OVERVIEW OF THE MID-AMERICA EARTHQUAKE CENTER

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ABSTRACT

The Mid-America Earthquake (MAE) Center, one of three earthquake engineering research centers funded by the National Science Foundation, focuses on system-level solutions for seismic risk problems in the eastern and central USA. Through its research, education and outreach projects, its extensive interaction with stakeholders and its active cooperation with overseas agencies, the MAE Center has emerged as a significant national and international force that compliments the Pacific and Multi-disciplinary Earthquake Research Centers (PEER and MCEER). With its headquarters at the University of Illinois, and with Georgia Institute of Technology, University of Memphis, Texas A and M University, Washington University, MIT, St. Louis University and University of Puerto Rico, the Center has a multi-disciplinary team that is delivering innovative solutions to earthquake risk mitigation problems in the central and eastern USA.

Consequence-Based Engineering

The MAE Center has pioneered the development of a holistic approach towards seismic risk assessment and mitigation. Consequence-based Engineering (CBE) is a formal framework for the execution of loss assessment, acceptable losses and alternatives towards reducing the assessed losses to an acceptable level. As simple and intuitive as CBE is, it provides a unique perspective on disaster management and mitigation. The procedure is summarized in Figure 1, where the system-level steps of consequence-based engineering are depicted. The operational steps of applying CBE in risk assessment and mitigation are presented below.

In Figure 1, 'Consequences' are all effects of earthquakes (or indeed any other form of natural or manmade hazard) on society, including engineering, economic and social impact. 'Acceptable Consequences' mirror the definition of 'Consequences' and are therefore all-embracing. 'Consequence-Minimization' refers to all measures of reducing the consequences of hazard events. This includes conventional measures of retrofitting of engineered systems, as well as network hardening and land-use management alternatives. The MAE Center approach couples 'Decision-Making' and 'Visualization' so as to provide the decision- and policy-maker with a vivid environment for informed decisions. All the above steps are executed in an uncertainty management shell. The ten operational steps of CBE as applied to seismic risk situations are depicted in Figure 2.

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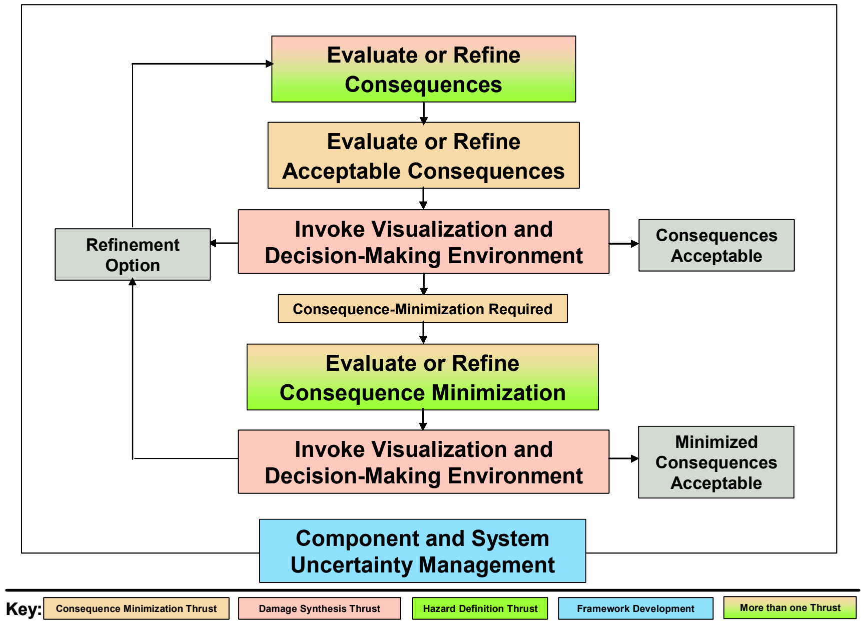

Figure 1: Consequence-Based Engineering Assessment Framework

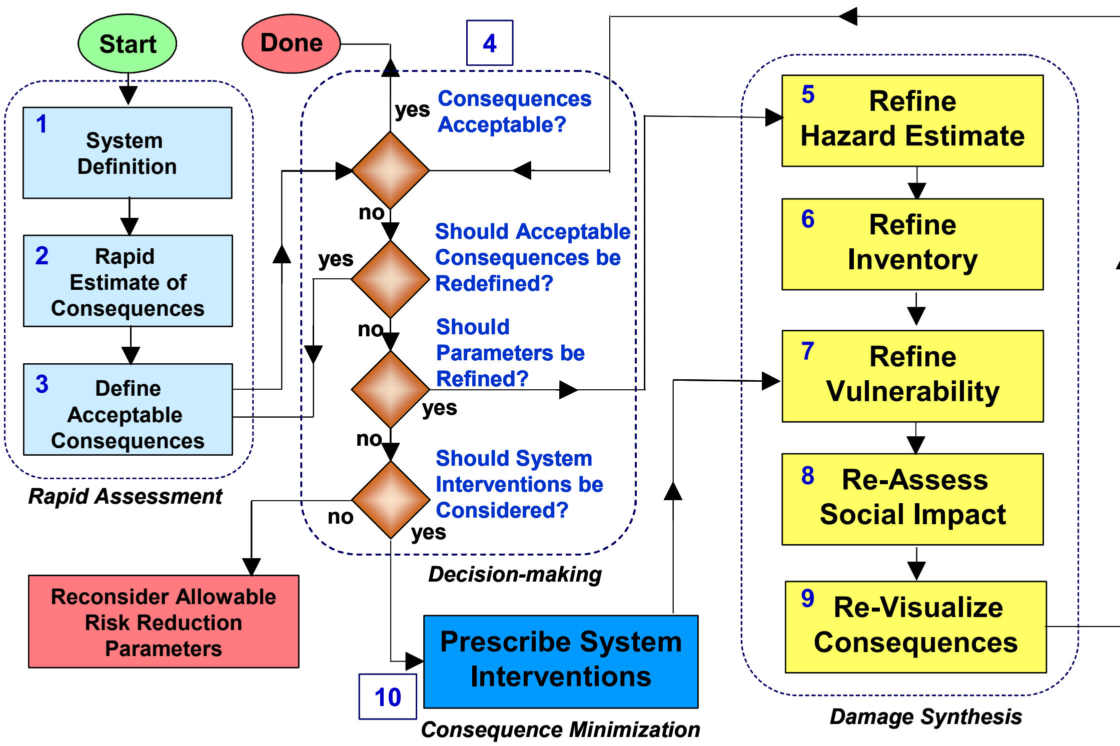

Figure 2: Operational Steps of CBE Application

Compared to existing open-source and proprietary seismic loss assessment models, CBE is a significant and advanced development. This is due to its inclusive nature, where all aspects of the functioning of a system are taken into account, such as social impact, economic consequence and engineering effects, as well as the interaction between them. Moreover, projecting the assessment-mitigation cycle through an advanced information technology decision-making and visualization platform provides a most effective environment for making informed decisions. All components of loss assessment and mitigation developed by the Center have been implemented in MAEViz, a high-end spatial visualization and data management system that can synthesize the plethora of loss assessment data to allow for more informed decisions. Due to the modular nature of the MAE Center implementation of CBE in MAEViz, the hazard can be changed to represent different earthquake magnitudes, distance from a community, and time of occurrence. Vulnerability of the societal systems can also be changed to reflect different societies with varying degrees of disaster preparedness; different intervention schemes can be applied to the vulnerable components of a system. Finally, integration of the above, taking into account the inventory data of a region can be applied, resulting in hundreds of different loss scenarios that can be visualized by a stakeholder, leading to informed decisions.

Significance of the CBE Approach

By defining in a transparent manner the interrelationship between stakeholders and researchers, the consequence-based approach is a most suitable tool for bridging the gap between research developments and system-level applications. The outcome of consequence (or loss) assessment for the as-built system, as well as the system under the application of a number of generalized intervention measures, is brought to the decision- and policy-maker with the appropriate uncertainty attached to the estimate, thus streamlining the process of deriving risk mitigation policies and associated decisions. Consequence-based Engineering also provides an ideal teaching and learning environment at all levels of education. The logical steps depicted in Figure 2 are an effective tool for designing curricula for formal teaching, demonstration examples for various types of displays, and even design of public information literature and outreach activities. This is manifested in the successful MAE Center educational initiatives, such as the CBE Institute that was run for the first time in 2003 and the new credit course in Consequence-based Earthquake Engineering, accepted by UIUC as a graduate full credit course, and under consideration by other core institutions.

Personnel and Facilities for Executing CBE Loss Assessment

The MAE Center has access to some of the most up-to-date experimental and analytical research infrastructure in the US. Moreover, the talent base of the Center is first-class. For example (non-exhaustive list), the following sub-tasks of CBE are under development by the indicated experts (bold indicates membership of Leadership Team, in addition to Sue Dotson, Administration Manager, and Tracy Smith, SLC president):

- Social sciences consequence and acceptable consequences: Ann Bostrom (GT), David Gillespie and **Phil Gould** (WU), Carla Prater, Walter Peacock and Mike Lindell (TAMU), and Bob Olson (consultant).
- Economic consequences: John Gnuschke (UM).
- Uncertainty Modeling: Bruce Ellingwood (GT), YK Wen (UIUC), Joe Bracci (TAMU), Daniele Veneziano (MIT).
- Fragility Analysis: **Mary Beth Hueste** and Joe Bracci (TAMU), **Reggie DesRoches**, Jim Craig, **Barry Goodno** and Bruce Ellingwood (GT), **Ricky Lopez** and Ali Saffar (UPRM), YK Wen and **Amr Elnash**ai (UIUC) and **Shirley Dyke** (WU).

- Geotechnical analysis: **Glenn Rix**, David Frost, Carlos Santamarina and Paul Mayne (GT), Youssef Hashash and Jian Zhang (UIUC).
- Earthquake hazard: **Christine Powell**, Chuck Langston, Robert Smalley, Paul Bodin, Roy VanArsdale (UM).
- Inventory technology: **Steve French** (GT).
- Transportation networks: Travis Waller and Mike Walton (UTA), T. John Kim (UIUC).
- Data management and visualization: Tom Prudhomme, Loretta Auvil, Michael Welge (NCSA), **Bill Spencer** (UIUC), Steve French (GT).

All MAE Center PIs are recognized experts in the subjects to which they contribute. In addition, the Leadership Team is always on the lookout for new talent to invigorate the research program, as evidenced by the ongoing discussion with potential new core institutions. One of the truly unique features of the MAE Center is the symbiotic relationship that has developed between PIs and the Center leadership. Whereas all PIs are top researchers, their pre-MAE Center work was not necessarily in directed toward earthquake hazard mitigation. Through their involvement in the Center, the national talent pool in seismic loss assessment and reduction has been enriched by researchers who would have not entered the field had the MAE Center not existed.

Strategic Research Plan

The Core Research Program of the MAE Center and its constituent thrust areas are shown in Figure 3. Major test bed applications have been designed and implementation has started in earnest. A comprehensive project on assessment of seismic risk in Memphis, referred to as the *Memphis Test Bed* (MTB) project was initiated, in collaboration with regional stakeholders. Moreover, the Transportation Task Force initiative has focused application efforts on seismic risk to transportation systems in the Midwest and detailed plans are being drawn for a *Transportation Network Seismic Risk* test bed. The second test bed project is being planned in conjunction with the thematic stakeholder group comprising Departments of Transportation in the central and eastern US. The core research plan has therefore gone from being driven by generic system requirements to being designed to respond directly to the specific requirements of the ongoing system-level test bed applications. The evolution to a fully test bed-driven core research program has led to a significant increase in stakeholder interest in MAE Center products.

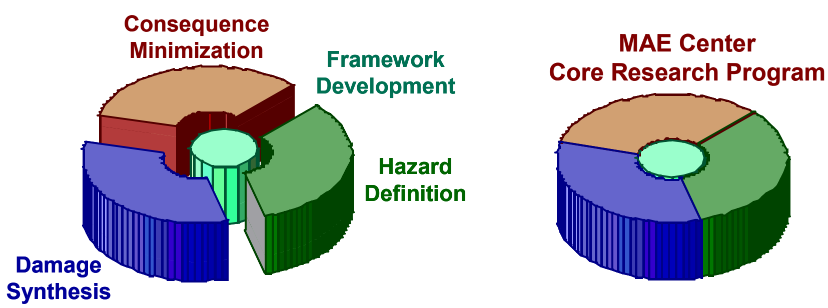

Figure 3: Thrust Areas of the MAE Center Core Research Program

Test beds provide a developmental environment whereby *System Level* concepts lead advancements in *enabling technologies* which in turn set *fundamental knowledge* research requirements. Through the investigations of its researchers and interaction with the other two US earthquake research centers, and stakeholders as well as international exchanges, the MAE Center research management continuously assesses the state-of-the-art and fine tunes the scope of different research projects accordingly. The three MAE Center thrust areas, Hazard Definition, Damage Synthesis and Consequence Minimization, guided by the principles of Consequence-Based Engineering developed in the overarching CBE Framework Development projects, integrate the projects in each thrust and across the thrusts, towards the systems level goal of advancing CBE as a formal and rational framework for seismic loss assessment and reduction. The test bed applications provide an effective means of verifying both the framework and the implementation tools of Consequence-Based Engineering.

The organization of the thrusts follows the sequences of steps of application of CBE, namely assessment of losses under the effect of earthquake ground motion (Damage Synthesis, with input motion characterization from Hazard Definition) and reduction of losses (Consequence Minimization, with input motion characterization from Hazard Definition). Finally, a regional (Memphis) and a thematic (transportation networks) test beds are employed to demonstrate the integration of research findings from the three thrust areas, to prove the concepts used and the products developed and to articulate the requirements for future developments.

An Integrated Research Program

Each project in the MAE research program is carefully formulated to provide the necessary input for the application of Consequence-based Engineering to the problem of seismic risk mitigation on a regional level. For example, the assessment on network losses would be the object of Projects DS-6b and DS-6c, with input from HD-1, which is, in turn, synthesizing the outcome of HD-2 through HD-7. The socio-economic consequences are evaluated in Project DS-8. Once the losses of the as-built system are evaluated, acceptable consequences, the outcome of Project CM-2, would be compared with the estimated consequences, thus arriving at an increment of consequences that should be minimized using the outcome of Projects CM-3b, CM-4, CM-6 and CM-8 with regard to options for retrofitting. The selection of the optimal retrofitting scheme makes use of decision support tools emanating from Project CM-1. The visualization module MAEViz of DS-1 is invoked before and after the application of the selected scheme. Similar scenarios for the application of the MAE Center project outcomes may be envisioned, and the intricate interrelationship between the projects is depicted in Figure 4.

Within each project, across the thrust areas, and in the overall MAE program, the formulation of research teams is meticulously considered in order that the required array of expertise is combined to achieve the project, thrust, and systems goals. The rationale behind the cross-disciplinary teaming of researchers is (i) the combined product required from the project and across projects within a thrust necessitates cross-disciplinary expertise; (ii) reaching the goal of truly interdisciplinary research requires such long-term partnerships; and (iii) mentoring of young researchers within the MAE Center is helped by eliminating disciplinary barriers. The MAE Center team is increasingly becoming a multi-disciplinary, age, gender and ethnically-diverse group pursuing an interdisciplinary research agenda.

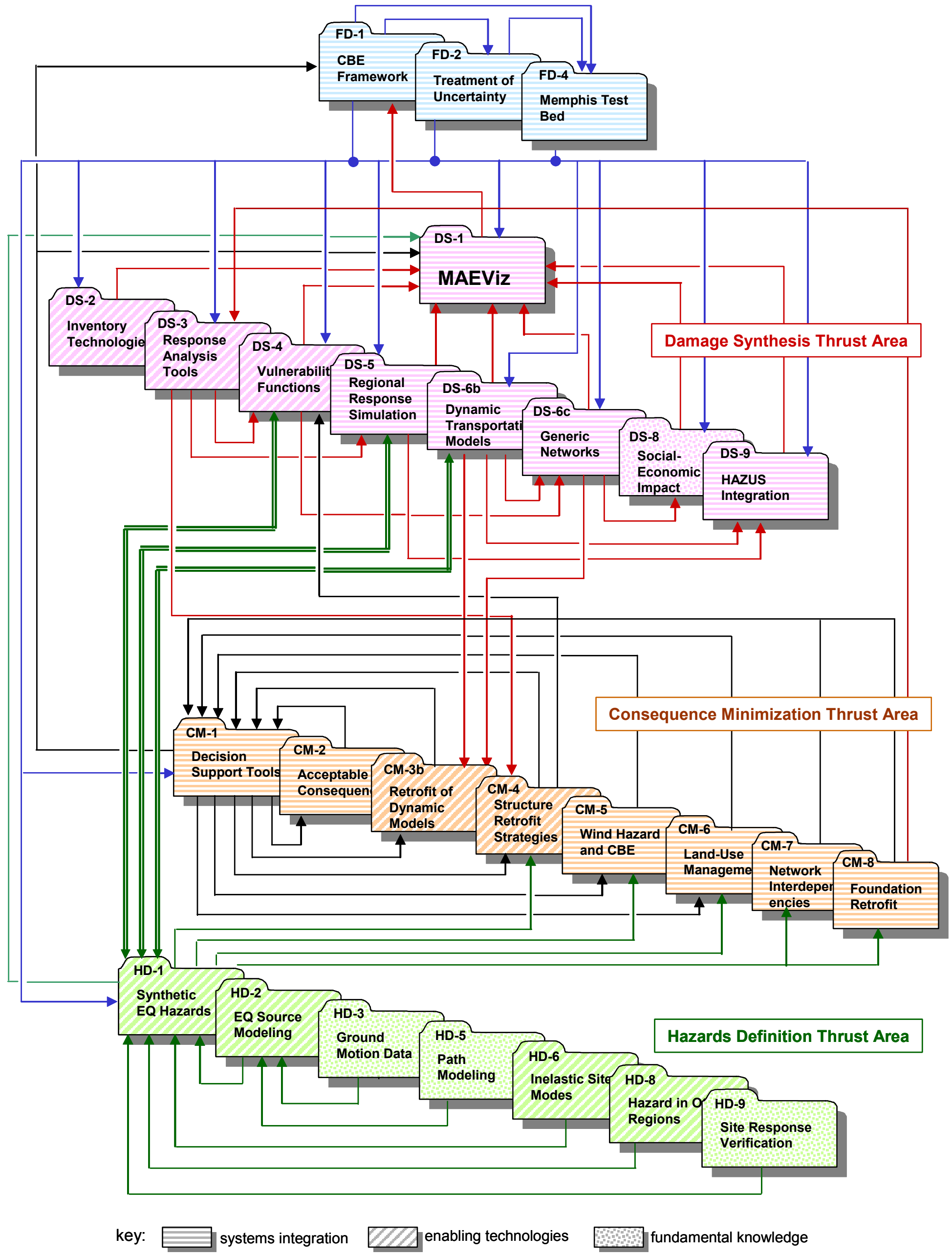

Figure 4: Outputs from and inputs to core thrust area projects

Test Bed Applications in Service of Systems Vision

The MAE Center has formulated a project-level, thrust-level and program-level test bed approach to verify, integrate and demonstrate, respectively, its technical developments in support of the application of CBE to regional seismic risk mitigation; Figure 5. The MAE Center has taken a giant leap through the design and launch of the Memphis Test Bed (MTB) project. The MTB project integrates project- and thrust-level deliverables towards a Consequence-Based

Engineering seismic risk assessment for the City of Memphis. As a consequence, the Center has moved toward an entirely System Application-Based Core Research Program.

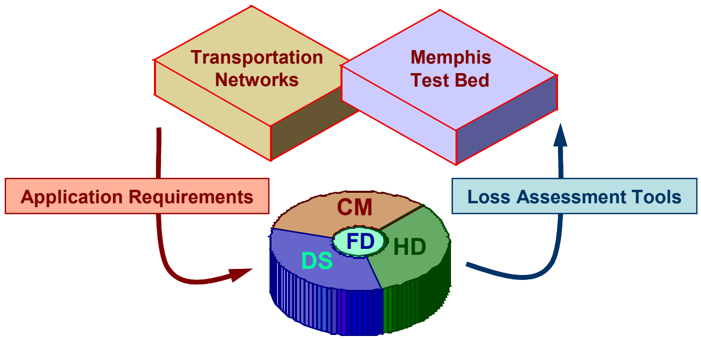

Figure 5: Relationship between Test Beds and Core Research

The Center continues with its approach of pursuing project-level and thrust-level test beds in addition to the system-level test beds of Memphis and Transportation Networks. A prime example of thrust-level and thrust interaction test beds is the full-scale test of an irregular RC frame, undertaken as a joint activity with the Joint Research Center at Ispra and a network of five other European and Japanese partners. The frame testing project is being used to calibrate products from DS-3 and to check the irregularity index and repair modeling approaches derived in CM-4.

Integration of MAE Center Developments

The accomplishments of the MAE Center in hazard, vulnerability and inventory are integrated in the advanced seismic loss assessment and visualization environment MAEViz. The latter may be viewed as having three main components, namely (i) Data management; (ii) Calculation engines; and (iii) Users Interface/Visualization. MAEViz breaks new ground in seismic risk assessment on all three fronts, as described below:

Data: Managing very large data sets, finding trends, deriving mathematical functions and further manipulating the complex data sets that represent hazard, fragility, inventory and regional demographics, is a major undertaking. MAEViz leverages the unique developments of NCSA in D2K (Data-to-Knowledge) for the first time in earthquake engineering as well as giving the developers of D2K an insight into domain applications.

Calculation Engines: MAEViz has built-in the most advanced techniques for deriving hazard based not only on the best available bedrock motion hazard, but also break-through inelastic site response models and the effect of topographical details on ground motion. It also utilizes fragility relationships judged by the earthquake engineering community to be pioneering. The MAEViz family of fragility curves has advanced uncertainty modeling, is applicable at the individual structure, populations of similar structures, and very large heterogeneous populations of structures. A completely new fragility concept is that advanced by the MAE Center to deal with social and economic vulnerability, also included in MAEViz. Moreover, new approaches employing parameterized fragility based on member strength ratios and system stiffness, strength and ductility make use of exceptionally powerful and fast tools to estimate damage, hence losses. Finally, a family of 'retrofitted' fragilities, including awareness and land use management, are available to estimate the losses after intervention. Last but not least, the MAEViz inventory data are pristine and employ the most advanced technologies and analysis algorithms to collect high quality inventory data at a fraction of the time and cost of conventional methods.

User Interface/Visualization: As a tool run by engineers for decision-makers, the user interface and visualization component of MAEViz is all-important. The most advanced technologies available have been deployed, comprising multiple panel plasma displays and CAVE and CUBE technologies. MAEViz is therefore at the absolute forefront of the interactive media and immersion visualization environment.

Closure

The MAE Center delivers to the community significant advancements on all components of assessing, visualizing and mitigating risk to which vulnerable regions are subjected, through the systematic application of Consequence-Based Engineering, the guiding framework of the Center.