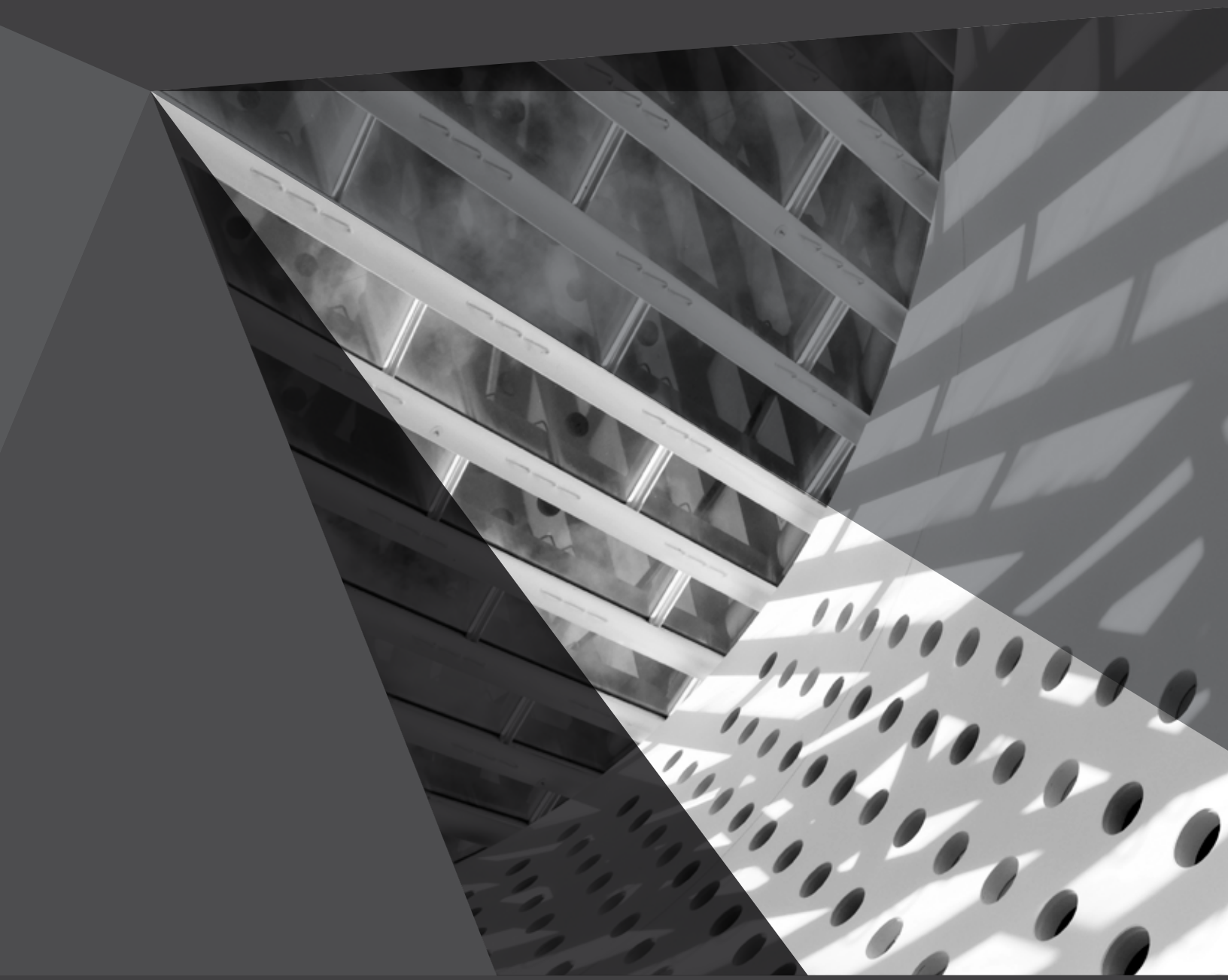
OLIVER WYMAN

OVERVIEW OF VENDED STRESS TESTING SYSTEMS



MARSH GUY CARPENTER MERCER OLIVER WYMAN

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CONTEXT

This document provides an overview of the role that vended systems can play in an enterprise-wide capital stress test (referred to in this document as a "stress test"). It complements the Oliver Wyman article "Stress relief: Are vended systems the answer?". We first provide an overview of the functions stress testing systems can perform, aligned to our standard stress testing process framework, before discussing general issues with stress testing systems. The addendum provides an overview of the offerings from the major vendors as of Q1 2015.

In developing the report, Oliver Wyman met with nine major providers of stress testing solutions: Seven enterprise stress testing systems vendors (QRM, SunGard, SAS, IBM, Wolters Kluwer, Oracle, Moody's Analytics) and two vendors which have more specialised offerings (Markit and Experian). In addition several interviews were held with financial institutions that are in the process of enhancing their stress testing capabilities.

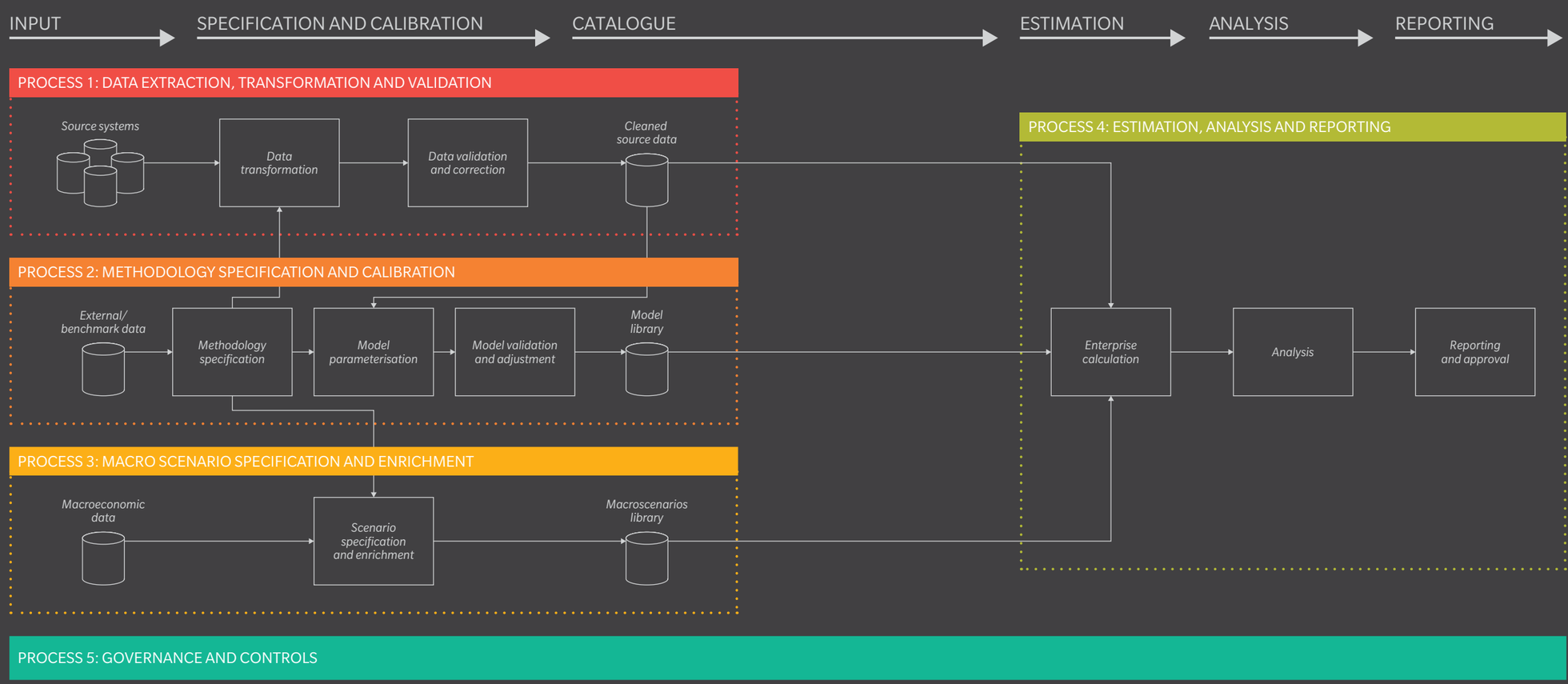
WHAT DO "STRESS TESTING SYSTEMS" ACTUALLY DO?

In order to give an idea of what stress testing systems actually deliver we discuss standard vended system capabilities against the various process steps in Exhibit 1, required to complete a stress test. Whilst to some extent all vendors can offer the full set of functionality; they differ by the extent to which significant build/tailoring would be required for different areas, and the heritage of the systems. Necessarily, all the offerings are "toolkits" rather than "out of the box solutions".

As a further dimension, alongside these main processes, different risk types[1] and functional entities of a bank can be added. We have specifically focused on enterprise level capital stress testing, rather than risk-type specific offerings or business unit level uses.

1 "Risk types" refers to elements such as Credit Risk, Operational Risk, Conduct Risk, Market risk, Counterparty credit valuation adjustment risk and Pre Provision Net Revenue (PPNR).

PROCESSES IN AN ENTERPRISE WIDE CAPITAL STRESS TEST



PROCESS 1: DATA EXTRACTION, TRANSFORMATION AND VALIDATION

Stress testing calculation modules require data to be delivered in a pre-specified and consistent format. Thus vendors providing the calculation engines have a data model and dictionary that a bank's data must align to in order to use the calculation engine (data models can be tailored, but changes will require investment and adjustment to other modules in the system). Assembling high quality data aligned to a data model requires information to be gathered from a multitude of disparate systems, including those containing information on credit exposures, trading book positions, the profit and loss account and so on. Importantly, the data required is likely to encompass aspects traditionally thought of as "owned by" both the Finance and Risk functions. The level of granularity of the extraction depends on the purpose and ambition of the stress test, as well as the quantification methodologies employed, and can range from facility/position through to portfolio level.

Most vendors offer tools to support data extraction and alignment to their data model, but significant implementation investment will be required to tailor this to the specifics of the source systems in most banks. Much of the extraction support software is not stress test specific per se, and in general data extraction software is a commoditised space. Some tools may be more easily deployed on a given bank's architecture than others (for example where the same vendor is already used for related functions), but in general the significant investment involved in transforming a bank's data into an appropriate data model cannot be short-circuited unless a consistent data model is already in place across the diverse types of data required for stress testing.

Common to all the vendors is that they offer a GUI[2] which allows a user to link a specific data field in the vendor's data model to a specific variable and table in another database; this allows the data to be extracted and loaded into the stress testing system. Some vendors are clear that they do not provide data extraction functionality beyond this process. Others have a history of data model implementation projects and bring tools to guide the integration process.

Most vendors offer standard error checking and validation in their extraction and transformation software. They offer the ability to measure and evidence the quality of data used. Regulators' requirements to evidence data quality have become more extensive and these may continue to increase in the future[3]. The range of offerings in this area is wide, with some vendors offering a data validation tool to override or correct the data when it contravenes user-defined rules, and others offering in-depth data lineage tracking tools and error reports to identify and correct data within the source systems. In general the offers are of a high quality, and are largely commoditised.

Data challenges are immense, and this is not an issue confined to stress testing. Most banks struggle with generating high quality Finance and Risk data for business-as-usual activities, and it would be remarkable if these issues were solved in a stress testing context. Indeed, the challenge of generating high quality data for stress testing is particularly acute as data from so many other sources is required and the stress test is the last link in a long calculation chain. Compounding this, the regulations are not settled on precisely what the output of stress tests will be, so designing a final data model and ETL process now is difficult. We see data management for stress tests as an area where banks will be "coping" rather than finalising their approach for some time.

2 Graphical User Interface: The program allows users to click on icons and select from menus, rather than needing to type in commands. This is generally a more intuitive interface for non-expert users.

3 See BCBS 239, AnaCredit.

PROCESS 2: METHODOLOGY SPECIFICATION AND CALIBRATION

Banks need a large suite of models to forecast the performance of elements of the balance sheet, profit and loss (P&L), and ultimately solvency as a function of inputs (internal position data, macro-economic conditions and management decisions).

At their most basic, the vendors' offerings usually have an interface through which the user can input a model's algorithm, or in some cases link to a model hosted outside the system. The system will then use the algorithm to make a projection using the bank's data and the scenario. In addition the systems offer some or all of the three functionalities detailed below.

Off-the-shelf methodology

Methodological frameworks for developing models and/or the models themselves. These sometimes give users access to data and benchmarks. The extent to which this is useful will depend on the bank's existing level of sophistication. However, they are highly unlikely to be accepted for standard regulatory purposes.

Sandpit development environments

Statistical packages to facilitate banks in developing their own algorithms. Often this will include statistical software to model relationships between factors, and "sandpit" environments to test model performance. Most banks already use these packages, they are easily available and they are often not specific to stress testing.

Model management and governance

Environments where meta information on models (e.g. documentation, validation status and so on) can be stored to ensure the model library is well governed.

This is obviously of critical importance and an area where banks often struggle, however we see this as being principally a management discipline issue rather than a systems challenge. The key benefit of this software is to be able to store, evidence and audit the model management process in one place. Some of the offerings will also monitor the performance of models (e.g. monitor predictive power) or allow models to be switched in and out of the production environment directly from the model management interface.

Most banks would want to use their own models and are already developing these in SAS/R/Excel or another data/statistical software, and we expect banks to continue developing their models this way in future, thus the value added by of-the-shelf models is relatively low. It is however important the degree to which the systems will allow the banks to integrate their existing and future models into their framework efficiently. Banks also need to consider the flexibility of the system to integrate future, not yet anticipated, regulatory changes without being dependent on an external IT provider.

Most banks will already have systems in place which provide part of the stress test methodology and calculation, for instance within market risk or asset liability management (ALM)[4]. There is a clear discrepancy between the vendors' offerings in terms of how easy it is to combine their system with current third party or in-house systems.

Some of the vendors' systems are deliberately built as a platform in which to host various third party or in-house systems. In these cases the vendor will supply adaptors to connect to third party systems. However, in most cases it is more difficult to combine third party systems (e.g. market pricing engines or ALM tools) with the vendor's offering; for example there may be no automatic process to communicate with those third party tools, or the automatic process might be limited in the range of tools it can communicate with. In these cases the vendor will simply offer a GUI to map fields in third party systems to its own system, which will only work as long as the third party system adheres to the "language" and format used by the vendor.

4 Asset Liability Management: Managing risks faced by a bank caused by the mismatch between assets and liabilities.

Some of the stress testing solutions have backgrounds as ALM tools which have been expanded to cover stress testing. These are often standalone tools, which can be more difficult to combine with any other third party or in-house system. They also often approach stress testing by simulating future cash flows and then deriving the accounting metrics from these cash flows (or separately from the cash flows) which can add complexity to the approach if it is desired that all metrics remain consistent.

PROCESS 3: SCENARIO SPECIFICATION AND ENHANCEMENT

Stress tests require a scenario consisting of a set of economic conditions under which the balance sheet will be projected. These may either be produced by the institution or provided by the regulator. The common functionality offered by the vendors in this area is simply providing a database for scenarios to be stored, audited and managed via a GUI in order to feed these into the enterprise stress test engine. This is essentially a database and we see limited opportunities for vendors to differentiate their offerings in this area.

Where scenarios are provided by the regulator they often incorporate only a limited number of risk factors. This puts the onus on banks to "enrich" the scenario with all the other factors that are needed to calculate the effect on their portfolio. Scenario enrichment is the capability to take scenario factors (e.g. an equity index drop or a headline interest rate change) and return consistent shocks to further risk factors (e.g. an individual equity price change or the term structure of interest rates). As this issue is most pressing for market risk, market risk scenario enrichment is offered by a subset of the vendors. None of the systems reviewed contained a methodology to enrich a purely macro-economic scenario, so this would take place outside the system environment.

Banks also require internal scenario definition capabilities, and in most cases vended systems do not provide support with this (or do so as a consulting service). We expect the development of the scenarios themselves to generally remain with economics departments and their respective model sets.

PROCESS 4: CALCULATION, ANALYSIS AND REPORTING

At the heart of the stress testing process is a projection of the future financial position of the bank, including components of the balance sheet, P&L and solvency, based on a combination of the data, models and scenarios. This estimation may take into account dynamic structures (such as loan portfolio growth and sale of business), management actions (e.g. share issues), accounting/regulatory changes and should take into account interactions between different model outputs and risk types (e.g. credit risk on future loan origination). The format, methodology and granularity of results often need to be tailored to specific uses (e.g. internal vs. regulatory submission) and hence different versions of the same scenario may be required. Once these estimates are generated, the bank will need to analyze the results and iterate them, applying expert judgment where necessary. After this stage, reports have to be produced and banks will also want to integrate the results into their existing MIS[5] or reports.

At its most basic the core advantage of a vended system is to reduce manual effort required to produce stress test results and increase repeatability. This should result in more accurate results (as they can be analyzed and tweaked more easily), easier inclusion of management actions in dynamic scenarios or applications of restrictions to certain values. This can be useful in determining strategy, in imposing "real world" regulatory limits or regulator-defined restrictions on methodology.

The aspect of reporting functionality which shows the most differentiation is the bridge between risk-level results (e.g. calculating the losses due to credit risk) and a full accounting and regulatory balance sheet projections. Some systems provide an application tailored to solving this issue, generally labelled as a capital management and planning module, whilst others are able to perform this function but require significant user-input to do so (i.e. essentially the user has to set up the relationship between key balance sheet items and regulatory rules themselves).

All the systems support dynamic balance sheets, and users can define constant or scenario-linked growth rates for portfolios or segments. Often this can be done at a relatively granular level and the characteristics (e.g. risk level, maturities) of new production can be specified. Most systems are relatively advanced in their treatment of constraints and feedback loops in the calculation of the stress test result. They are able to apply additional constraints over and above the models discussed above (which tend to represent economic relationships rather than business decisions or regulatory restrictions) such as limiting the loan to deposit ratio due to new origination during the projection, placing a floor on provision levels relative to loan balances or ceasing new production as the CET1 ratio is projected to fall below a threshold. However, the systems vary in their approach to this: some are able only to apply simple constraints; others more complex and some are able to effectively "optimize" given decision variables subject to the constraints.

All systems can report results of the stress test in a reasonably flexible manner. The user, either through the vendor's customized GUI, often based on an in-memory OLAP cube[6], or using a spreadsheet front end, can drill down into the results and build comparisons between scenario and assumption sets. The reports can then be produced using different segmentations.

The provision and updating of regulatory report templates (i.e. the ability to output results directly into a regulatory submission format) is a useful feature for banks as the formats are standardised. Configuring this is time consuming for banks, and a task that is repeated in each bank, so support from vended systems providers is particularly valuable here (if relatively rare). Not all systems offer this, and those that do often focus on the US Comprehensive Capital Analysis and Review (CCAR) requirements.

PROCESS 5: GOVERNANCE AND CONTROLS

Banks will increasingly be pushed to incorporate stress testing into a robust strategic planning process as regulators demand more management oversight, governance and controls. The primary contribution of systems here is to provide an audit trail of the data and methodologies used.

Common to all the systems is that they offer some form of user access control, audit log and version control (models, data sets etc.) with some vendors offering capabilities beyond this. For example, while some vendors view the audit log as a file that can be presented through a GUI, others allow the user to "roll back" the system (i.e. reversing the logged changes to reach a previous state, improving the ability to reproduce specific runs).

A few systems offer a more comprehensive stress test governance functionality, to allow the user to map the workflow of a stress test, assign responsibilities, monitor progress and be able to identify which changes were made by whom, when and why. The few systems offering this functionality have a GUI in which the various work blocks in a stress test can be set up and linked. Each task then has assigned users and approvers; once one task is finished the user responsible for the next task is notified and can start their work. It also allows the user to append documents and comments to each task for use in an audit process.

5 Management information system: Software that managers use to organize, evaluate and manage their business.

6 Online analytical processing: This is a business intelligence analysis tool that stores data in a particular multidimensional structure to allow fast analysis and reporting.

CAPABILITIES OF SPECIFIC SYSTEMS

In developing this report, Oliver Wyman met with nine major providers of stress testing solutions and went through a structured process of evaluating their offerings, supplemented by interviews of users, or potential users, of the systems. The following section provides a summary of the capabilities of the providers we have evaluated.

Some accounting and consulting firms will deliver a stress testing solution built using the systems provided by the vendors in this report. In these cases the system banks will receive is likely to be a modified version of the toolkits described here. The solution delivered is dependent on the capabilities of the accounting/consulting firm, the demands of the specific client and those of previous clients as well as the capabilities of the underlying vended system. No such implementations of these systems have been tested or discussed, and as such this paper will not pass further comment on them.

A1. EXPERIAN

Experian is an information services company that provides data, analytics and technology platforms to businesses. Their clients range from financial services and insurance companies to media and telecommunications businesses. They collect data on people and businesses. Experian's background has traditionally been in analytics, with an emerging trend in supporting their clients in the stress testing space.

Experian's solutions do not intend to provide a complete stress testing solution across all asset classes. This means that they do not have the capabilities to calculate total capital needed, but rather focus on the capital requirement implied for retail portfolios. One intended output is a management plan and portfolio optimization plan given capital constraints and specific macro scenarios. Their aim is to provide a system focusing on retail credit, balancing responsible lending with capital efficiency in stress scenarios.

Experian provides a granular approach to stress testing, risk management and capital optimization. Their offering suits organizations that require a framework for their retail portfolios. It includes credit data, economics data, analytics, and multiple modules and expertise that cover the stress testing framework within the retail credit space. Experian's software tool, Marketswitch, automates the estimation, analysis and reporting process. They also offer data extraction, methodology (including expected loss models) and scenario specification as bespoke services, some of which can be integrated into Marketswitch but are less automated. Experian also has a slightly different stress testing offer for the US, focussed on the specific US requirements. The Experian US offer is not covered here.

> "In the stress testing space, we deliberately focus on retail credit to make relevant use of our significant expertise. And we do this very well"

> "Experian's solution is focused around the customer, determining if the customer has the ability to repay in a stress scenario, taking into account the liabilities the customer might have with other institutions"
>
> – Experian representative

Differentiating Factors

Process 1: Data extraction, transformation and validation	• Experian provides a data dictionary and can include additional representative bureau data to enrich a bank's own data if necessary. However there is no automated extraction process within Experian's software solution • Experian does provide customized data validation for the user's specific needs, but there is not an automated validation of the data during the data loading process
Process 2: Methodology specification and calibration	• The Experian system covers retail credit portfolios only • Within retail credit, the economics team at Experian can develop granular models tailored to an individual bank as a bespoke service. The models are integrated into client systems and can be modified by the client as required, but no statistical software to derive models or model lifecycle management is provided within the system • Experian can provide granular stress test results for retail credit portfolios but it is neither a hosting platform nor an integrated enterprise wide stress test system. Instead, it is likely that modules from Experian will be used to slot into an external platform which provides more of a framework for the entire stress testing process
Process 3: Scenario	• Experian will provide scenario enrichment, giving detailed macro-economic projections at a relatively granular level (using the same NiGEM model used by the ECB and PRA) but this is as a consulting service only (either bespoke or off the shelf)
Process 4: Calculation, analysis and reporting	• Experian's Marketswitch provides the vehicle for calculation, analysis, and reporting of capital utilisation under different scenarios, with the additional ability to optimize capital under different scenarios • The system does not aim to bring the model results into an overall enterprise-wide balance sheet • Reporting and analysis on stress scenarios for current and optimal portfolio views are provided as standard, though these do not address any specific requirements of regulatory reporting • Supporting analytical techniques are included as standard to allow deeper analysis of individual scenarios
Process 5: Governance and controls	• Experian provides governance and control processes that include user access controls and audit functionality, but no additional roll-back/sign-off or documentation repository is included

A2. IBM

IBM is a global technology and consulting corporation that sells both hardware and software. It has a risk management services division that caters to a wide range of industries. IBM's core strength is in data management and analytics, and they aim to tailor this process to risk in their stress testing framework. IBM's stress testing offering is based on Algorithmics software, an IBM acquisition which provides risk management for financial institutions. Stress testing clients typically employ selected components of the IBM Risk Analytics suite for stress testing, rather than all components on an end-to-end basis.

The IBM stress testing framework builds upon Algo's long experience in analytical work and thus provides a range of models across multiple risk types (e.g. valuation library for market risk, RWA models). It is a bottom-up calculation tool which provides full cash flow valuations. The system contains different applications which can be integrated with a bank's current systems or combined to provide most aspects of enterprise-wide stress testing.

"The IBM framework interconnects risk around the enterprise addressing regulators' and banks' needs for granular, open and scalable architecture"

"IBM has combined the analytical capabilities of Algo with the database and reporting capabilities of IBM into one stress-testing framework"

– IBM representative

Differentiating Factors

Process 1: Data extraction, transformation and validation	• IBM has a strong background in data management. Data can either be brought into the IBM framework and/or it can coexist with existing data warehouses • IBM has a data profiling functionality to examine patterns in missing data etc. For example, users can see the percentage of missing variables through a dashboard and thus determine if there is a systemic database problem or just a few bad data points • There is a lineage tool which allows the user to determine the source(s), current use of and any calculations applied to all data points currently in the system
Process 2: Methodology specification and calibration	• Models are derived externally to the system and then implemented; the system does not provide statistical software for model development. The IBM statistical software package SPSS can be used but it is not integrated into their stress-testing software • There is a comprehensive model governance process to store key information around models (e.g. validation process, documentation, data used, tracking different versions of models) in one place, and the status of all models can be seen through reports and dashboards. However, IBM has yet to integrate the model governance functionality with the stress testing solution (i.e. models are described in the governance module rather than referred to from elsewhere. A decision made in the governance module must be reflected manually in the system) • In terms of implementation, the system can take results from a third party system by mapping the inputs and outputs, or users can specify a parameterised functional forms and the system will calculate the results itself. The system can supply results to third party systems • In terms of integration, IBM's system provides modules that provide the necessary parts to produce an enterprise-wide stress test, but IBM's stress testing framework is yet to aggregate results into enterprise-wide financial metrics on an end to end basis for the purpose of regulatory stress testing
Process 3: Scenario	• Scenario enrichment covers both market risk factors and credit drivers. This uses variance covariance matrices, which can be provided by IBM or defined by the user
Process 4: Calculation, analysis and reporting	• IBM has most of the key components in place for a stress test, but has yet to combine the outputs of various modules into a forward-looking enterprise-wide balance sheet and income statement. The system is not yet set up to produce standard reports for regulatory stress testing e.g. CCAR • As such, restrictions on capital (such as gearing and DTAs) are currently not included
Process 5: Governance and controls	• The IBM system is set up with a governance and control system that is stronger than average. It includes the standard features of user controls, audit logs and version control • The administrator can chart workflows for a stress test, assigning responsibilities for tasks and dependencies between them, including sign off capabilities

A3. MARKIT

Markit is a provider of financial information services. Their origins are in CDS data and pricing, providing independent portfolio evaluation and complementary data services. Their risk management business has grown through acquisitions and organic growth. The Markit Solutions division had revenue of $74 MM in Q3 2014. Traditionally, the client base for the Analytic solution has been in Europe and Asia, with some business in the US and an expanding presence in Japan.

Currently clients use the Markit Analytics system for both regulatory and internal stress testing in relation to the trading book, market risk and CCR risk management.

> "The Markit stress testing framework combines data management, stress scenario path generation and portfolio simulation"
>
> – Markit representative

With regard to enterprise stress-testing (EST) Markit Analytics would serve predominantly as a component in a larger system.

Their stress testing offering comprises:

- Markit Enterprise Data Management (EDM): the data extraction and management tool – this "enables risk data to be simply source, imported, validated, enriched, aggregated, and distributed"
- Markit Analytics, using Stress Definition Language (SDL): this generates stress scenarios and was originally designed for RWA/CVA risk management. Calculations are either run in this system or using external calculation engines. Markit supplies a library of valuation models which can be customized by the user or in cooperation with Markit
- Markit Analytics Cube: Produces results that can be dynamically sliced and diced, as well as exported to external reporting tools

Differentiating Factors

Process 1: Data extraction, transformation and validation	• Markit's data platform, EDM, has a history in market risk data, but has been expanded for use across all data types • There is a lineage tool which allows the user to determine the source(s), current use of and any calculations applied to all data points currently in the system
Process 2: Methodology specification and calibration	• Markit Analytics is focused on market and counterparty risk but it is possible to extend this to other risk types • Models are derived externally to the system and then implemented; the system does supply templates for model development, but no statistical software • Markit provides implementation of models from within the system, and it can also link to external models • Model lifecycle management is assumed to happen outside the system • Markit's position in the enterprise stress testing market would be as a component in a larger system, and together with a stress scenario it will provide the calculation for the market risk and CCR impact on capital
Process 3: Scenario	• Scenario enrichment is included for market risk factors. The system comes with an 'inference model' to enrich scenarios with extra financial risk factors. This inference model determines the changes to one set of risk factors given known changes to another • The Markit Analytics tool can produce a covariance matrix for the scenario enrichment or the bank can provide this matrix and enter it into the system
Process 4: Calculation, analysis and reporting	• Markit does not aim to bring model results into an overall enterprise-wide balance sheet • Instead, it aims to produce results for market and counterparty risk which can feed a larger system • Standard analytical tools are provided • Neither regulatory reporting nor management reporting are covered
Process 5: Governance and controls	• Markit provides a governance and control process that includes user access controls and an audit function, but no additional roll back/sign off or documentation repository • The administrator can chart workflows for a stress test, including comments • If workflow module is used, there is a functionality to roll the system back to a previous state

A4. MOODY'S ANALYTICS

Moody's Analytics provides products, solutions, and services for risk management. Moody's Analytics is known for its data as well as its risk analytics. Moody's Analytics core strength in terms of models lies in credit risk, but they do provide off-the-shelf models required for stress testing. Their stress testing software solution uses an overarching framework, Scenario Analyzer, which provides the front end from which to coordinate the stress test. Moody's Analytics also allows for integration with third party systems. The financial and risk datamart is the base for all of Moody's Analytics solutions.

The main strength of the current solution lies in its datamart and integration with other Moody's Analytics applications and external systems. The datamart is the foundation of the system and is likely to already be in use by many potential clients who use Moody's Analytics other products, making the integration of their current process with stress testing easier. The Moody's Analytics system can also integrate with third party systems; however, it will require the installation of their datamart. Moody's Analytics have extensive pipeline development plans for Scenario Analyzer.

"Our name brings a reputation to the table, and our name is important for us, so we have invested and will continue to invest in our product"

"Moody's Analytics datamart provides a single data model which can be used for multiple systems"

– Moody's Analytics representative

Differentiating Factors

Process 1: Data extraction, transformation and validation	• Moody's Analytics does not provide their own data integration/ETL layer, this comes from a view that banks are more likely to use existing ETL tools than purchase a specific stress testing ETL tool • In addition to software, Moody's Analytics can offer services and assistance such as gap analysis to assist organizations in meeting BCBS 239 requirements and to help clients in their own efforts to solve underlying data issues • Moody's Analytics has a data profiling functionality to examine patterns in missing data etc. For example, users can see the percentage of missing variables via a dashboard and thus determine if there is a systemic database problem or just a few bad data points
Process 2: Methodology specification and calibration	• Models are derived externally and then implemented; the system does not provide statistical software for model development • There is a model management process, where model assessments and validation can be stored in a documentation repository, allowing the user to test the models, store for future use and select which ones to use in a particular stress test • In terms of model implementation, the system can invoke third party systems, or user-parameterised functional forms that the system uses to calculate the results itself. The system is set up to call on external pricing engines for particular estimations, feeding in the variables needed and extracting the results to use in the capital planning phase. There is automatic iteration of any changes • Moody's Analytics modular approach accommodates the fact that most institutions will already have a number of third party or in-house solutions. Moody's Analytics has invested in building interfaces allowing communication with other commonly used stress testing systems • Moody's Analytics solution can be used as a component part within a larger system or as a standalone integrated stress testing environment
Process 3: Scenario	• Moody's Analytics provides scenario enrichment as a subscription service for regulatory-related stress testing exercises (e.g. CCAR in the US, BoE PRA stress testing in the UK)
Process 4: Calculation, analysis and reporting	• Moody's Analytics can bring together the results from various systems, produce income and balance sheet forecasts and supports dynamic balance sheet calculations, including dependencies between financial ratios and management assumptions • Specific regulatory restrictions on capital (such as those on gearing and DTAs) are not explicitly included. They can be added, but do not come as standard • Regulatory reports (e.g. CCAR FRY14, EBA Excel templates) are provided and Moody's Analytics will regularly update the formats and any calculations behind them • Rules can be included at the reporting stage (such as screening negative PDs) and any rule violations will be highlighted but not automatically recalculated
Process 5: Governance and controls	• Moody's Analytics provides a governance and control process that includes user access controls and an audit function, but no additional roll back/sign off or documentation repository • The administrator can chart workflows for a stress test, assigning responsibilities for tasks and dependencies between them. There is a sign-off protocol for each task

A5. ORACLE

Oracle is a technology company that specialises in computer hardware and enterprise software products, and has its own database management system. The historical core strength of the company is in data management and storage. Oracle Financial Services Analytical Applications (OFSAA) has grown through acquisitions and R&D investment. Clients typically use some part of OFSAA, either for a risk module or for the whole stress testing offering. A number of clients also use their Data Foundation as a standalone tool.

"Oracle's expertise is in collection, cleansing, enhancement and storage of data"

"Oracle offers an entire solution from the ground up"

– Oracle representative

Oracle provides an enterprise stress testing solution that gives banks a single environment from which to manage all aspects of stress testing. Their solution has an open architecture, allowing the user to customize it themselves. Through their investment in OFSAA Oracle can provide models for various risk types such as ALM, credit risk and market risk. Oracle also offers a partnership model through which clients can buy the solution along with the partner's work to configure the system to their own specific needs and perform the implementation.

Differentiating Factors

Process 1: Data extraction, transformation and validation	• Oracle has a strong background in database management. This gives them expertise and knowledge from previous implementation projects around data management • Oracle has a profiling functionality to examine patterns in missing data etc. For example, users can see the percentage of missing variables through a dashboard and thus determine if there is a systemic database problem or just a few bad data points • There is a lineage tool which allows the user to determine the source(s), current use of and any calculations applied to all data points currently in the system
Process 2: Methodology specification and calibration	• Oracle provides an integrated modelling environment, with 'sandbox' capabilities, in which to build and tests models using R • There is a model management process, where model assessments and validation can be stored in a documentation repository, allowing the user to test the models and store them for future use and allowing users to select which to use in a particular stress test • In terms of model implementation, the system can invoke third party systems, or user-parameterised functional form and the system will calculate the results itself. The system is set up to call on external pricing engines for particular estimations, feeding in the variables needed and extracting the results to use in the capital planning phase. There is automatic iteration of any changes • Oracle does not have a background in any one specific risk type and has adopted a modular approach that addresses several types of risk. Additionally Oracle has invested in building interfaces allowing communication with other commonly used stress test systems • The way the system is set up leaves it with a large degree of flexibility, but consequently with less structure
Process 3: Scenario	• Oracle provides a GUI for managing and stressing imported macro-economic scenarios
Process 4: Calculation, analysis and reporting	• In contrast with the rigidity of an out-of-the-box system, Oracle has an open architecture which allows a large amount of flexibility and customization; consequently, implementation might require a higher level of technical expertise • Specific regulatory restrictions on capital (such as those on gearing and DTAs) are included • Oracle has started a partnership and integration with Lombard Risk, which will significantly increase its regulatory reporting capabilities
Process 5: Governance and controls	• Oracle provides a governance and control process that includes user access controls and an audit function, but no additional roll back/sign off or documentation repository

A6. QRM

QRM (Quantitative Risk Management) is an enterprise risk management consulting firm. The core focus of QRM lies not in data extraction but in using data for capital planning and risk management. Currently over 150 clients use QRM risk management software, including 93 of the top 100 banks in North America, 60 clients in Europe and seven in Australia. The system is not solely used by banks – credit unions and hedge funds also use it. QRM is committed to rolling out improvements to their software to all clients every quarter.

QRM's stress testing solution is called Enterprise Risk Framework and it aims to cover the full range of stress testing, from data extraction all the way through to final reporting. However, in QRM's own assessment their core strength lies in Process 4, the ability to integrate various data sources, models, macro scenario and management plans into one single system for an enterprise wide view.

The solution works by calculating fundamental cashflow projections for each financial contract or bucket of contracts. This allows QRM to calculate consistent economic and accounting capital. QRM provides models for a range of risk types off the shelf, but equally they also provide consulting services to build and parameterize the necessary models needed for stress testing depending on client needs.

"QRM's stress testing system was originally designed in 2004, not as a regulatory tool but as a way in which financial institutions could examine risks and scrutinize the balance sheet"

"We have a platform and the roadmap for clients to implement comprehensive stress test system"

– QRM representative

Differentiating Factors

Process 1: Data extraction, transformation and validation	• QRM can be connected to and extract data from various source systems using either QRM's ETL tools or in house solutions, however it's focus is not on solving data issues but on preparing data for analysis. Thus the system assumes there is access to a relatively cleaned database
Process 2: Methodology specification and calibration	• The QRM system has a background as an ALM tool that has been extended to cover wider set of risk factors • Models are derived externally to the system and then implemented; the system does not provide statistical software for model development • Model lifecycle management is assumed to happen outside the system • In terms of model implementation, the system can take results from a third party system by manually mapping the inputs and outputs, or users can specify a parameterised functional form and the system will calculate the results itself • The system can incorporate third-party stress testing systems by automating the export of a scenario to an external model, and then importing the results. QRM does not provide integrated adaptors to other stress testing systems out of the box. However, we have seen that other vendors often have built-in adaptors to integrate the QRM ALM tool into their solutions • QRM's system would be suited to an institution already using QRM, but could also be used as a standalone tool or as a component in a larger system
Process 3: Scenario	• QRM provides a GUI for managing and stressing imported macro-economic scenarios
Process 4: Calculation, analysis and reporting	• Enterprise-wide capital calculations supporting dynamic estimations are included for both economic capital and regulatory capital, leading to an integration of stress testing and economic capital. The system enforces consistency across these dimensions • QRM has a portfolio optimization engine which can also optimize future asset production in the stress and base scenario based on management targets for revenue, risk appetite or other KPIs • It is possible to include multiple set-ups of the same components (databases, scenarios, methodology) for various users; these components can then be put together in a number of different combinations • Specific regulatory restrictions on capital (such as those on gearing and DTAs) are not explicitly included. They can be added by the user • QRM provides standard EBA and CCAR templates which can be populated from the system. There is no integrated validation checking (e.g. screening negative PDs)
Process 5: Governance and controls	• QRM provides a governance and control process that includes user access controls and an audit function, but no additional roll back/sign off or documentation repository

A7. SAS

SAS is a developer of analytics software with clients across a wide range of industries, from insurance to education. Their risk management and stress testing solutions are used by more than 200 banks and some clients already use some SAS tools in CCAR and EBA stress testing. The majority (58%) of their clients are in Europe, with another 22% in North America and 65% of clients are Tier 1. Along with providing sophisticated econometric models, SAS provides a stress testing system that is "designed to integrate with the customer's own approved internal models, to provide an end-to-end stress testing process that can meet regulatory tests and support ownership of the process by the bank." The system is composed of different modules, which can be used as a complete solution or as individual components that are integrated with third party systems.

"SAS provides a flexible environment for building, implementing, and integrating stress testing models"

"The SAS stress testing solution is used by institutions to build and manage the stress testing process"

– SAS representative

SAS currently have limited "out of the box" models, but is investing in the model development and plan to release new model son an ongoing bases. SAS also plans to provide support for EBA reporting templates.

Differentiating Factors

Process 1: Data extraction, transformation and validation	• SAS has a long history of working with data organization and structuring. About 60-80% of a customer's projects' time is spent on data organization; SAS provides the tools and an integrated platform with which to manage their data • SAS has a profiling functionality to examine patterns in missing data etc. For example, users can see the percentage of missing variables through a dashboard and thus determine if there is a systemic database problem or just a few bad data points • There is a lineage tool which allows the user to determine the source(s), current use of and any calculations applied to all data points currently in the system
Process 2: Methodology specification and calibration	• An integrated interactive GUI environment allows the user to build and test models using SAS's own statistical software, combining both internal and external data • There is a model management process, where model assessments and validation can be stored in a documentation repository, allowing the user to test the models, store for future use and select which ones to use in a particular stress test • In terms of model implementation, the system can invoke third party systems or user-parameterised functional forms and the system will calculate the results itself. The system is set up to call on external pricing engines for particular estimations, feeding in the variables needed and extracting the results to use in the capital planning phase. There is automatic iteration of any changes • SAS has historically been used mostly in retail credit risk but has adopted a modular approach to accommodate existing systems. It can now be regarded as a 'hosting ecosystem' for various systems. SAS has invested in building interfaces allowing communication with other commonly used stress testing systems • This modular approach, together with an environment geared towards inserting existing models, leaves the system with a large degree of flexibility, but also less structure
Process 3: Scenario	• SAS provides a GUI for managing and stressing imported macro-economic scenarios
Process 4: Calculation, analysis and reporting	• SAS's system can bring together the results from various systems, produce income and balance sheet forecasts and supports dynamic balance sheet calculations, including dependencies between financial ratios and management assumptions • The user can change some assumptions in a web or the Excel workbook interface which will trigger a recalculation of the results • Specific regulatory restrictions on capital (such as those on gearing and DTAs) are not explicitly included. They can be added by the user • SAS currently includes US regulatory reports. These are populated from the system but there is no integrated validation checking (e.g. screening negative PDs)
Process 5: Governance and controls	• The SAS system is set up with a governance and control system that is stronger than average. It includes standard features of user controls, audit logs and version control • There is functionality to roll back the system to a previous state • The administrator can chart workflows for a stress test, assigning responsibilities for tasks and dependencies between them. There is a sign-off protocol for each task

A8. SUNGARD

SunGard is a software and technology services company that provides software and processing solutions for financial services, education, and the public sector. Their stress testing offering is built on their ALM tool which can now also be used to project stressed results for pre-provision net revenue (PPNR), loan loss provision, trading and counterparty losses, gains/losses on securities, and capital calculation and actions. In Europe clients have predominantly used the system to conduct PPNR assessment or for liquidity risk. The system has also been used across the complete process by some banks in the US DFAST stress tests (banks with 10-50 BN in assets).

While the system has been designed as a complete solution in itself, SunGard's stress testing offering can also integrate with customers' existing systems. This means that it offers flexibility to banks to retain their existing, regulator-approved, pricing engines. The system also supports management and regulatory reporting, with standard templates included and updated when necessary. These are directly populated from the system. The stress testing system has had a US focus but reporting capabilities are expanding in Europe as regulatory requirements are defined. Given its background, SunGard provides models for ALM in addition to consulting services to build and calibrate a wider range of models if needed. In addition, they have a separate system for market risk, for which they can provide a library of valuation models.

"SunGard aims to provide a fully flexible enterprise-wide stress test framework"

"You don't need to be an IT expert to be able to run our system"

– SunGard representative

Differentiating Factors

Process 1: Data extraction, transformation and validation	• SunGard can be connected to and extract data from various source systems using either SunGard's ETL tools or in house solutions, however, its focus is not on solving data issues but on preparing data for analysis. Thus, the system assumes there is access to a relatively cleaned database
Process 2: Methodology specification and calibration	• The SunGard system has a background as an ALM tool that has been extended to include stress testing functionality • Models are derived externally to the system and then implemented; the system does not provide statistical software for model development • Model lifecycle management is assumed to happen outside the system • In terms of model implementation, the system can take results from a third party system by mapping the inputs and outputs, or users can specify a parameterised functional form and the system will calculate the results itself • The system can incorporate third-party systems by automating the export of a scenario to an external model, and then importing the results. However, SunGard does not provide integrated adaptors to other stress testing systems out of the box, though we have seen that other vendors often have adapters to integrate the SunGard ALM tool in their solutions • SunGard's system can be used to solve particular issues such as ALM within a larger system or as a standalone integrated stress testing environment
Process 3: Scenario	• SunGard provides a GUI for managing and stressing imported macro-economic scenarios • SunGard's advisory service helps banks define their own stress, and can customize regulatory provided scenarios to the region and sectors in which the bank operates
Process 4: Calculation, analysis and reporting	• SunGard supports dynamic balance sheet calculations including dependencies between the resulting financial ratios and management assumptions • Specific regulatory restrictions on capital (such as those on gearing and DTAs) can be added and customized by the bank, but do not come as standard • SunGard provides standard EBA and CCAR templates which can be populated from the system. There is no integrated validation checking (e.g. screening negative PDs)
Process 5: Governance and controls	• SunGard provides a governance and control process that includes user access controls and an audit function, but no additional roll back / sign off or documentation repository

A9. WOLTERS KLUWER

Wolters Kluwer Financial Services is a global provider of risk finance and regulatory reporting solutions and services. This is a segment within Wolters Kluwer's Finance and Compliance services division. In 2014 Wolters Kluwer Finance and Compliance services reported annual revenues of €401 MM, of which 47% is Finance, Risk and Compliance specific. At more complex and larger banks Wolters Kluwer is currently predominantly used as a specific component (e.g. ALM) in a larger framework although it has the capabilities to be used as an enterprise wide stress testing solution. For smaller (tier 2 or 3) banks it may be used to execute the majority of a firm wide stress test.

OneSumX is Wolters Kluwer's enterprise wide finance, risk and governance solution, covering a full range of activities including data management, risk management, finance, compliance and audit. The stress testing offering sits within OneSumX and is a bottom-up tool that is centred around modelling cash flows. Wolters Kluwer background lies in ALM and they have integrated their ALM models into the stress test product, which have been extended to also provide additional models for stress testing (e.g valuation library for market risk and credit risk). All of Wolters Kluwer's modules build on the same data platform and its stress testing capability is greatly increased with the use of the full ecosystem. For instance, when using the financial reporting system, new requirements under IFRS 9 with respect to hedge accounting are supported in its stress testing solution. The April release is meant to include a roll back/sign off and documentary repository functionality for Process 5, but not included here.

"Wolters Kluwer aims to provide an end-to-end integrated finance and risk solution"

"The system works best if the client uses all components of the ecosystem, though modules can be used as standalone parts alongside other vendors' systems"

– Wolters Kluwer representative

Differentiating Factors

Process 1: Data extraction, transformation and validation	• Wolters Kluwer has integrated database management into their stress testing framework and can work with clients to provide data cleansing and management • Wolters Kluwer has a profiling functionality to examine patterns in missing data etc. For example, users can see the percentage of missing variables through a dashboard and thus determine if there is a systemic database problem or just a few bad data points • There is a lineage tool which allows the user to determine the source(s), current use of and any calculations applied to all data points currently in the system
Process 2: Methodology specification and calibration	• The Wolters Kluwer system has a background as an ALM tool that has been extended to cover a wider set of risk factors • Models are derived externally to the system and then implemented; the system does not provide statistical software for model development • It does include a model governance process to store key information around models • In terms of model implementation, the system can take results from a third party system by mapping the outputs, or users can specify a parameterised functional form and the system will calculate the results itself • The system can incorporate third-party stress testing systems by automating the export of a scenario to an external model, and then importing the results. Wolters Kluwer does not provide integrated adaptors to other stress testing systems out of the box but can be constructed in the implementation phase • Wolters Kluwer's system can be used as a component within a larger system or as a standalone integrated stress testing environment
Process 3: Scenario	• Wolters Kluwer provides a GUI for managing and stressing macro-economic scenarios
Process 4: Calculation, analysis and reporting	• The system supports dynamic balance sheet calculations. Rules and restrictions can be included and can be ranked in order of importance • Specific regulatory restrictions on capital (such as those on gearing and DTAs) are not included in the stress test. They can be added, but do not come as standard • Wolters Kluwer provides all the standard regulatory reporting templates (EBA, CCAR etc.) and these are automatically populated with results from the system. The reports are updated when necessary, along with any supporting calculations, such as restrictions on capital. There is integrated validation functionality
Process 5: Governance and controls	• Wolters Kluwer provides a governance and control process that includes user access controls and an audit function, but no additional roll back / sign off or documentation repository. However, it does provide sign-off workflow support for data management and regulatory purposes

AUTHORS

JAMES MACKINTOSH
Partner
james.mackintosh@oliverwyman.com

MATTHEW SEBAG-MONTEFIORE
Partner
matthew.sebagmontefiore@oliverwyman.com

Oliver Wyman is a global leader in management consulting that combines deep industry knowledge with specialized expertise in strategy, operations, risk management, and organization transformation.

For more information please contact the marketing department by email at info-FS@oliverwyman.com or by phone at one of the following locations:

AMERICAS
+1 212 541 8100

EMEA
+44 20 7333 8333

ASIA PACIFIC
+65 6510 9700

www.oliverwyman.com

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