

# IBM Research Report

## Spreadsheets in Operations Management Modeling: IBM Research Experience

**Sheneeta W. White**

Virginia Polytechnic Institute and State University  
Blacksburg, VA 24061

**Kaan Katircioglu, Tarun Kumar**

IBM Research Division  
Thomas J. Watson Research Center  
P.O. Box 218  
Yorktown Heights, NY 10598



Research Division

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# Spreadsheets in Operations Management Modeling: IBM Research Experience

**Sheneeta W. White\***

Virginia Polytechnic Institute and State University  
Blacksburg, Virginia 24061 sheneeta@vt.edu

**Kaan Katircioglu and Tarun Kumar**

IBM T.J. Watson Research Center  
Yorktown Heights, New York 10598 kaan@us.ibm.com, ktarun@us.ibm.com

Many academics and practitioners have found spreadsheets to be a viable platform for quantitative analysis of supply chain related problems. This paper will give an IBM Research account of the way spreadsheets have been helping us in our projects. We will briefly describe a number of projects that benefitted from the use of spreadsheets. For each project, we will mention the reasons and considerations that led to the choice of spreadsheet usage, and explain how this choice impacted the success of the project. We will summarize the lessons learned and try to put them in perspective as to when and how spreadsheets can be used under different circumstances. We will give a prescriptive view of what factors to consider, what questions to ask, what advantages/disadvantages and weaknesses/strengths to consider about the use spreadsheets. We will do this from both technical and business perspectives.

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*Key words:* spreadsheets; IBM; supply chain; optimization

## 1. Why Spreadsheets and When to Embrace Them?

It is well known that spreadsheets are the most widely tools used for quantitative analysis in the world today. Because of their flexibility and functionality, people find numerous ways of using spreadsheets for tasks that require both text manipulation and number crunching. From our perspective, as the OR practitioners, spreadsheets are also appealing in their ability to help us develop fairly advanced quantitative models. Two noteworthy trends in supply chain management are making such uses of spreadsheets more popular. The recognition of the value of quantitative analysis in business decisions and the market's desire for more thorough analysis of alternative IT investments after the bursting of the dot-com bubble.

Part of the reason for the recognition of the value of quantitative analysis is the availability of data. As a result of wide spread use of ERP-like systems across different industries by almost all sizes of companies and the rapid emergence of internet based technologies, we have seen a tremendous influx of data availability. To such an extent that many believe information overload has become a serious problem. Consequently, when more data is available there is naturally more need to do data analysis. For us the OR professionals, these are undoubtedly the best times since our models are not much of help without good data that can support their use. It has become easier to prove the value of our models to business decision makers using the available data in many cases. Showing the value based on real data is much more convincing than purely logical arguments based on mathematical rigor and a bunch of assumptions.

Of course, for smart business people who always seek to find a competitive advantage, it is obvious that the available data must be put to good use. This has created significant demand for solutions that are heavy on quantitative analysis ranging from areas such as demand planning,

\*The author was a summer intern at IBM Research when this paper was written.

pricing, revenue management to areas such as call center operations management and all kinds of internet marketing management optimization solutions. Only in the area of supply chain management and inventory optimization are there dozens of solutions available on the market. Having experienced many bad IT investments during the dot-com bubble period, companies have become more articulate in their solution purchase decisions. As a result of all this, we have witnessed shrinking price tags of many software solutions.

How does this impact the use of spreadsheets - other than the fact that technically speaking spreadsheets have become much more powerful in their own rights? The answer is pretty clear if one can imagine a business executive's thinking: "I have a ton of data I need to take advantage of; every day a software company is knocking on my door to show me how sophisticated their algorithms are; I have no way of understanding their algorithms and make any intelligent comparison amongst them; Oh! By the way, I have no IT budget for any fat investment!". Such thoughts amongst business executives are more common than many realize. Even large companies can have very restrictive IT budgets which leads to tough decision making by their IT executives.

Since IBM is no different, in terms of scrutinized use of IT budgets, we at IBM Research find that in many circumstances spreadsheet based solutions can be very effective to deliver the desired business value within tight budget limitations. We have successfully developed and implemented quantitative solutions ranging from the relatively simple to the very sophisticated in various areas such as supply-chain / inventory optimization, forecasting, simulation, etc. In all these projects, we have indeed experienced the power of spreadsheets and admittedly the point(s) at which this power diminishes.

Once spreadsheet is a good alternative, there are numerous resources that are available to help plan the development of spreadsheet tools or models. To mention a few here Ragsdale (2003) is an excellent book for those who are new to building decision models with spreadsheets. It provides numerous examples of classic linear programming models including scheduling, transportation, product mix, etc. Each example is explained with step by step instructions of how to organize the data in Excel and run the optimization solver. Some guidelines for good spreadsheet modeling design can also be found in Conway and Ragsdale (1997). Spreadsheet methodologies can be developed from a paradigm Grossman and Özlük (2004) articulates by giving a break down of elements that should be considered before the development and/or evaluation of a methodology can begin. Caine and Robson (1993) provides a method that can help improve the structure of a spreadsheet model. They provide detailed advice in many aspects of spreadsheet programming such as how to design different stage of a model, how to organize the variables, how to create good documentation, etc.

Here we will focus on technical and business aspects that must be considered before deciding to use spreadsheets. We will do this based on our experience with numerous projects that one way or another utilized spreadsheets. We will give short stories of three such projects with a mention of lessons learned.

### **1.1. What to Consider?**

We have found spreadsheets to be very useful tools in our research. Whether you want to quickly illustrate a concept to someone who is less technically inclined or when you need to develop a quantitative model with a full user interface, spreadsheets have shown themselves very robust.

There are a number of factors to consider when deciding whether or not to use spreadsheets. Based on our experience, we can summarize these factors as follows:

- Type of solution
- Technical requirements
- Business process requirements
- Level of priority and business value

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- Amount of funding available
  - Phasing plans in development and use

Clearly, not a single of these factors is enough by itself to determine whether a spreadsheet solution is the best fit for a problem. Keeping in mind that they all need to be considered simultaneously, let us elaborate on each of these factors.

First, the modeler should determine what type of solution is being desired: Its objectives, its functionality, where it will be used in business operations, by whom and how, etc. One of the first questions to ask is "Can the required functionalities be delivered using spreadsheets from a technical perspective?". Although spreadsheets have become fairly powerful, by and large they are single user tools and they can only provide single user solutions; they cannot process vast amounts of data (files larger than approximately 10 megabytes can have serious performance problems); they do not have looping capability to create complex algorithms (although this limitation can be overcome by the use of macros such as VBA in Excel). Spreadsheets can be used in combination with other tools as well. For instance, accessing data in databases, manipulating the data and uploading the results back to the database tables are all possible. It is also possible to call computationally heavy programs written in languages such as C or C++ in spreadsheets. However, if the key functionality of the desired solutions requires some kind of database application or an algorithm in C, for instance, the spreadsheet being used may play a somewhat diminishing role. In such cases, their role will most likely be reduced to being a nice user GUI, which is not to be underestimated. Most importantly, one needs to keep in mind that by far the most common spreadsheet, Excel, is most effective in MS-Windows environment; although there are spreadsheets available in UNIX and Linux, their performance and reliability are not well documented.

Understanding the details of the business process in which the solution will be used is another key to deciding if a spreadsheet is a good idea. One needs to see what input data are required and where it will come from; what kind of computations will have to be performed; what outputs will have to be created; where the results will go in business processes and how exactly they will be used. If the process requires close collaboration of multiple users and needs interaction and manipulation of a central database spreadsheets may not be the right tools, although it is not unusual to see them being used in such environments. Even if they are used, they can only serve as temporary solutions. If it is possible to isolate some parts of the entire business process in to well defined and well confined problems, spreadsheets can be good alternatives to handle such parts of the entire process. In rare cases, the entire process might fit into a spreadsheet if it is not too complicated. High level strategic or tactical planning processes are examples of this. For instance, an SOP process where some kind of budget or capacity allocation is done across product families through a certain period of time is mostly done at a high level making it possible to use spreadsheets for the entire planning.

The level of priority and the value of the solution can determine the choice of the platform for solution development. Unless it is a simple problem, use of spreadsheets for strategically important solutions may not be a very good idea. In all likelihood, such important solutions require frequent use of many different groups of people and hence need to be more robust, more integrated and centrally accessible by many users or by other systems. Spreadsheets are not designed to play the role of central planning systems nor can they be relied on as platforms of strategic solutions across a company.

Many times, the development of fully functional solutions may be too costly and the cost estimates can be highly inaccurate depending on the complexity of the solution. When tight budget limitations exist, spreadsheets can quickly become the only viable solution. In terms of cost, they can effectively provide at least the essential parts of what is desired.

It is also important to understand if the idea behind the solution is a well established or a well known idea. It makes a big difference if what is required is a first of a kind solution or just another

version of an existing solution. Well known solutions have much less ambiguity and it is easier to estimate the cost and time involved in development. This not only makes the deliverables clear but also reduces the risk. In such cases if the common platforms used to develop such solutions are not spreadsheets, all else being equal, there is not much reason to use spreadsheets. On the other hand, if this is a unique solution, and there are many unknowns about what it can do, its potential uses, functionality it needs to have, then trying spreadsheets first can be a good idea provided, of course, that it is technically feasible to do so. This would not only reduce the risks, but also reveal many of the unknowns about the concept and its use after a short development cycle.

The time frame of the project is also an important factor. If the a quick turnaround is required, use of a spreadsheet may be the only alternative in many cases. Many times operations may have pressing deadlines or targets to improve existing manufacturing processes; or there may be an urgent need to find a quick fix for a hard pressing problem. Then a quick solution will be desirable even it has to be a temporary one.

Yet another consideration is whether the user(s) are in need of a prototype to understand the solution and its uses better. This may be the case when the underlying concept is new and needs to be articulated. Since spreadsheets can be put together very quickly, they can be used to create prototypes or mock-ups just to articulate the solution and its value. This can help before committing large funds to the development of fully functional complex tools. These prototypes and mock-ups can also be used to articulate the requirements and specifications for the solution to be developed. For instance, all the requirements about user interface, navigation functionality, input/output data fields, data tables, graphs, even OLAP and the equations to perform the calculations can all be communicated to the developers in spreadsheets. In fact, if there are significant computations in the requirements, example calculations provided in spreadsheets would be great help to the developers to test if they codes do the calculations correctly.

## 1.2. How to Decide?

We summarized our findings based on our practical experience in Figure 1 to provide a prescription of how to decide whether using a spreadsheet is the best alternative. The figure shows some of the requirements that we had to consider one way or another in many of the cases we faced in the past. Not all of these requirements may be as important as others depending on the nature of the project. One needs to weigh the importance of each of these requirements. Perhaps a weighted scoring mechanism can be used to aid the decision.

### **Insert Figure 1 here**

Another interesting and perhaps less obvious way spreadsheets can be used is when things are uncertain. Although there may be many sources of uncertainty, we will focus on three that are more common than others: Uncertainty around business value, lack of proof of concept, and risk of development/implementation.

We have already mentioned the importance of business value. Often, cost and benefit estimates of a solution can be highly uncertain. This does not mean businesses should not consider development and implementation of such solutions. From efficient frontier perspective, one cannot conclude that a high risk high return solution is worse than a low risk low return solutions. We also mentioned the cases where the solution is not a standard one and therefore what it can do, its features, and how it can be used effectively in decision making may not be very clear. In addition, a proof of concept may not be readily available or may not be possible to develop without substantial investment. In other cases, full development and implementation costs and risks may be high. For instance, it may be difficult to achieve a desired quality level during implementation. In difficult cases such as these when the right decision is not clear, spreadsheets can be extremely helpful in reducing the risk. If the nature of the problem makes it possible to create a spreadsheet version of the solution, doing so might shed light to the uncertainty of business value, or provide a good proof of concept,

and eliminate the risk of costly trials of full development. We put together a simple flow chart in Figure 2 that can be followed to take advantage of spreadsheets to control risks. Since spreadsheet development is a low cost alternative, using them as stepping stones to full development decisions can make a lot of sense in many cases. Even if they can only play the role of a temporary solution, their limited use can be informative to make the right "Go or No Go" decisions for full development.

**Insert Figure 2 here**

## **2. Example Uses of Spreadsheets: IBM Research Experience**

We at IBM Research have had fairly extensive experience with spreadsheet modeling in many projects. We will mention three successful examples in some detail. We will give brief background information about each of them, share the dynamics that led to the choice of spreadsheets, and how this choice worked out.

### **2.1. Inventory Optimization in Semiconductor Manufacturing**

The first example we will give is a project that was done in 2002 for IBM Microelectronics Division (IMD) to help with their safety stock planning. IMD is one of IBM's premier technology divisions. It manufactures semiconductor chips that are used in a number of industries. Inventory is typically held after fabrication, wafer test, bond assembly, and testing operations. IMD uses highly complex software to manage the manufacturing scheduling of manufacturing operations which consist of many machines processing wafers with complex flows and routes. Although this solution has been in use for a long time, it did not have the capability to optimize safety stocks at the end of each of these operations. The supply chain management group at IMD was interested in a decision support tool that can recommend optimized safety stock levels. They also wanted to be able to make operational and financial projections and assess the risk of inventory obsolescence at different phases of the product life cycle. Since the group was closely linked to both marketing, manufacturing, and finance they had a wider scope of interests and tasks to improve operational and financial metrics. The solutions that were being used were more focused on either manufacturing or demand planning. They needed a tool that can analyze the supply chain and calculate both operational and financial metrics. They were specifically interested in understanding the impact of various operational parameters such as: forecast error, manufacturing lead times, price and cost decline rates, and service targets on financial metrics such as inventory turns, inventory obsolescence, revenue, profit margins, and manufacturing costs. This tool did not need to model each operation in manufacturing in detail but it needed to have an end to end view of essential manufacturing and demand characteristics. It was acceptable to analyze each product separately; complex capacity allocation across products need not be a part of the tool; it did not have to have real time connection to various systems for input data. It did not need to have multiple users as analysts had their assigned set of products to manage. They needed a stand-alone, easy-to-use tool that can be used by inventory analysts that can be used by inventory analysts to analyze the implications of changing manufacturing and demand characteristics.

Additionally, the group did not have enough funding for a major development effort. After careful consideration of the requirements and constraints, IBM Research recommended to create a stand-alone spreadsheet tool provided that the analysts can find an efficient way of gathering input data needed to run the tool. This was acceptable by IMD. Our plan was to get the input data in flat files, create the optimization algorithms in VBA, execute them in Excel through macro buttons; provide various what-if analysis capability through macro buttons and provide extensive reporting of analysis results through Excel tables and charts. We also planned to create a GUI that could help users navigate through the tool and easily invoke the available tasks, and go over the results.

We created the tool in two phases. In phase I, our objective was to focus on providing the essential functionality along with the operational and financial metrics to the users. We put less emphasize

on rigor of the mathematical model; we made simplifying assumptions such as stationary and deterministic lead times and yields, no lot size restrictions, and stochastic but stationary demand. In this phase there was no simulation capability built. We were able to complete this phase in a matter of weeks. It was important to articulate what the tool can do; how it can help make critical decisions about inventory planing; and how it can provide useful insights about what levers impact operational and financial results to what extent. When we gave a detailed demo of this version to IMD, the value was clear. We provided some analysis results that were very insightful. Figure 3 shows a sample of the kinds of analyzes the tool was able to do. Being able to quantify the

**Insert Figure 3 here**

Phase I was successfully completed with strongly convincing evidence to IMD's supply chain group that adding more mathematical rigor to the model and making it more accurate representation of the actual environment was warranted. This led to additional funding for phase II development.

In phase II, we added substantially more depth to the mathematical model and added simulation capability. We relaxed the constraints on fixed lead times and yields, made demand non-stationary, added various types of lot size restrictions. We extended the what-if analysis capability as well. In order to solve the inventory optimization problem with our model assumptions, we modified heuristics available in inventory control literature, and incorporated them directly in the spreadsheet calculations without any VBA macros. This reduced the run time to reasonable levels. The interesting aspects of the mathematical model resulted in a couple of technical papers (see Gallego et al (2002), Gallego et al (2005)) and a practice paper that focuses more on the business story and the tool functionality (see Katircioglu et al (2006)).

Phase II took several months to complete. When we were done we were approaching the limits of Excel. We had created a file close to 20 megabytes with extensively recursive calculations. We must admit that it was a challenge to maintain simplicity of the calculations. In fact, without good documentation it was very difficult to follow and understand the calculations although they were all explicitly there in Excel. However the confidence we gained in Phase I helped us convince IMD that these complex calculations were fairly accurate representation of their operations. We substantiated this claim by running base cases and matching their performance metrics for sample products. Figure 4 shows the GUI of the tool with main menu in the view that helps navigation.

**Insert Figure 4 here**

After the completion of Phase II development, IBM Research provided documentation and training to a senior engineer in IMD's supply chain group who trained a number of inventory analysts on the tool. The tool was subsequently put to use for a large subset of the active products. The use essentially consisted of regular analysis and safety stock optimization in the planning cycle and on-demand what-if analyses. When safety stocks are updated they are provided as inputs to IMD's manufacturing planning system. Our analysis results showed that the implementation of safety stock policies recommended by the tool can reduce the inventory levels by about 4% which is also testified by the executive management of the supply chain group. This meant an outstanding return on investment for IMD in this project.

## **2.2. On Demand Business Value Modeling Tool**

The second example we give is a project that was done in 2003 for IBM Global Business Services (GBS). GBS is the consulting arm of IBM and provides IBM customers with know-how to improve the business performance across organizational silos, across business processes and across technology platforms. They provide customers with new concepts and solutions to deliver competitive advantage for business success. A typical customer engagement starts by analyzing the customer's current business processes and identifying the pain points and issues. Once the pain points are identified, the consultant/practitioner works to identify underlying root causes that must be addressed

to improve the client's business performances. This results in a step-wise process including data analysis, growth initiative identification and solution proposal.

One of the main challenges faced by the IBM consultants was to associate the solution being proposed to customer's financial metrics, and quantify its impact on these metrics. In order to address this problem, IBM Research in collaboration with IBM Global Business Services developed a decision-support tool called *Value Modeling Tool (VMT)*. The tool was based on a comprehensive methodology for linking operational metrics to financial performance, and aligning operational transformations with business strategy. The methodology begins by identifying qualitative and quantitative evidence for the presence of business issues and problems. Once business issues have been identified, *VMT* is capable to provide detailed financial and qualitative analysis to pinpoint appropriate solutions. By helping clients understand the relationship between operational drivers and financial performance, *VMT* provides a rigorous basis for selecting the most effective solution alternatives. It uses scenario analysis to determine the impact of proposed solutions, compare different options, and assess their likely effectiveness within the context of the client's particular business and operating environment.

Figure 5 shows the hierarchical logic behind the calculations performed in *VMT* through a couple of examples: inventory and SG&A. When a transformation initiative impacts some of the operational parameters in the tree and the impacts on the parameters high up in the tree are calculated through mathematical equations that relate the all parameters in the tree to each other.

**Insert Figure 5 here**

There were a couple of reasons for choosing a spreadsheet based solution. One of the foremost requirements for the solution was that the consultants should be able to use it off-line as a stand alone tool (since most of the consultants are either traveling or work mostly from customer's site). Also, this was the first attempt to develop such a methodology based tool and hence there were a lot of unknowns both from the user requirement and the implementation perspectives. Another nature of this methodology involved building analytical models specific to each industry services using subject matter experts (SME). Since the SMEs perform most of the data analysis in spreadsheets, building the tool in a spreadsheet would help reduce data transformations. Also, since this involved verifying a new methodology by applying it to customer engagements, the development time needed to be very short as there were immediate sales opportunities in the pipeline. Last but not least, the end users for the tool were the consultants / practitioners who had extensive experience using spreadsheets. This would make a spreadsheet based tool more advantageous for user adoption and training to the extent that even self training could be an option.

Based on all these reasons, IBM Research proposed the development of the tool in Excel. The solution design involved extensive use of graphics based navigation using hyperlinks to enable consultants to easily understand the process flow and seamlessly perform the quantitative assessment of alternative solutions for their clients. We gave the tool a web site look and feel in order to facilitate navigation through different tasks. Figure 6 shows the main menu of the tool.

**Insert Figure 6 here**

The tool had two modules: User Interface and Analytical Model. The User Interface was developed as a five-stage process that a consultant performs in sequence. Each stage of the process corresponds to an Excel sheet that allows user to enter input data, select the solution to be assessed, perform as-is / to-be analyses, get answers to what-if questions and view output reports using automatically generated charts. We used VBA macros extensively to automate calculations, generate reports, and enable seamless workflow.

The second modules is the analytical model that was also developed in Excel. The analytical model relates operational key performance indicators such as forecast errors, demand variability, order fulfillment cycle times, planning cycle times, customer service targets, safety stocks to financial performance measures such as costs, inventory turns, etc. It can do so for many solution



areas such as Supply Chain Management, Customer Relationship Management, Demand Planning, Supply Network, Financial Management, Integrated Technology Services to name a few. Each analytical model was a self contained worksheet that extensively used formulae to calculate the impacts of changes in key performance indicators (KPIs) on financial metrics. The analytical model in conjunction with the User Interface enabled the consultants to quickly perform an end-to-end assessment of the customer's current business and the impact of implementing alternative solutions. It also enabled users to perform a side-by-side comparison of the alternatives based on parameters such as net present value, payback period, ROI and internal rate of return (see Figure 7).

**Insert Figure 7 here**

Once an engagement reaches its final stage, IBM Consultants generally make a final presentation to the C-Level executives regarding the proposed solution. Since their time line is almost always very tight, we wrote macros to generate and save all reports automatically in to a power point file. Having an automated generated set of slides containing the detailed results of the assessment provided an immense help to the consultants, and saved them lots of precious time.

With all the automation, using the tool was as easy as putting the input data in the tool's input templates, and from built-in pull down menus selecting alternative solutions and scenarios to analyze. All the rest was handled by the tool.

The tool has been very successful in client engagements and has helped both consultants and clients in analyzing their current business processes and assessing the impact of initiatives on a company's bottom line financial statement. IBM Research and Global Business Services conducted training classes for teaching the use of the tool to IBM consultants. Subsequently, the tool was used in many customer engagements. Other than being able to do a quick quantitative assessment, consultants also enjoyed enthusiastic response from their customers due to a tool-based methodology and rigorous analytical models they used in the assessment process. This was very helpful for building confidence with their customers who normally use benchmarks to estimate business value knowing that they may be very inaccurate and misleading indicators for their unique business environment.

### **2.3. IBM Learning Services Lease Evaluation Tool**

The third example we want to give is an application that was built when IBM Learning Services (ILS) came to IBM Research to ask for quick and effective solution for their classroom management problem.

ILS offers about 700 public classes nationwide every quarter and in a dozen US cities. These classes are taught either by IBM or one of its training partners (TP). The classes taught by ILS are held in classrooms that are located in IBM-owned facilities if the necessary classrooms are available. Otherwise, these classes are held in rooms procured from external vendors (on a daily rental basis) through short-term leases. The classrooms in IBM-owned facilities are procured through long-term leases (6 to 10 years) from IBM Real Estate. When a lease comes up for renewal (for a period between 6 to 10 years), ILS decision-makers have 3 options: (i) Get out of the leased space and go to a TP, (ii) Sign on to the exact same space (same number of rooms), (iii) Partition the space, if negotiable. If they need more number of rooms than what's available, then they may meet the demand by either going to a TP or by going with IBM Real Estate and vendors in the spot market. A long-term lease results in predictable classroom availability at a relatively low marginal cost; however, the flip side is that they incur a high fixed cost and this translates into a financial loss when the seat utilization is low. On the other hand, short-term leasing may be more expensive, but can provide a higher degree of flexibility in responding to demand fluctuations. Therefore, depending on the demand and its level of uncertainty, it may be preferable to have a short-term lease instead of a long-term lease, keeping in mind that future demand projections may favor long-term leases versus short-term ones.

Historically, ILS has adopted a simple “rule of thumb” planning method that was based on practical experience. This has resulted in low room utilization and poor revenue realization.

The business impetus to transform various IBM business operations to be “On Demand Businesses” motivated ILS to get out of existing unprofitable long-term facility leases, and move to a variable cost structure. As a result, over the last year or so, ILS has gotten out of a few long-term leases at facilities in Atlanta, San Jose, and Tampa. However, these exit decisions were taken in the absence of a scientifically articulate lease evaluation tool.

As a result ILS approached IBM Research to develop a mathematical model that would allow them to make informed decisions based on demand forecast for future classes. IBM Research developed a stochastic model that provided an optimal mix of IBM Real Estate contracts and TP facilities to be acquired. The optimization model was developed using IBM OSL optimization solver. In order for ILS planners to effectively use the optimization engine, there grew a need for developing a user interface layer to allow planners to enter data, perform optimization and view the results. Since there were a handful of users and project had a small budget, it was clear that a spreadsheet based user interface layer to wrap the optimization engine was the most sensible approach. Figure 8 shows the main menu of the tool.

**Insert Figure 8 here**

Using the ILS tool involves three steps: In the first step, the user enters data corresponding to available facilities and expected demand. This is implemented in Excel by defining ranges and tables that could be expanded using functionality provided in VBA macros. The second step is to perform optimization. In this step once the user initiates optimization, VBA macros passes data to the optimization engine and initiates optimization solver. The third step involves pulling the output of the optimization engine back in to the spreadsheet and displaying them to user. This step is automatically done after the user initiates the second step. The optimization engine is implemented as an integer program that uses OSL as its solver. OSL is a linear program solver developed by IBM. The objective of the model is to maximize the expected profit given the uncertainty associated with the future demand for the classrooms.

User can enter multiple scenarios having a unique probability and expected demand for the classes. Also, users will be required to enter fixed and variable costs associated with the booking of each class. The model assumes that the training partner will be able to meet all the demand for each class type. The optimizer uses the information entered by the user to perform a stochastic analysis to maximize the expected profit for the set of scenarios.

**Insert Figure 9 here**

Figure 9 shows the results of a sample analysis. The analysis is performed for 4 years in this case. The tables detail the expected revenue income from using Training Partner and IBM Real Estate. Results also detail the weekly allocation of rooms between IBM Real Estate location and Training Partner. Choosing Excel proved to be a cost effective solution since the project had to be completed in under six months. Using Excel as the UI layer helped IBM Research team focus more on building the model and less on designing the UI, which could have taken long to build on other platforms.

The ILS planners have been using the ILS tool since 2003 to make decisions regarding long term lease contracts with IBM Real Estate vs TP facility use. This has helped ILS in reducing their operational risk. This sophisticated tool has enabled ILS decision-makers to analyze complex leasing options very quickly and for providing sound justification for the optimal leasing decisions.

### **3. Some Important Technical and Business Considerations for Modeling in Spreadsheets**

Now we will list and briefly explain some of the key advantages and disadvantages that we most commonly face in our attempts to use spreadsheets. Some of these are technical in nature and some are driven by business considerations.

### 3.1. Advantages of spreadsheet modeling

There are certain aspects of spreadsheets that make them very appealing in many situations. Most of these present important advantages in quantitative modeling, as well. Although one can make a long list of these, what we found to be the most useful characteristics of spreadsheets are the following:

- **Interface familiarity:** Most people use spreadsheets in some form or another whether it is for some simple viewing of data or for more complicated calculations. We have found that by using spreadsheets we are able to make the customers feel comfortable that they will be able to use the tool with ease and make changes as desired.

- **Ease of use:** Building off the point of the familiarity of the spreadsheets to most people, they are also very easy to use. It is simple to organize information into cells so that users can quickly enter inputs and view results. Even complex calculations can be made simple to use through embedded macro buttons. Such calculations can be invoked by the users with a single click of a macro button. These can be advanced optimization routines, search algorithms, simulations, etc.

- **Rapid prototyping and development:** It is pretty much accepted that developments in spreadsheets can be done very quickly. This makes them excellent alternatives particularly for low budget environments. Furthermore, spreadsheets are also very useful in articulating and illustrating new concepts. During the initial stages of a project the customers may not be clear on what they want in terms of requirements and specifications. By using spreadsheets, one can develop a quick prototype to show basic calculations and allow them to begin to visualize the concept. In many of our projects we use spreadsheets for illustration purposes. For instance, in many instances we like to show process mapping of operations with underlying data elements using spreadsheets. Some times we combine process mapping with simulation to show how the process would perform under different scenarios.

- **Built-in functions & Graphs:** We benefit tremendously from built-in mathematical and statistical functions in spreadsheets. This is very convenient when building quantitative models and minimizes coding. The array of built in functions can greatly speed up the development of a solution. Other than very effective user interface and simple data storage capabilities, functions such as lookup, index, match, count, sum and average functions and their conditional versions are very helpful and we use them very often. Of course, there is no need to mention the usefulness of flexible graphs readily available to provide great visualization capabilities. For more complex calculations or tasks that cannot be handled by built-in functions, macro development environment provided by spreadsheets is an absolute necessity.

- **Effective communication of operations research techniques:** Many managers are accustomed to using spreadsheets and are quite comfortable with them. Therefore, by using spreadsheet to quantitative models, we help them develop a much better understanding of the underlying dynamics of the model merely by playing with the tool because they easily can. This enables key people in the organization to become the advocates of operations research techniques and communicate them very effectively to decision-makers.

### 3.2. Limitations of spreadsheet modeling

There are also important drawbacks or limitations of spreadsheets that we come across very often. Here are some cases that we most often face and find that spreadsheets have serious drawbacks.

- **Mission critical applications:** In today's world of Information Technology, each business /enterprise depends on certain application that are essential to keeping the business up and running. Examples include any component of a supply chain application, a CRM application, ERP applications, etc. Companies rely on these applications for continuity of there business. Hence if an organization were to build such an application, spreadsheet will clearly not be an appropriate solution. In essence, spreadsheets provide a complete development and deployment environment

for efficiently building and delivering a relatively simple solution. However, there are cases such as these where it becomes necessary to develop and deploy the solution in a more robust environment.

- **Large number of users:** A spreadsheet based solution is also referred to as a fat-client solution. A fat-client application is one that is deployed on the client machine. It may connect to remote applications to send / receive data, but much of the application logic and processing is performed on the client machine. For each user the application must be installed on the client machine. If there are a large number of users, delivering a spreadsheet based solution might be difficult. One potential problem is that not every one may have the same version of the spreadsheet. This may cause some new functions or features not to operate properly for those who have not updated their versions. Even if there is no version problems, multiple users manipulating data in their own copy can easily create a nightmare of inconsistent data. In such cases a tool that can operate based on a central database with advanced capabilities to preserve data consistency is a must.

- **Amount of data and recalculation:** Most spreadsheets have certain limitations in terms of number of rows and columns in each sheet. If an application needs to have more rows / columns (due to larger data), this may become a problem. Another problem that can arise as a result of large data is the speed of calculations. If a spreadsheet uses lots of formulas in addition to large data, this may slow down the computations significantly. It may also take incrementally more time to re-compute each time the spreadsheet data is modified. Changing from auto-compute to manual compute, or using other recalculation options may help but this does not get rid of the performance problem completely. If recalculation is set at manual for instance, the user has to remember to re-compute each time the data is changed to get correct results. Even so, calculations can be unacceptably slow. We faced this weakness in computation and data heavy applications a few times. Even though calculations and tasks are simple suggesting the use of spreadsheets, the size of the data required to process can be prohibitive of spreadsheet use. This must be assessed carefully before starting on the path of spreadsheet development.

- **Security (Data / Application):** In spreadsheet based solutions data and application security can only be enforced by restricting the availability to the authorized users through file-open password protection / cell locks / hiding of sheets, etc. However, to many security standards this may not be acceptable. When higher levels of security is required, use of spreadsheets is questionable. Hence if data / application security is of prime concern, appropriate thought should be given to using the right solution with advanced security capabilities.

- **Extensibility:** It is important to consider the long-range goals of a project when deciding to use spreadsheets. For the immediate goals, spreadsheet might make sense and hence might come handy. However, when future extension possibilities are considered spreadsheets may not be able to handle all the options. For example, if the customer is envisioning to transform a simple application than can be developed in a spreadsheet to an enterprise tool that must be accessible via the web by many users, then using another software platform that allows database capabilities and web front end access would be a better decision. Another possible extension could be to increase the complexity of algorithms and the size of data. This can also create performance problems with spreadsheets. When trying to understand the big picture of a project one needs to keep in mind that spreadsheets are not the most extensible tools.

## 4. Summary and Conclusions

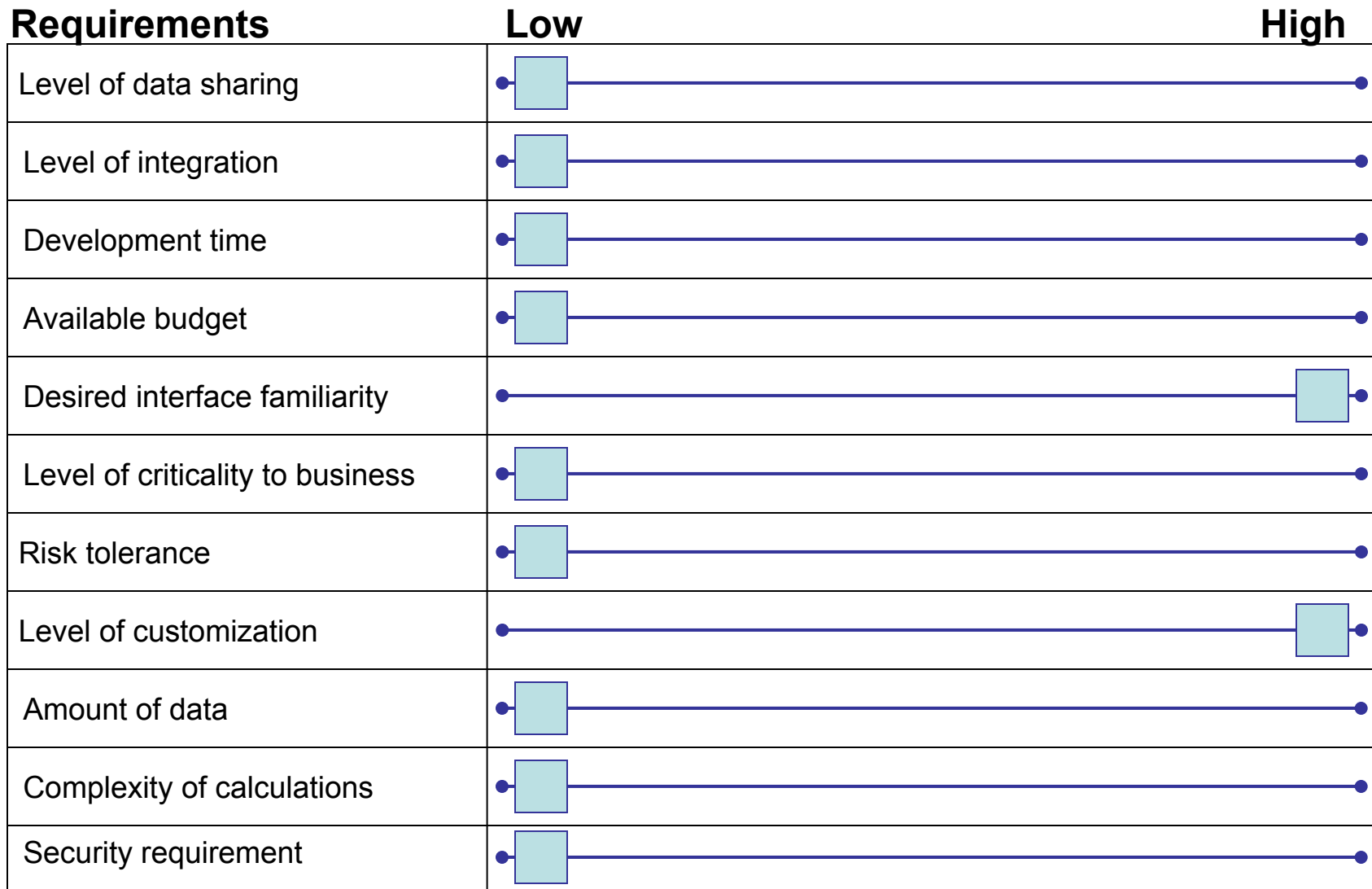
In this paper we briefly explained some of the projects we have done in IBM Research where we utilized spreadsheets as the solution platform. We tried to articulate the reasons behind selecting spreadsheets, how this selection worked out for each project. We also summarized the lessons in perspective way to be helpful for those who might want to consider spreadsheets for their projects. Spreadsheets can be cost effective solutions to many problems that require analytical

models provided that their strengths and weaknesses are considered properly to see if their use is viable. In many cases, they can be satisfactory as permanent solutions. In other cases where a more advanced platform is desired, they can be used as temporary solutions to test business value, or provide a proof of concept, or reduce the risk of costly developments that may not provide desired outcome.

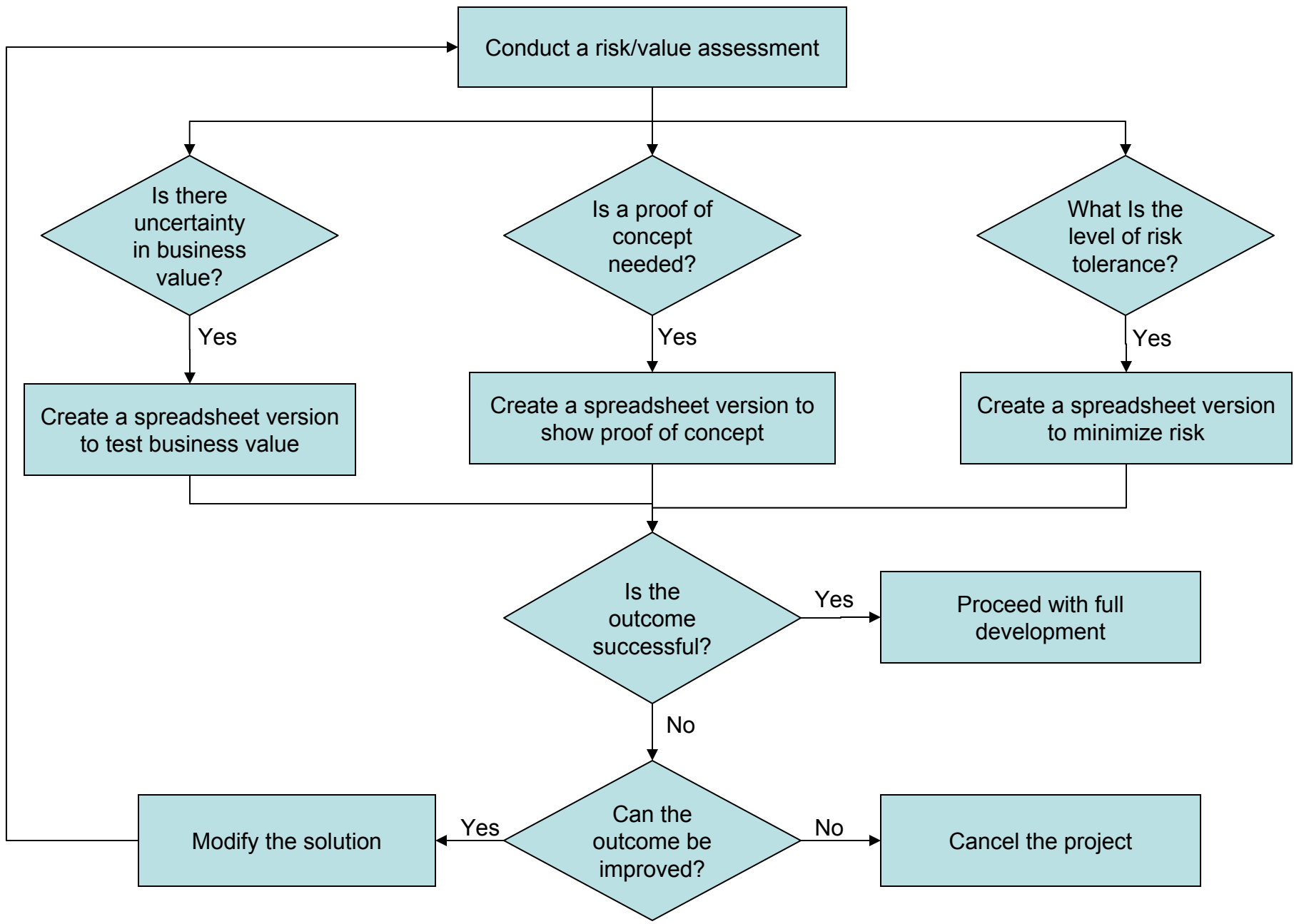
In practice, solutions that require significant investments must provide significant business value in order for them to be financially attractive. In many cases, this depends on the size of the company and the level of criticality for business operations. Solutions such as MRP, CRM, SCM are a few examples. On the other hand, there can be many different types of relatively small scale problems that require analytical models and solutions. The benefit of solving these problems may be limited either due to the lack of economies of scale (for small companies for instance), or the problem may not be impacting one of the critical operations that influence most of the business performance. This does not mean these problems have to be ignored. Since spreadsheets are very cost effective, they can in fact be the only alternative solutions with acceptable ROI for such problems. For exactly this reason, they are used by great many people as ad-hoc tools to handle many different aspects of the operational decision making tasks. In our experience, through a disciplined approach in their development, spreadsheets can easily rise to being essential parts of many business processes and become functionally robust tools providing solid business value.

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**Figure 1:** Project requirements that are important to consider when deciding about the use of spreadsheets.



**Figure 2:** Use of spreadsheets to facilitate a phasing strategy for development under uncertain/risky circumstances.

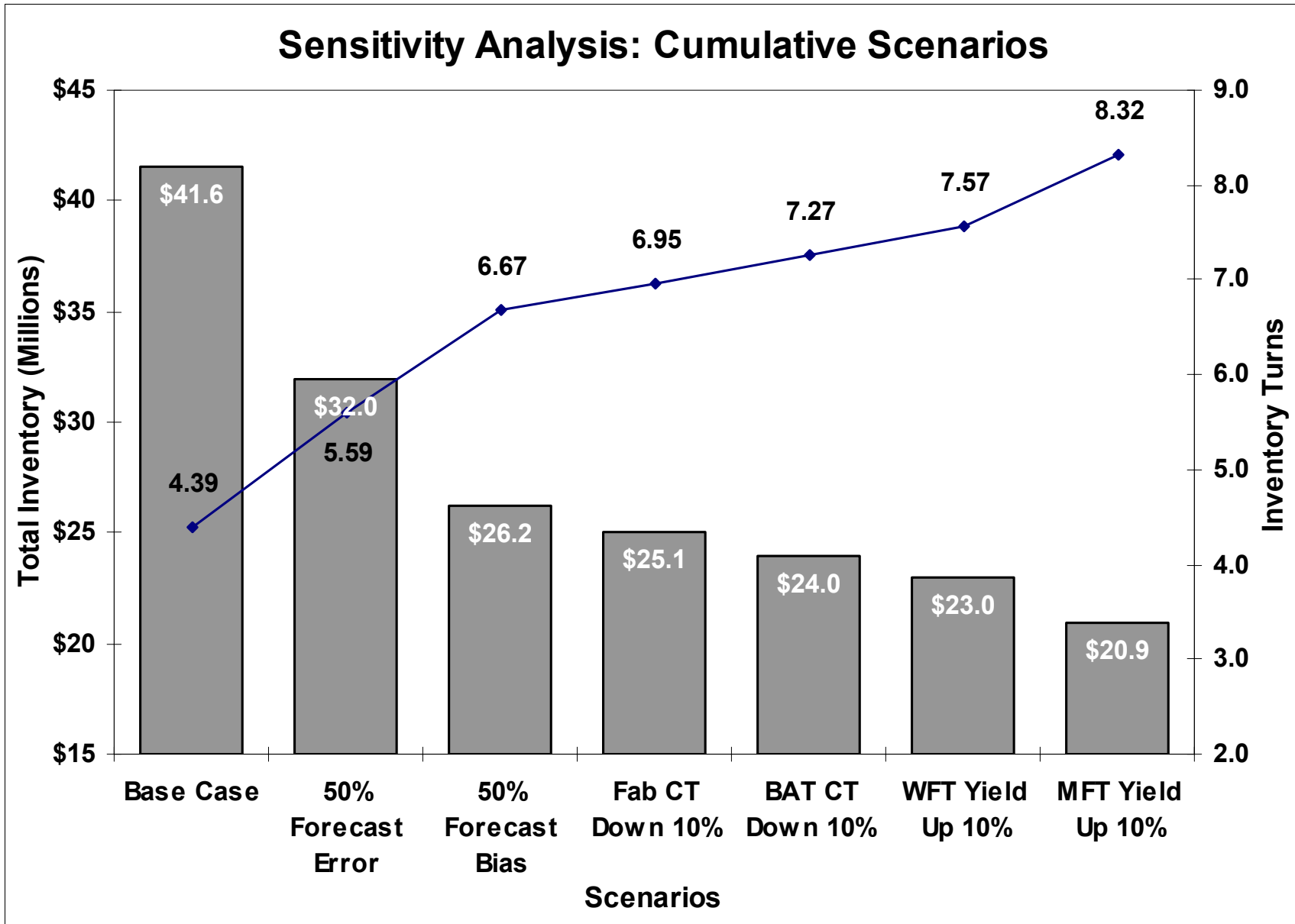


Figure 3: Cumulative impact of levers on inventory



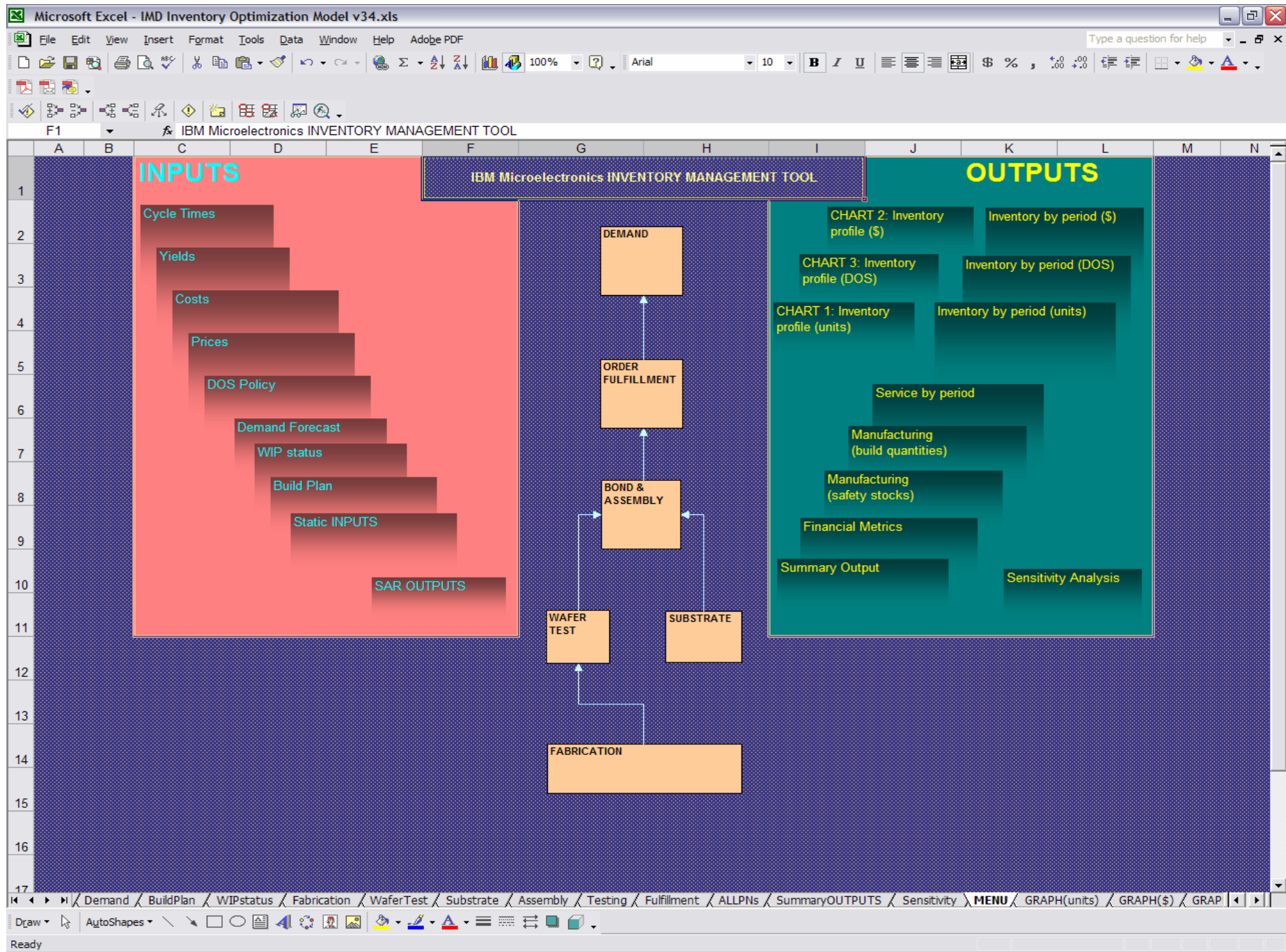
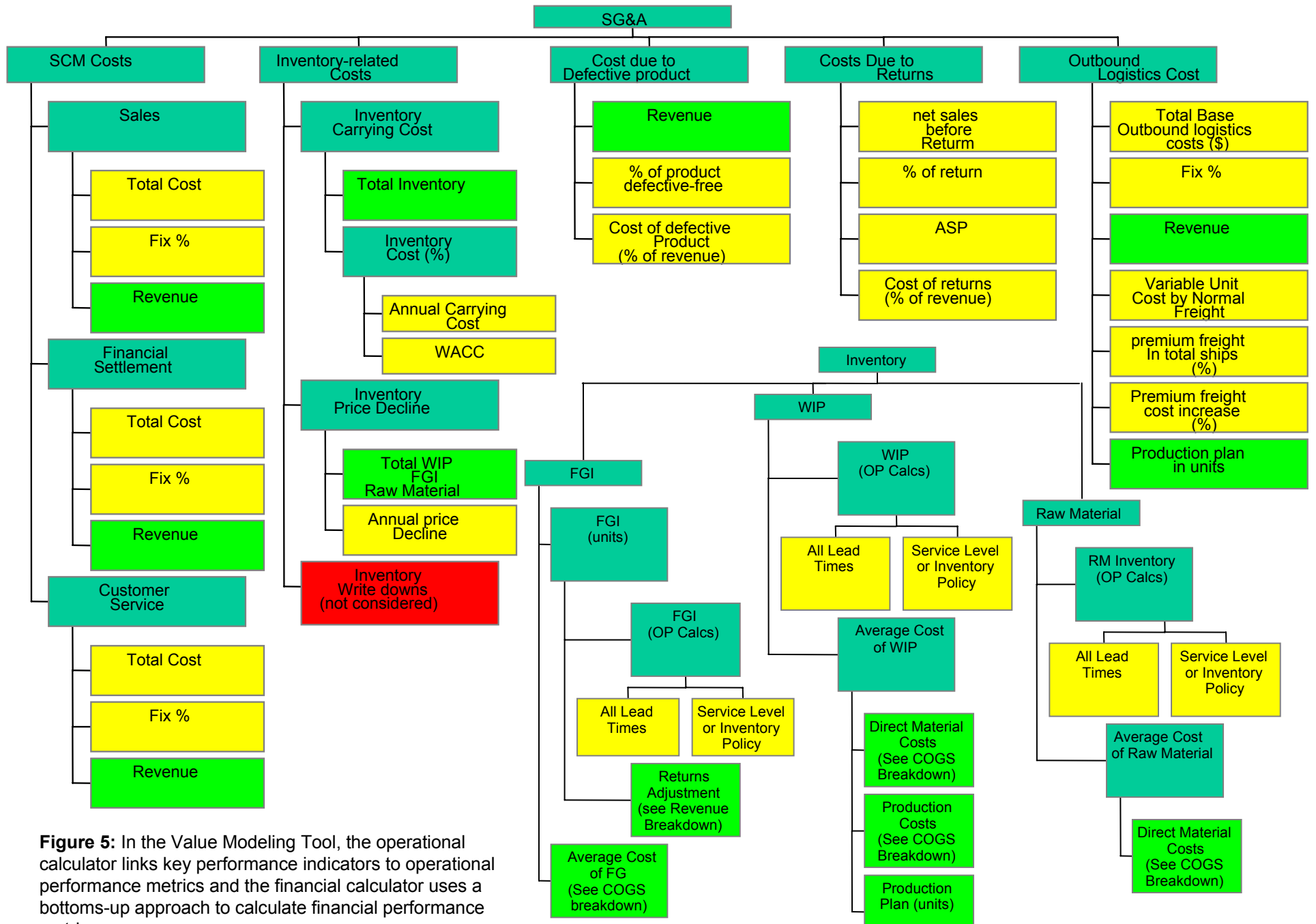
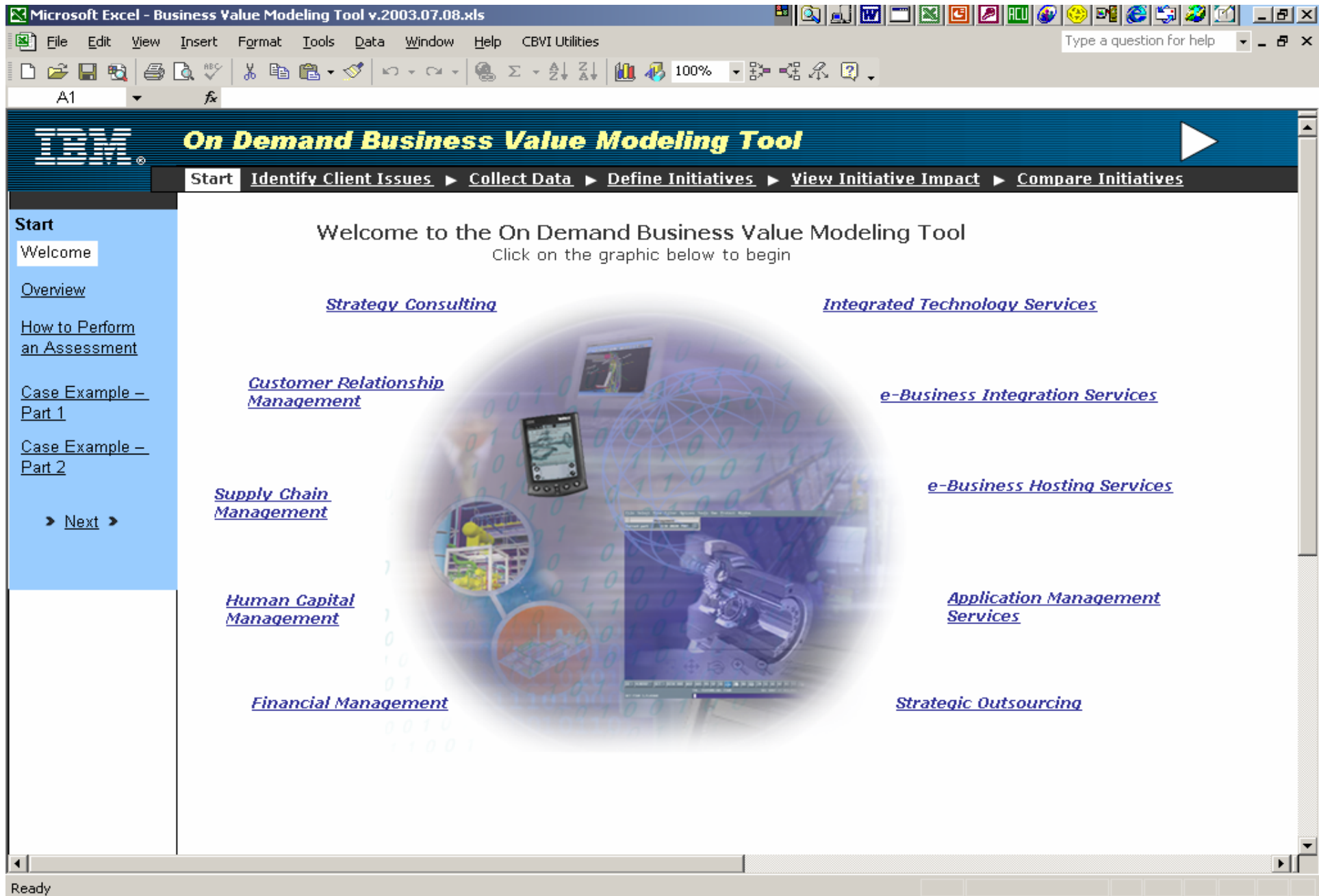


Figure 4: IBM Microelectronics Inventory Optimization Tool



**Figure 5:** In the Value Modeling Tool, the operational calculator links key performance indicators to operational performance metrics and the financial calculator uses a bottoms-up approach to calculate financial performance metrics.



**Figure 6:** The Value Modeling Tool uses a web-like interface to guide the consultant through the value analysis process

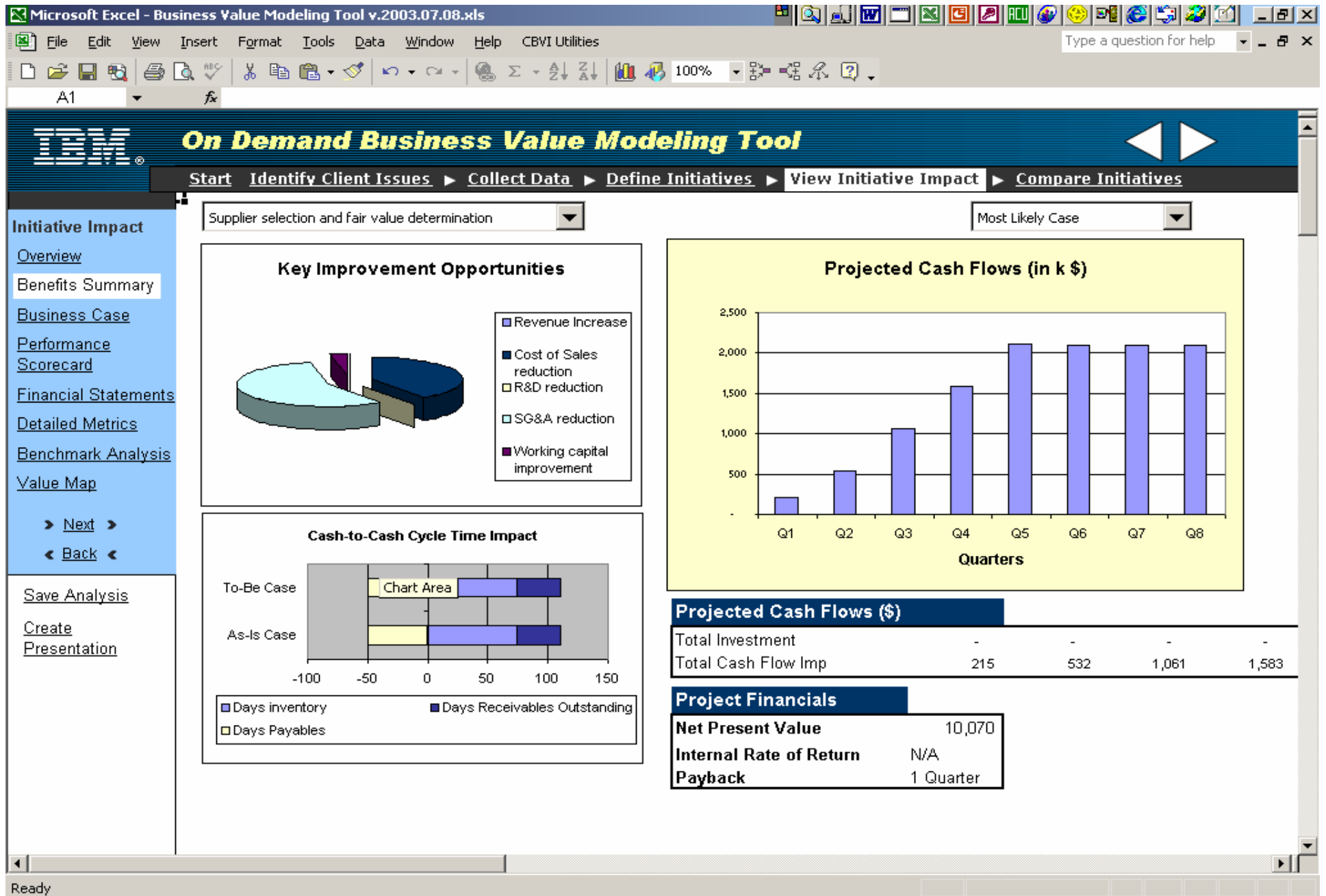


Figure 7: The Value Modeling Tool has extensive analysis and reporting capabilities.

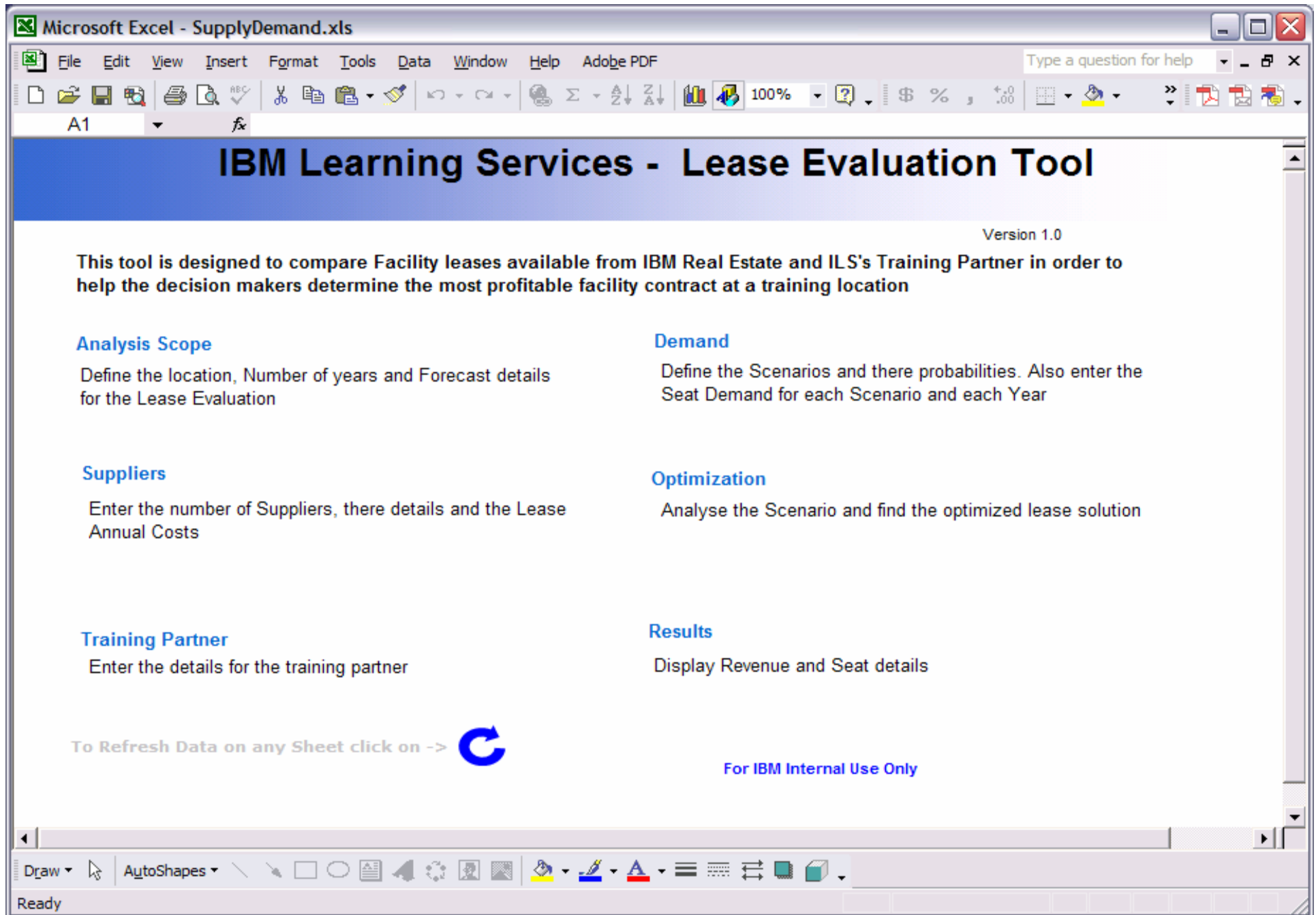
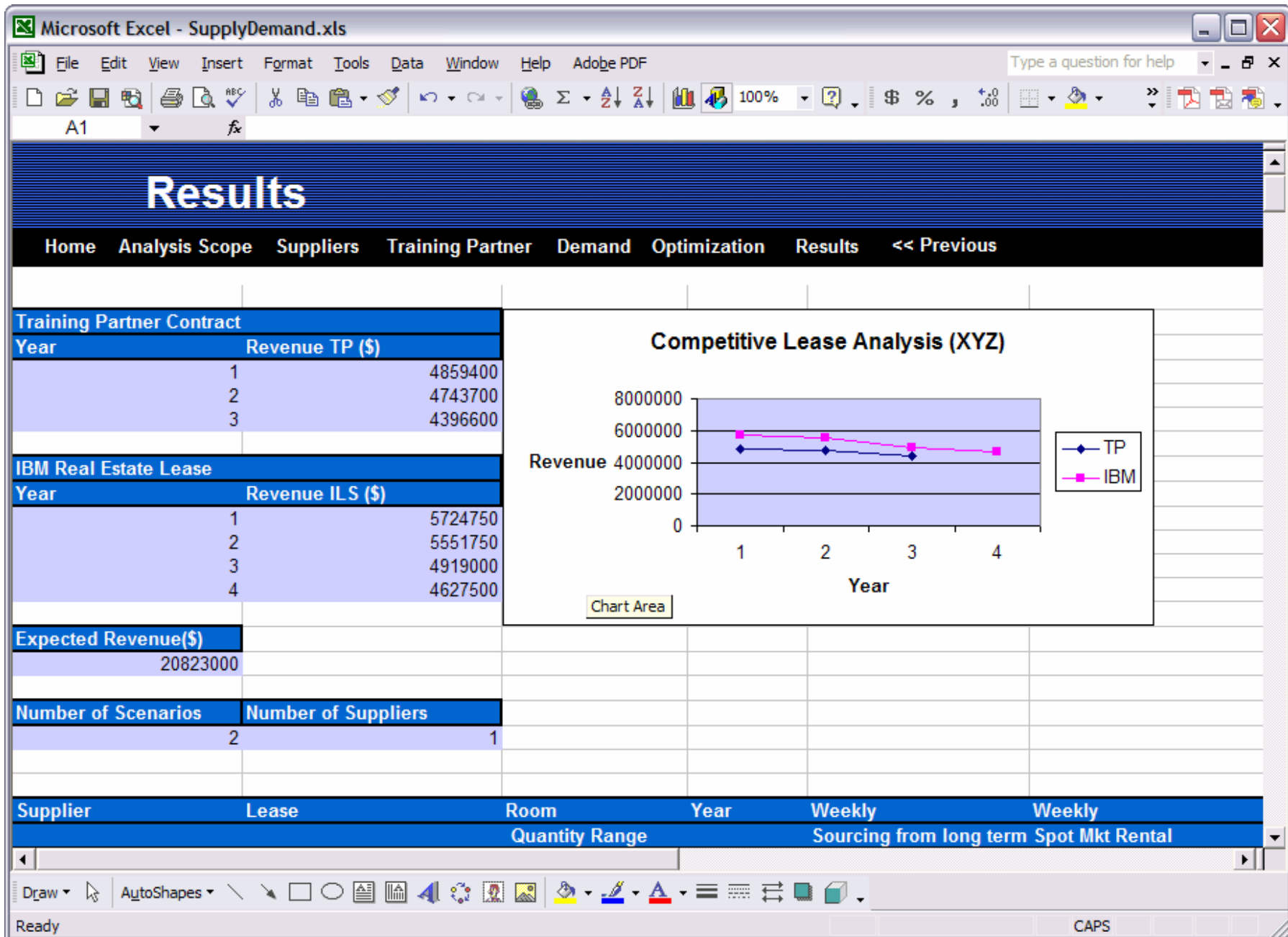


Figure 8: Main menu of ILS tool provides easy navigation through a variety of tasks.



**Figure 9:** An example output of ILS tool that shows an automatically generated report for the users to view the optimal revenue comparison between IBM real estate lease versus training partner contract.