Paper SAS1861-2015

Regulatory Stress Testing—A Manageable Process with SAS®

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ABSTRACT

As a consequence of the financial crisis, banks are required to stress test their balance sheet and earnings based on prescribed macroeconomic scenarios. For example, in the US, this exercise is known as the Comprehensive Capital Analysis and Review (CCAR) or Dodd-Frank Act Stress Testing (DFAST). In order to assess capital adequacy under these stress scenarios, banks need a unified view of their projected balance sheet, incomes, and losses. In addition, the bar for these regulatory stress tests is very high regarding governance and overall infrastructure. Regulators and auditors want to ensure that the granularity and quality of data, model methodology, and assumptions reflect the complexity of the banks. This calls for close internal collaboration and information sharing across business lines, risk management, and finance. Currently, this process is managed in an ad hoc, manual fashion. Results are aggregated from various lines of business using spreadsheets and Microsoft SharePoint. Although the spreadsheet option provides flexibility, it brings ambiguity into the process and makes the process error prone and inefficient. This paper introduces a new SAS® Stress Testing solution that can help banks define, orchestrate, and streamline the stress-testing process for easier traceability, auditability, and reproducibility. The integrated platform provides greater control, efficiency, and transparency to the regulatory stress testing process. This will enable banks to focus on more value-added analysis such as scenario exploration, sensitivity analysis, capital planning and management, and model dependencies. Lastly, the solution was designed to leverage existing in-house platforms that banks might already have in place.

INTRODUCTION

The 2007 financial crisis saw a lack of preparation for the liquidity crunch and capital drains in many financial institutions. Inadequate preparation for crises can lead to systemic risk and severe economic and political turmoil. With the lessons learned from the 2007 financial crisis, regulators are now requiring both quantitative and qualitative methodologies for robust, forward-looking capital-planning processes that account for each bank's unique risks under common regulatory scenarios.

In the wake of the 2007 financial crisis, the SCAP exercise began in the U.S. in 2009. Now its successor, CCAR (Comprehensive Capital Analysis and Review), has become a major focus of the top banks in the U.S. Thirty one banks including a few global bank holding companies in the U.S. are required to submit annual capital plans to the Federal Reserve for review in the 2015 submission. However, smaller banks are also joining the group. The DFAST (Dodd-Frank Act Stress Testing) regulation requires U.S. banking organizations with consolidated assets of $10 billion or more to conduct stress tests. The same evolution of the firm-wide stress testing has been followed by other regulators around the world, for example, in Europe with the EBA/ECB stress testing. In Europe, banks may also face country-specific firm-wide stress test regulations. An example is the Prudential Regulation Authority in the UK where the prescribed macroeconomic scenarios are also to some extent overlapping with the EBA prescribed macroeconomic scenarios. The outcome of the regulatory stress testing can have significant impact on the banking system as well as the individual banks. It is true for the SCAP era to the annual CCAR in the U.S. and the most recent EBA stress testing (24 out of 123 participating banks failed the stress check, according to The European Banking Authority 2014).

Initially, regulators emphasized credit losses and revenue by stressing a few macroeconomic risk factors - as was the focus of SCAP in the U.S. in 2009-10. Today, regulators are interested in not only the effect of stress scenarios on credit performance and revenue, but also the stressed results on a broader array of measures that include liquidity and full balance sheet projections. In other words, stress testing must now be an integral part of the bank's capital plan. The requirement to assess the influence of stress scenarios across these different measures has created many challenges for financial institutions. Stress testing has become a systematic way to examine and identify an institution's financial vulnerability.

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MANAGING A HOLISTIC STRESS TESTING PROCESS

Building a solid firm-wide stress testing process is done through several iterations that need constant improvement and investment. The firm-wide stress testing process not only allows a bank to gauge its capacity to meet regulatory capital requirements such as CCAR and DFAST, but also significantly improves an institution's ability to identify and prevent potential issues that may affect its revenue, liquidity, market growth, and earnings. In a typical stress testing ecosystem as shown in Figure 1, various parties including risk, treasury, finance, and lines of business employ a number of systems to accomplish the necessary processes ranging from data management, modeling, and scenario management to the calculations, planning, and adjustment needed for the final capital stress testing. The entire process must be well governed with properly documented policies and assumptions.

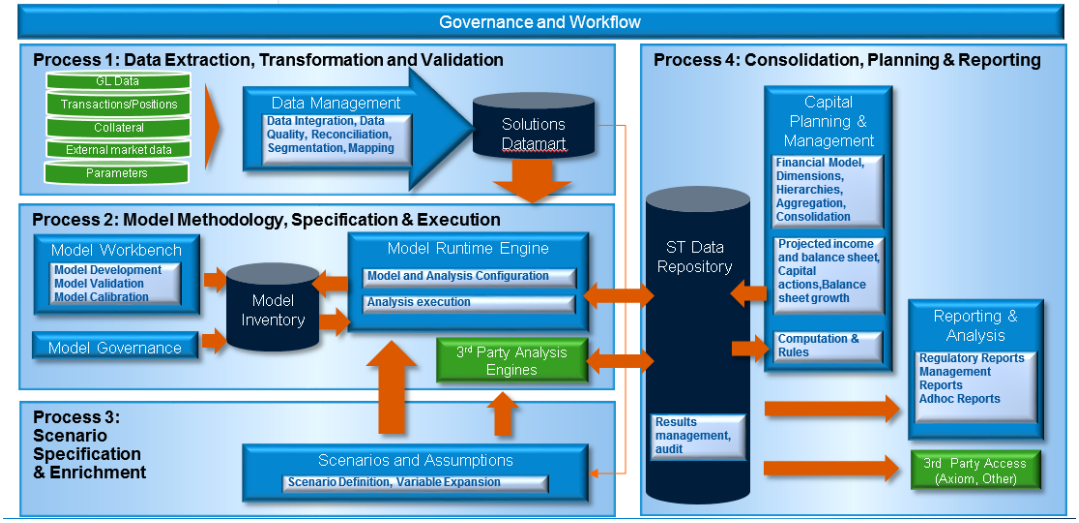


Figure 1: Illustration of a Stress Testing Ecosystem

The total balance sheet-based firm-wide stress testing exercise certainly calls for adherence to sound data management principles. The need to integrate both risk and financial measures into stress scenarios when creating the capital plan is the other challenge in the firm-wide stress testing. These common requirements appear in most regulatory stress testing regimes and require banks to quantitatively project assets, liabilities, income, losses, and capital across a range of macroeconomic scenarios. Since these functions are traditionally operated in independent silos, the regulatory firm-wide stress testing constitutes a change in practice for many financial institutions and has an impact on how banks manage risk beyond the stress testing itself. Such collaboration requires a coordinated systematic support that maintains a good degree of efficiency and accountability. Project governance thus becomes important.

The first process in the entire stress testing ecosystem is obviously on the data-related issues. Comprehensive stress testing poses higher demands on the data provisioning, data consolidation, and data aggregation. Different parties in the stress testing project must operate on a reconciled data source, with a consistent data definition and they must map to a common data hierarchy so that the input and the output of every party's operation can be brought to a common ground.

The second challenge in this round of the regulatory stress testing lies in the quality of the quantitative results. Models are required to best describe the behavior of both asset and liability projections that can capture the loss, income, risk provisions, and capital in a scenario-sensitive manner and reflect the bank's true unique risk. The granularity and transparency of the models continue to be challenged by the regulators. The model development, calibration, and validation are therefore brought to

center stage of the regulatory stress testing. Model governance and implementation therefore faces unprecedented challenges in that only models that go through rigorous validation process can be used in the stress-testing submission and these models are often applied to a very granular level of a bank's portfolio capturing all the key aspects of the consumer and business behavior.

Regulators provide stress scenarios that contain a number of key macroeconomic factors. However, many of these factors do not impact, or only indirectly impact, a bank's specific business. Banks are thus required to augment and enhance the scenarios to include the regional and bank's idiosyncratic risk factors that influence the regulatory scenario. Even if banks can purchase some enhanced scenario from vendors, banks are still responsible for managing and explaining the significance of the scenarios. In some jurisdictions reverse stress testing is required to support the stress testing scenarios. Sensitivity analysis and additional bank-specific scenario analyses are useful to support the bank's regulatory stress testing and present values beyond that.

The firm-wide stress testing is a process that requires many iterative calculations on credit loss, and in some cases market profit and loss, based on global shock on the international investment banks provisions and risk-weighted assets as well as the pre-provision net revenue from interest income and expenses and non-interest income. The forward looking projection also requires that all these calculations take into account the growth assumption as well as the bank's capital and business policies under the respective scenarios. There are inevitably back and forth communications of the results, adjustments, and management overrides in the entire process. Unfortunately because of the disparate systems operated by various teams the communication of the results are usually ad-hoc and hard to track. Many banks rely on spreadsheets and manual recording of the results for the collaboration. As a result, the process lacks efficiency, is hard to audit, and progress is difficult to monitor. During the months of a regulatory stress-testing season, the teams involved in the project constantly remain in fire drill mode but are often still unable to satisfy the regulations. The disconnection between the model development and production is another challenge especially for the large banks. For sophisticated granular level models, banks typically face challenges in model integrity, implementation efficiency, and execution speed.

These challenges are reflected by the regulatory stress testing outcomes. For example the Board of Governors of the Federal Reserve System (2014) in their retrospective themes from CCAR 2014 and are expected to be properly addressed in 2015 and onward. Banks (for examples, Hansis 2012, PWC 2014 and Faenza 2015) are also striving to address these challenges and call for an effective stress testing ecosystem that not only alleviates the burden of stress testing projects but also makes stress testing more relevant to the actual business planning and management. The SAS Stress Testing solution addresses these challenges in a holistic manner by providing an end-to-end orchestration of a stress testing exercise ranging from data management, model life cycle management, model integration and implementation, scenario management, aggregation, and capital planning all the way to reporting. The solution also allows banks to apply modules in the solution to augment their existing stress testing system to address specific challenges. This paper will focus on three specific areas that SAS can help in making a regulatory stress testing process manageable.

ANALYSIS CONSOLIDATION, CAPITAL PLANNING AND REPORTING

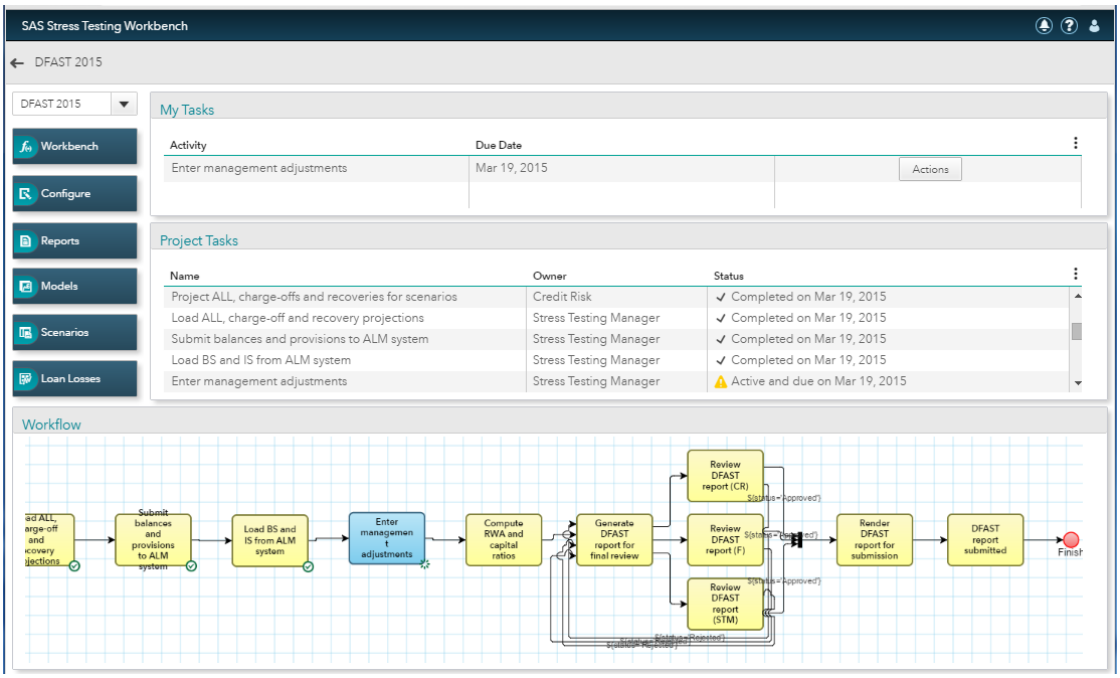
The SAS® Stress Testing Workbench provides an integrated environment for managing financial data collection, aggregation, allocation between multiple hierarchies, and forward projection to support capital planning and reporting. Even if not all the tasks in a stress test are in one system like SAS, the workbench serves as a hub for all the results to be consolidated across different working hierarchies, and can be used for final reporting. The workbench also provides out-of-the-box basic accounting capabilities such as balancing a balance sheet, rolling over line item values over projection horizons, and auditing all the adjustments and overrides.

Firstly, a bank can customize one or more stress testing workflows to standardize stress testing processes and improve the governance and documentation of the stress testing projects. The workflow capability also will assist stress testing users in tracking and completing the assigned action items. It allows stress testing managers in overseeing and auditing the end-to-end process.

Display 1 is an example of the workbench hub where a user can create or work on a user-defined regulatory stress testing project called "DFAST 2015". The layout of the layout is user configurable. In this

illustration the hub shows a graphical view of the standardized workflow with status indicators. It provides a list of the open task(s) under the user. If the task can be accomplished within SAS then the user can launch an action directly from the task list. In addition the user can also get an overview of the status and the task owner of the key tasks in the project so that the user may understand the context of his or her work.

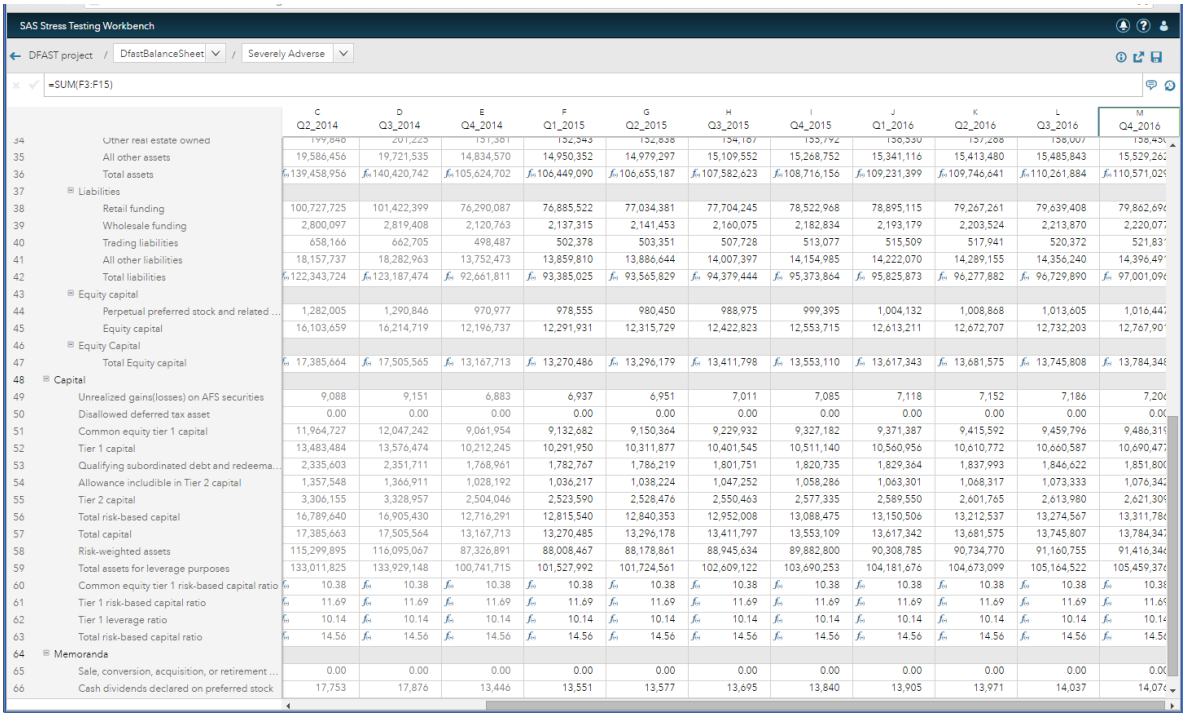
The SAS Stress Testing workbench provides a user all the key functionalities that are critical to a stress testing project. The user can configure how calculations are done through models, define hierarchies of the data sources, and reconcile different hierarchies through many-to-one or one-to-many mappings with user selected aggregation and allocation rules. The workbench also allows a user to manage models, define scenarios, and carry out other analyses such as a loan loss analysis. In the rest of this section we will focus on data collaborations and reporting. The other parts of the workbench hub include summary information on the project workflow indicators of the status of the various tasks in the project and the tasks that the login user is scheduled to complete as well as high level financial information.



Display 1: SAS Stress Testing Workbench Hub

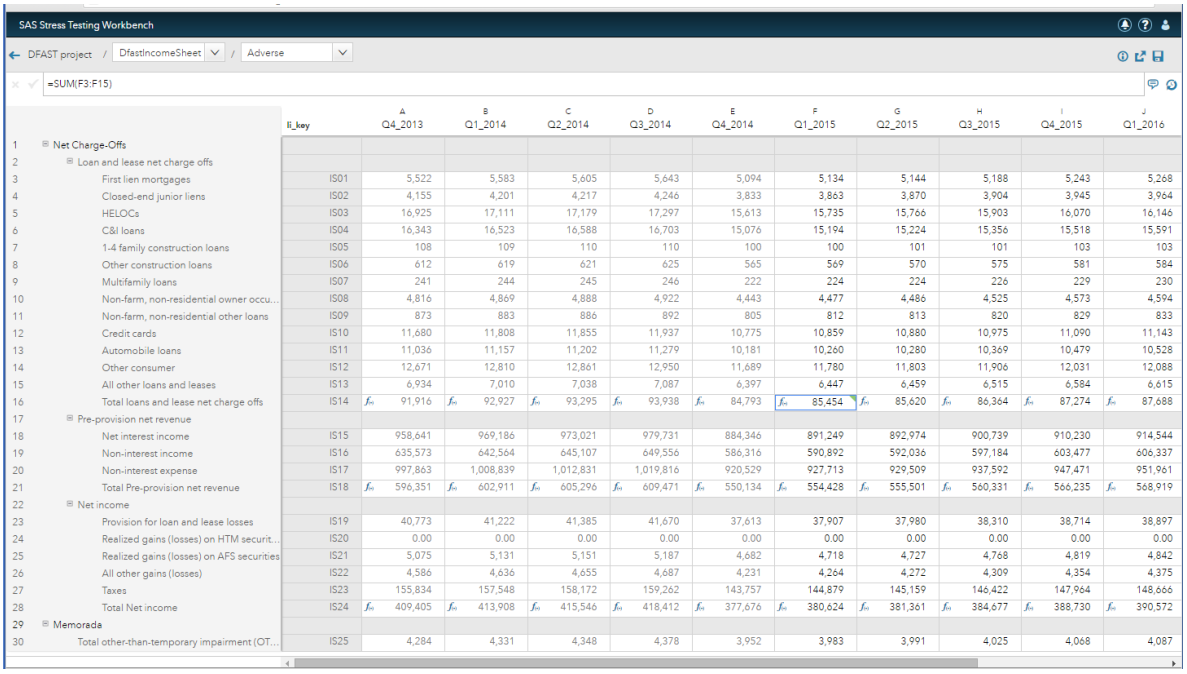
The workbench comes with an editable spreadsheet-like view of the historical and projected balance sheet (see Display 2), income statement (see Display 3) and any other user-defined sheets for multiple scenarios. Finer grained financial projections from SAS models and external systems can be loaded and aggregated to the stress testing line items via the hierarchy configurations. Multiple users with proper roles can collaborate simultaneously to review, enter, and adjust amounts and formulas, enter comments, and compare scenarios. Read and write security controls which sheets, scenarios, and cells each user has permission to view or modify. The data-driven data loading and web-based workbench reduces manual data manipulations through one-off spreadsheet work and increases the collaborations and planning activities among all the relevant parties in a stress testing process.

In addition, all changes and comments entered into the workbench sheets are tracked in a history log as illustrated in Display 4. Changes can be tracked either from the cell level or the system level, which makes it convenient for auditing purposes.



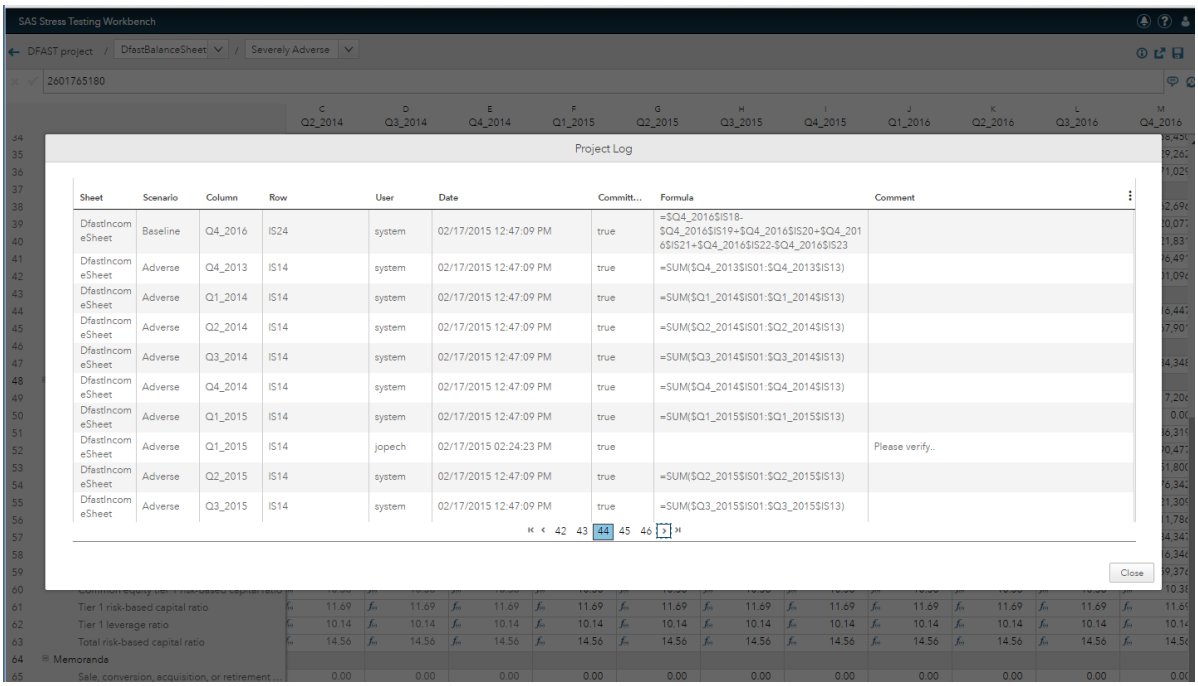
		C Q2_2014	D Q3_2014	E Q4_2014	F Q1_2015	G Q2_2015	H Q3_2015	I Q4_2015	J Q1_2016	K Q2_2016	L Q3_2016	M Q4_2016
34	Other real estate owned	199,846	201,225	151,381	152,343	152,838	154,187	155,792	156,330	157,268	158,007	158,450
35	All other assets	19,586,456	19,721,535	14,834,570	14,950,352	14,979,297	15,109,552	15,268,752	15,341,116	15,413,480	15,485,843	15,529,262
36	Total assets	139,458,956	140,420,742	105,624,702	106,449,090	106,655,187	107,582,623	108,716,156	109,231,399	109,746,641	110,261,884	110,571,029
37	Liabilities											
38	Retail funding	100,727,725	101,422,399	76,290,087	76,885,522	77,034,381	77,704,245	78,522,968	78,895,115	79,267,261	79,639,408	79,862,69
39	Wholesale funding	2,800,097	2,819,408	2,120,763	2,137,315	2,141,453	2,160,075	2,182,834	2,193,179	2,203,524	2,213,870	2,220,07
40	Trading liabilities	658,166	662,705	498,487	502,378	503,351	507,728	513,077	515,509	517,941	520,372	521,83
41	All other liabilities	18,157,737	18,282,963	13,752,473	13,859,810	13,886,644	14,007,397	14,154,985	14,222,070	14,289,155	14,356,240	14,396,49
42	Total liabilities	122,343,724	123,187,474	92,661,811	93,385,025	93,565,829	94,379,444	95,373,864	95,825,873	96,277,882	96,729,890	97,001,09
43	Equity capital											
44	Perpetual preferred stock and related ...	1,282,005	1,290,846	970,977	978,555	980,450	988,975	999,395	1,004,132	1,008,868	1,013,605	1,016,44
45	Equity capital	16,103,659	16,214,719	12,196,737	12,291,931	12,315,729	12,422,823	12,553,715	12,613,211	12,672,707	12,732,203	12,767,90
46	Equity Capital											
47	Total Equity capital	17,385,664	17,505,565	13,167,713	13,270,486	13,296,179	13,411,798	13,553,110	13,617,343	13,681,575	13,745,808	13,784,34
48	Capital											
49	Unrealized gains(losses) on AFS securities	9,088	9,151	6,883	6,937	6,951	7,011	7,085	7,118	7,152	7,186	7,20
50	Disallowed deferred tax asset	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
51	Common equity tier 1 capital	11,964,727	12,047,242	9,061,954	9,132,682	9,150,364	9,229,932	9,327,182	9,371,387	9,415,592	9,459,796	9,486,31
52	Tier 1 capital	13,483,484	13,576,474	10,212,245	10,291,950	10,311,877	10,401,545	10,511,140	10,560,956	10,610,772	10,660,587	10,690,47
53	Qualifying subordinated debt and redeema...	2,335,603	2,351,711	1,768,961	1,782,767	1,786,219	1,801,751	1,820,735	1,829,364	1,837,993	1,846,622	1,851,80
54	Allowance includible in Tier 2 capital	1,357,548	1,366,911	1,028,192	1,036,217	1,038,224	1,047,252	1,058,286	1,063,301	1,068,317	1,073,333	1,076,34
55	Tier 2 capital	3,306,155	3,328,957	2,504,046	2,523,590	2,528,476	2,550,463	2,577,335	2,589,550	2,601,765	2,613,980	2,621,30
56	Total risk-based capital	16,789,640	16,905,430	12,716,291	12,815,540	12,840,353	12,952,008	13,088,475	13,150,506	13,212,537	13,274,567	13,311,78
57	Total capital	17,385,663	17,505,564	13,167,713	13,270,485	13,296,178	13,411,797	13,553,109	13,617,342	13,681,575	13,745,807	13,784,34
58	Risk-weighted assets	115,299,895	116,095,067	87,326,891	88,008,467	88,178,861	88,945,634	89,882,800	90,308,785	90,734,770	91,160,755	91,416,34
59	Total assets for leverage purposes	133,011,825	133,929,148	100,741,715	101,527,992	101,724,561	102,609,122	103,690,253	104,181,676	104,673,099	105,164,522	105,459,37
60	Common equity tier 1 risk-based capital ratio	10.38	10.38	10.38	10.38	10.38	10.38	10.38	10.38	10.38	10.38	10.3
61	Tier 1 risk-based capital ratio	11.69	11.69	11.69	11.69	11.69	11.69	11.69	11.69	11.69	11.69	11.6
62	Tier 1 leverage ratio	10.14	10.14	10.14	10.14	10.14	10.14	10.14	10.14	10.14	10.14	10.1
63	Total risk-based capital ratio	14.56	14.56	14.56	14.56	14.56	14.56	14.56	14.56	14.56	14.56	14.5
64	Memoranda											
65	Sale, conversion, acquisition, or retirement ...	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
66	Cash dividends declared on preferred stock	17,753	17,876	13,446	13,551	13,577	13,695	13,840	13,905	13,971	14,037	14,07

Display 2: SAS Stress Testing Workbench Balance Sheet View



		fi_key	A Q4_2013	B Q1_2014	C Q2_2014	D Q3_2014	E Q4_2014	F Q1_2015	G Q2_2015	H Q3_2015	I Q4_2015	J Q1_2016
1	Net Charge-Offs											
2	Loan and lease net charge offs											
3	First lien mortgages	IS01	5,522	5,583	5,605	5,643	5,094	5,134	5,144	5,188	5,243	5,268
4	Closed-end junior liens	IS02	4,155	4,201	4,217	4,246	3,833	3,863	3,870	3,904	3,945	3,964
5	HELOCs	IS03	16,925	17,111	17,179	17,297	15,613	15,735	15,766	15,903	16,070	16,146
6	C&I loans	IS04	16,343	16,523	16,588	16,703	15,076	15,194	15,224	15,356	15,518	15,591
7	1-4 family construction loans	IS05	108	109	110	110	100	100	101	101	103	103
8	Other construction loans	IS06	612	619	621	625	565	569	570	575	581	584
9	Multifamily loans	IS07	241	244	245	246	222	224	224	226	229	230
10	Non-farm, non-residential owner occu...	IS08	4,816	4,869	4,888	4,922	4,443	4,477	4,486	4,525	4,573	4,594
11	Non-farm, non-residential other loans	IS09	873	883	886	892	805	812	813	820	829	833
12	Credit cards	IS10	11,680	11,808	11,855	11,937	10,775	10,859	10,880	10,975	11,090	11,143
13	Automobile loans	IS11	11,036	11,157	11,202	11,279	10,181	10,260	10,280	10,369	10,479	10,528
14	Other consumer	IS12	12,671	12,810	12,861	12,950	11,689	11,780	11,803	11,906	12,031	12,088
15	All other loans and leases	IS13	6,934	7,010	7,038	7,087	6,397	6,447	6,459	6,515	6,584	6,615
16	Total loans and lease net charge offs	IS14	91,916	92,927	93,295	93,938	84,793	85,454	85,620	86,364	87,274	87,688
17	Pre-provision net revenue											
18	Net interest income	IS15	958,641	969,186	973,021	979,731	884,346	891,249	892,974	900,739	910,230	914,544
19	Non-interest income	IS16	635,573	642,564	645,107	649,556	586,316	590,892	592,036	597,184	603,477	606,337
20	Non-interest expense	IS17	997,863	1,008,839	1,012,831	1,019,816	920,529	927,713	929,509	937,592	947,471	951,961
21	Total Pre-provision net revenue	IS18	596,351	602,911	605,296	609,471	550,134	554,428	555,501	560,331	566,235	568,919
22	Net income											
23	Provision for loan and lease losses	IS19	40,773	41,222	41,385	41,670	37,613	37,907	37,980	38,310	38,714	38,897
24	Realized gains (losses) on HTM securit...	IS20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	Realized gains (losses) on AFS securities	IS21	5,075	5,131	5,151	5,187	4,682	4,718	4,727	4,768	4,819	4,842
26	All other gains (losses)	IS22	4,586	4,636	4,655	4,687	4,231	4,264	4,272	4,309	4,354	4,375
27	Taxes	IS23	155,834	157,548	158,172	159,262	143,757	144,879	145,159	146,422	147,964	148,666
28	Total Net income	IS24	409,405	413,908	415,546	418,412	377,676	380,624	381,361	384,677	388,730	390,572
29	Memoranda											
30	Total other-than-temporary impairment (OT...	IS25	4,284	4,331	4,348	4,378	3,952	3,983	3,991	4,025	4,068	4,087

Display 3: SAS Stress Testing Workbench Income Statement View



Display 4: SAS Stress Testing Workbench Auditing Log View

The workbench produces reports using standard report templates (such as the annual DFAST template by Office of the Comptroller of the Currency 2014) or customer-specific templates. Users can render reports at any time in a stress testing process if the user wishes to check the progress or generate an interim report for internal approval. Reports can be rendered in Excel or other formats such as plus-delimited (for direct submission to the Fed's Reporting Central) or CSV.

```
H1039502+FRY16+02-17-2015
LCSTX8901+John Doe
LCSTX8902+(212) 720-1234
LCSTX9116+415-292-0000
LCSTX4086+johndoe@gmail.com
LCSTX4769+Cover page remarks
SCSPTP006+4
LCSPTN193++5,660,050+5,704,226+5,715,270+5,764,968+5,825,710+5,853,320+5,880,930+5,908,540+5,925,106
LCSPTN194++4,258,875+4,292,115+4,300,425+4,337,820+4,383,525+4,404,300+4,425,075+4,445,850+4,458,315
LCSPTN195++17,348,125+17,483,525+17,517,375+17,669,700+17,855,875+17,940,500+18,025,125+18,109,750+18,160,525
LCSPTN196++16,751,575+16,882,319+16,915,005+17,062,092+17,241,865+17,323,580+17,405,295+17,487,010+17,536,039
LCSPTN197++110,700+111,564+111,780+112,752+113,940+114,480+115,020+115,560+115,884
LCSPTN198++627,300+632,196+633,420+638,928+645,660+648,720+651,780+654,840+656,676
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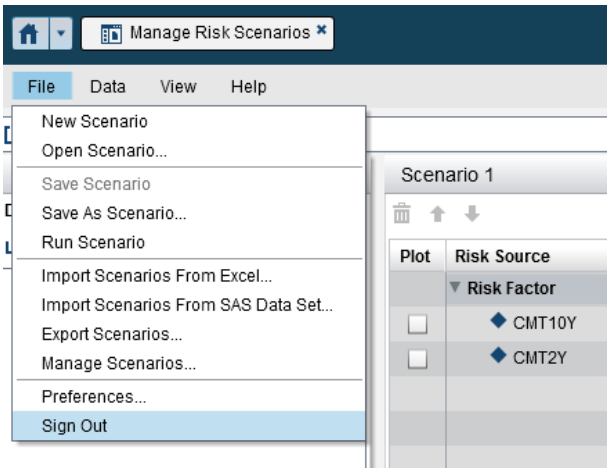
Output 1: A Plus-delimited DFAST Report File Output

Finally, the reporting capability of the system maintains the history of every report rendered and a snapshot of the source data used for each report, supporting audit, and reproduction of historical reports. These make the internal auditing control and regulatory examination of the stress testing more manageable.

SCENARIO MANAGEMENT

In a regulatory stress test like CCAR or DFAST scenarios contain a set of macroeconomic factors that are often given by the regulators. Banks are supposed to augment and enhance the regulatory scenarios by including the economic factors that are pertinent to their business. For example, when a bank has concentrated mortgage exposures in Florida, California, and North Carolina, the bank is expected to shock the housing price index, unemployment rate, and other risk factors at the level local in these geographic entities. When a bank has significant exposure to the commercial loans in the fracking sector that can be hit by low oil prices, the bank must include the crude oil price in the scenario for its stress testing. Although many banks tend to purchase scenarios from third-party vendors it remains the banks' responsibility to manage and justify the scenarios. As a stress testing best practice a bank is supposed to incorporate stress testing into its management decisions with bank-specific scenarios. Sensitivity analysis and what-if analyses can even require additional scenarios.

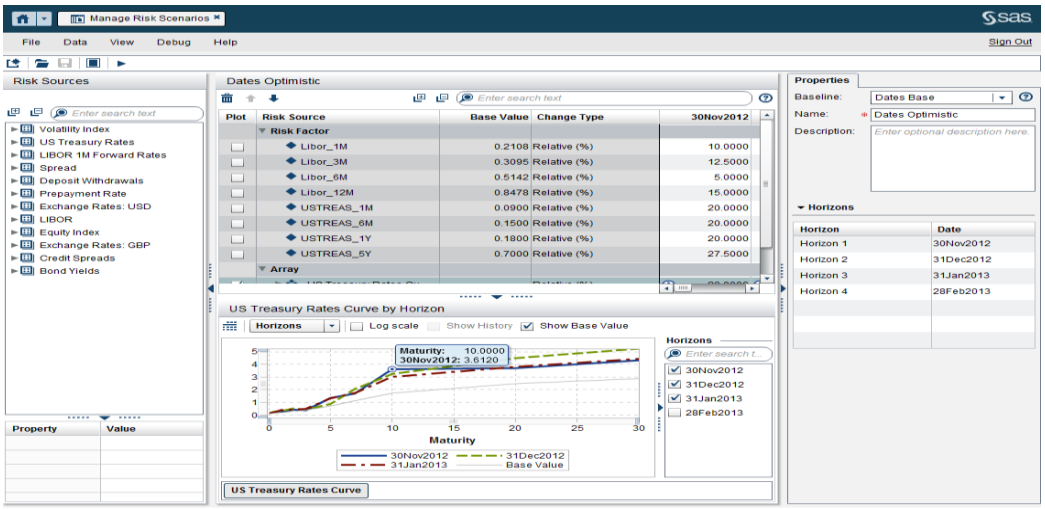
The SAS stress testing scenario manager allows a user to import scenarios from spreadsheets, SAS data sets, create new scenarios, modify, augment, and enhance existing scenarios. Display 5 shows the scenario actions a user can take through the SAS Stress Testing Scenario Manager.



Display 5: SAS Risk Scenario Manager

The user can also explore the scenarios graphically to compare the projected scenario values with the historical values for the same risk factor. When a user is going to create or modify a scenario, the user can choose or assign a baseline scenario and then define scenarios relative to that baseline. The user can define horizons either in relative interval increments or in absolute dates. Likewise, a user can shock risk factors relatively or by a certain value. For the risk factor curves like yield curves or forward curves, the user can either shock the entire curve or shock each individual member of the curve. Users can also define risk factor groups such as large cap stocks, interest rates, and credit spreads and shock the entire group homogeneously or move each subset individually. Display 6 shows a scenario that is being developed by a user where the user can choose all the defined risk factors in the system from the left panel and build the desired scenario, perturb them at the single risk factor, curve, or even driver level, associate scenarios to a baseline, define future horizons, compare risk factor values across scenarios, and explore risk factor history. All the scenarios are stored in a scenario library where the scenario management information such as creation and modification date and time, owner, and data source type are recorded. In a typical stress testing process, the stress testing manager can use the scenario manager to create and centrally manage the scenario and export the scenarios to various parties involved

in the stress testing project so that all the parties use the same scenario for their part of the calculation and projection. This avoids the need for each party to individually manage the scenarios.



Display 6: SAS Risk Scenario Manager: Scenario Development and Exploration

Using the scenario manager and the workbench together a bank can leverage the well-defined stress testing workflow to initiate or copy a stress testing project based on any ad-hoc scenarios for the bank's own scenario and sensitivity analysis to support their regulatory stress testing.

In the next section we are going to introduce the SAS risk engine as a model implementation platform that is connected with the scenario manager. That is, if the models are implemented with the SAS risk engine then a user can execute the scenario directly from the scenario manager. This connection will allow a quick smoke test run of a scenario or model implementation as well as an ad-hoc risk analysis.

MODEL INTEGRATON AND IMPLEMENTATION

A big challenge for many banks is bringing all stress testing models together in a controlled environment where models can be implemented efficiently. Pertaining to the stress testing life cycle illustrated in Figure 1, SAS technology helps make this possible by providing a way to store all models in a model inventory where models can be governed through SAS® Model Risk Management and can be executed in the SAS® High-Performance Risk engine in the SAS Stress Testing Solution. It is very important for firms to have a controlled, integrated model inventory where all production models can be stored, and the modeling process can be streamlined. This ensures that only model parameters that have gone through appropriate model governance channels can be used in the stress testing process. Models can be appropriately versioned so that different model iterations can be tracked and documented.

The implementation of systems of models can be made more efficient by making direct calls to this inventory, removing the need to hard code parameters into the implementation code. This section provides more detail on the benefits of the SAS High-Performance Risk engine for efficient model implementation.

In the risk engine, a system of models can be connected together to accomplish the desired analytics such as loss and income analysis. This engine can run on a single computer or a supplied grid of any size. The engine distributes complicated calculations to a grid for the user. Depending on the complexity of the models and the processing speeds required, this grid hardware can be scaled to meet the needs of each institution. Instead of taking many hours or even days to get the results of a suite of models, it is possible to get results in minutes by using the distributed computing power without the burden of manual control of the job distribution.

This system also provides modeling templates for the implementation of commonly used modeling methodologies to reduce significantly the effort required to set up implementation code. These implementation templates can call the production models directly from the model inventory, which provides a clear audit trail for all models that are run during a stress testing process. The user can also leverage existing code, which can be modified based on firm specific factors. It reduces the model risk during the implementation process and shortens the time to production of these models.

As the discipline of stress testing matures, regulators are increasingly requiring banks to adopt more advanced modeling techniques. For example, where pool level roll rate loss models may have been acceptable several years ago, regulators are now increasingly pushing for loan level models that can model the full life cycle of a loan and take into account important factors such as delinquencies, prepayments, modifications, and varying types of liquidations. To appropriately handle all of these factors well, increasingly complex modeling frameworks need to be put into place. However, this can place a high cost on an institution. While the resource burden of estimating a complex suite of models is daunting enough, the implementation of these models can add an additional layer of difficulty. This is especially the case when an implementation requires expertise in languages other than SAS, such as C++. With this risk engine, there is no need to have a separate C++ implementation team, as models can both be estimated and implemented within SAS. Moreover, the SAS code base is very manageable because it handles several important aspects of model implementation internally.

A real example of a complex system of models that would traditionally have been very difficult to implement would be the Monte Carlo state transition model. In this type of model, a loan can move through various states of delinquency during its life. It explicitly captures the movement through delinquency states prior to termination by default. In addition, it captures the risk that a loan can prepay in full in any given month.

Figure 2 illustrates an example of this type of model. In the transition matrix, there are models that dictate the movement of a loan through different delinquency states. A loan that is current can either stay current (make a payment), transition to D30 (miss a payment), pay off the loan in full, or directly move to default. Similarly, a model from any starting state has a finite number of potential states that it could migrate to. This type of model is very powerful because it is able to explicitly model the movement of loans through delinquency states and the resulting path dependency of these movements. For example, a loan that is current, but has been delinquent in the past bears a much higher risk than a loan that has always been current. This type of model can capture this dynamic both at the beginning of the model run and throughout all forecasted horizons. It also allows the output of specific cash flows that would result from each simulated path that a loan could take.

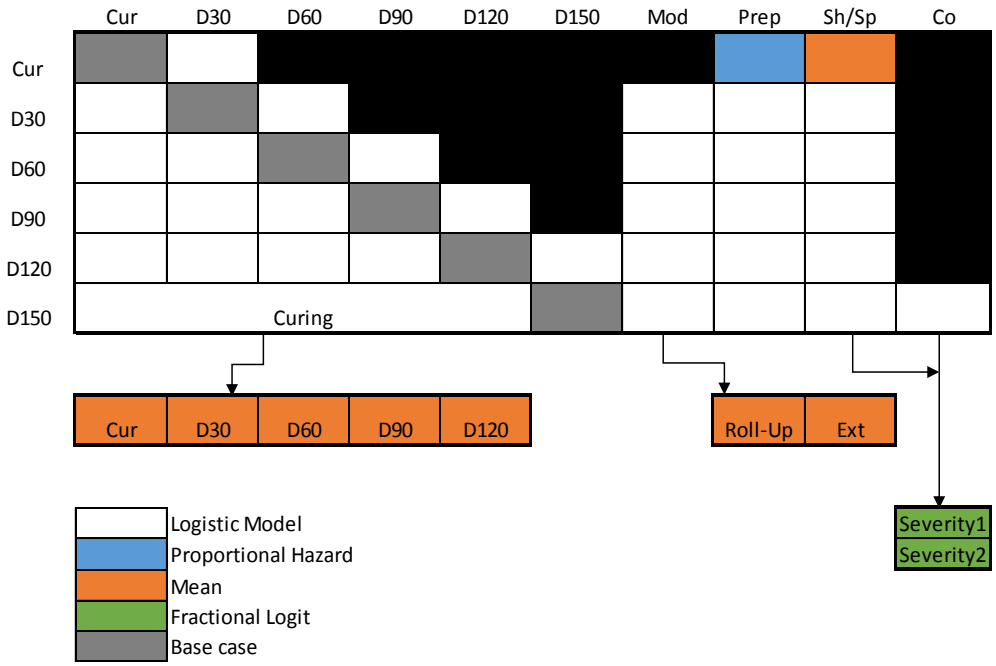


Figure 2: Example of a Monte Carlo State Transition Model

Although this model framework has many benefits, it has traditionally been very difficult to implement. It requires many interconnected models, the movement through forecasted time horizons, and the ability to simulate a loan (potentially several thousand times) across many different states. The SAS High-Performance Risk engine not only makes it possible to implement this type of model, but makes it easy with a prebuilt implementation template produced by SAS. This greatly increases the range of modeling options from which an institution can choose in their stress testing processes.

Below is a summary of some of the key implementation benefits of the SAS risk engine:

- One system can quickly implement many kinds of structures (hazards, Monte Carlo, Markov chain)
- Thread-safe parallelization is automatically handled
- Built-in movement through forecasted time horizons
- No need to join economic variables to loan data at each time horizon
- Ability to handle complex transition (for example, many models over a single time step)
- Simplification of post-processing calculations such as averaging across many simulations
- Smart distributed processing allows for quick model output aggregation
- Direct interface with a model inventory where model governance can also be placed

Furthermore, templates for commonly used modeling methods are provided, which can be customized for a specific firm's needs. In other words, almost any model type can be run on the same platform. Also, the software internally handles thread-safe parallelization that allows for a large grid of servers to be utilized. There is no need for a user to write code to send data to each of the nodes or to make sure that processes on each node are handled efficiently. This allows model developers to focus on building models instead of having to worry about how to set up a distributed computing environment. In the Monte Carlo simulation model outlined above, this is critical since many thousands of loan simulations are required. Without significant processing power, this would be nearly impossible.

Incorporating economic forecasts within a suite of models typically involves first expanding the loan

level data out into the future for the desired forecast horizon (potentially extending out to the life of the loan). Then all economic factors need to be merged into the expanded table so that the models can be applied at each forecasted horizon. Depending on the size of the portfolio, this expansion of the loan data and merging of the economic variables can create a significant bottleneck in the implementation process. However, the SAS High-Performance Risk engine eliminates the need to do both of these time consuming processes. All that is required is that the user point to the loan level data and the economic forecasts and the relevant information is retrieved by the system as needed by the underlying models.

Additionally, the risk engine provides sophisticated built-in features for simulation and calculates risk measures such as the expectation of standard Monte-Carlo methods. One merely needs to specify a Monte Carlo framework and the engine will handle simulation flows, re-setting variables, tracking paths, and the necessary calculations after the simulation is finished to provide the user with the desired output. For example, when running a Monte Carlo simulation model, the post-processing calculations of averaging across many simulations are taken care of within the engine. In addition, the engine can easily handle sub-models within a single time step. If a time step is a single month, it is possible to capture the possibility of a loan going through several different states within that single month.

Finally, after a model is run, there is significant work required related to aggregation and analysis of the data. Since the SAS High-Performance Risk engine uses the advanced in-memory grid computing technology, the loan level results can easily be aggregated through any desired hierarchy almost instantly. This allows users to slice and dice their portfolios in many different ways when analyzing results. Besides the batch programming interface, a graphical user interface is available to make the aggregation intuitive to model implementation teams as well as to business analysts. This user interface is also connected to the scenario manager introduced in the last section. Once a scenario is defined, the system can streamline the scenario input, model execution from the model inventory, risk aggregation, and exploration all the way to the data collaboration and planning.

CONCLUSION

This paper introduces a new SAS Stress Testing solution that provides a holistic stress testing platform for managing the regulatory stress testing ecosystem for banks. The solution can also be applied modularly for banks to pragmatically augment a bank's stress testing process leveraging existing systems and models. The paper covers in some details a few key components in the solution that can be used for stress testing collaboration, capital planning, governance, reporting, scenario management as well as model implementation. Together with other solution capabilities and series such as model risk management, benchmark modeling, and loan data consortium services, the SAS Stress Testing solution aims to support the best practices for and beyond the regulatory stress testing.

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