Leading practices in model management

Industry Paper

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CRO FORUM

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1 Introduction

Models have long been used in the insurance industry as many participants have acknowledged the value of models in decision-making processes. Models provide for a common language about risk and returns associated with a business transaction. There is transparency about the fact that a model will always be an incomplete representation of reality. Therefore, clarity around basic model assumptions should be a main ingredient of decisions based on model results.

There is model risk associated with every model. Although this is a well-known fact and extensively covered in the literature, recent developments in insurance regulation, information technology and insurance product design have raised awareness of model risk and the need to appropriately manage models.

The models range from company-specific and aligned to the company's individual risk profile to standard models applied across the industry. Our analysis will focus on company-specific models.

The EU regulation [9] defines *model risk* as the potential loss an institution may incur, as a consequence of decisions that could be principally based on the output of internal models, due to errors in the development, implementation or use of such model [9]. Whilst this definition specifically focusses on internal capital models, the definition is – in principle - similar to the ones given in US regulation [3] and other sources [7]. The elements of this definition have been considered in this paper in order to formulate a number of best practice principles to model management.

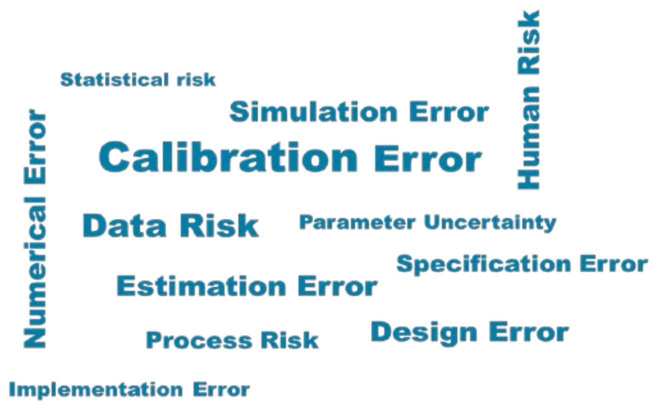

Figure 1: Potential sources of model risk.

The document is intended as a contribution to the recent discussions on this topic and, in particular, covers how CRO Forum companies have implemented model management frameworks. We share our main conclusions on the current status of model management frameworks, supported by the results from a survey which was conducted among the CRO Forum members in 2016.

We highlight the conclusions drawn from the CRO Forum members' survey in separate boxes.

We start with a discussion of the specific role of models in the (re-)insurance industry in section 2. In section 3, we propose a classification of the sources of model risk and describe techniques and instruments that can be used in model management. In section 4, we provide some considerations how these techniques and instruments may be used in a model risk framework. Before we conclude, we summarise recent developments in regulation and relevant publications. We note that we do not cover interconnectedness between companies potentially created by using similar risk or valuation models.

2 The role of models in insurance

The insurance business model is to take on and manage risks over various time horizons. The success of the insurance sector is supported by the successful and sustained use of models.

A wide variety of more or less sophisticated models is used for different applications, e.g. day-to-day business operations or strategic decision making. The principal need for models has several foundations, e.g. the necessity to simplify real-world phenomena, the need to explain previous experience and to forecast future observations and the need to understand the impact of particular scenarios. Therefore, models are used throughout the life cycle of insurance products.

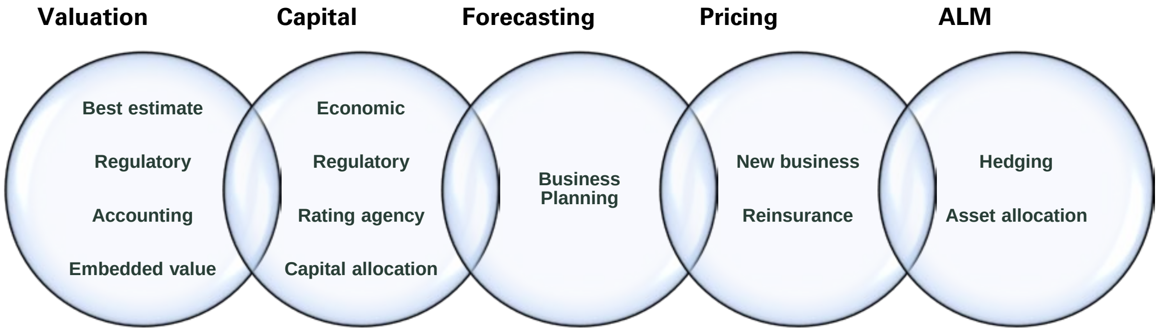

Figure 2: Types of models used in the insurance industry

The insurance sector faces a number of unique challenges in relation to model development, implementation and use, among them:

- Liabilities may be very long-term in nature and may depend on asset valuations or on policyholder behavior;
- Liabilities are to some extent unique to each insurer such that no market price exists;
- The valuation of liabilities and underlying risks depends on assumptions for which the available data is by nature limited, e.g. relates to rare (catastrophic) events, or is exposed to structural changes.

These challenges require specific consideration with respect to model management.

For our further discussion, we consider a model as a quantitative method, system or approach using mathematical, statistical, economic and financial theories, techniques and assumptions to transform observed data into quantitative estimations. The future evolution of the parameters of a model is uncertain and no model can be perfect. Indeed, the choice of a different model or parameter may lead to different results, even though it may be based on the same set of data.

3 Tools, processes and methods for model management

As a basis for the discussion of tools, processes and methods we provide a selection of short examples of risks associated with the use of models.

For many decisions, models are *only one* component of the decision-making process and it may be difficult to carve out the contribution of a model to a potentially flawed decision. This is in particular true for real-world examples where the full scope of the decision-making process is hardly ever known to external parties. We provide illustrative rather than real-world examples to go around this difficulty.

Example 1: ALM model: The liability cash flow projection is based on erroneous assumptions. In turn, the asset allocation of the company is adjusted towards the incorrect duration (or cash flow pattern). As a consequence, a loss may occur when asset cash flows do not match liability cash flows and subsequently a forced asset reallocation triggers market value losses in the asset portfolio.

Example 2: Pricing model: A pricing model uses inadequate assumptions such that prices are systematically too low for a specific product. As a consequence, the portfolio may suffer systematic losses.

Some decisions are dependent on model outcomes in a more automated way. Common examples are hedging programs and automated underwriting systems.

Example 3: Hedging model: The model does not behave as expected under stressed conditions and the implemented hedging program becomes ineffective. Losses may occur e.g. if policyholder options are exercised in such a situation.

3.1 The scope of model management

The risks associated with the use of models arise from various sources, depending on the nature and complexity of the models, the data and assumptions used to reflect the reality and the application context. More specifically, model risk may arise from data errors or limitations, parameter uncertainty, process errors in model operation or model use, insufficient knowledge among decision makers about limitations of a model, numeric or simulation errors and limitations in the model design and specification [9]. Therefore, it is important to ensure an appropriate model management framework is in place.

Risks and errors may arise throughout the modelling process.

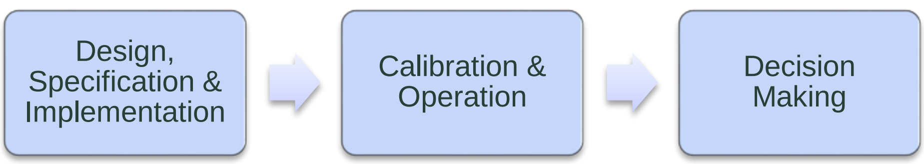

Figure 3: Modelling process

Model design relates to the model choice, e.g. analytic or Monte-Carlo-type model. Errors may arise when the model is not adapted to the data or when the model is based on inappropriate mathematical, economic or financial theories or assumptions. Model design risk may also arise when the analytical solutions are inappropriate even though the algorithm is fit for purpose, e.g. the use of a local optimum instead of a global one, the assumptions of the model are not met, or the assumptions and simplifications used do not reflect the reality, e.g. the choice of a distribution or assumptions on economic environment. Model specification relates to defining elements of a model, e.g. the number of simulations in a Monte-Carlo model or the degrees of freedom.

Parameter estimation or calibration errors arise from insufficient or inappropriate data and from limitations in the estimation method. Examples are inappropriate data horizons and undetected structural changes in time series. Distinct estimation methods may also lead to distinct results, i.e. estimation errors exist independent from the choice of the method (being right or wrong).

Limitations in the modelling process can arise from implementation errors, other limitations of the IT systems or inappropriate use of the model, e.g. due to insufficient education of the staff. These risks (IT, data, process, decision) are operational risks.

Inappropriate use of the model (decision risk) may arise for example when model assumptions deemed appropriate in the past but which are wrong in the current situation are not updated or when using a model that is deemed appropriate for one risk to estimate another risk with similar characteristics without thoroughly checking the applicability.

Data risk, parameter risk and decision risk are perceived as most important sources of model risk by the CRO Forum companies.

For further discussion of model management and to identify appropriate mitigation measures and methods, we distinguish between operational and structural risk.

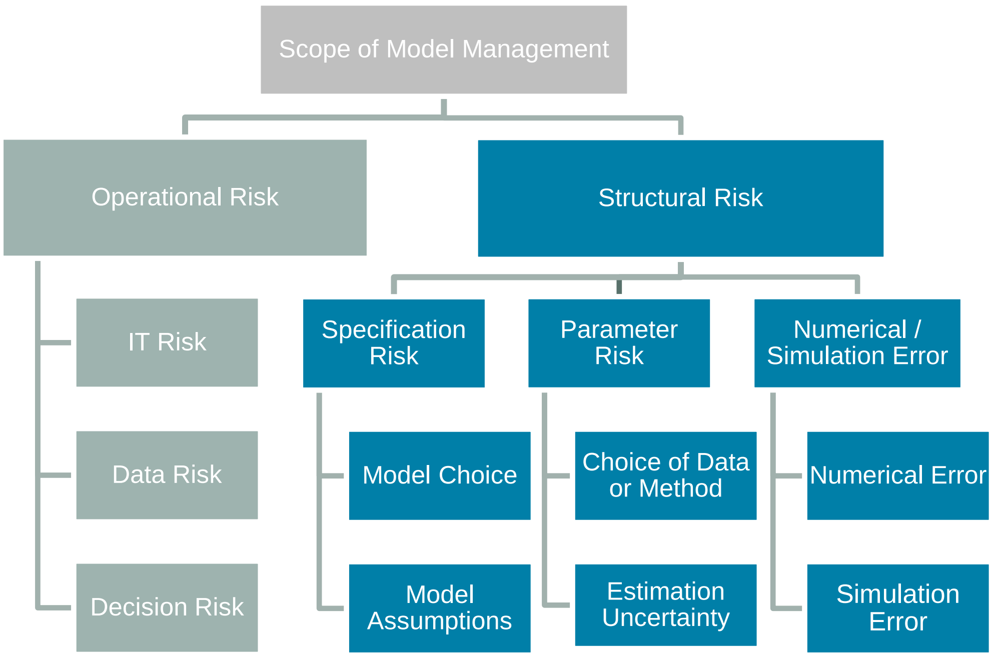

Figure 4: Risks in the scope of model management

As part of the CRO Forum survey 77% of the companies confirmed that they consider model risk to be closely linked to operational risk.

Operational risk exists because human error cannot be mitigated completely, or due to organizational limitations, including technology, controls infrastructure or lack of appropriate implementation capabilities. Structural risk exists because models are simplifications of the real world, modelling approaches and estimation techniques are refined continuously and computational power is not infinite. Complex stochastic models, e.g. simulation models, produce results with inherent numeric or simulation errors, i.e. they inherently contain structural risk.

The following table shows the relationship between operational and structural model risk.

	Operational Risk	Structural Risk
Financial Losses	Can directly cause financial losses	Cannot directly cause financial losses
Source	Human errors or system failures	Models are a limited representation of the real world
Mitigation	Appropriate process controls and adequate communication of model results	Model validation
Quantification	Operational risk quantification methods, e.g. scenario evaluation	Error estimation methods

Table 1: Relation between operational and structural risk

Operational risk can directly lead to financial losses, for example, when an implementation error needs to be resolved in short time and creates additional internal or external costs. Operational risk may also give rise to capital requirements in a Solvency II context.

Structural risk can lead to incorrect decisions if not properly explained when the model is used. In this way, structural risk is one source of decision risk. Decision makers can draw flawed conclusions when model uncertainties are not properly disclosed. However, structural risk does not directly lead to financial losses and thus is no source of capital requirements per se, e.g. in a Solvency II context.

3.2 Model governance

Different sources of model risk require different mitigation instruments. Generally, operational risk can be mitigated using appropriate process governance and control systems. Structural risk can be addressed through model validation and by adequate communication of model limitations.

In some cases, particularly for some structural risks, certain mitigation actions may be limited due to the current available theory or IT resources (e.g. computation capacity can limit the number of simulations that can be run in a reasonable amount of time which may alter the precision of the model result in the case where convergence has not reached an appropriate level).

Model governance has become a separate area within companies' internal control systems. It encompasses a framework for model changes, model validation, model use and the disclosure of model results, assumptions and limitations. This way, model governance supplements the general internal control system.

Elements of Model Governance			
Change Management	Validation	Use / Application	Disclosure Management

Table 2: Elements of Model Governance

46% of the CRO Forum companies consider governance issues surrounding the models as main the element of model risk management. Most of the participants stress model governance and controls as a model risk mitigating measure.

The evolution of model governance for capital models has been strongly influenced by recent regulatory developments such as Solvency II. However, the application of model governance for capital models to other model classes, such as hedging or pricing models, must take materiality and complexity of these models into account, see section 4.3.

85% of the CRO Forum companies consider the principles of Solvency II to be sufficient to address model risk for capital models.

A complete and thorough validation can be seen as one of the main mitigation actions for structural model risk. The model validation aims at checking the reasonableness and accuracy of the inputs, modelling approach, model implementation and the results thereof. The initial validation performed by modellers during the model design or run may be complemented by an independent validation performed by competent professionals independent from the model design or run. A wide range of tools can be used to quantitatively assess the stability and robustness of a model, including back testing, stress and sensitivity testing, reverse stress testing, benchmarking, analysis of change or profit and loss attribution, and can be completed by qualitative reviews including a review of the model uses (use test). We discuss model risk mitigation via model validation in more detail in section 3.3.

The implementation of thorough governance around the validation, including the escalation of the main model limitations to the various governance bodies, as well as a thorough follow-up process for validation recommendations, contributes to the understanding of the model's limitations and to the continuous improvement of the model over time.

Solvency II principles related to models also encompass the mitigation of operational risk (misuse risk) arising from structural risk by appropriate disclosure of assumptions and limitations such that decision-makers can assess the appropriateness of the model for the intended use.

An appropriate governance of models as well as thorough validation and model change processes ensure that the model limitations and errors are identified, understood and monitored such as appropriate mitigation actions can be implemented.

Operational risk is less accessible to quantitative methods and therefore also the mitigation of financial losses from model risk of an operational risk nature has a focus on qualitative methods, such as governance [6].

However, there is a rich set of quantitative methods to lower and disclose model uncertainty. We provide an overview of existing methods in section 3.4.

3.3 Model validation

Overall, the role of validation is to identify and understand the model's limitations, assess its accuracy and robustness, and contribute to its continuous enhancement and its validity over time. Key elements to implement an efficient validation process are the definition of appropriate policies, procedures, tools and reporting templates to support consistent execution across all validations as well as efficient allocation of experts with specialized skills.

Model validation is considered as the most relevant key function involved in the monitoring and mitigation of model risk in the organisation.

The model's validation is composed of two steps:

- Initial validation relates to the tests and analyses performed by modellers during design, development and model run.
- Independent validation relates to tests and analyses performed by a party independent from the model design and operation.

An additional level of control may also be implemented and could be performed by the internal audit function (third line of defence). This type of control is independent by definition and generally less focused on the appropriateness of the model to the underlying risks and the mathematical aspects used within the model. The purpose of the internal audit is usually rather to check the appropriate operation of the processes and controls implemented around the model in order to assess its adequacy, including as well a control of the correct implementation and efficiency of the validation process itself based on the internal policies and guidelines defined.

The subsequent part of this section will focus on the independent validation.

The scope and level of sophistication of the validation is proportionate to the complexity of the model and the significance of its use. The validation should cover all the steps of the model's life cycle: design, development and run as well as all the steps of the modelling process: inputs, estimations, outputs and use. Validation should cover documentation, implementation, controls and governance in all these steps. The key principles below can help to design and implement an effective validation process. The unique nature of insurance liabilities, see 2, and the company specifics must be taken into account for the implementation of the principles.

Proportionality: The validation will be more extensive for the most material risks and modules. Materiality can be assessed based on the consequences of using the model, see also section 4.3.

Expertise and Resources: The resources performing the validation should have the appropriate level of skills in order to be able to challenge the models and be in a position to engage in discussions about the modelling approaches but also about the underlying risks, the documentation, the data, the implementation, the governance, the model limitations and its use.

The overall model development and run processes should allow for sufficient time for the validation tasks. The validation tasks are often complex, e.g. due to evaluation of rare events, scarce data, absence of standard approaches. The amount of validation work needed to assess the appropriateness of the model and its uses may therefore be significant, especially for more complex models, and the time needed for modellers to support the validation may also be substantial. It is therefore crucial to properly estimate the time and resources needed to complete the validation.

Independence: The validators should have sufficient independence and authority to challenge the model and escalate the findings and recommendations at the appropriate level of governance in order to ensure that the limitations identified are appropriately addressed in a timely manner. The independence of the validators over the years needs to be assessed to ensure that the quality of the challenge of the model is maintained.

Validation tools: A wide variety of quantitative or qualitative tools can be used to assess the adequacy of a model, including stress and scenario testing, back-testing and analysis of change, stability tests, benchmarking, reverse stress testing, profit and loss attribution and qualitative tests, cf. section 3.5. The selection of tests depends on the type of model and its complexity, e.g. stochastic or deterministic, or the aspect that is reviewed, e.g. input vs. output. The purpose of the tests used, their use/implementation and the expected outcomes, need to be clearly defined and justified.

Governance: The validation governance should include a clear escalation path, which will support the definition and implementation of corrective actions to address the errors and limitations identified during the validation.

Ongoing monitoring: The validation of the models should be performed on a regular basis to monitor and follow-up on the errors and limitations already identified and the corrective actions implemented to address them but also to detect any new limitations that may arise following changes occurred in the market, economic or business environments, the model, the exposures, the data, the IT environment or the use of the model. Implementing a thorough follow-up process for recommendations is important to ensuring the effectiveness of the validation and contributing to the continuous improvement of the models.

The overall quality of the validation process can be assessed by looking at the evolution and improvement of the model, its documentation and use over the years, through the errors and limitations, identified by the validation and the correction actions implemented to address the validation recommendations.

3.4 Model use, change and disclosure management

The use of models requires knowledge about the main assumptions and limitations of the models, in particular, the disclosure of aspects of the real world which have not been reflected.

A rigorous disclosure of model limitations with every validation cycle and any major model change should be set up to create this knowledge among the relevant decision-makers.

The validation report should contain a clear description of the scope of the validation and the model purpose, the strategy and approach taken to perform the validation as well as the potential errors or limitations identified and the corresponding recommendations for improvement. The communication of the validation findings and recommendations to the various levels of management of the company needs to be sufficiently detailed such that all the governance bodies and users of the model are informed and understand the potential model errors, limitations and sensitivities to the various data, parameters or assumptions.

The risk of flawed decisions is minimized if model assumptions and limitations which are particularly relevant for the application at hand are (re-)disclosed at the time of use.

3.5 Quantification methods

Model risk quantification is the estimation of uncertainty related to model results and of economic costs related to this uncertainty. As noted above, uncertainty of model results arises from limitations in model design or specification, model parameter estimation and modelling processes.

Economic costs can arise from inappropriate use of the model (e.g., due to insufficient education of the parties using the results or of inappropriate communication of model limitations) or from using inappropriate model results, cf. also section 3.1.

The quantification of the individual sources of model risk is not a green field approach but can build upon a rich literature.

> ***Confidence intervals, sensitivities and stress tests are most often used among the CRO Forum companies to quantify the structural risk.***

Stochastic methods to estimate structural risk: Statistical theory provides methods to calculate error estimates in stochastic models for model (design) errors, parameter errors and simulation errors. These methods require stochastic models themselves. We provide a number of examples.

The uncertainty surrounding estimated parameters or functions thereof can be evaluated by confidence intervals measured by asymptotic theory or bootstrapping [14], [5].

Predicted model outputs are commonly ex-post compared with realizations of predicted random variables. This is also referred to as back-testing. The Solvency II profit and loss attribution is a variation thereof. To get an ex-ante estimate for the model uncertainty one may hold out a part of the data set while estimating a model and face model predictions to that part of the sample. Such techniques are known as out-of-sample prediction or cross validation [15].

To account for model uncertainty regarding the choice of different models (Bayesian) Model Averaging can be applied [11]. In the Forecasting literature combining the predictions of distinct models is also a common approach [1].

Several other approaches for the quantification of the uncertainty related to the model choice have been presented in the literature, based on the same principle: the selection of a class of potential candidate models for the estimation of the risk and a risk measure to assess the model risk of the selected model. Such approaches include conditional and unconditional probability-weighted Bayesian approaches taking into account the set of candidate models and the a-priori information of their parameters [18], [2].

In general, Bayesian estimation techniques can be used to deal with model uncertainty. In such a framework the underlying model is not assumed to be correct. Moreover, parameters are specified as random variables instead. However, Bayesian estimation techniques often require significant computational efforts [4], [13].

Stochastic models relying on Monte-Carlo simulations commonly face a numerical simulation error. Bootstrapping techniques or asymptotic theory on the tail of the distribution can be used to assess the range of the model uncertainty. Variance reduction or importance sampling are examples of methods which allow to reduce the numerical simulation error.

Many of the statistical or mathematical approaches listed above can be used to estimate confidence intervals for statistical results produced by the underlying model. All of the approaches are also subject to model risk related to the choice of the approach, the assumptions, the specification, the estimations, the data used and the interpretation of the results and may lead to wrong conclusions if used inappropriately.

Sensitivities and stress tests: Assumption, parameter, data or model sensitivities represent another class of methods to quantify model risk. Model results are compared with results from a different model, a different set of parameters or alternative model calibration data. Sensitivity tests are easy to implement and thus widely used. The method is limited in the sense that it does not provide a statistical quality measure. Variations of sensitivities are stress tests where larger parameter variations are considered and scenario analysis where simultaneous variations of several parameters are investigated.

Operational risk: Various methods exist to quantify operational risk. Scenario analysis is one common approach [6]. Such methods can also be applied to quantify sources of model risk such as decision risk or the financial impact of data errors.

However, operational risk is less accessible for quantification compared to most financial or underwriting risks. Therefore, operational risk management often focusses on qualitative management approaches such as adequate process control.

Ordinal scaling: Ordinal scaling summarizes all methods which do not result in a monetary figure but in a score such as high / medium / low. Examples are score card systems or graphical illustrations of the model landscape, e.g. showing complexity vs. materiality for different models.

Aggregation: The approaches listed above can be used to reveal and quantify individual sources of model risk. Most companies within the CRO Forum do not see extra value in an aggregation of operational risk associated with model risk and structural risk which are quantified as part of the model validation.

There is no mathematical theory which would underpin such an aggregation method and thus any aggregated results should be used with care.

Naturally, ordinal scaling approaches can include all sources of model risk at the same time. Given the absence of a theoretical concept for the aggregation of operational and structural risk, such methods may be preferable as an aggregation method.

4 Model management frameworks

The insurance business model uses a wide variety of more or less sophisticated models. Models are present for the whole life cycle of the insurance products. The graph below shows potential models in the scope of a model management framework.

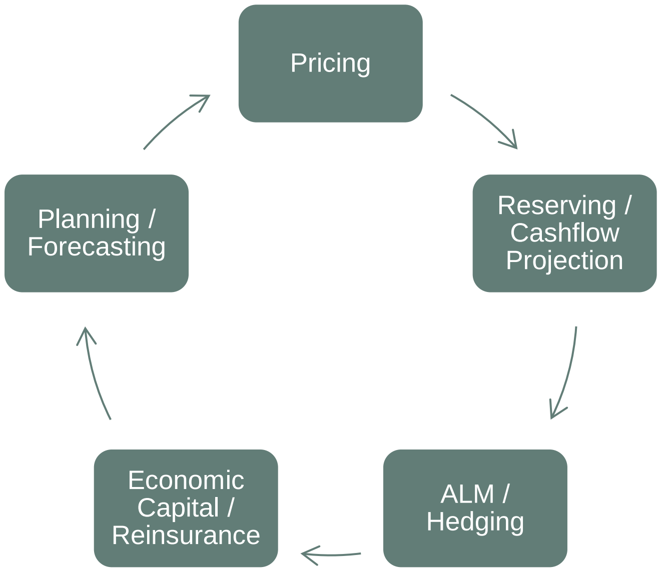

Figure 5: Selected model across the insurance product life cycle

Over the past decades, the evolution of information and data technology of insurance regulation as well as of the insurance activity itself led companies to rely more and more on advanced mathematical, statistical and numerical models to assess, support and improve business or strategic decisions. Model risk management frameworks have and will continue to develop along with this evolution.

The CRO Forum companies dedicate the most significant efforts in model management to Solvency II models followed by reserving and economic capital models.

In this section we will discuss a number of aspects which will be important for the set-up of a model management framework.

4.1 Individual and comprehensive frameworks

A fundamental decision for the set-up of a model framework is the scope of models. Model management frameworks can deal with *individual* models individually or treat all models within a unified or *comprehensive* framework. Companies may also decide for blended approaches based on their individual model landscape. There is indication that larger companies move towards comprehensive approaches which cover more than one model type.

62% of the CRO Forum companies have implemented a comprehensive model management approach, 40% of the remaining 38% intend to develop a comprehensive approach within 2 years.

Some companies operating a Solvency II internal model have decided to include pricing or cash flow projection models into the Solvency II model governance framework.

There are advantages and disadvantages of the comprehensive approach. The benefits of a comprehensive approach are obviously in the area of comparability of model risk assessments and model risk mitigation effectiveness. If run by a single team the approach supports prioritization of the implementation of model risk mitigation instruments.

Individual frameworks would provide individual guidance for model risk management of different model types. There is no framework or guideline uniformly applied to all models. One assumption underlying this approach is that application and modelling processes including responsibilities, model maturity and timelines are very different and a comprehensive framework would have to be generic and of limited use in model operation. More precisely, the models as displayed in Figure 5 are very different in the mathematical set-up, the results they produce and the assumptions relevant for their application. Therefore, it may be difficult to define a common set of key risk indicators which are still specific and meaningful to all models. Moreover, companies may have different expert groups for different models.

The following table summarizes some properties of individual and comprehensive frameworks.

Comprehensive frameworks support	Individual frameworks support
Comparability of risk assessments	Specific and more detailed risk assessment
Prioritization of risk mitigation instruments	Acknowledgement of model maturity
Unified independent assessment	Alignment to different expert groups and production cycles

Table 3: Comparison of model risk frameworks

4.2 Model inventory and model classification

A model inventory can support both frameworks but is almost essential in a comprehensive model risk management framework. The purpose of the inventory is to steer the model risk management. To this end it can be helpful to incorporate the following criteria:

- Model use, including whether outputs are for internal use only or are externally disclosed, the frequency of model use, the importance of the model output in terms of potential financial impacts, customer impacts and regulatory or strategic implications, and the intended audience for the model output.
- Model complexity, including the mathematical framework, IT infrastructure and the number of people required to maintain the model.

A possible approach to deal with model risk is to separate models into tiers or rating classes utilizing the criteria above. Once a rating is available for each model, a materiality filter can be applied.

Many of the CRO Forum companies either already have a central model repository or are planning to develop such a repository.

Models which are 'high' materiality will be subject to more onerous requirements in terms of model risk management, including more extensive validation, more frequent monitoring and more extensive reporting. Ensuring that these models are being risk managed appropriately will also be the highest priority for the firm. Model risk management practices will apply with decreasing intensity as the materiality of the models reduces.

An example of a model risk assessment for a model to calculate the Best-Estimate Liability (BEL) for a specific line of business (LoB) is given below. The methods described in Section 3.4 to quantify model risk can be used to support the model risk assessment.

Model Use	**Rating**	**Rationale**
External disclosure	High	Externally disclosed since LoB accounts for 30% of total company BEL
Frequency	High	Quarterly
Impact		
Financial	High	Any error would impact the regulatory solvency position.
Customer	Medium	A material error may impact the firm's ability to meet obligations to policyholders.
Model Complexity	**Rating**	**Rationale**
Mathematical framework	Low	Deterministic model.
IT infrastructure	Medium	Legacy IT system.
Degree of expert judgement	Low	Adequate data available to inform derivation of best estimate assumptions.
Overall rating	**High**	

Table 4: Exemplary model rating

So, the overall purpose of the rating approach is to determine the appropriate risk mitigation instruments discussed in sections 3.3 and 3.5 to apply to the model.

62% of the CRO Forum companies do not have an explicit risk appetite for model risk, 23% of the participants have explicit quantitative and qualitative risk appetite statements for model risk, while the remaining 15% have qualitative risk appetite statements.

4.3 Proportionality considerations

Proportionality in the context of model risk can be considered as adapting model risk management practices based on the risk classification of the model. Proportionality considerations apply to each stage of the model risk management process, including model governance, model design, implementation and testing, independent model validation and model risk monitoring and reporting.

Although Model Risk Management is a broader concept than model validation, the concept of proportionality is important as it relates to the degree to which independent model validation is required as mitigation to model risk and, to a lesser extent, the extent of monitoring and reporting requirements. Proportionality is a key element in ensuring both that model risk management practices can be implemented successfully and model risk management is appropriately focussed on those models which pose the highest risk to the company.

The following risk management practices could be expected to apply for material models:

Governance	▪ There is clear evidence that senior management and the executive Board recognizes the appropriateness of the model and use the model for decision making purposes. ▪ Model results and material underlying assumptions are discussed by Board level committees.
Design, Implementation and testing	▪ Formal committee structures are in place to discuss and approve key model related decisions and appropriately detailed minutes are retained. ▪ The "four-eye" principle is adhered to for all key model related decisions, i.e., that at least two senior individuals with delegated responsibility oversee the decision making process. ▪ Procedures are in place to ensure that models are signed off at each production cycle by the model owner and an independent reviewer.
Independent validation	▪ All material model inputs, methodologies and results are subject to extensive independent peer review and challenge by individuals with the relevant skills and expertise. ▪ Consideration of whether external review is required as part of the regular validation cycle.
Monitoring and Reporting	▪ The model is reviewed at least annually to ensure that the model remains fit for purpose and that any limitations of the model are identified and understood. The outcome of the review is covered by appropriate Management Information ('MI') on model risk and presented to the Board.

Table 5: Practical management guidance for models internally classified as *material*

Lower materiality models are as a minimum subject to the internal control system but warrant less detailed governance e.g. in terms of approval, review frequency.

5 Recent publications and regulatory developments

Regulatory requirements in the financial industry are a strong influencing factor for model management and publications in the area. The advent of Solvency II [8] and internal model application processes by insurers have spurred more interest in model management by the regulators, senior management, and practitioners in the industry. An independent model validation function is required by SII for internal models and is an essential component of model management.

The Financial Services Authority (FSA) of the UK has given guidance on model validation where observed better practices are presented and can almost be interpreted as a minimum standard [10].

EIOPA has also issued guidelines on the use and pre-application of internal models in the run to Solvency II coming into effect. Similar to FSA, EIOPA expects (re)insurers to establish validation policies and consider materiality of models not only in isolation but also in combination.

The US Federal Reserve has published guidance which provides a broad definition of a model and comprehensive guidance on effective model management [3]. Model validation remains at the core of the guidance, but the scope of model management is broadened to encompass model development, implementation, and use, as well as governance and controls related to models. While the guidance targets primarily banks and saving institutions, the principles apply equally to the insurance industry.

Practitioners of model management are concerned with risk management for a wider range of models other than SII models. A recent addition to the model management literature in the insurance industry is a model management "constitution" of the North American CRO Council (CROC). It aims to share a set of sound model management practices and principles that the CROC has observed based on a survey conducted among CROC firms in 2015 [16]. The constitution highlights the importance of right-sizing model management practice; materiality consideration assessed by quantitative and qualitative impacts and likelihood of harm should drive assessment of model risk as part of the model management framework, both in isolation and in the aggregate. The constitution views models as company assets. Companies should maintain a set of core governance activities to manage the asset: model management policies and procedures with clear delineation of ownership by the three lines of defence; a model inventory as complete as possible as a starting point for assessment of model risk; planning of model risk assessment guided by proportionality; data and technology dependence consistently considered in model risk assessment; model validation embedded in all three line of defence with different emphasis.

The model risk working party of the UK Institute and Faculty of Actuaries has published a monograph on model risk measurement and management in 2015 [12]. The text identifies the core of model risk not being the model error but the materiality of its consequences. Management frameworks should cover risk appetite, risk identification, assessment and monitoring.

6 Conclusion

Models are very useful tools to understand a complex reality and operating environment. They help support decision making. This is particularly true for the insurance industry, where models have played an important role for a long time. The evolution of IT technology and mathematical theory, the availability of more and more detailed data and also regulatory requirements have increased and will increase the complexity of models.

Therefore model management is an important element of insurers' control frameworks. The implementation of an efficient model management process will allow monitoring and mitigating risks associated with the use of models. The implementation of a thorough and effective process for model validation, change and use will help companies to better asses, monitor and mitigate the risks associated with the use of models. A particular driver for increasing sophistication of model management is the use of internal models to assess (regulatory) capital requirements.

The model management toolset is different for operational risk compared to structural model risk. Operational risk can be mitigated by adequate process controls. The quantification is typically difficult and not the central starting point for risk management. In contrast, there are many sound methods for the quantification of structural risk and these methods are the key element for the communication of model potentials and limitations.

Appendix 1 References

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Laan van Langerhuize 1, 1186 DS Amstelveen, or
PO Box 74500, 1070 DB Amsterdam
The Netherlands
www.thecroForum.org