Model Risk Management

Key considerations in effective management of models

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1. Introduction

Over the past few years, we are witnessing a surge in the use of models based on complex quantitative methodologies to guide the financial institutions in strategic decision-making, management of various risks and entire credit lifecycle.

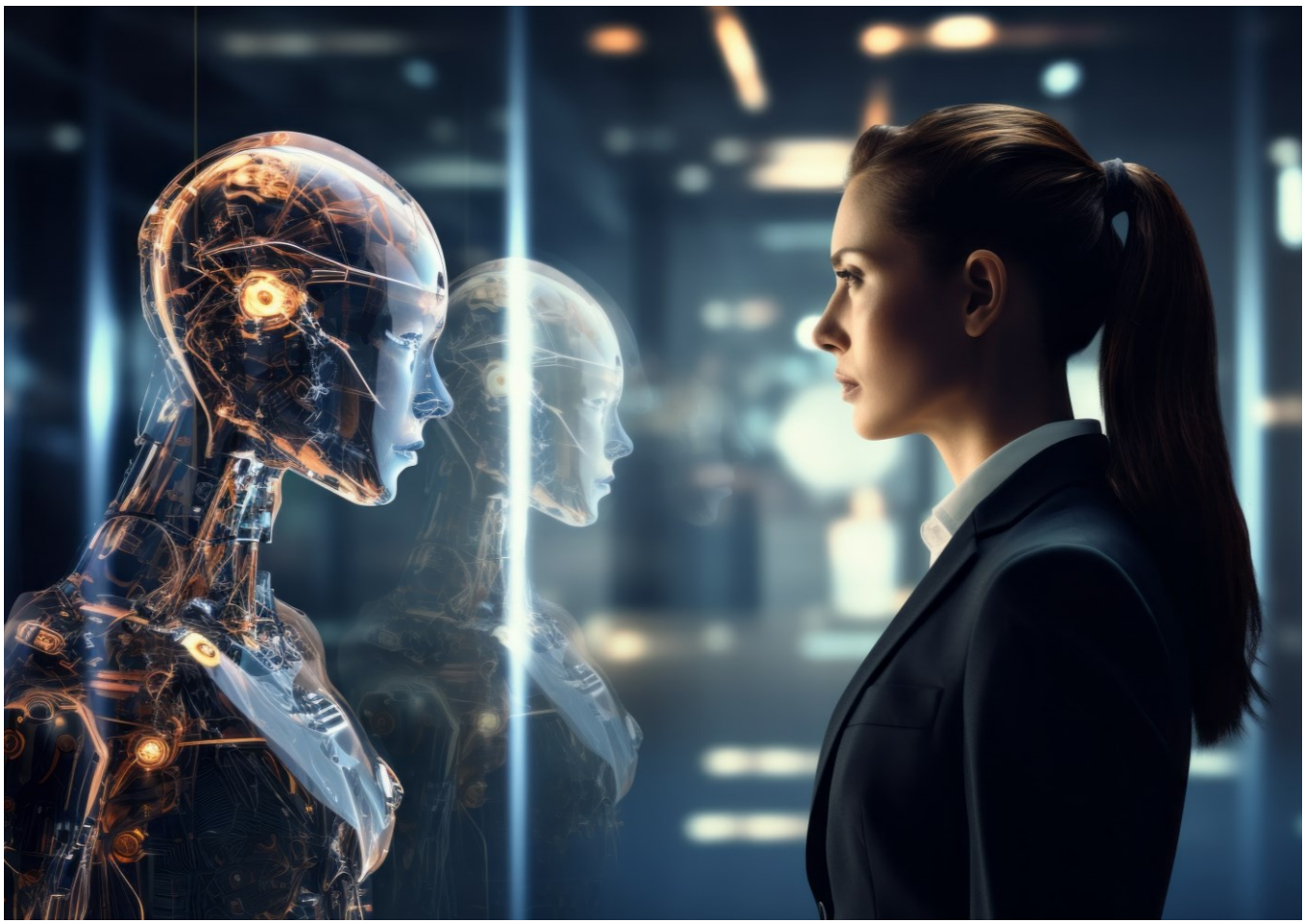
With ever changing business environment, Financial Institutions (FIs) are required to develop/redevelop models either to meet new regulatory directives such as Fundamental Review of Trading Book (FRTB), Expected Credit Loss (ECL) computation, and Stress Testing, or using advanced techniques based on Artificial Intelligence (AI)/Machine Learning (ML).

As the use of models increase, so does the risk associated with them, potentially leading to financial and reputational losses, business setbacks due to poor strategies and decisions, regulatory penalties, and in extreme cases, suspension of licenses for financial institutions in case model risk is not properly assessed and managed.

The increasing complexity and reliance on model outputs have significantly heightened model risk, prompting regulators worldwide to focus more on this issue. As a result, new regulations and guidelines are being developed. Recently, in August 2024, the Reserve Bank of India (RBI) issued draft guidelines on Model Risk Management (MRM) and independent model validation.

Thus, to manage model risk and comply with regulatory requirements, FIs should develop and implement robust MRM policy and framework. Such a framework will ensure that the output generated by the model is reliable and can be used for the intended purpose. Additionally, such a framework will assist FIs in regulatory compliance, better financial performance, taking timely strategic decision basis use of advanced methodology and analytics models.

In this paper, we discuss key considerations in managing model risk. The paper is organised as follows. The subsequent section provides an overview of the model lifecycle. Section 3 provides a general framework for management of model lifecycle for key components. Section 4 provides an overview of additional controls that need to be implemented for AI/ML based models. Section 5 provides conclusion and how FIs can manage model risk in today's dynamic business conditions.



2. Model lifecycle

As per major regulatory guidelines such as SS 1/23 issued by UK's PRA dated May 17, 2023, and SR 11-7 issued by US Fed dated April 04, 2011, the model lifecycle can be considered to cover the following three main processes:

1. Core model development, implementation, and use
2. Independent model validation which comprises:
    - Initial validation to assess factors such as model suitability, conceptual soundness, assumptions, limitations, calibration (if applicable) and data used.
    - Ongoing monitoring to ensure model performs as intended.
    - Validation of implementation as done in production, along with controls.
3. Model risk controls with set governance, processes, and procedures to assist FIs in managing, controlling, or mitigating model risk.

At a broad level, efficient model risk framework should have five interdependent steps:

01 The first step is to develop model as per defined scope and use.

02 Second step is to submit the model for independent validation where depth and rigour of validation will depend upon model tiering.

03 Third step involves decision basis model validation outcome i.e., either implement the model in production if it passes the validation or redevelop the model if it fails the validation.

04 Fourth step involves implementation of model in production environment and conduct different system tests, UAT to ensure implementation is robust with adequate controls and governance.

05 Fifth step involves on-going monitoring and periodic validation. Frequency of the same can be based on model tiering and any other relevant factors.

3. Managing model risk for complete model lifecycle

Models are critical for the success of an organisation, and thus the identification and management of risks emanating from such models also becomes imperative. In recent history, several risk events have shaken the financial industry due to reliance on inaccurate model output, leading to huge losses for FIs and even bankruptcy in certain cases.

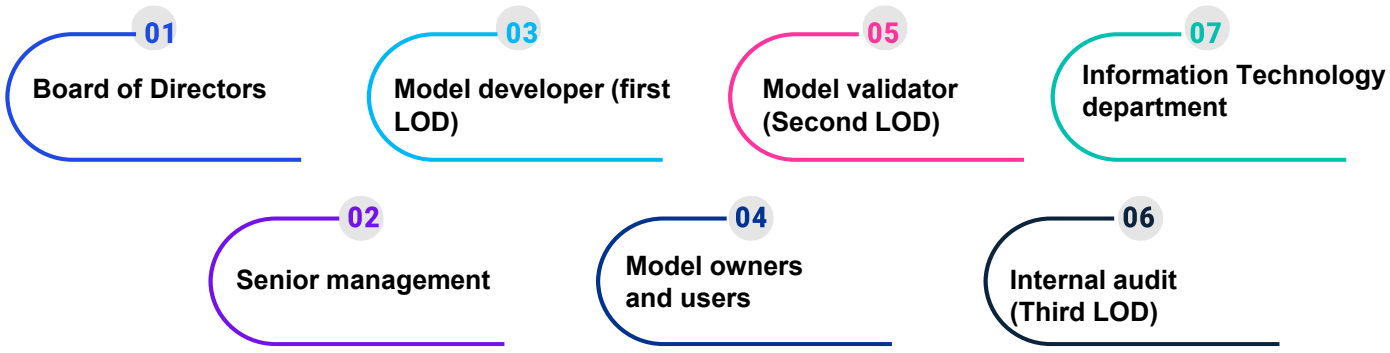
Due to the systemic importance of financial institutions for the success of any economy, regulators across the globe have started stressing the importance of managing model risk efficiently. Federal Reserve (of the United States) issued the first-ever regulatory guidance for model risk management in April 2011 when they introduced SR 11-7. Since then, this has been followed by regulators across geographies, including the European Central Bank in the EU, the Prudential Regulation Authority in the United Kingdom, the Office of the Superintendent of Financial Institutions in Canada, and the CBUAE in the United Arab Emirates. Recently, Reserve Bank of India (RBI) has also issued draft guidelines asking all Regulated Entities (REs) to develop policy and framework to manage model risk.

All this requires the management to adopt efficient model risk management practices within their risk management framework. In the following section, we discuss key pillars required for management of risk throughout the model lifecycle.

3.1 Model governance process

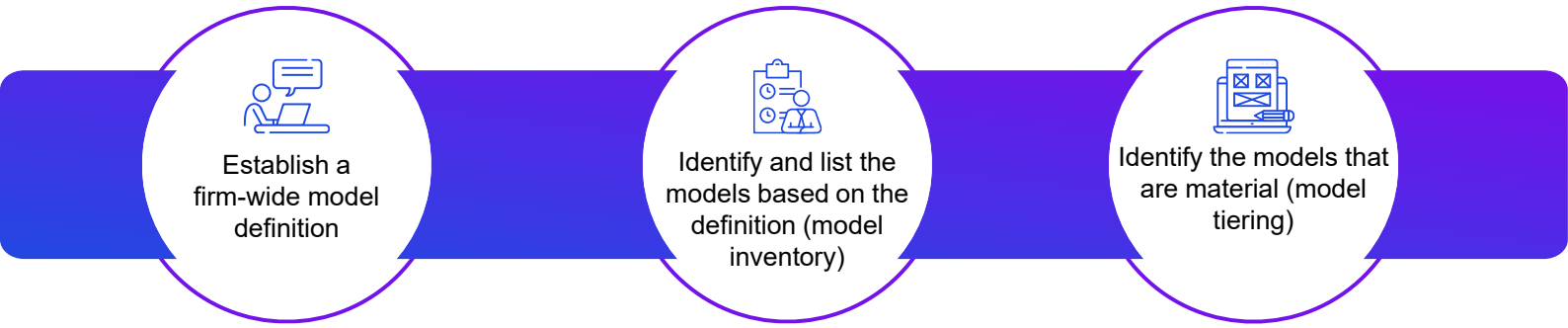
Effective management of model risk requires efficient governance structure with defined policies and procedures, along with risk reporting. Regulators are increasingly emphasizing the importance of well-defined model governance, ensuring that the board of directors, senior management, and three lines of defense (LOD) are accountable in case of any model risk event.Therefore, it is imperative that senior management possesses the necessary expertise and experience to manage model risk. Some of the global regulators such as, PRA which has proposed to create Senior Management Function (SMF) with relevant expertise to enhance accountability in model risk management. Similarly, the CBUAE proposes a model oversight committee to act as reporting entity for the stakeholders at all stages of the model life cycle.

Key stakeholders that are instrumental in managing model risk are:



3.2 Model definition, inventory, and tiering

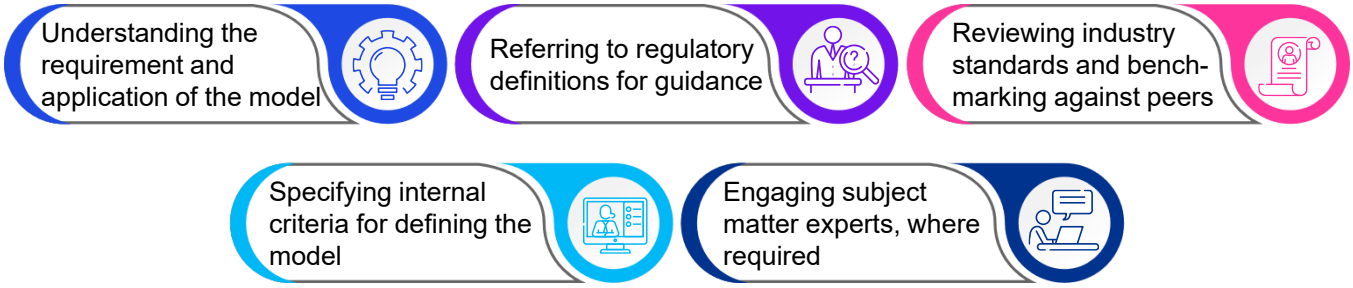
A financial institution needs to determine whether its existing applications can be classified as ‘models’. To achieve this, the institution is required to:



Model definition

To identify the models, the financial institution must establish a firm-wide definition. One example of definition is as provided by PRA which states, “A model is a quantitative method, system, or approach that applies statistical, economic, financial, or mathematical theories, techniques, and assumptions to process input data into output. The definition of a model includes input data that are quantitative and/or qualitative in nature or based on expert judgment, and output that is quantitative or qualitative.”

In case of missing regulatory guidelines, financial institutions must determine a definition that aligns with its overall risk assessment while considering the following aspects:



Model tiering

Every model is assigned a risk rating which can be assessed basis different parameters. This is also termed as model tiering. Based on the model tier, the frequency and depth of validation is determined. For example, for high-risk models, validation needs to be performed more frequently and in greater depth while for medium and low risk models, it can be at lesser frequency and some of the parameters might not be validated.

Creating and maintaining model tiering is a key challenge faced by many institutions. Regulators expect transparency in the classification methodology, with limited subjectivity, and clear documentation of tiering criteria and assessment. While financial institutions may categorise models into different risk category such as high, medium, or low risk, defining what constitutes high, medium, or low poses conceptual challenges.

Below we highlight some of the parameters which financial institutes can consider for model tiering purpose:

Materiality
The materiality is assessed in terms of the portfolio that gets impacted via the outputs from the model.

Model Usage
Model usage refers to area of application of the model outputs. Models used for regulatory and financial reporting should generally be treated as high tier models.

Upstream or downstream model
Tiering can also depend on whether the model uses output of another model/s (upstream models) or output of the underlying model is used as input for other model/s (downstream models)

Model complexity
The complexity is defined in terms of the modelling methodology that is in the model development process such as AI/ML based model or simple arithmetic computation.

Level of manual intervention
The extent of human judgment or intervention required at various stages of a model’s lifecycle to generate outcomes becomes necessary when the entire process cannot be automated.

Reliance
The extent of dependency on the model for making decisions, managing risks and performing day-to-day operations. High reliance on any specific model can increase the potential impact of model risk.

Model inventory

Model inventory refers to the comprehensive cataloging and management of all models used within a financial institution. With the increasing reliance on models for different purposes, regulatory authorities have emphasised the importance of maintaining a thorough inventory of these models to ensure transparency, accountability, and effective risk management practices.

The process of model inventory typically involves identifying all models across the organisation, regardless of their complexity or purpose, and documenting key information such as their objectives, use, model tier, upstream or downstream models, validation status, and key stakeholders for the model management such as model owner, and model developer. This information is crucial for understanding the scope and usage of each model, as well as managing model risk basis key information such as model validation status.

In our view, model inventory should be dynamic and should be updated during complete model lifecycle on real time basis i.e., model commissioning, validation and decommissioning.

3.3 Model development

Model development is one of the most critical aspects with respect to financial resilience, regulatory compliance, and risk management. By adopting a holistic approach to model development, financial institutions can optimise their capital allocation, enhance regulatory compliance, and fortify their defenses against systemic risks. The effectiveness of models, whether based on statistical techniques, mathematical frameworks, or expert judgment, depends on their alignment with organizational objectives, regulatory requirements, and market dynamics. As the financial landscape continues to evolve, the imperative for robust and agile model development practices remains paramount in navigating uncertainty and driving sustainable growth.

Key considerations for a financial institution while developing any model are:

Model objective

The development of any new model should be guided by a clear statement on the model objective, the problem statement and the expected solution, stated by the team which has requested for the model development. The stated model objective will drive other key decisions in the development, such as type and duration of historical data, model methodology, and model tiering.

Data

Data is the foundation of any analytical process and the key to successful model development. A model developed based on insufficient, inaccurate or poor quality of data can lead to ineffective decisions, financial loss, or reputational damage. Remediation of data quality issues and creating effective infrastructure acts as a pre-condition for developing a model.

The Basel Committee on Banking Supervision issued set of 11 principles for banks for effective risk data aggregation and reporting (BCBS 239) in January 2013. The principles cover all aspects of a good data architecture and data governance group which will assist FIs in storing high quality data that can be used for model development and validation purposes.

FIs need to ensure a proper and effective data quality framework which encompasses assessment of data quality dimensions, full data life cycle from data entry to reporting, for both current and historical databases.

Assumptions and limitations

All model assumptions and limitations should be clearly defined and documented. Assumptions can be broadly classified as analytical assumptions or subjective assumptions. Depending on nature of assumptions, FIs should assess them by carrying out statistical tests (where applicable) or conducting sensitivity analysis with respect to different model parameters/inputs to test the impact of the assumptions on model output. PRA's SS 1/23 mentions that FIs should be able to demonstrate that risks relating to model limitations and model uncertainties are adequately understood, monitored, and managed, including using expert judgement.

As a best practice, FIs should document all assumptions and limitations including their impact and any control to mitigate risk. These assumptions and limitations should be tested during model validation as well as monitoring exercise using tests such as root cause analysis and sensitivity analysis along with a qualitative assessment of their impact on the model's output.

Methodology

The effectiveness of models depends on the appropriateness and rigour of the methodologies employed in their development. Statistical models leverage mathematical techniques to analyse historical data and derive probabilistic forecasts of future outcomes. These models, ranging from linear regression to machine learning algorithms, offer quantitative insights into risk exposures and predictive analytics.

Mathematical models, characterised by their deterministic frameworks and mathematical equations, provide a structured approach to modelling complex financial phenomena. From option pricing models to stochastic calculus-based models, these tools offer a systematic means of understanding and quantifying financial risks and dynamics.

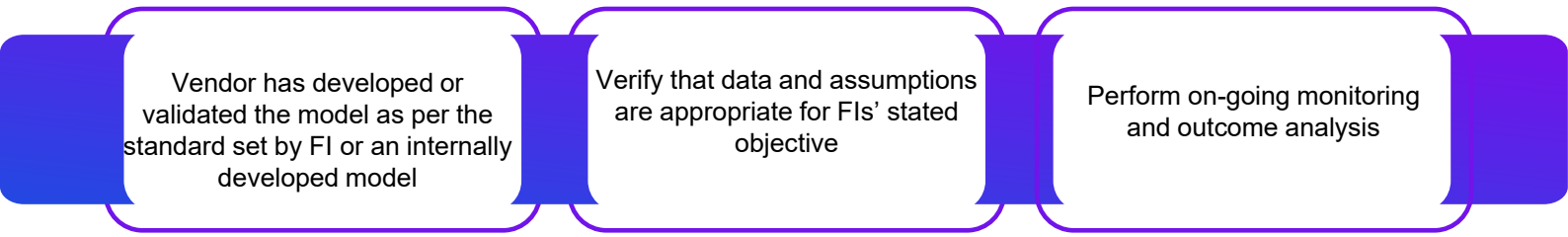
Expert judgment-based models incorporate qualitative insights and domain expertise into the modelling process. In situations where historical data is limited or unreliable, expert judgment serves as a valuable complement to quantitative methodologies. By leveraging the collective wisdom of subject matter experts, these models enhance the robustness and reliability of risk assessments and decision-making processes.

Some of the key considerations that should be taken care of while selecting model methodology are listed below:

- Methodology is best fit for the intended model purpose
- Methodology is best fit basis data available, as well as materiality and impact of model output
- Appropriate alternative methodologies should be tested, and the champion model should be selected.

Vendor model/ Third- party consultants

FI should ensure that oversight on model is consistently applied to both internally developed models and vendor models. As per PRA SS 1/23, for any vendor model, FIs should ensure that:



In case any of the activity of model lifecycle has been outsourced, FIs should ensure that the work is carried out as per the standard followed by FIs along with documentation. In general, rigour of model risk management is applicable for vendor model/third party consultant in the same way as for in-house model. FIs shall be ultimately responsible and accountable for the integrity and outcome of outsourced models.

Model testing

Model testing is an integral part of the model development cycle. It shall include verification of the model's accuracy, demonstrating that the model is robust and stable, assessing potential limitations, and evaluating the model's behaviour over a range of input values. Testing is required to be applied to actual circumstances under a variety of market conditions, including scenarios that are outside the range of ordinary expectations. The nature of testing and analysis will depend on the type of model and will be judged by different criteria depending on the context. Testing activities shall include the purpose, design, and execution of test plans, summary results with commentary and evaluation, and detailed analysis of informative samples.

Model development documentation

As per SR 11-7 guidelines issued by the Federal Reserve, documentation of model development and validation should be sufficiently detailed so that parties unfamiliar with a model can understand how the model operates, its key assumptions and limitations. Documentation provides for continuity of operations, ensures compliance with policy, and helps in tracking recommendations, responses, and exceptions.

As part of model risk management framework, FIs should have defined template to document model development process. Details to be provided in the document can depend on model tiering. Model document should also cover details about key stakeholders such as model owner, model developer, model user, as well as other key details such as version control, date of approval, any controls, and limitations as put by model validator before approving model usage.

3.4 Model validation

Model validation is a significant component of model risk management framework. Model validation activities help any organisation to ensure that the underlying models are reliable and aligned with their business objectives and uses. It is typically performed by an independent team or individuals not participating in model development activities. It is a crucial consideration as it facilitates an impartial analysis of the models and aids in the accurate assessment of results.

While validation should be performed to monitor a model's performance in line with goals, it is also required as part of the regulatory requirements for any financial institution. Generally, it has been observed that based on the type of portfolio, risk or region, there are various regulations that a financial institution must adhere to.

A validation team should be knowledgeable to conduct an efficient review of models mainly focusing on but not limited to these four core elements:

Assessment of conceptual soundness should include review of:

- model design,
- documentation and empirical evidence that support the model methodology, data used, and variables selected,
- key model limitations and weaknesses, and
- decisions taken based on the model outputs.

This assessment includes both qualitative and quantitative assessment. Model effectiveness depending on the market conditions and model type must be assessed during validation. The model specification must be tested for champion and challenger/alternate models ensuring the most efficient framework is used.

Qualitative judgment should include evaluating the logic, soundness, and information used to ensure that the model is appropriate and robust for its intended use.

Performance testing that should include back-testing/outcome analysis, benchmarking, and sensitivity analysis

Model performance can be assessed through various tests including model back-testing on historical data, sensitivity analysis to check impact of minor changes in inputs and parameters on the model outputs, model stability and robustness by evaluating model outputs in extreme macroeconomic scenarios and out of time data. Additionally, as a part of validation exercise, a benchmark model is expected to be built by the validator that challenges the development model on the conceptual soundness and performance over a reasonable and supportable forecast period.

Ongoing monitoring

Changes in products, exposures or market conditions necessitate adjustments or replacements of the models. Ongoing monitoring plays a significant role in evaluating if the model is fit for use given the changing conditions. Several controls are set by the development team for this purpose and are conducted on a regular basis. These might also include performance tests. This is further discussed below in detail.

Model implementation, use and controls

These are processes and systems in place to ensure that a business model is implemented, monitored, and adjusted to achieve its objectives. Model usage and controls must be well documented through an implementation framework. Some of these controls have been described in detail in the subsequent sections.

System implementation

The developed model, post testing and necessary approvals, is implemented in the controlled production environment. The first set of outputs generated in production shall be subject to a review to assess the effectiveness of model operations.

The validator is required to ensure that the proper documentation, viz. - Business Requirement Document (BRD), Functional Specification Document (FSD), System Integration Testing (SIT) and model technical documentation, as applicable, is prepared, approved and maintained by the FI.

This is further elaborated in Section 3.7 on model implementation, use and control.

3.5 Model monitoring

Model monitoring is crucial for identifying and mitigating model risks, which can have adverse consequences on business decisions. Ongoing monitoring is essential to evaluate whether changes in products, exposures, activities, clients, or market conditions necessitate adjustment, redevelopment, or replacement of the model and to verify that any extension of the model beyond its original scope is valid. Any model limitations identified during development and validation need to be regularly assessed over time, as part of ongoing monitoring. Banking organisations and financial institutions are expected to monitor the model periodically over time. The frequency of monitoring shall depend on the nature of the model and magnitude of risk involved. Standard frequencies observed across geographies vary between quarterly, semi-annually, and yearly time periods. Banks are expected to design a monitoring framework that outlines the core components of effective monitoring. This can include but not limited to:

A. Qualitative risk monitoring

- Model change log
- Changes in portfolio distribution
- Changes in policy
- Changes in external environment
- Changes in data and model use
- Evaluation of model overlays
- Rationale of assumptions and overrides

B. Quantitative tests such as:

- Discriminatory (Gini, KS, Brier) and Calibration (Chi-square, Binomial test)
- Stability (PSI, CSI) and Concentration (HHI)
- Back testing (RMSE, MAE, MAPE), Sensitivity and Benchmarking
- Regression assumptions such as normality, stationarity, and multi collinearity
- AI/ML model tests such as (hyperparameter tuning, cross-fold validation, Bayes factor)

One can refer to different papers such as BCBS Working Paper No. 14, SR 11-7, SS 1/23.

C. Model performance thresholds are set to identify material deviations in model behavior. The monitoring framework should include empirical analysis for calculating thresholds and determining the frequency of their evaluation. Institutions should define threshold levels, and model validators should assign appropriate status based on qualitative and quantitative performance. Clear guidelines and rationale must be established for breach escalation and corrective actions.

Key challenges in the monitoring exercise faced are:

01 Ethical considerations are crucial in the monitoring of model risk to ensure fairness, transparency and interpretability.

02 Real time monitoring is essential to ensure the models are working as intended at the outset of the model development stage.

03 Inadequate, missing, or inconsistent data can significantly hinder the effectiveness or capability to conduct any model monitoring tests.

04 Managing the growing model landscape within organisations is often a challenge for monitoring. Increasing number of models leads to more dependencies in the upstream and downstream models which require independent validation and monitoring.

05 Managing risks associated with third-party model development and validation.

3.6 Model validation vis-à-vis model monitoring

We have noticed that many FIs only conduct model monitoring and do not perform periodic model validation. As mentioned above, model monitoring only covers certain model level quantitative and qualitative tests. Model monitoring ensures the model continues to perform as per the expectations in day-to-day operations and focuses on validating model's performance over time, checking for issues like data drift, performance degradation and anomalies.

On the other hand, model validation will cover parameter level validation along with validation of other areas. Some areas that need to be validated during periodic model validation are listed below:

- Model inputs and overrides
- Model documentation
- Challenger modelling
- Control and governance
- Production code and model implementation
- Assumptions and limitations
- Upstream/downstream model
- Post Model Adjustments (PMAs)

Generally, FIs should conduct model monitoring at shorter frequency to ensure early detection of any issue while frequency of model validation can be determined basis model tiering. Below table shows indicative frequency for model validation and monitoring:

Model tier	Initial validation By model validator	Ongoing monitoring			Periodic validation By model validator
		Model performance monitoring and confirmation By model owner	Model performance monitoring and confirmation By model validator	Model tier update By model validator	
High risk	Full validation	At least annually	At least annually	Annually	Annually
Medium risk	Full validation	Annually	Annually	Annually	Case by case as set by model validator
Low risk	Full validation	Annually	Annually	Annually	Case by case as set by model validator

3.7 Model implementation, use and controls

Model implementation in the production environment is a critical component of Model Risk Management. This includes designing adequate controls and conducting tests to ensure robust model implementation, effective systems integration, and appropriate model output. To ensure proper model implementation, FIs should consider the key points mentioned below:

1. Development and production platform: The model on development and production platforms is same. There should not be any difference in the code language, libraries and setting selections.
2. Data source: The source of data for development and production should be identical.
3. There needs to be appropriate security control. These include but are not limited to:
    - Privacy and user access controls,
    - Data input and output controls, and
    - Change management controls.
    - Control over any overrides

Key challenges faced during implementation:

1. Lack of documentation around model description, input data specifications, assumptions and limitations results in lack of robustness in the implementation procedure.
2. Verification and user acceptance testing: Test plans designed by developer, including developer specified test scenarios are not executed by an independent Quality Assurance team. Also, user acceptance criteria are not properly defined and implemented. These lead to incorrect system implementation.
3. Inadequate system integration testing might result in system failure or error after go-live of the model.
4. Inadequate controls on production code can lead to incorrect or inadvertent changes, potentially resulting in inaccurate model output.

3.8 Model risk mitigants

The FIs are required to establish policies and procedures for the use of model risk mitigants. For an under-performing model, it is essential to deploy mitigants to address and rectify the issues. These include:

Post Model Adjustments (PMAs) and overlays

Post model adjustments and overlays are used where the risks and uncertainty cannot be predicted or quantified. Overlays are the adjustments made to the existing models, these adjustments can be subjective or judgmental or at times both. These risks are not captured by the models as they are not designed to address any uncertainties, (e.g., GFC 2007-08, Brexit, Covid-19). Some of the key considerations for computation of PMA and overlays are:

- Approach for applying PMAs should be appropriate and explainable, and adjustments should ensure to compensate the model limitations
- Methodology to compute and apply PMAs should be clearly documented
- There should be defined governance and approval process from relevant stakeholders before making any adjustment
- PMAs should be backtested for relevance and sufficiency and accordingly should be updated.

Restrictions, exceptions, and escalations

FIs are often required to place partial or complete restrictions on the use of model or define maximum tolerable exception limits and an escalation matrix where deficiencies and limitations are identified during monitoring or periodic validation.

The policies and procedures must provide for the mitigation plan to manage significant model deficiencies and proper governance by the board approved committees.

4. AI/ML based model

“Innovation distinguishes between a leader and a follower.” – Steve Jobs

The exciting world of technology brings nuanced challenges with it. AI/ ML/GenAI models are now increasingly deployed by various FIs and have become an integral part in business decisions. Some common use-cases and applications include credit screening, fraud detection, default prediction, price forecast, customer churn prediction, and other analytics. AI/ ML/GenAI models serve predictions as the output which are subsequently used to make business decisions, the result of which feeds back as inputs into the future training data.

For such models, FIs should design and implement additional controls to mitigate model risk. Some of the key controls that FIs should implement for AI/ML/GenAI based models are:

01 Incorporate governance and controls basis global guidance such as MAS principle of Fairness, Ethics, Accountability, and Transparency (FEAT) and NIST guidance on four core function i.e., Govern, Map, Measure, and Manage.

02 Additional controls and testing for data inputs and model methodology to ensure factors such as feature engineering, hyperparameter tuning and prompt engineering is appropriate as per model use.

03 Quantitative and qualitative test to ensure timely detection and remediation of issues relevant to AI/ML models such as bias, and explainability.

04 Aligning ongoing monitoring and periodic validation frequency for a model basis model materiality, usage and other relevant factors.

05 Implement additional controls to establish the transparency and accountability of the departments and individuals involved in the model development, validation, and MRM implementation.

06 Enhance controls, governance, model methodology and other parameters basis outcome of monitoring and validation.

5. Conclusion

Increasing reliance on the models and their importance in the overall operations of the financial institutions requires an efficient model risk management framework. The key considerations for a financial institution to implement a robust model risk management framework would include:

Establishing and communicating an approved policy and framework to all the stakeholders, and regularly test for adherence.

Clearly defining governance structure with identification of key stakeholder such as model owner, model developer, model validator, and model user with defined roles and responsibilities of the stakeholders.

Developing a comprehensive model inventory based on model definitions, and implement a tiering process considering risks, complexity, and materiality.

Develop champion model basis clearly defined model purpose and conduct quantitative and qualitative tests to ensure champion model is the best among various challenger models.

Defining model validation framework, including model rating framework and validation template.

Define model monitoring and periodic model validation frequency and scope.

Ensuring regular oversight by the Board and senior management to manage model risk, with timely reporting and an escalation matrix for critical issues.

Identifying three independent lines of defense, namely - model developer, model validator and internal audit.

Implementing controls and processes to regularly monitor compliance with the model risk management framework, and prompt reporting of any deviations.

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Glossary

AI	Artificial Intelligence
BCBS	Basel Committee on Banking Supervision
CBUAE	Central Bank of the United Arab Emirates
CSI	Characteristic Stability Index
ECL	Expected Credit Loss
Fed	The United States Federal Reserve
FI	Financial Institute
FRTB	Fundamental Review of Trading Book
Gen AI	Generative Artificial Intelligence
Gini	Gini coefficient
GFC	Global Financial Crisis
HHI	Herfindahl-Hirschman Index
KS	Kolmogorov–Smirnov test
LoD	Line of Defence
MAE	Mean Absolute Error
MAPE	Mean Absolute Percentage Error
MAS	Monetary Authority of Singapore
ML	Machine Learning
MRM	Model Risk Management
NIST	National Institute of Standards and Technology
PSI	Population Stability Index
PMA	Post Model Adjustment
PRA	Prudential Regulation Authority
RE	Regulated Entities
RBI	Reserve Bank of India
RMSE	Root Mean Square Error
SMF	Senior Management Function
SS	Supervisory Statement
UAT	User Acceptance Testing

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