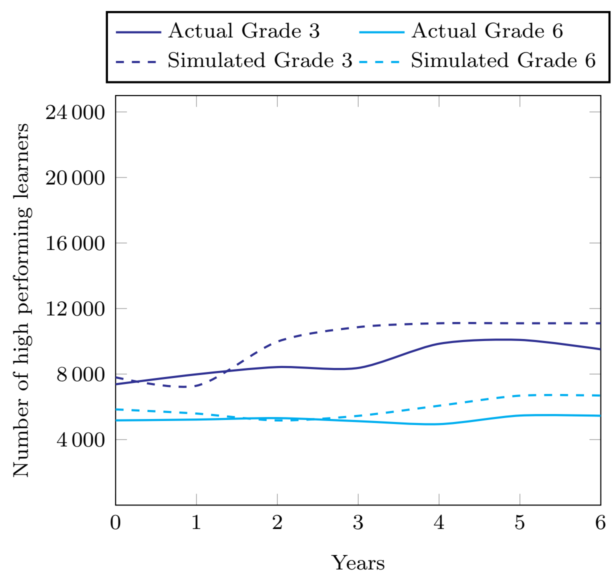

FIGURE 6.5: *Model approximation of reality for the calibrated weights for the number of high performing learners per achievement category in Quintiles 4 to 5.*

The results of the eSEM are influenced by assuming goodness scores for principal strength, SMT strength, and the school sense of order. Figure 6.12 shows the impact of change on the success measure when the initial values for principal strength, SMT strength and school sense of order are changed. The number of factors between the impact of management decisions and academic performance causes the model to be robust against changes to the initial values of these three factors. The success measure changes by at most 1% or 2% for 50% to 100% changes to the initial factor values.

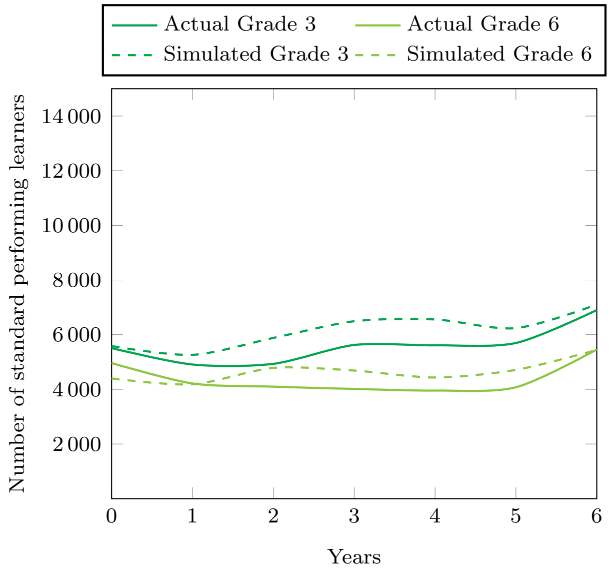

FIGURE 6.6: *Model approximation of reality for the calibrated weights for the number of standard performing learners per achievement category in Quintiles 1 to 3.*

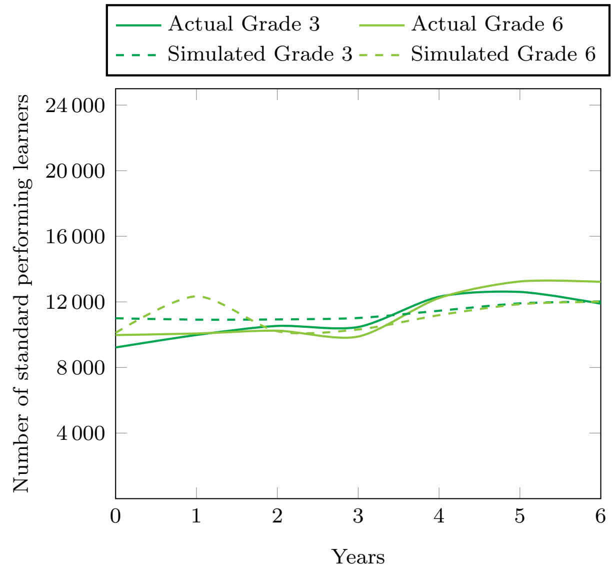

FIGURE 6.7: *Model approximation of reality for the calibrated weights for the number of standard performing learners per achievement category in Quintiles 4 to 5.*

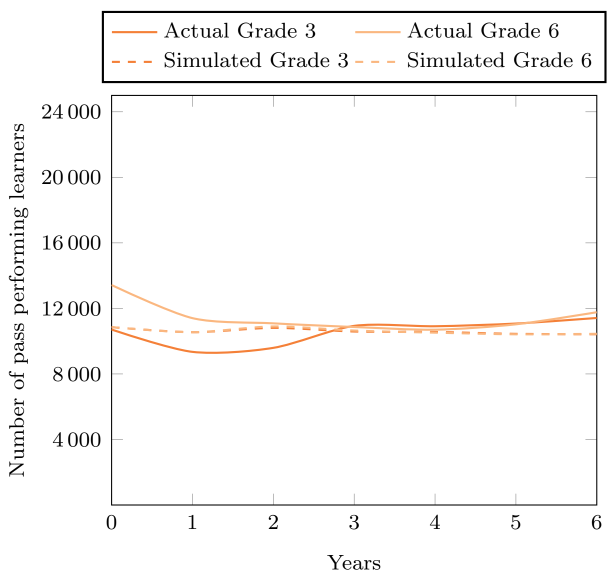

FIGURE 6.8: *Model approximation of reality for the calibrated weights for the number of pass performing learners per achievement category in Quintiles 1 to 3.*

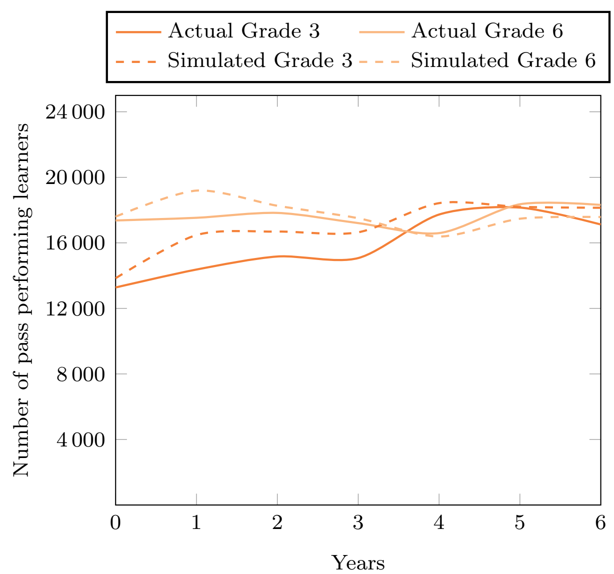

FIGURE 6.9: *Model approximation of reality for the calibrated weights for the number of pass performing learners per achievement category in Quintiles 4 to 5.*

6.2 Results and interventions

The school system in Figure 6.3 influences the teacher progression in Figure 3.6 by means of the teacher effectiveness score (F^E) as described in equation (3.14). It also influences the childhood progression in Figure 4.5 by means of the child aptitude score (F^B) as described in equations (4.13) and (4.14). It furthermore influences the learner progression in Figure 5.5 by means of the academic performance score as described in equations (5.10) and (5.13). An increase

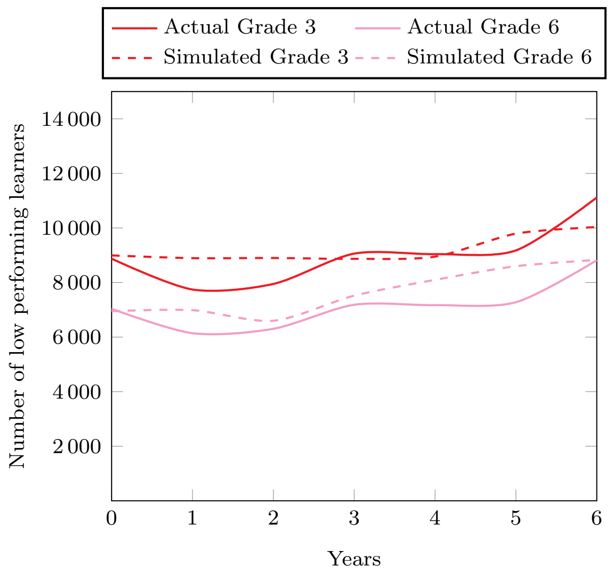

FIGURE 6.10: *Model approximation of reality for the calibrated weights for the number of low performing learners per achievement category in Quintiles 1 to 3.*

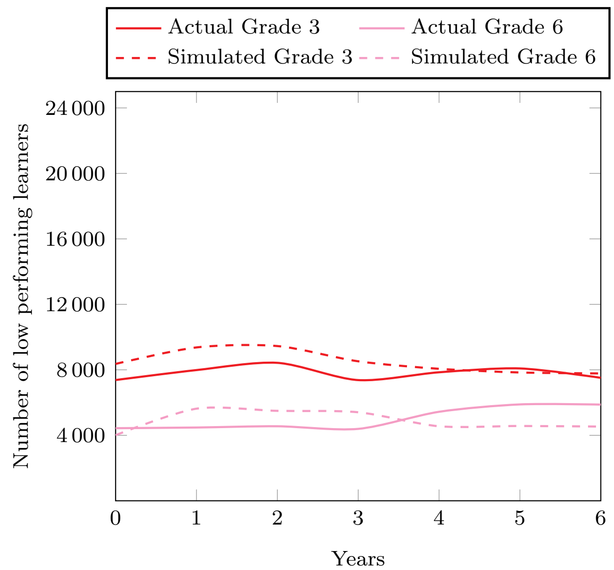

FIGURE 6.11: *Model approximation of reality for the calibrated weights for the number of low performing learners per achievement category in Quintiles 4 to 5.*

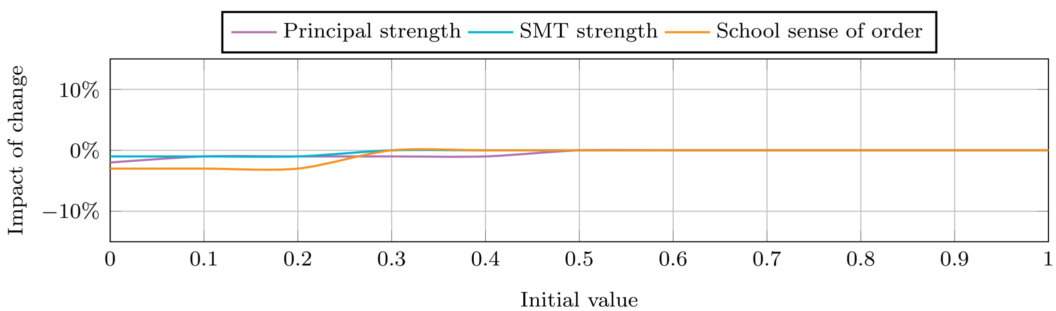

FIGURE 6.12: *The impact on the final success measure per change in the initial value of principal strength, SMT strength, and school sense of order for the eSEM.*

or decrease in these three scores are therefore the most important to monitor their influence on the final success measure, *i.e.* the percentage of learners in each academic performance category.

The best intervention for each of the sub-models is applied to the eSEM. From the TEM it was discovered that an increase in the number of teachers and the resulting decrease in the learner-to-teacher ratio caused a greater increase in the success measure than when the quality of the existing number of teachers were improved. This may be referred to as the *teacher quantity intervention*. However, increasing both the quantity and quality of teachers caused the greatest increase in the success measure. This may be refered to as the *teacher quality and quantity intervention*.

From both the ECDM and PSM it was discovered that increased family support and decreased family poverty caused an increase in the success measure. This may be referred to as the *home intervention*. However, increasing the classroom factors (EDC programme quality, ECD infrastructure, ECD practitioner quality, engaged time) causes the greatest increase in the success measure. This may be referred to as the *home and classroom intervention*. These four interventions along with a combination of all interventions are therefore applied to the eSEM for the lower socio-economic group in an attempt to decrease the inequality in results between the two systems.

Figures 6.13 to 6.15 contain the base case and intervention results for the resultant teacher effectiveness, child aptitude and academic performance scores. Teacher effectiveness is least improved by the home intervention and most improved by teacher quantity and quality intervention. Child aptitude is least improved by the teacher quantity and quality intervention and most improved by the home and classroom intervention. Most interestingly, primary school academic achievement is least improved by the teacher quantity and quality intervention and most improved by the home and classroom intervention. Each of the interventions cause the factor scores to outperform the base case for the Quintiles 1 to 3 system. None of the interventions are able increase the factor scores to match their strength in the Quintiles 4 to 5 system although the combined intervention most closely achieves this.

Table 6.4 contains the final distributions of learners in each performance category for the base case and interventions. Each intervention increases the percentage of high and standard achieving learners for both Grade 3 and Grade 6 with the combination scenario again performing best. The Quintiles 4 to 5 system still delivers the lowest percentage of low achieving learners, making it superior still. Table 6.5 contains a summary of the success measure scores from each sub-model for the base case and interventions. None of the interventions enable the sub-models in the Quintiles 1 to 3 system to match the success achieved by the sub-models of the Quintiles 4 to 5 system. However, the combined intervention again is closest to achieving a match.

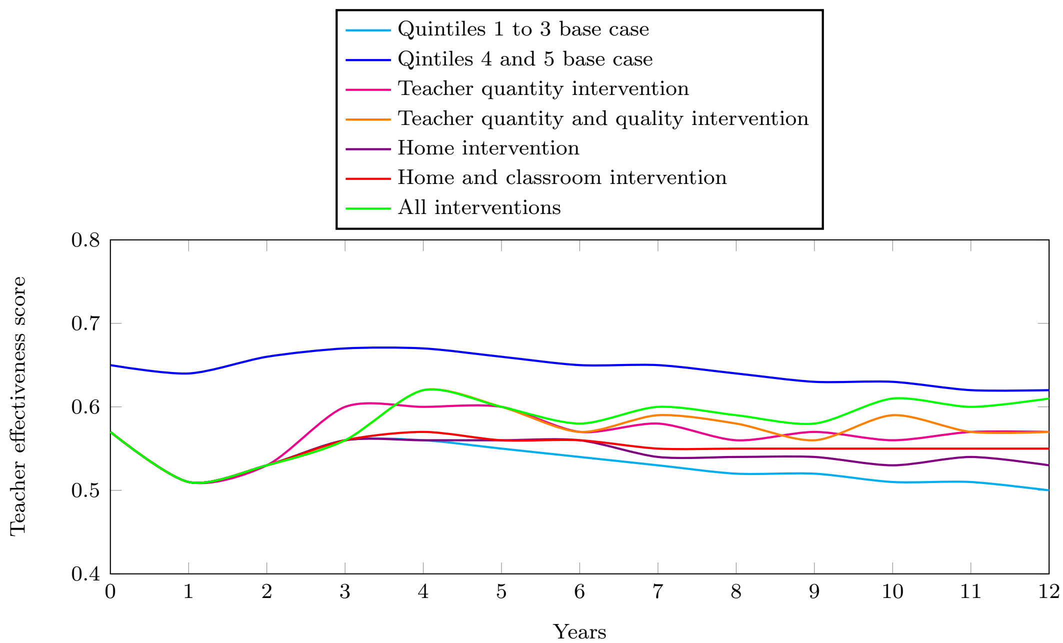

FIGURE 6.13: *Teacher effectiveness for each intervention for the eSEM during the twelve year simulation period.*

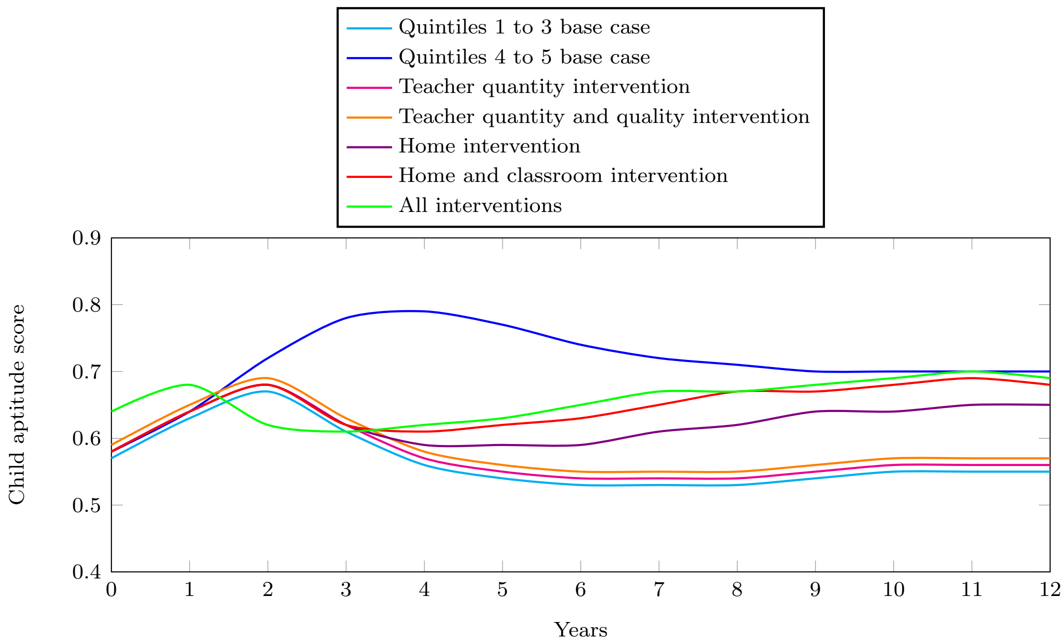

FIGURE 6.14: *Child aptitude for each intervention for the eSEM during the twelve year simulation period.*

6.3 Conclusion

The extended School Effectiveness Model can be used to make the generic School Effectiveness Model useful within the South African, and specifically Western Cape context. The values describing principals, SMTs and the school sense of order are calculated with data from national datasets and the model is run for the twelve years leading up to 2030. The model is validated against reality and this results in an average RMSE of 12% for both the Quintiles 1 to 3 system and Quintiles 4 to 5 system when the simulated number of learners per performance category is fit to the actual number.

The eSEM is a combination of four sub-models and the best interventions from each sub-model is applied in an attempt to remove the performance discrepancy between the Quintiles 1 to 3 system and the Quintiles 4 to 5 system. Figure 6.15 contains a summary of the academic performance score for each base case and scenario over the simulation period. No interventions were able to achieve this goal. However, an order of preference of interventions for improving the academic performance of Western Cape public primary school learners emerged. Firstly, interventions should be focused to stabilise learners' home circumstances, assisting their parents to find employment and making the existence of dual parent nuclear families sustainable. Secondly, interventions should be focused on improving the classroom experience for learners and on increasing engaged time for learning. Thirdly interventions should be focused on improving the quantity and quality of teachers that learners are subjected to during their education. This ranking of interventions makes sense within the Western Cape context as the Western Cape Department of Education has been diligently improving the school system through wise policy setting and competent implementation. Decreasing community poverty and intervening socially within the home is, understandably, a much harder intervention for a government to execute. A combination of interventions delivered closest to the desired results.

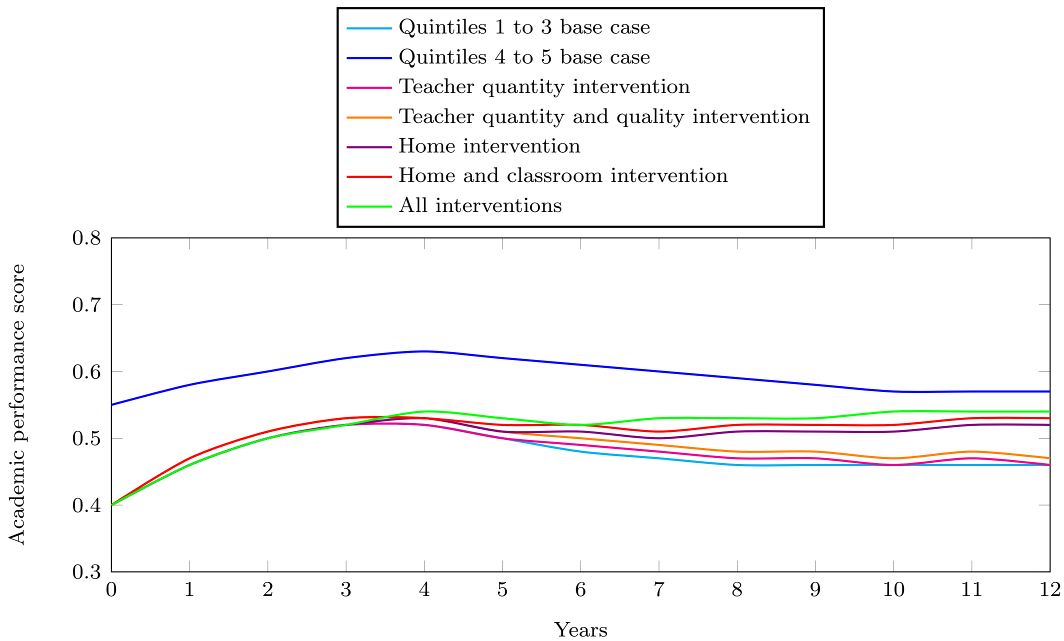

FIGURE 6.15: *Academic performance for each intervention for the eSEM during the twelve year simulation period.*

	Gr 3 achievement			
	High	**Standard**	**Pass**	**Low**
Quintiles 1 to 3 base case	18%	19%	33%	29%
Quintiles 4 to 5 base case	21%	21%	40%	18%
Teacher quantity intervention	19%	19%	34%	27%
Teacher quantity and quality intervention	19%	19%	34%	27%
Home intervention	20%	21%	35%	24%
Home and classroom intervention	26%	18%	33%	22%
All interventions	28%	18%	32%	22%
	Gr 6 achievement			
	High	**Standard**	**Pass**	**Low**
Quintiles 1 to 3 base case	8%	17%	38%	36%
Quintiles 4 to 5 base case	10%	20%	48%	22%
Teacher quantity intervention	9%	18%	38%	35%
Teacher quantity and quality intervention	9%	18%	38%	35%
Home intervention	11%	20%	39%	30%
Home and classroom intervention	18%	17%	37%	28%
All interventions	19%	17%	36%	28%

TABLE 6.4: *The summary of the final learner distributions per achievement category for each base case and intervention for the eSEM.*

	Teacher success measure	**Child success measure**	**Learner success measure**
Quintiles 1 to 3 base case	0.50	0.67	0.50
Quintiles 4 to 5 base case	0.62	0.93	0.58
Teacher quantity intervention	0.60	0.62	0.51
Teacher combined intervention	0.70	0.66	0.51
Home intervention	0.50	0.53	0.54
Home and classroom intervention	0.51	0.55	0.56
All interventions	0.59	0.67	0.57

TABLE 6.5: *The summary of the final success metric for each base case and intervention for the eSEM.*

CHAPTER 7

Conclusion

Contents

This chapter contains a summary of the dissertation and lists the major contributions of the work. Final conclusions and remarks are discussed including recommendations for policymakers. Some recommendations for future work are also listed.

7.1 Dissertation summary

The severity of the basic education crisis in South Africa was described in Chapter 1. The concept of bimodality in academic achievement within the basic education system was introduced and the inequality between the largely dysfunctional system (associated with learners from a lower socio-economic status) and the well-performing, functional system (associated with learners from a higher socio-economic status) was illustrated. The goals set by the DBE to improve basic education outcomes by 2030 are listed. Systems thinking and specifically system dynamics computer simulation modelling was introduced as an adequate technique with which to analyse the viability and effectiveness of these goals.

In Chapter 2 the SEM was introduced at a level of abstraction as a proof of concept for the use of system dynamics to model the South African basic education system. The SEM was constructed such that the school principal may act as an agent to choose the timing, the magnitude, and area of intervention during school management. The model was populated with data obtained from delphi groups, workshops and personal interviews with subject matter experts.

Chapters 3 to 5 contain descriptions of submodels expanding the SEM to produce the eSEM that has a finer granularity. In Chapter 3, the TEM was introduced with which the system of teachers in Western Cape public primary schools was analysed. The research question was answered as to whether it is the low teacher quality or the low teacher quantity that contributes most to the education crisis. In Chapter 4, the ECDM was introduced with which the system of pre-school children aged two to five years in Western Cape was analysed. The research question was answered as to whether it is the number of enrolments into ECD programmes that increases a cohort's school readiness, or whether it is the quality of the ECD programmes into which they are enrolled that increases this readiness. In Chapter 5, the PSM was introduced with which the system of primary school learners in the Western Cape public school system was analysed. The research question was answered as to whether interventions to increase the classroom's capacity to support learning or an intervention pertaining to the household's ability to support learning should be applied to increase the academic performance of Grade 3 and 6 learners. For each submodel, system factors were identified from literature and the quantitative data for the model was obtained from open-source datasets. In each instance the performance of the weaker education system was analysed against the performance of the stronger system to determine which factors contribute the most to inequality.

The construction of the eSEM as a combination of the SEM, TEM, ECDM, and PSM is described in Chapter 6. The best interventions of each submodel was applied to this model and the most influential factors leading to the inequality in academic performance between the two education systems (specifically within the Western Cape) were determined.

7.2 Recommendations

In Chapter 2 it was shown that a decision maker's choice of timing, magnitude, and area of intervention plays a significant role in the intervention's effectiveness. Interventions are most effective when they are applied early as a maintenance strategy instead of as a reaction to an emergency. Interventions must also be applied consistently and in multiple areas as the nature of the system is such that it resists change in only one area.

When this strategy was applied to the system of Western Cape primary school teachers, it was found that increasing the number of teachers had a greater positive impact on academic performance than when the quality of teachers were improved. However, applying both interventions delivers the best results. In Chapter 3 it was shown that the allocation of funds for improving a teacher corps should be focussed on better remuneration for qualified teachers (instead of, for example, exhausting funds on bursaries to student teachers) so that the career becomes attractive to high quality practitioners.

Early, continuous, and multiple factor interventions to the system of Western Cape pre-school two- to five-year-olds revealed that increasing the quality of ECD programmes for the current number of formally enrolled children leads to a greater percentage of school-ready five-year-olds in the Western Cape than increasing the number of formally enrolled children. Applying both interventions delivers better results, but decreasing family poverty for all children is the most effective intervention. In Chapter 4 it is shown that interventions should focus on increasing the employment rate of parents and allocating more funds to training practitioners rather than procuring resources for ECD facilities.

Early, continuous, and multiple factor interventions to the system of Western Cape learners attending public primary schools revealed that intervening in the home circumstance is slightly more effective than intervening in their classroom experience, but that intervening in both environments delivers the highest increase in Grade 3 and 6 literacy and numeracy achievement. In Chapter 5 it was shown that interventions should focus on strengthening the family and community structure so that it is able to provide adequate support for learners. This intervention should be combined with increased engaged time in the classroom through better resource allocation.

Finally, in Chapter 6 the best interventions for each submodel are applied. The results revealed that no single intervention was effective enough to bridge the achievement inequality between learners from the lower and the higher socio-economic quintiles. The application of all of the best interventions in combination came closest to the desired results. The eSEM thus illustrates again that even the best interventions from each submodel cannot be considered as a silver bullet solution to bring about a quick fix. Systems interventions have to be applied in early, regularly and in multiple areas within the system.

7.3 Achievement of objectives

In Section 1.4 the following objectives were identified:

Objective I

a Describe the current state of the South African basic education system to show its complexity and the extent to which it finds itself in crisis;

b Describe systems thinking and SD modelling to argue for its applicability as a method for analysing complex systems;

Objective II

a Develop the SEM as an abstraction of a South African school to serve as proof of concept for the use of SD simulation in education modelling within the South African context;

b Apply different interventions to the SEM to understand the effect of various intuitive solutions;

Objective III

a Develop the TEM as an extension of the SEM's complexity to analyse the effect of the quality of the educator pool on the overall quality of the education system.

b Populate the TEM with data from recently populated national datasets for validation and base case results;

c Apply different interventions to the TEM to understand their effect on the professionalism, teaching skills, subject knowledge, and computer literacy of teachers throughout their entire careers;

Objective IV

a Develop the ECDM as an input model to the PSM to analyse the effect of pre-school programs on the overall achievement of primary school learners.

b Populate the ECDM with data from recently populated national datasets for validation and base case results;

c Apply different interventions to the ECDM to understand their effect on the number of pre-school enrolments and the quality of the programs;

Objective V

a Develop the PSM as an extension of the SEM's complexity to analyse the effect of primary school management on the overall quality of the education system.

b Populate the PSM with data from recently populated national datasets for validation and base case results;

c Apply different interventions to the PSM to understand their effect on Grade 3 and Grade 6 literacy and numeracy scores;

Objective VI

a Combine all the models to form the eSEM to analyse the impact of each subsystem on the system as a whole.

b Determine which, if any, of the DBE's five priority goals for 2030 have the greatest impact in fixing the South African basic education system.

Objective I was achieved in Chapter 1. The statistics describing the state of the South African basic education system was summarised. A detailed description of the mechanics and policies of the system provided a background to the system within which South African learners find themselves. System dynamics was introduced as a computer simulation modelling technique and an argument was made for its use to analyse this complex system.

Objective II was achieved in Chapter 2. Causal-loop and stock-and-flow diagrams for the SEM were conceptualised and a description of the model as constructed in a simulation modelling software package was given. The results of the what-if interventions provided proof of concept and insight into the nature of effective interventions to the system.

Objective III was achieved in Chapter 3. Causal-loop and stock-and-flow diagrams for the TEM were conceptualised and details on the software modelling were presented. The TEM was populated with data from the SNAP Survey for Ordinary Schools and the GHS from 2010 to 2016. Three interventions were applied to determine their impact on the quality of teaching within the primary school system.

Objective IV was achieved in Chapter 4. The ECDM's causal-loop and stock-and-flow diagrams were conceptualised and details on the software modelling were given. The ECDM was populated with data from the GHS, the NIDS, and the ELOM from 2010 to 2017. Three interventions were applied to determine their effect on the number of pre-school enrolments and the quality of pre-school education programmes.

Objective V was achieved in Chapter 5. Causal-loop and stock-and-flow diagrams for the PSM were conceptualised and details on the software modelling were presented. The PSM was populated with data from the SNAP Survey of Ordinary Schools, the GHS from 2010 to 2016, and from the NSES from 2007 to 2009. Three interventions were applied to determine their effect on the academic achievement of Grade 3 and 6 learners in the Western Cape public education system.

Objective VI was achieved in Chapter 6. An expanded SEM was conceptualised to form the eSEM and details on the software modelling were presented. Five interventions were applied to determine which of the priority goals listed in the Action Plan for 2030 of the DBE has the greatest effect on improved academic performance at the basic education level.

7.4 Contribution and ideas for further study

The poor performance of the South African basic education system has been a tenacious problem for well over two decades. The problem is exacerbated by the growing inequality between a minority of adequately performing learners and a majority of learners disadvantaged by a dysfunctional system. Multiple stakeholders have suggested solutions to the problem. A popular solution is to allocate more funds without taking the complexities of the system into account.

This dissertation presents a new approach to analysing the problem within the South African context. It contains a description of a method by which the failure of the system can be studied holistically since multiple variables interact to form a complex network of cause-and-effect interactions. The application of this method enables an analyst to look across the breadth of the problem in order to gain the "big picture" view, and to consider the system as a cause to itself. It adds, for the first time, a level of behavioural thinking so that patterns rather than events can be identified.

The eSEM brings together a large number of variables describing a basic education system from literature. The impact and relationships of variables formerly considered to form "a black box" of complexity can now be analysed. Causal relationships are drawn by looking at the research from multiple area specific experts. Data from primary school learners, school management, and toddlers were taken into account.

The SEM, TEM, ECDM, and PSM are constructed as applications with which what-if scenarios in specific areas can be analysed. The impact of these models on the greater system can be understood by means of the eSEM. In Chapter 2, a way to compare the impact of different factors of different units is introduced. Assigning a goodness score to each factor is a novel way to make their strengths comparable and to test the impact of interventions that ultimately increases the goodness score. The use of a goodness score allows the use of qualitative and fuzzy replies to survey questions in the quantitative modelling so that no section of a survey is rendered unusable for simulation modelling and precious data does not have to remain unused. In Chapters 3 to 6 this method of goodness scoring continues to be used, albeit in the form of linear score assignment. Future work would include investigating the impact of assigning goodness scores according to more varied distributions (for example, goodness could improve exponentially as the number of survey replies increase towards the most favourable option).

A specific research question was selected for each of the models in Chapters 3 to 6. However, the models are constructed in such a way that any other research question about the factors within each system can be answered. The worlds of the South African teacher, toddler, and primary school learner may be explored by applying any permutation of intervention location and size to any of the system factors to analyse their impact on the greater system. In this way, this dissertation describes a simulation engine that may be calibrated for any specific school and presented to decision makers and stakeholders as a simulation game with which they can test the effects of their intuitive solutions. Future work would include creating a user interface for the eSEM and exporting the model as a mobile or desktop game for a requested system calibration. Each model is constructed such that any additional variables and relationships from new literature can be included to deepen the model insights.

Practical interpretations for the concept of "a large intervention" for each of the models in Chapters 3 to 6 are offered. The formal classification of real world actions as small, medium, or large interventions and the specific implementation time associated with each is beyond the scope of this dissertation. The practical meaning of "intervention" is left to policy makers to define. The models are constructed such that any meaning or time period of an intervention may be tested.

The TEM, ECDM, PSM, and eSEM were populated to compare the systems of the Western Cape lower SES community to the higher SES community. They were constructed in such a way that they may be used for other communities with other characteristics, or any other province. Future work to broaden the model insights would include comparing the performance of the lower SES system within the Western Cape with the performance of the lower SES system within, for example, the Limpopo province (arguable the worst performing South African province). In this way, solutions for an improved system can be obtained that are not only focussed on the massive problem of economic inequality in South Africa.

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