Technology Forecasting Using Structural Equation Modeling Based Data Fusion: Analysis of Strengths and Weaknesses Using a National Research and Education Network Example

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Abstract--**This paper considers strengths and weaknesses of the framework for Technology Forecasting using Structural Equation Modeling based context sensitive Data Fusion, which was first presented by Staphorst et al. in 2013. The framework is an exploratory Technology Forecasting technique that employs a Partial Least Squares based Structural Equation Modeling implementation of context sensitive Data Fusion in order to model complex multi-layered interrelationships between technology inputs, outputs and context related exogenous factors. Strengths and weaknesses considered for this framework, emanating from the extensive bodies of knowledge on Data Fusion and Structural Equation Modeling, include its ability to incorporate contextual information in its forecasting calculations and high sensitivity to structural model misspecification, respectively. An example model instantiation of the framework for the National Research and Education Network technology domain is used to quantitatively analyze the impact of these strengths and weaknesses. This example model instantiation, which is a significantly improved version of the one originally presented by Staphorst et al. in 2014, was constructed using knowledge gained through action research in the South African National Research Network, hypotheses from peer-reviewed literature and insights from the Trans-European Research and Education Network Association's annual compendiums for National Research and Education Network infrastructure and services trends.**

I. INTRODUCTION AND RESEARCH METHOD

Technology Forecasting (TF) involves the two primary activities of information gathering and analysis in order to investigate and ultimately predict changes in technology and the contextual forces that impact technology (e.g. national policies). TF techniques can be divided into two main categories, namely exploratory techniques and normative techniques [6]. Exploratory techniques, such as Technology Forecasting using Data Envelope Analysis (TFDEA), S-curve analysis and trend extrapolation, assume that technology progress is non-random and evolutionary in nature, allowing one to predict trends based on the analysis of historical data [6]. Conversely, normative techniques, such as morphological analysis and relevance trees, assume a desired technological end-state and then determine the steps and/or paths required to achieve this end-state [6].

In 2013 Staphorst et al. introduced a framework for Technology Forecasting using Structural Equation Modeling based context sensitive Data Fusion (TFSEMDF) [19], which is an exploratory technique that employs a Partial Least Squares (PLS) based Structural Equation Modeling (SEM) implementation of context sensitive Data Fusion (DF) in order to model complex multi-layered interrelationships between technology inputs, outputs and context related exogenous factors. Application of the proposed TFSEMDF framework was first illustrated in 2014 by Staphorst et al. [20] using a rudimentary example model instantiation in the technology domain of National Research and Education Networks (NRENs), which are specialized broadband network connectivity and service providers that explicitly caters for the needs of the research and education communities of a nation [1][2]. Staphorst et al. thereafter proposed an updated example model instantiation for the NREN technology domain in [21], constructed using insights gained through action research in the South African National Research Network (SANReN) [3], findings from Trans-European Research and Education Network Association's (TERENA) NREN compendiums for 2011 and 2012 on global NREN infrastructure and services trends [1][2], as well as hypotheses and postulations in peer-reviewed literature.

To date, research into TFSEMDF has been limited to the initial development of the framework [19][21] and its application to example model instantiations in the NREN technology domain [20][21] by Staphorst et al. This paper's primary purpose is to add to this limited body of knowledge by exploring strengths and weaknesses of the TFSEMDF framework. The research methodology employed during the study involved an initial literature and theory review to determine the primary strengths and weaknesses of the SEM statistical modeling and DF information integration techniques that constitute the foundation of TFSEMDF. This was followed by a quantitative analysis based on secondary data from the 2011 TERENA NREN compendium [1]. The quantitative analysis involved an evaluation and comparison of key TFSEMDF modeling parameters obtained for a baseline example NREN model instantiation against those for selected NREN model instantiation variations that were configured specifically to gain insights into selected strengths and weaknesses.

The paper commences with a discussion on its contribution to the practice of Engineering Management. An overview of the research methodology applied during the study is then provided. This is followed by a literature and theory review that summarizes the TFSEMDF framework proposed by Staphorst et al. [20], introduces the NREN technology domain as contextual environment for this study and explores the strengths and weaknesses of TFSEMDF emanating from the capabilities and limitations of its underlying SEM and DF foundations. Using the 2011

TERENA NREN compendium as secondary data, a PLS regression analysis is then presented for a baseline example NREN model instantiation, as well as variations of this model instantiation that were configured to explore selected TFSEMDF strengths and weaknesses. A discussion of the PLS regression analysis results is then presented, focussing on the effects of the considered TFSEMDF strengths and weaknesses on the hypothesised relationships in the baseline example NREN model instantiation and its model instantiation variations. Lastly, conclusions and areas for future research are presented.

II. CONTRIBUTIONS TO THE PRACTICE OF ENGINEERING MANAGEMENT

According to the American Society for Engineering Management (ASEM) the practice of Engineering Management is the art and science of directing and controlling activities that have a technological component, which includes the management functions of planning, organizing and allocating resources [17]. In order to successfully perform these activities, the Engineering Management Body of Knowledge (EMBOK) [17], developed by ASEM and other collaborators, postulates that engineering management professionals need to acquire skills and capabilities in a number of competency areas that include strategic planning, as well as the management of technology and research and development (R&D). The TFSEMDF framework developed by Staphorst et al. [19][21], as well as this study's efforts to gain a better understanding of its strengths and weaknesses, contribute to these two specific competency areas in the EMBOK by providing engineering managers with a framework for the forecasting of technology trends. Knowledge of these technology trends can contribute to their strategic planning, as well as technology and R&D management activities.

III. RESEARCH METHODOLOGY

The research methodology applied in this study consisted of an initial literature and theory review to determine the primary strengths and weaknesses of SEM and DF, which are the foundational building blocks of TFSEMDF. This was followed by a quantitative analysis of a baseline example NREN model instantiation, as well as several variations of this model instantiation, which were configured to gain insights into some of these strengths and weaknesses. Specifically, the strength of contextual information inclusion and weakness of improper structural model definition were considered. PLS regression analysis, using secondary data from the 2011 TERENA NREN compendium [1], was used to determine the SEM path coefficients and their respective significance levels for this baseline example NREN model instantiation and the variations thereof considered.

While a portfolio of reliability and validity metrics, ranging from the Coefficients of Determination to Predictive Validity, are available to compare SEM model instantiations whenever covariance based regression analysis is used [22], it has been shown that these metrics are not appropriate to compare model instantiations when PLS regression is used [7], as was the case with this study. Hence, an alternative approach, suggested in [7], was used in order to determine the effects of contextual information inclusion and improper structural model definition. This involved evaluating the integrity of the baseline example NREN model instantiation and its variations by observing the absence or presence of SEM paths. To that end, the path coefficients and significance results were used to determine the absence or presence of SEM paths in the baseline example NREN model instantiation and its variations.

IV. LITEREATURE AND THEORY REVIEW

A. Overview of the TFSEMDF Framework

By recognizing that SEM is capable of the simultaneous modeling of relationships among multiple dependent and independent constructs, Steinberg postulated that SEM is one potential statistical tool that can be used to implement context sensitive DF [23][24]. Steinberg harmonized DF and SEM terminology by noting that DF problem variables, context variables and sensor measurements can be viewed as SEM endogenous constructs, exogenous constructs and measurement indicators, respectively [23][24].

Nyberg and Palmgren [14] describe technological indicators as indices or statistical data that allow for the direct characterization of technology throughout their life cycles in order to allow decision makers to take strategic actions. According to Grupp [10], such indicators can in general be divided into the following three major categories based on their intended function: input indicators, byput indicators and output indicators [10][14]. Grupp [10] states that input indicators are variables related to drivers of technological progress, byput indicators are variables that are related to sub-phenomena of the technological progress and output indicators are variables related to the qualitative, quantitative or value-rated progress in process or product development [14].

According to Sohn and Moon [18] most TF techniques rarely take into account the structural relationships amongst technology indicators and TF output metrics. SEM, however, provides an advantage over these limited TF techniques by allowing for the modeling of complex hierarchical relationships between technology indicators and TF outputs metrics. Sohn and Moon showed in [18] that SEM could be used as an effective regression technique to evaluate a multi-layered hierarchal model, through progressive aggregations and refinements of input technology indicator data, in order to produce a reliable statistical estimate of the Technology Commercialization Success Index (TCSI) TF output metric.

By overlaying the relationship framework for technology indicators on the generalized framework for context sensitive DF framework and applying a SEM construct grouping and layering framework, Staphorst et al. in [19][21] developed the TFSEMDF framework shown in Fig. 1.

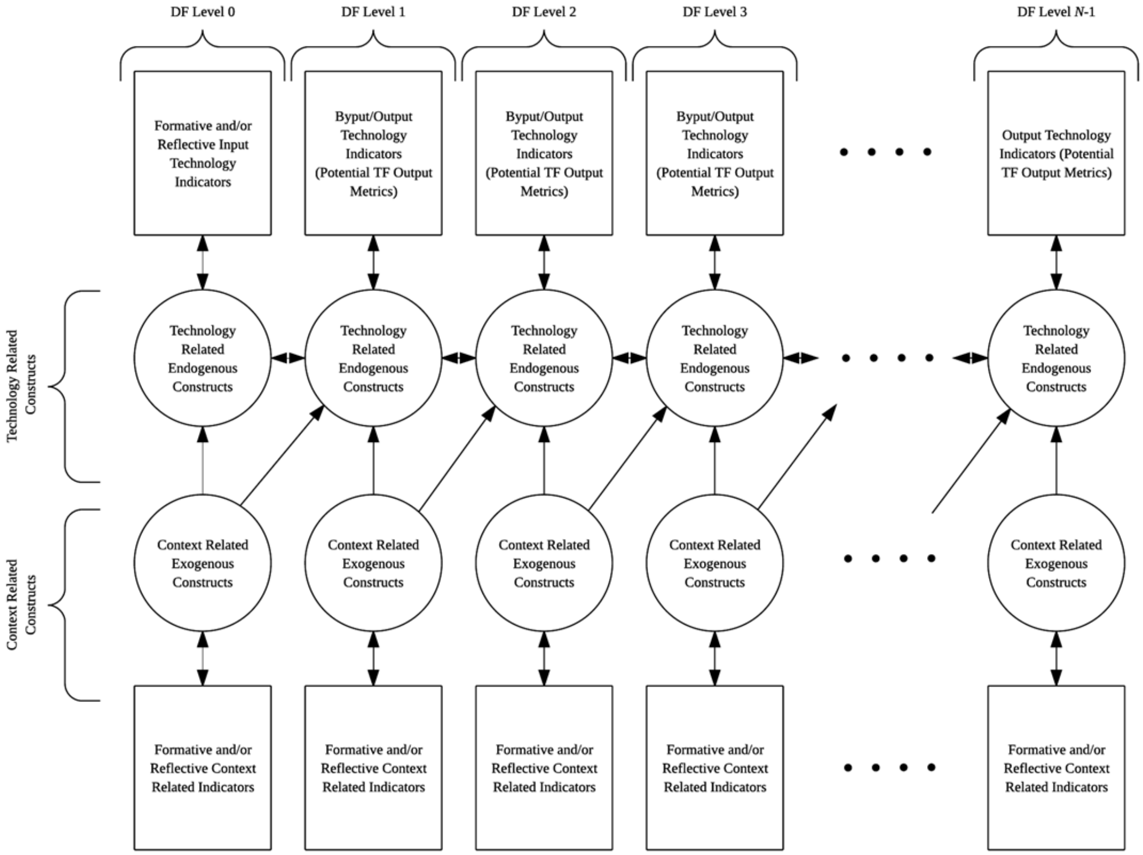

Fig. 1: Proposed Framework for SEM Based DF for TF

This framework effectively combines Soon and Moon's [18] use of SEM for TF with Steinberg's use of SEM to implement context sensitive DF [23]. Staphorst et al.'s TFSEMDF framework [19][20][21] performs multi-layered aggregation and refinement of technology and context related information by means of regression based processing at DF Levels 0 through *N*-1, where *N* is user selected. Input technology indicators [10][14] and context related indicators [23] are used as inputs to technology related endogenous constructs and context related exogenous constructs, respectively. The number of levels *N* are a function of the complexity of the technology domain under consideration, as well as time and cost constraints involved in collecting technology and context related input data. To gain a deeper insight into the detailed functioning of this framework, the interested reader is referred to [19][20][21].

B. Theoretical Strengths and Weaknesses of TFSEMDF

While the body of knowledge for the TFSEMDF framework and its applications is still in its infancy, one can infer some of its strengths and weaknesses by considering the abilities and limitations of its foundational building blocks, i.e. SEM and context sensitive DF. The following subsections consider some well-know strengths and weaknesses of SEM and context sensitive DF. Note that any emergent strengths or weaknesses, which emanate from the integration of SEM and DF, falls outside the scope of this paper and will be addressed in future research.

1. SEM Strength: The Ability to Model Complex and Hierarchical Interrelationships

The first notable strength of SEM is its ability to model complex and hierarchical structural relationships between various indicators and constructs, even allowing for non-linear and non-Gaussian factors, as well as cyclical dependencies amongst model variables [20]. Classic regression techniques that have found application in TF, such as multiple regression, discriminant analysis, logistic regression and analysis of variance, can be classified as first generation techniques, since these techniques explicitly assume independence between multiple dependent variables [22]. This, unfortunately, limits the ability of first generation techniques from comprehensively modeling complex interrelationships, such as the interplay between two or more output variables. More specifically, classic first generation regression techniques are not able to model the potential mediating or moderating effect that one construct could have on another. A further inherent limitation of first generation regression techniques is their explicit assumption that all dependent and independent variables are directly observable

[22] This assumption implies that all variable values can be directly obtained from real-world sampling [22]. As such, any variables that cannot be directly observed need to be considered unobservable and have to be excluded from first generation regression models [22]. However, such unobservable variables, commonly referred to as latent constructs, are supported by SEM [22].

2. SEM Strength: Small Sample Sizes can Produce Trustworthy Results when using PLS Regression

An important strength of SEM implemented using PLS regression, is that it addresses several problems inherent in survey-based business research that limit the usability of classic covariance-based regression techniques [22]. These problems include lower than expected response rates, respondents that do not answer all items contained in the survey and highly correlated survey items [22]. Typically, classic covariance-based regression techniques deliver unstable results under conditions of small sample sizes and missing values, while multi-colinearity increases the standard error of the estimated regression coefficients, which could result in valid predictors being rejected from the regression model [22]. PLS regression is also capable of modeling multiple model output (dependent) variables, which are potentially correlated [22].

3. SEM Weakness: Model Misspecification can Result in the Rejection of Valid Relationships

While SEM has the strength of modeling complex and hierarchical structural relationships between various indicators and constructs, a well-know weakness of SEM is its sensitivity to poorly defined model structures, also referred to as model misspecification [7]. Poorly defined models could lead to known and proven relationships between constructs being deemed statistically insignificant. This weakness is investigated in more detail during the remainder of the paper.

4. Context Sensitive DF Strength: Inclusion of Context Related Information Improves Regression Results

Strengths and weaknesses for DF are very much a function of the underlying tools and techniques selected to perform the multi-layered processing of input information. This is due to the fact that DF simply defines a high-level framework for the alliance of data originating from different sources, with the aim to produce information of greater quality, without specifying the tools and techniques available for implementation. There is, however, a strength that emanates specifically from using contextual information in DF, which is its ability to contribute positively to the refinement of data alignment and association, as well as situation state estimation [23]. This strength receives detailed attention throughout the remainder of the paper.

C. The NREN Technology Domain as Context for this Study into the Strengths and Weaknesses of TFSEMDF

NRENs are specialized broadband network connectivity and service providers that explicitly cater for the needs of a nation's research and education communities [1][2]. In some instances, NRENs also service the needs of other public sector entities, such as hospitals, municipalities and libraries. Typically, one NREN is present per country, for example SANReN [3] in South Africa and the Joint Academic Network (JANET) in the United Kingdom. However, separate NREN entities could potentially exist in a country in order to service distinct in-country research and education sectors or geographic areas, for example the Energy Sciences Network (ESnet) and Kansas Research and Education Network (KanREN) in the United States [2]. Most NRENs are state funded to some extent [1][2].

NREN's are built primarily on fiber optic infrastructure and provide researchers, educators and students with unparalleled connectivity and advanced services, at a fraction of the price of commercial solutions [2]. These networks are currently experiencing rapid technology driven changes, resulting in evolving business models, innovative infrastructure solutions and service offerings, as well as increased international collaboration [1][2].

NRENs operate within the highly regulated and standards driven space of information and communication technology (ICT). As such, technology related factors (e.g. bandwidth usage of the infrastructure provided), as well as contextual factors (e.g. regulatory legislation and government fiscal policies) impact strategic decision-making at NRENs [1][2]. Since the underlying SEM foundation of TFSEMDF allows for the modeling of complex multi-layered interrelationships between technology and context related constructs [19][20][21], such as those present within NRENs, the NREN technology domain is an ideal candidate within which to explore the strengths and weaknesses of TFSEMDF.

V. ANALYSIS AND RESULTS

An example NREN model instantiation of the TFSEMDF framework, which is an improved version of the one originally proposed and analyzed in [20], is used in this paper as baseline to explore strengths and weaknesses of TFSEMDF. This baseline example NREN model instantiation was developed for [21] using insights captured in TERENA's NREN compendium for 2012 [2], knowledge gained through action research [11] performed by the authors during their involvement with the management and operations of SANReN [3], as well as hypotheses presented and tested in peer-reviewed literature.

SEM path coefficients and path coefficient significance results are presented for the baseline example model instantiation and variations of the baseline configured to simulate the strength of contextual measurement inclusion and weakness of improper structural model definition. These results presented were generated using PLS regression analyses, with secondary data from the TERENA's NREN compendium for 2011 used as inputs to the baseline model instantiation and its variations.

Several reliability and validity measures are available test the trustworthiness of the inputs data used, as well as results obtained during SEM analyses [22]. Measurement portion measures include Indicator Reliability, Construct Reliability and Convergent Validity, while structural portion measures include the Coefficients of Determination, Path Coefficient Significance and Predictive validity [22]. However, since the analysis approach adopted for this study involved comparing the absence or presence of SEM paths in the baseline NREN model instantiation and its variations [7] in order to investigate the effects of contextual information inclusion and improper structural model definition, only Path Coefficient Significance results are presented in this paper.

The interested reader is referred to [21] for a detailed analysis and evaluation of the full suite of reliability and validity measures for an example NREN model instantiation that is identical to the baseline example model instantiation used in this study. The analysis and evaluation results presented in [21], obtained using the secondary data from the 2011 TERENA NREN compendium [1], positively affirm the reliability and validity of the indicator data, as well as PLS regression analysis results obtained for the baseline NREN model instantiation [21]. Hence, this study's indicator data and PLS regression analysis results can safely be regarded as trustworthy.

A. Baseline Example NREN Model Instantiation

1. Baseline Example NREN Model Instantiation Overview

Fig. 2 presents the baseline example NREN model instantiation originally developed and analyzed in [21] by Staphorst et al. This example model instantiation employs *N*=3 DF levels. Level 0, Level 1 and Level 2 focus on NREN Connectivity (i.e. the NREN provided infrastructure to deliver advanced services), NREN Services (i.e. the portfolio of advanced services provided to users in order to make use of the NREN provided infrastructure) and NREN Utilization (i.e. a measure use of the NREN provided through the advanced services available to users), respectively.

In essence the NREN Connectivity level in Fig. 2 is an aggregation of Layer 1 (Physical) through to Layer 6 (Presentation layer) in the 7-layered Open Systems Interconnection (OSI) model [27], while the NREN Services level represents Layer 7 (Application layer). The 7-layered OSI model has been unofficially extended through the addition of Layers 8 to 10, representing Human-Computer Interaction (HCI) related aspects [4]. NREN Utilization is one possible representation of these HCI related layers.

At Level 0 of the example NREN model instantiation, which focuses on infrastructure related technology metrics, a single technology related endogenous construct, namely *NREN Infrastructure Capability* (η_1), is defined. The purpose of this construct is to model the extent to which the NREN has invested in dark fibre infrastructure and managed circuits [1][2][16]. Dark fibre is defined fibre infrastructure that is either owned outright by the NREN, or where the NREN has secured a long-term Indefeasible Right of Use (IRU) for the use of fibre [1][2]. Managed circuits are fibre infrastructure owned by another party and leased by the NREN [1][2]. Based on [16], in the example NREN model instantiation it is postulated that the *NREN Infrastructure Capability* (η_1) construct is related to two formative input technology indicators (i.e. both indicators jointly represent the construct) that measure the length of available dark fibre infrastructure (denoted as *Length of Dark Fiber Infrastructure Owned by the NREN* (Y_1) with indicator loading π_{y1}) and the number of rented managed circuits [1][2] (denoted as *Number of Managed Circuits Rented by the NREN* (Y_2) with indicator loading π_{y2}), respectively.

Also defined at Level 0 is a single context related exogenous construct entitled *Government Influence over the NREN* (ξ_1). This construct has three reflective indicators (i.e. each indicator is capable of individually representing the construct) that measure the NREN governance mode (denoted as *NREN Governance Mode* (X_1) with indicator loading λ_{x1}), level of government funding provided to the NREN (denoted as *Level of Government Funding* (X_2) with indicator loading λ_{x2}) and the range of institutions the NREN is mandated to connect (denoted as *Range of Institutions the NREN is Mandated to Connect* (X_3) with indicator loading λ_{x2}), respectively. NREN governance mode can range from full government driven governance through to no government driven governance [2][22]. The range of institutions that the NREN is mandated to connect can vary from only type of institutions, such as universities, to a suite of various types of institutions, such as research organizations, universities, schools, etc. [2]. A positive relation between *Government Influence over the NREN* (ξ_1) and *NREN Infrastructure Capacity* (η_1) is postulated and represented by the path coefficient γ_1. This relation was derived from the notion that government intervention is required at various points in the NREN value chain, such as infrastructure funding, policy definition, regulation, etc. in order to ensure that an NREN successful matures in terms of the connectivity and advanced services that it provides [9][12].

It is important to note that additional context related measurement indicators and constructs from the political, economic, sociological, legal and environmental domains can be added to a model instantiation such as this example NREN model instantiation in order to potential improve the model's ability to forecast output technology metrics. However, given that this example NREN model instantiation was tested using the data available from the 2011 TERENA NREN compendium, the context related measurement indicators were limited to those associated with the *Government Influence over the NREN* (ξ_1) construct.

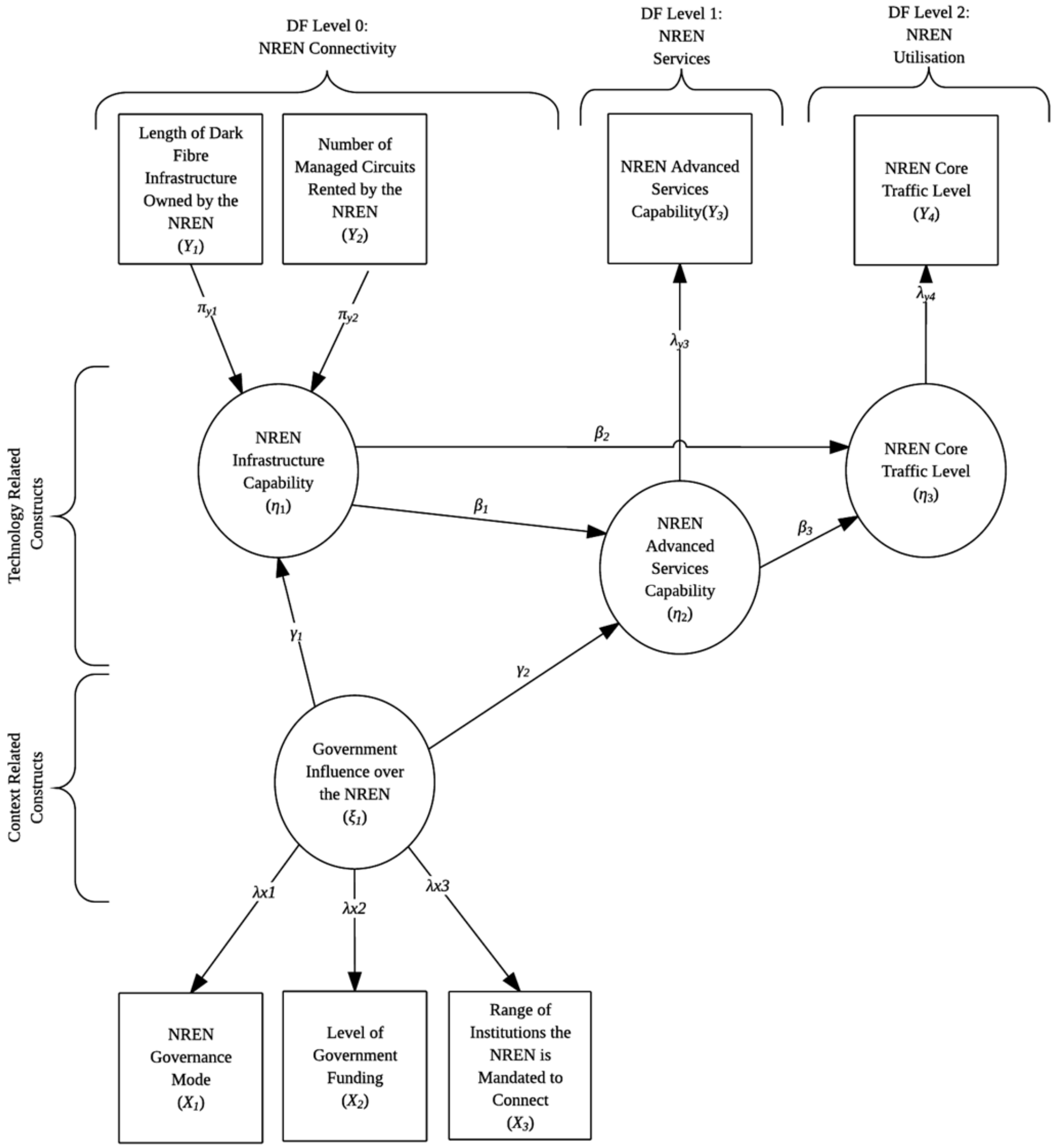

Fig. 2: Baseline Example Model Instantiation for the NREN Technology Domain

Level 1 of the example NREN model instantiation, which focuses on services related technology metrics, defines a single exogenous technology related construct entitled *NREN Advanced Services Capability* (η_2). This construct embodies the NREN's capability to provide a suite of advanced NREN services [1][2], such as Authentication and Authorization Infrastructure (AAI) services, provisioning of Identity Federation Services, hosting of Identity Federation Services and inter-federating with other NRENs [2]. The construct has a single reflective byput technology metric as reflective indicator, measuring the size of the portfolio of advanced services offered and hosted by the NREN (denoted as *NREN Advanced Services Capability* (Y_3) with indicator loading λ_{y3}). A postulated positive relationship between *NREN Infrastructure Capability* (η_1) and *NREN Advanced Services Capability* (η_2) is represented by the path coefficient β_1. This relationship emanates from the postulation in [9] that an NREN requires an advanced infrastructure capability in order to be able to deliver a portfolio of advanced services.

While no exogenous context related construct is defined for data fusion Level 1, it is postulated that the Level 0's *Government Influence over the NREN* (ξ_1) is positively related to the NREN's ability to deliver advanced services [2]. This relationship is captured in the SEM model of Fig. 2 by means of path coefficients γ_2. The postulated relationship is based on the reasoning in [9][12] that government intervention is required at various points in the NREN value chain in order to ensure that an NREN successful matures in terms of the advanced services portfolio that it provides.

Level 2 in the example model instantiation focuses on the utilization of the NREN, which is frequently used as a proxy to measure the impact that an NREN creates in its beneficiary communities [2][3], as well as the Return of Investment (ROI) of the funders of the NREN [5]. A single context related exogenous construct, entitled *NREN Core Traffic Level* (η_3), which represents the bandwidth usage in the core network of the NREN, is used to represent the utilization of the NREN [1][2]. This construct is directly measure by means of the reflective measurement indicator *NREN Core Traffic Level* (Y_4), with indicator loading λ_{y4}. This measurement indicator is also the TF output metric for the example NREN model instantiation.

Postulated positive relationships between *NREN Infrastructure Capability* (η_1) and *NREN Core Traffic Level* (Y_4), as well as between *NREN Advanced Services Capability* (η_2) and *NREN Core Traffic Level* (Y_4), are represented by path coefficients β_2 and β_3, respectively. The positive relationship between infrastructure capability and network utilization (i.e. core network traffic level) is supported in [16]. In [9][12] it is postulated that the maturity of the advanced service portfolio is a driver in the utilization of broadband networks, thereby justifying the positive relationship between the advanced services capability and network utilization.

2. Research Propositions for the Baseline Example NREN Model Instantiation

The postulated relationships between constructs in Fig. 2's example NREN model instantiation give rise to the set of research propositions below. These research propositions' association with the various paths defined in the baseline example NREN model instantiation is detailed in Fig. 2, as well as Table 3.

- **Research Proposition H1:** The NREN's infrastructure capability is positively related to the level of government influence over the NREN. This hypothesis stems from notion that government influence is required in order to ensure that an NREN is successful in maturing its infrastructure capability [9][12].
- **Research Proposition H2:** The advanced services capability of the NREN is positively related to the NREN's infrastructure capability. This hypothesis is supported by the postulation in [9] that an NREN requires an advanced infrastructure capability in order to be able to deliver a portfolio of advanced services.
- **Research Proposition H3:** The advanced services capability of the NREN is positively related to the level of government influence over the NREN. This hypothesis stems from notion that government influence is required in order to ensure that an NREN is successful in maturing its advanced services portfolio [9][12].
- **Research Proposition H4:** The level of core network traffic in the NREN is positively related to the infrastructure capability of the NREN, as postulated in [16].
- **Research Proposition H5:** The level of core network traffic in the NREN is positively related to the advanced services capability of the NREN, as postulated in [9][12].

3. Analysis Results for the Baseline Example NREN Model Instantiation

Secondary data from TERENA's NREN compendium for 2011 [1] was used to determine Fig. 2's indicator loadings and path coefficients through PLS regression analysis. TERENA, which now forms part of GÉANT, was an was a not-for-profit association of European NRENs with the objective to provide a platform for NREN's to collaborate and openly share knowledge on networking technologies, services and infrastructure. TERENA performs an extensive yearly survey amongst the global NREN community in order to determine current technology and services trends. The results and interpretation of these surveys are then openly published as part of TERENA's NREN compendium series.

Table 1 below summarizes the composition of the baseline example NREN model instantiation indicator data using the secondary data extracted from the 2011 TERENA NREN compendium [1]. A total of 61 NRENs responded to TERENA's survey to collect data for this. The original survey distributed by TERENA to NRENs is available from [1].

In this study the SmartPLS [15] freeware software package was employed to realize the example NREN model instantiation of Fig. 2 and calculate all loadings and path coefficients through PLS regression. SmartPLS was configured to normalize all indicator data, as a variety of scaling approaches and ranges was used by TERENA in collecting the original data. Note that only 28 NRENs provided all of the survey inputs in order to calculate the indicator inputs according to Table 1. Hence missing data was flagged and SmartPLS configured to use a mean replacement algorithm to compensate for this [15].

The indicator loadings for the measurement portion of the baseline example NREN model instantiation were calculated and it was determined that all loadings for the reflective indicators exceeded the minimum Indicator Reliability level of 0.4 [19]. Hence, all reflective indicators defined in Fig. 2 were retained for the remainder of the analysis. By default, all formative indicators were also retained [19]. The only latent construct with reflective indicators present in the baseline example model instantiation was Government Influence over the NREN ($\xi 1$). This latent construct complied with the minimum requirement of 0.6 for the Composite Reliability [8]. Also, when measured against the study's elected threshold value of 0.5 for the Convergent Validity metric [22], it was concluded that the reflective indicators for this latent construct exhibited a sufficient Average Variance Extracted (AVE) level, indicating that for this construct the majority of the total variance measured was due to indicator variance and not due to measurement error. Lastly, since the baseline example NREN model instantiation only had one latent construct with reflective indicators, the Discriminant

TABLE 1: INDICATOR DATA COMPOSITION FROM THE 2011 TENERA NREN COMPENDIUM [1]

Technology or Context Related Indicator	***Indicator Composition***
NREN Governance Mode (X_1)	Extracted from the online profiles of the respondent NRENs of the 2011 compendium [1] using following the scaling: • The NREN is a government agency or part of a ministry = 3 • Government appoints at least half of the NREN's governing body = 2 • Indirect relationship between the NREN and government = 1 • No formal relationship between the NREN and government = 0
Level of Government Funding (X_2)	Level of government funding (as a percentage of total funding) received by respondent NRENS, as summarized in Graphs 6.4.2 and 6.4.3 in the 2011 NREN compendium [1]
Range of Institutions the NREN is Mandated to Connect (X_3)	Sum of the institution types in Table 2.2.1 of the 2011 NREN compendium [1] supported by respondent NRENs
Length of Dark Fiber Infrastructure Owned by the NREN (Y_1)	Total length of dark fiber [in kilometers] owned by respondent NRENs as summarized in Table 3.6.3 of the 2011 NREN compendium [1]
Number of Managed Circuits Rented by the NREN (Y_2)	Total number of managed circuits rented by respondent NRENs as summarized in Table 3.3.2 of the 2011 NREN compendium [1]
NREN Advanced Services Capability (Y_3)	Total number of positive answers to the following questions in Table 5.3.1.1 in the 2011 NREN compendium [1]: • Does the NREN provide of Authentication and Authorization Infrastructure (AAI) services? • Does the NREN provide Identity Federation services? • Does the NREN operate the Identity Federation services? • Does the NREN's Identity Federation services inter-federate with those provided by other NRENs?
NREN Core Traffic Level (Y_4)	Annual level (measured in terabytes per year) of traffic sent on to the backbone networks of respondent NRENs, as measured by T_1+T_4 in Graphs 4.2.1 and 4.2.2 in the 2011 NREN compendium [1]

Validity test was unnecessary [22]. Note that a detailed review of the various measurement portion reliability and validity results for the baseline example NREN model instantiation will be presented in [21].

The path coefficients for the structural portion of the baseline example NREN model instantiation are listed in Table 2. These path coefficients, with their associated path significance test results shown in Table 3, were used to evaluate the research propositions for the baseline example NREN model instantiation.

The significance of path coefficients, also sometimes referred to as Goodness-of-Fit, was tested via asymptotic *t*-statistics, resulting in associated *p*-values. From Table 3's Path Coefficient Significance test results, obtained using SmartPLS's bootstrapping function [15] configured to generate 500 sets of subsamples from the 61 cases in the original sample, the only path that exhibited a *p*-value larger than the maximum acceptable significance level of $\alpha = 0.10$ was *NREN Infrastructure Capability (η_1) → NREN Advanced Services Capability (η_2)*. Hence, this path was deemed insignificant.

TABLE 2: BASELINE EXAMPLE NREN MODEL INSTANTIATION'S STRUCTURAL PORTION PATH COEFFICIENT RESULTS (PATHS NOT SUPPORTED, DUE TO NEGATIVE OR ZERO PATH COEFFICIENTS, SHADED IN GREY)

Research Proposition: SEM Path	***Path Coeff***	***Value***
H1: *Government Influence over the NREN (ξ_1) → NREN Infrastructure Capability (η_1)*	γ_1	0.599
H2: *NREN Infrastructure Capability (η_1) → NREN Advanced Services Capability (η_2)*	β_1	0.016
H3: *Government Influence over the NREN (ξ_1) → NREN Advanced Services Capability (η_2)*	γ_2	0.855
H4: *NREN Infrastructure Capability (η_1) → NREN Core Traffic Level (η_3)*	β_2	0.289
H5: *NREN Advanced Services Capability (η_2) → NREN Core Traffic Level (η_3)*	β_3	0.187

TABLE 3: BASELINE EXAMPLE NREN MODEL INSTANTIATION'S PATH COEFFICIENT SIGNIFICANCE TEST RESULTS (PATHS JUDGED INSIGNIFICANT AT $A = 0.10$ SHADED IN GREY)

Research Proposition: SEM Path	***p-Value***
H1: *Government Influence over the NREN (ξ_1) → NREN Infrastructure Capability (η_1)*	0.001
H2: *NREN Infrastructure Capability (η_1) → NREN Advanced Services Capability (η_2)*	0.901
H3: *Government Influence over the NREN (ξ_1) → NREN Advanced Services Capability (η_2)*	0.001
H4: *NREN Infrastructure Capability (η_1) → NREN Core Traffic Level (η_3)*	0.044
H5: *NREN Advanced Services Capability (η_1) → NREN Core Traffic Level (η_3)*	0.097

The analysis revealed that all interrelationships between the endogenous latent constructs and their related constructs produced explained variances, measured by the Coefficients of Determination *(R^2)*, exceeding the minimum level of 0.1 [22]. Also, a review of the Predicative Validity test results for the *NREN Core Traffic Level (η_3)* construct, directly observable via the output forecasting technology metric of interest *NREN Core Traffic Level (Y_4)*, revealed that both the Cross-validated Communality (H^2) and the Cross-validated Redundancy (F^2) tested positively. Hence, the both the baseline example NREN model instantiation's measurement indicators and the defined structural relationships are well suited to forecasting the NREN's core network traffic level. Note that a detailed review of the various structural portion reliability and validity results for the baseline example NREN model instantiation will be presented in [21].

B. TFSEMDF Strength: Contextual Information Inclusion

1. Analysis Approach for the Investigation into the Effects of Contextual Information Inclusion

TFSEMDF's ability to include measurement indicators and constructs from the political, economic, sociological, legal and environmental domains in order to produce improved TF output metrics, can be regarded as one of the primary strengths of the framework proposed by Staphorst et al. [20]. In order to investigate the effects of using contextual information in the TFSEMDF framework, the baseline example NREN model instantiation of Fig. 2 was reanalyzed for various combinations of measurement indicator inclusion for the contextual construct *Government Influence over the NREN (ξ_1)*. Moreover, the path coefficients and path coefficient significance results obtained by omitting combinations of the reflective indictors *NREN Governance Mode (X_1)*, *Level of Government Funding (X_2)* and *Range of Institutions the NREN is Mandated to Connect (X_3),* were compared against the results obtained for the baseline example NREN model instantiation. It is important to note that, for this investigation, the set of research propositions (i.e. SEM structural model paths) defined above for the baseline example NREN model instantiation still holds true.

2. Analysis Results for the Investigation into the Effects of Contextual Information Inclusion

The secondary data from TERENA's NREN compendium for 2011 [1], which was used to determine the PLS regression results for the baseline example NREN model instantiation, was also used according to Table 1's data composition scheme for the investigation into the effects of contextual information inclusion. Table 4 below summarizes the path coefficients obtained for various combinations of inclusion of the contextual indicator metrics X_1, X_2 and X_3 for the construct *Government Influence over the NREN (ξ_1)*, while Table 5 details the path coefficient significance results.

Table 5's results were obtained using SmartPLS's bootstrapping function [15] configured to generate 500 sets of subsamples from the 61 cases in the original sample.

TABLE 4: PATH COEFFICIENT RESULTS FOR THE INVESTIGATION INTO THE EFFECTS OF CONTEXTUAL INFORMATION INCLUSION (PATHS NOT SUPPORTED, DUE TO NEGATIVE OR ZERO PATH COEFFICIENTS, SHADED IN GREY)

Research Proposition: SEM Path	***Path Coeff***	***Contextual Indicators Included***						
		None	*X_1*	*X_2*	*X_3*	*X_1, X_2*	*X_1, X_3*	*X_2, X_3*
H1: *Government Influence over the NREN (ξ_1) → NREN Infrastructure Capability (η_1)*	γ_1	0	0.587	0.525	0.441	0.610	0.585	0.531
H2: *NREN Infrastructure Capability (η_1) → NREN Advanced Services Capability (η_2)*	β_1	0.523	0.313	0.193	0.170	0.144	0.045	0.070
H3: *Government Influence over the NREN (ξ_1) → NREN Advanced Services Capability (η_2)*	γ_2	0	0.368	0.635	0.812	0.631	0.829	0.862
H4: *NREN Infrastructure Capability (η_1) → NREN Core Traffic Level (η_3)*	β_2	0.306	0.274	0.300	0.296	0.287	0.283	0.297
H5: *NREN Advanced Services Capability (η_2) → NREN Core Traffic Level (η_3)*	β_3	0.179	0.194	0.182	0.184	0.188	0.190	0.183

TABLE 5: PATH COEFFICIENT SIGNIFICANCE TEST RESULTS (*P*-VALUES) FOR THE INVESTIGATION INTO THE EFFECTS OF CONTEXTUAL INFORMATION INCLUSION (PATHS JUDGED INSIGNIFICANT AT $A = 0.10$ SHADED IN GREY)

Research Proposition: SEM Path	***Contextual Indicators Included***						
	None	*X_1*	*X_2*	*X_3*	*X_1, X_2*	*X_1, X_3*	*X_2, X_3*
H1: *Government Influence over the NREN (ξ_1) → NREN Infrastructure Capability (η_1)*	1.000	0.001	0.001	0.013	0.001	0.001	0.001
H2: *NREN Infrastructure Capability (η_1) → NREN Advanced Services Capability (η_2)*	0.001	0.173	0.242	0.223	0.371	0.775	0.562
H3: *Government Influence over the NREN (ξ_1) → NREN Advanced Services Capability (η_2)*	1.000	0.284	0.001	0.001	0.005	0.001	0.001
H4: *NREN Infrastructure Capability (η_1) → NREN Core Traffic Level (η_3)*	0.225	0.375	0.337	0.355	0.255	0.443	0.216
H5: *NREN Advanced Services Capability (η_2) → NREN Core Traffic Level (η_3)*	0.462	0.520	0.547	0.561	0.449	0.602	0.430

C. TFSEMDF Weakness: Poor Structural Model Definition

1. Analysis Approach for the Investigation into the Effects of Improper Structural Model Definition

In order to explore the effects of a poorly defined structural portion for a model instantiation of the TFSEMDF framework, Fig. 3's variation on Fig. 2's baseline example NREN model instantiation was considered. This chosen variation model instantiation was selected such that its measurement portion did not differ from the baseline example NREN model instantiation. Hence, the variation model instantiation has the same set of technology and context related measurement indicators and constructs. The structural portion of the variation model instantiation, however, was chosen such that the structure did not reflect the theoretical foundation used in creating the baseline example NREN model instantiation. Moreover, the variation model instantiation's structure was chosen to be in conflict with the OSI model [27] and the NREN capability maturity model in [9], both which promote the concept that an infrastructure capability forms the foundation for an advanced services capability, not the reverse as is shown in Fig. 3. In other words, for the variation model instantiation DF Level 0 and DF Level 1 in Fig. 2 are swapped for Fig. 3.

2. Research Propositions for the Investigation into the Effects of Poor Structural Model Definition

All research propositions defined for the baseline example NREN model instantiation holds for the investigation into the effects of poor structural model definition, with the exception for H2. This research proportion changes due to the direction change in the path between the *NREN Infrastructure Capability* (η_1) and *NREN Advanced Services Capability* (η_2) constructs. Thus, the full set of research propositions for the variation model instantiation shown in Fig. 3 is as follows:

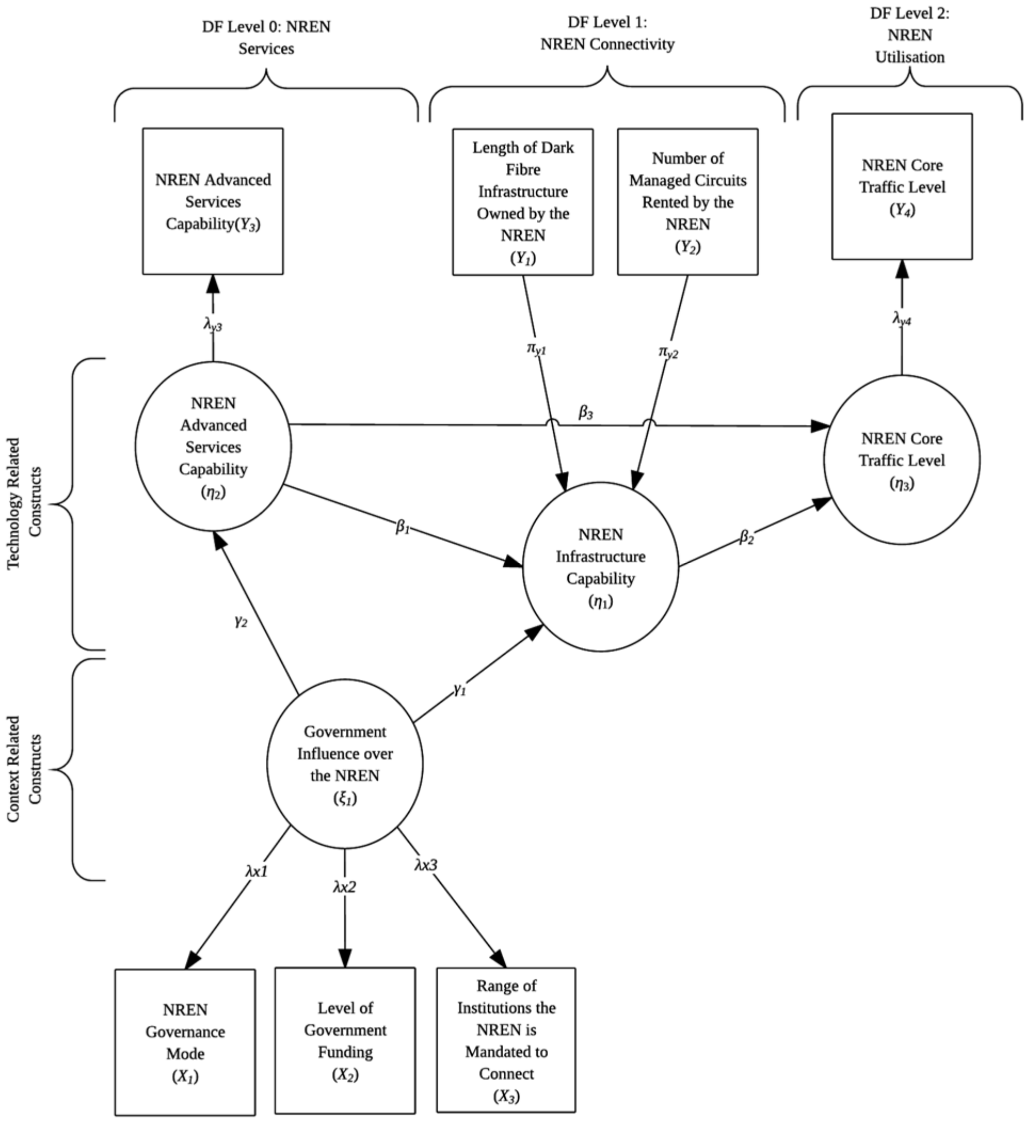

Fig. 3: Poorly Structured Variation Model Instantiation for the NREN Technology Domain

TABLE 6: PATH COEFFICIENT RESULTS FOR THE INVESTIGATION INTO THE EFFECTS OF POOR STRUCTURAL MODEL DEFINITION (PATHS NOT SUPPORTED, DUE TO NEGATIVE OR ZERO PATH COEFFICIENTS, SHADED IN GREY)

Research Proposition: SEM Path	***Path Coeff***	***Value***
H1: *Government Influence over the NREN* (ξ_1) → *NREN Infrastructure Capability* (η_1)	γ_1	0.557
H2: *NREN Advanced Services Capability* (η_2) → *NREN Infrastructure Capability* (η_1)	β_1	0.046
H3: *Government Influence over the NREN* (ξ_1) → *NREN Advanced Services Capability* (η_2)	γ_2	0.865
H4: *NREN Infrastructure Capability* (η_1) → *NREN Core Traffic Level* (η_3)	β_2	0.295
H5: *NREN Advanced Services Capability* (η_2) → *NREN Core Traffic Level* (η_3)	β_3	0.184

TABLE 7: PATH COEFFICIENT SIGNIFICANCE TEST RESULTS (*P*-VALUES) FOR THE INVESTIGATION INTO THE EFFECTS OF POOR STRUCTURAL MODEL DEFINITION (PATHS JUDGED INSIGNIFICANT AT A = 0.10 SHADED IN GREY)

Research Proposition: SEM Path	***p-Value***
H1: *Government Influence over the NREN* (ξ_1) → *NREN Infrastructure Capability* (η_1)	0.818
H2: *NREN Advanced Services Capability* (η_2) → *NREN Infrastructure Capability* (η_1)	0.985
H3: *Government Influence over the NREN* (ξ_1) → *NREN Advanced Services Capability* (η_2)	0.001
H4: *NREN Infrastructure Capability* (η_1) → *NREN Core Traffic Level* (η_3)	0.034
H5: *NREN Advanced Services Capability* (η_1) → *NREN Core Traffic Level* (η_3)	0.130

- **Research Proposition H1:** The NREN's infrastructure capability is positively related to the level of government influence over the NREN. This hypothesis emanates from the same theoretical foundation used to define H1 for the baseline example NREN model instantiation.
- **Research Proposition H2:** The infrastructure capability of the NREN is positively related to the NREN's advanced services capability. As stated above, this hypothesis is not supported by any theoretical foundation and is the embodiment of the poor structural definition of Fig. 3.
- **Research Proposition H3:** The advanced services capability of the NREN is positively related to the level of government influence over the NREN. This hypothesis emanates from the same theoretical foundation used to define H3 for the baseline example NREN model instantiation.
- **Research Proposition H4:** The level of core network traffic in the NREN is positively related to the infrastructure capability of the NREN. This hypothesis emanates from the same theoretical foundation used to define H3 for the baseline example NREN model instantiation.
- **Research Proposition H5:** The level of core network traffic in the NREN is positively related to the advanced services capability of the NREN. This hypothesis emanates from the same theoretical foundation used to define H5 for the baseline example NREN model instantiation.

3. Analysis Results for the Investigation into the Effects of Poor Structural Model Definition

Table 1's data composition scheme for the secondary data from TERENA's NREN compendium for 2011 [1], which was used to determine the PLS regression results for the baseline example NREN model instantiation, was also used for the investigation into the effects of poor structural model definition. Table 6 below summarizes the path coefficients obtained for the variation model instantiation of Fig. 3, while Table 7 details the path coefficient significance results. Note the change of direction in the path for H2 when compared to Table 2.

Table 7's results were obtained using SmartPLS's bootstrapping function [15] configured to generate 500 sets of subsamples from the 61 cases in the original sample.

VI. DISCUSSION

A. Baseline Example NREN Model Instantiation

Using the calculated path coefficients in Table 2 and the path coefficient significance test results in Table 3, the research propositions defined for the baseline example NREN model instantiation were evaluated as follows:

- **Research Proposition H1:** The path coefficient of $\gamma_1 = 0.599$ supports the direction of the proposed relationship between *Government Influence over the NREN* (ξ_1) and *Infrastructure Capability* (η_1) *Government Influence of the NREN* (ξ_1). Furthermore, the path coefficient was judged to be significant at the maximum allowed significance level of $\alpha = 0.10$. Hence, this hypothesized relationship was not rejected and supports the notion in [9][12] that government influence is required in order to ensure that an NREN is successful in maturing its infrastructure capability. Moreover, the positive influence that the government has over the infrastructure capabilities of an NREN was to be expected, since most NRENs are government interventions geared are supporting a country's research and education communities by enhancing the available research and education infrastructure and services [9][12].
- **Research Proposition H2:** This hypothesized relationship between *NREN Infrastructure Capability* (η_1) and *NREN Advanced Services Capability* (η_2) was rejected. While the path coefficient $\beta_1 = 0.016$ supported the direction of the proposed relationship, the path coefficient was judged to be not significant at the

maximum allowed significance level of $\alpha = 0.10$. This finding is counter to the assertions in [9] that an NREN requires an advanced infrastructure capability in order to mature its portfolio of advanced services. This can be explained by noting that, in the telecommunications industry providers in developing countries frequently leapfrog their more developed counterparts by offering advanced services, even though their infrastructure capability might still be nascent [13]. In the case of the NREN community, European NRENs frequently support fledgling NRENs in Africa and Asia to rapidly deploy advanced services through development programs driven by the GÉANT Association [1][2].

- **Research Proposition H3:** The path coefficient $\gamma_2 = 0.855$ supported the direction of the hypothesized relationship between *Government Influence over the NREN* (ξ_1) and *NREN Advanced Services Capability* (η_2). Furthermore, the path coefficient was deemed significant. Hence, this research proposition was not rejected and supports the notion in [9][12] that government influence is required in order to ensure that an NREN is successful in maturing its advanced services portfolio. As with Research Proposition 1, this finding was to be expected, since most NRENs are government interventions geared are supporting a country's research and education communities by enhancing the available research and education infrastructure and services [9][12].
- **Research Proposition H4:** The postulated relationship between *NREN Infrastructure Capability* (η_1) and *NREN Core Traffic Level* (η_3) was not rejected since the path coefficient $\beta_2 = 0.289$ was judged to be significant at the maximum allowed significance level of $\alpha = 0.10$. Therefore, the postulated relationship in [16] that an NREN's infrastructure capability is positively related to its usage is supported. This finding correlates with the notion that enhancing NREN infrastructure will lead to improved usage [2][9].
- **Research Proposition H5:** This research proposition was not rejected, since the path coefficient $\beta_3 = 0.187$ support the direction of the hypothesized relationship between *NREN Advanced Services Capability* (η_2) and *NREN Core Traffic Level* (η_3). Also, this path was deemed significant at the maximum allowed significance level of $\alpha = 0.10$, thereby supporting the notion in [9][12] that an NREN's advanced services capability is positively related to the usage of the NREN. This finding correlates with the notion that, by providing the beneficiaries of an NREN with a portfolio of advanced services to fully utilize the infrastructure available, the usage of an NREN will increase [2][9].

B. TFSEMDF Strength: Contextual Information Inclusion

An investigation into the results presented in Table 4 and Table 5 shows that, for all combinations of removal of contextual construct *Government Influence over the NREN* (ξ_1)'s reflective indicator metrics *NREN Governance Mode* (X_1), *Level of Government Funding* (X_2) and *Range of Institutions the NREN is Mandated to Connect* (X_3), at least 3 of the paths (i.e. research propositions) in the example NREN model instantiation were found to no longer be valid, either due to path coefficients having values of zero, or path coefficient significance results exceeding $\alpha = 0.10$.

Since the inclusion of the full set of contextual measurement indicators resulted in only a single path being invalid for the baseline NREN example model instantiation, it can be inferred from these results that the inclusion of contextual measurement indicators in the forecasting calculations of the TFSEMDF framework for the NREN technology domain had a positive effect in enhancing the overall structural validity [22] of the example NREN model instantiation, thereby arguable improving its ability to estimate the TF output metric *NREN Core Traffic Level* (Y_4), geared at measuring the usage of an NREN.

An interesting result observed during this investigation was that Research Proposition H2, i.e. path *NREN Infrastructure Capability* (η_1) → *NREN Advanced Services Capability* (η_2), was not rejected for the case of all contextual information excluded. This result was unexpected, as H2 was the only Research Proposition rejected for the baseline example NREN model instantiation when all contextual information was included, a finding that was explained by observing the prevalence of technology leapfrogging in the NREN global community [13]. One should, however, be careful to interpret this result in isolation, as the exclusion of all contextual information resulted in all Research Propositions, except H2, being rejected. Hence, this single path remained, which does not constitute a SEM model capable of estimating the TF output metric *NREN Core Traffic Level* (Y_4).

C. TFSEMDF Weakness: Poor Structural Model Definition

The results contained in Table 6 and Table 7 highlights the severe effects emanating from a poorly defined structure for a model instantiation of TFSEMDF. In the case considered, only the path between *NREN Infrastructure Capability* (η_1) and *NREN Advanced Services Capability* (η_2) was changed such that it no longer reflected the theoretical foundation used to develop the baseline example NREN model instantiation, but the resultant effect was a catastrophic rejection of three paths, including one path connected to the construct *NREN Core Traffic Level* (η_3) for the TF output metric. As such, the resultant poorly structured example NREN model instantiation is not capable of successfully forecasting *NREN Core Traffic Level* (Y_4).

Another example that highlights the importance of properly defining the model structure of model instantiations of the TFSEMDF framework can be found by comparing the path coefficient and significance results for the baseline example NREN model instantiation in this paper with the initial example NREN model instantiation proposed and analyzed by Staphorst et.al in [20]. The latter, whose development did not include the use of hypotheses from peer-reviewed literature like this paper's baseline model instantiation, was shown to only have three valid paths out of the eight proposed.

VI. CONCLUSIONS AND FUTURE RESEARCH

This paper explored strengths and weaknesses of the TFSEMDF framework, initially proposed by Staphorst et al. in [19] and improved in [20]. Specifically, the framework's strength of being able to incorporate contextual information in order to improve its forecasting calculations, as well as its weakness of suffering from sensitivity to poorly defined structures, were investigated within the context of the NREN technology domain. To accomplish this, a baseline example NREN model instantiation was constructed using knowledge gained through action research in SANReN [3], hypotheses from peer-reviewed literature and insights from TERENA's annual compendiums for NREN infrastructure and services trends [1][2]. Variations of this model instantiation were also created to gain insights into these specific strengths and weaknesses. PLS regression analysis was performed for the baseline example NREN model instantiation and its variations using secondary data from the 2011 TERENA NREN compendium [1] as technology and contextual measurement indicators. Of specific interest were the path coefficients and related significance results, as these formed the basis of the SEM model comparison method [7] used to highlight the effects of the specific strengths and weaknesses considered.

It was determined that TFSEMDF's ability to include contextual information in its forecasting calculations had a significant positive effect on increasing the path validity, and hence its ability to predict the chose TF output metric for NREN usage, in the structural portion of the baseline example NREN model instantiation. While this is strength of TFSEMDF, it could also be viewed as a potential weakness in that, by not considering all available and applicable contextual information for a specific technology domain during model specification, the end result may be the definition of poorly structured models that lack the complexity and depth to properly reflect the full extent of dynamics present in the technology domain under consideration.

Furthermore, it was found that a poorly defined model structure, which may be as a result of not being properly rooted in a theoretic foundation, could have a significant negative effect on the path validity of the defined model instantiation. Moreover, not only are those paths (i.e. research propositions) that are not based on theory readily invalidated, either through zero or negative path coefficient results or through low path coefficient significance, but a ripple effect can be experienced whereby paths that were actually based in theory are also invalidated. While this is a noteworthy weakness of TFSEMDF, one should always keep in mind that one of the primary strengths of TFSEMDF is its ability to model complex and hierarchical structural relationships between technology indicators and TF output metrics, even allowing for non-linear and non-Gaussian factors and cyclical dependencies amongst model variables [20].

Future research activities that will be undertaken include an exploration into emergent strengths and weaknesses emanating from the integration of SEM and DF, comparing the proposed framework to various popular TF techniques currently receiving attention from the technology management research community, as well as improving the model instantiation for the NREN technology domain. This latter activity will entail a two-phase process, with the first phase involving a qualitative study [26] that will attempt to identify improved endogenous and exogenous model constructs, technology indicators, as well as interactions between the various indicators and constructs. The unit of analysis [26] for this envisioned qualitative phase will be a single NREN, while the population will be all NRENs in existence worldwide at the time of the study. Data collection will be accomplished through the Delphi method [27] using a panel of experts comprising the senior technical managers at leading NRENs from the global community. Analysis of the qualitative data collected through various rounds of engagements with the panel of experts will start with narrative inquiry by means of a process of theme extraction [22]. This will then be followed by performing a frequency analysis on the extracted themes in order to produce a final set of importance ranked indicators, constructs and interconnections from which the improved NREN model instantiation will be constructed [22]. Testing the reliability and validity of the collected qualitative data will be accomplished by means of theory triangulation [22], as well as data triangulation [22] using as baseline published technology indicators from secondary data sources, such as TERENA's NREN compendium series.

The second phase of the future research to improve the model instantiation for the NREN technology domain will be quantitative in nature and will aim to determine, using PLS regression analysis, the indicator loadings and path coefficients of the NREN model constructed during the qualitative first phase. As with the qualitative phase the population will be all NRENs in existence at that point in time, with the unit of analysis being a single NREN [26]. While the data available from the TERENA NREN compendium series will be used as far as possible to populated technology and context related measurement indicators, any additional qualitative data required will be obtained using an online survey consisting of close-ended questions with Likert scaling [26], targeted a sample of senior technical managers at the NRENs in the population, selected through a process of convenience sampling [26].

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