Allocation of Engineering Resources for RF Front End Modules R&D

Submitted by

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ABSTRACT

Commercial electronics is a highly competitive industry. Shortening product life cycles and aggressive time to market have placed critical demands on engineering development of new technologies. Implementing designs into silicon is an expensive and time consuming process. Engineering teams must also balance the needs of multiple projects with available resources. When the amount of work to be performed is greater than the available limited resources, it is necessary for the company to make decisions about what work will and will not be done. Regardless of whether the resource concerns financial, staff, time or any number of types of resources, the question remains the same, to decide what work will be done with the resources available. In this paper, the authors have addressed the question of allocation of engineering resources across a group of eleven projects. The projects have all been requested and selected by Marketing and Engineering departments as meeting important criteria for the continued growth and health of the company. A model has been constructed using the Analytical Hierarchy Process (AHP) which helps to make decisions based on well defined and measurable objectives. The authors defined six key objectives that help to define the benefit that each of the projects will contribute to the company as well as the priorities for those projects. Constraints based on physical design limitations (die size) and on the amount of engineering resources available were defined and added to the model. The result showed that seven of a portfolio of eleven requested projects provided the maximum benefit to the company given the constraints.

INTRODUCTION

Background

Skyworks Solutions Inc. is a leading supplier of semiconductor solutions for Wireless Local Area Network (WLAN) products. Skyworks is unique among WLAN semiconductor suppliers in their ability to combine products such as power amplifiers, switches and filter functions into a single convenient module that dramatically reduces system design time and cost. (Skyworks, 2004)

The Skyworks Design Center in Cedar Rapids, Iowa, develops WLAN front-end module products ranging from individual components to Radio Frequency (RF) modules. The RF front-end module family of products supports the 802.11 application (and a, b, g extensions) including several frequency bands and multiple modulation techniques. As part of ongoing engineering development, the Cedar Rapids Engineering Team is in the planning phase for development of a ‘test’ chip that will contain several design elements. Each design element will eventually be either a stand alone component or part of a larger RF module. The Radio Interface Test Chip is being planned to provide early engineering development of wireless RF components for use in several future products.

Problem Statement

Marketing and Engineering identified eleven different RF design components considered necessary for the future product roadmap. Available design and layout engineering resources are limited and there is a limitation to the physical die size available for new designs.

The paper will demonstrate how to decide which project to develop when resource constraints preclude the design team from developing all of the desired components. These limitations require that the engineering team make decisions on how best to prioritize the design components so as to maximize the benefit from designs that can be completed.

Prioritizing of design components could result in a decision to outsource engineering layout services or plan for future foundry shuttle runs. This paper focuses on developing a model to prioritize projects given current resource constraints and suggest solutions for alleviating resource shortages in areas identified by the model. Both Marketing and Engineering have established specific objectives for this effort. These objectives are the basis for judgments used by the model to prioritize the list of alternatives and drive a decision as to which components may or may not be developed.

Marketing: The marketing department has established four critical objectives for product development that will allow the company to continue in existing markets and expand into new ones. The products developed by the engineering team must meet these criteria. First, the continued and expanded support of existing 802.11 application RF front-end module products will reinforce their basic business and allow the company to maintain its core business. Second, continue and expand support of 2.4 GHz RF front-end module products will provide for the most recent existing market to be supported and to grow. Third, there is a need for entry into 802.16 application RF front-end market as one of the two new markets where the company wants to grow. Fourth, the company needs to begin to position itself for the next new market. Entry into new technological markets means new library models and expertise will need to be developed for 5 GHz RF front-end products.

Engineering: The engineering department has determined three critical success criteria for these products. First, whatever is selected needs to help expand the technological knowledge and experience of design team so they can be positioned for future work. Second, they do not want to shortcut the process but need to follow the best practice design methodology for testing and reusability. Third, the process and alternatives must serve to validate the design tools used for this development.

Solution Alternatives

Based on the criteria established by engineering and marketing, eleven different design components have been presented to the Cedar Rapids Engineering team to implement. These products will require more engineering resources than are currently available. This is not an engineering paper so a technical description of each product will not be detailed. Suffice it to say that they each meet some aspect of the criteria required for the selection.

It is not required that any project selected meet all identified objectives. Projects that meet more of the objectives set by Marketing and Engineering will be identified by the model as having a higher priority for development. It is possible that an identified objective will not be satisfied by any of the prioritized projects. If during reassessment Marketing decides an objective is not being sufficiently fulfilled, the model will be reviewed and the objective can be given additional weighting.

The eleven alternatives are:

- 5 GHz Transmit AGC Amplifier
- 5 GHz Transmit Pre-driver
- 5 GHz IQ Modulator
- Transmit BaseBand Filters
- I/Q divide by 2
- 5 GHz Low Noise Amplifier
- 5 GHz Mixer
- 2.4 GHz Voltage Controlled Oscillator (VCO) with on chip inductors
- 2.4 GHz VCO with off chip inductors
- 2.4 GHz VCO with x3 multiplier
- 2.4 GHz VCO with I/Q divide by 2

METHOD

Analytic Hierarchy Process

Dr. Thomas Saaty developed the Analytic Hierarchy Process (AHP) almost 40 years ago. The process focuses on making decisions on the basis of the objectives of the decision makers. This distinguishes it from some other types of decision-making tools that focus on criteria or attributes. AHP defines a process for breaking down a problem (analysis), and managing the complexity of the problem by organizing its elements into a hierarchy or structure. After the elements are analyzed in chunks that the human brain can manage, they are measured against each other using pair-wise comparisons, rating intensities or utility curves. Finally, it uses mathematical principles to synthesize the result that helps to guide decisions. However, to make a real-world decision using AHP, the number of calculations that must be performed would daunt even a devoted mathematician equipped with pencil and paper. To perform these complex calculations and present them in a user-friendly form, the Expert Choice software was developed. (Dixon, 2004)

To apply the principles of AHP to the problem at hand, a model was built using the Expert Choice software. An overview of the process, whose details will be provided below, will demonstrate how benefit to the company was maximized by determining the optimum allocation of limited engineering resources for a proposed set of eleven projects. A set of objectives and sub-objectives were identified to shape judgments on that will determine the final decision. This became the hierarchy needed for AHP. These objectives were defined by the Marketing and Engineering departments from the company strategic plan to provide for the long-term health and growth of the company. A pair-wise comparison between all pairs of the objectives with respect to the goal was completed to help determine how much each objective should be rated compared to the others. The limitations or constraints upon the effort were defined and specified for each of the alternative proposed projects. A scale was defined to explain how much each project contributes to each of the objectives. The projects are then rated on this scale for each objective in the Expert Choice data grid. (Expert Choice, 2004)

A cost factor was assigned to the project based on engineering resource work weeks instead of direct dollars. The budget then could be set to determine the project that could be competed at each level of engineering resource availability. The Expert Choice Resource Aligner tool was then used to synthesize the results. From this synthesis a decision was made which will allow the company to make further decisions about the future.

DEVELOPING THE MODEL

Objectives

Six objectives (See Figure 1) were defined that needed to be considered in the choices among the projects. These are Product Roadmap, Model Accuracy, Future Risk, WLAN 802.16 Spec Compatibility, Reusable Intellectual Property (IP), and Testability.

Product Roadmap: Marketing has a plan for the sales and development for products. This starts with the product base that has already been established in IEEE 802.11 application RF front-end module family of products. Within this base, the company needs to continue support of existing products and develop performance and cost enhancements to those products. There also needs to be development of an expanded product line of new 802.11 compatible components to continue within the existing base. On the other side there is a need to develop new markets and new upcoming types of products for those. With this in mind, the company has an objective to gain entry into IEEE 802.16 application RF front-end market. This will involve developing products targeted toward 802.16 applications. To complete this there is a foundation that needs to be laid. The company will need to develop library models for 802.16 RF front-end products and expand knowledge and expertise for 802.16 RF front-end products.

Model Accuracy: There are some background factors to consider for this objective. First, standard cell libraries provide the basic set of logic gates, and design cells engineers use to interconnected and form basic design elements. Second, behavioral models simulate the electrical characteristics of the standard cell allowing engineers to design for specific performance. Third, design tools used to develop analog devices rely on accurate models to describe how the design will perform under extreme voltage, temperature and performance conditions. Fourth, these behavioral models are constantly being updated and improved based on measured test results, new processes and higher performance demands. (NASA, 2004)

Based on these factors, currently models exist for 2.5 GHz designs, but can be improved. However, these models do not exist for 5 GHz designs. The project selected will use designs to determine model accuracy at 5 GHz. The objective is to use the test chip to improve the accuracy of 2.5 GHz models and determine the accuracy of behavioral library models at 5 GHz.

Future Risk: There is a need to reduce future program risk by developing sub-circuits where Skyworks does not have experience. There are current risks in doing this through new product development. This contains an element of risk as technologies, processes, and design expertise is pushed to the edge. Schedule, cost and performance are especially at risk given the inherent unknowns of developing emerging technologies. Program risk can be mitigated by using research projects to gain design and process maturity in new technologies prior to full product development.

WLAN 802.16 / 802.11 Spec Compatibility: IEEE has developed 802.11 and 802.16 specifications to insure that all WLAN manufacturers' products are interoperable. The identified design projects are specifically targeted toward supporting future WLAN products for 802.11 and 802.16 markets. Therefore, all design components must be compliant with WLAN specifications for IEEE 802.11 a/b/g and for IEEE 802.16 e.

Reusable IP: Product development times can be greatly reduced when designers have the ability to reuse existing design blocks, referred to as Intellectual Property (IP). Skyworks needs to develop IP which will be reusable on future products. Elements created by research and development usually focus on expanding understanding of the technology being developed. Although useful as a baseline design, these R&D elements are frequently not directly reusable as production IP. Where possible, it is desirable the design elements in the Test Chip be developed as reusable IP.

Testability: The final objective is to develop designs that can be easily tested. Design elements are always fully tested for voltage, temperature, functionality and performance. A clear understanding of how and why a design is functioning often requires visibility of components that are internal to the design. Not all designs allow for internal data extraction. Where possible, design elements should include testability ports to provide visibility of internal performance

Constraints

There are two critical constraints that need to be considered in building the model for this decision. The first is the actual physical space available for the efforts, the die area or size. The second is the limitation on engineering resources and the requirements for each project.

In the background of these constraints is a monetary issue that might be addressed as a separate decision and must be considered in reviewing the results of this model. Given the risks involved in this development and the budget constraints, that decision has been made for this set of projects.

The Pilot Production Run versus Shuttle Run can be compared as follows.

Pilot Runs

- Flexible Schedules
- No Die Size Limitations
- Very Expensive

Shuttle Run

- Inexpensive
- Schedule & Size Constraints
  - Die Size
  - Resource Schedule.

Changing foundries requires a huge investment on the part of engineering to develop libraries, qualify processes and negotiate prices so shopping for a different foundry is not an option. Skyworks also has a long term business and working relationship with the UMC foundry in Taiwan. UMC is the only foundry option available on this project.

Foundry costs at are very expensive. A production lot (or Pilot Run) of silicon wafers cost $35,000. Production Masks used to create the photo-etching of the design in silicon can cost $350,000. Design tape-out for a Pilot Run is flexible and can accommodate schedule slips. (UMC, 2004)

To mitigate these expenses, the foundry creates special lots (or Shuttle Runs) for multiple users. Shuttle Runs allows multiple users to share Mask and wafer costs so that each ‘slice’ costs a one time charge of $60,000. The downside is a fixed schedule and a limited die area. The use of the Shuttle Run creates two constraints.

- Die Size
- Resource Schedule.

Die Area Constraint: Due to the fact that the space on an individual wafer is shared by several customers, there is a limited amount of die area available on a Shuttle Run. Wafer slices on Shuttle Runs are reserved in advance. There are no additional ‘slices’ available on the next Shuttle Run. Engineering testing procedures require that at least 90 parts be available from each wafer run. Available wafer space divided by 90 parts translates into a total Die Area of 5 mm^2

Alternatives and the Die Area: An estimated die area for each alternative design element has been calculated and presented here. Because the total Die Area available for the Test Chip is 5 mm^2, the total area for any combination of design elements chosen must be equal to, or less than, 5 mm^2. This constraint will have a limiting effect on how many elements can designed into the Test Chip.

Table 1: Die Size of Alternatives

Alternative Element	**Estimated Area (mm^2)**
• 5 GHz Transmit AGC amplifier	1.5
• 5 GHz Transmit Pre-driver	1.2
• 5 GHz IQ Modulator	1.6
• Transmit BaseBand Filters	0.25
• I/Q divide by 2	0.4
• 5 GHz LNA	0.8
• 5 GHz Mixer	1.2
• 2.4 GHz VCO with on chip inductors	0.2
• 2.4 GHz VCO with off chip inductors	0.2
• 2.4 GHz VCO with x3 multiplier	0.4
• 2.4 GHz VCO with I/Q divide by 2	0.8

Resource Schedule: The next Shuttle Run is scheduled in three months. There are only two design/layout engineers that are available for this three months period. This will provide a total of 24 work weeks available for development (2 Engineers for 3 months of 4 weeks each).

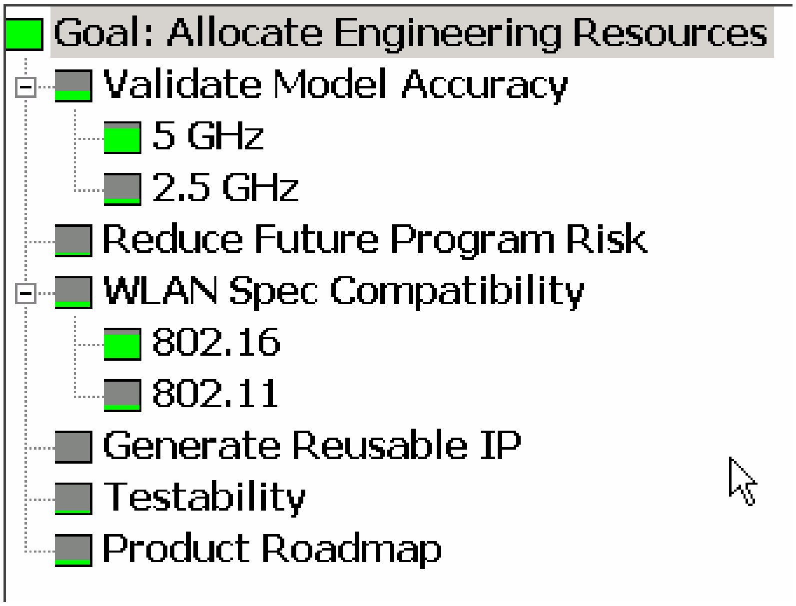
Alternatives and Resources: The second constraint is the availability of engineering resources required to develop the various proposed design elements alternatives. The individual engineers can work on multiple design elements and multiple tasks (design, verification and layout) for those elements simultaneously. The limited number of engineers available combined with the shuttle schedule means that there are a total of twenty-four work weeks available for development. The estimated amount of engineering effort for design, verification and layout for each alternative is projected in Table 2.

Table 2: Resource Requirements of Alternatives

Design Element Alternatives	**Estimated Resource (Work Weeks)**
• 5 GHz Transmit AGC amplifier	2
• 5 GHz Transmit Pre-driver	2
• 5 GHz IQ Modulator	3
• Transmit BaseBand Filters	3
• I/Q divide by 2	3
• 5 GHz LNA	5
• 5 GHz Mixer	3
• 2.4 GHz VCO with on chip inductors	4
• 2.4 GHz VCO with off chip inductors	4
• 2.4 GHz VCO with x3 multiplier	3
• 2.4 GHz VCO with I/Q divide by 2	3

BUILDING THE MODEL IN EXPERT CHOICE

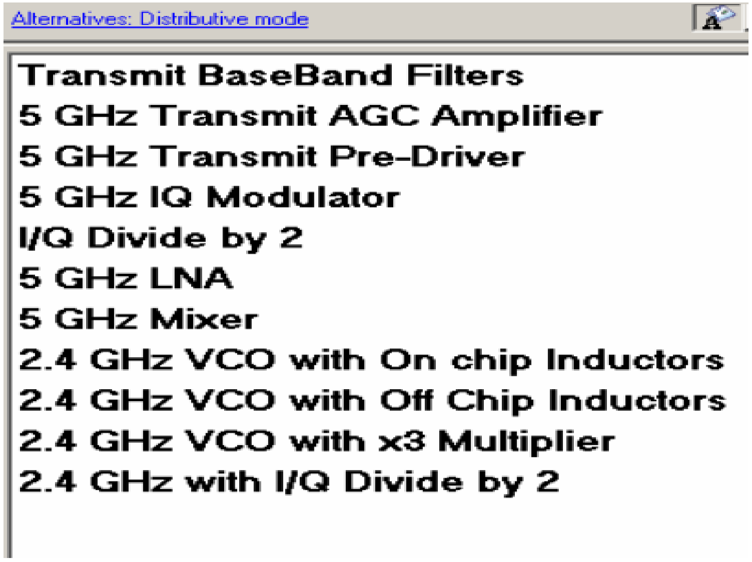
As described above, the decision was broken down into objectives and sub-objectives to create the hierarchy that is shown below (Figure 1.) This is the tree view in Expert Choice.



Goal: Allocate Engineering Resources
- Validate Model Accuracy
  - 5 GHz
  - 2.5 GHz
- Reduce Future Program Risk
- WLAN Spec Compatibility
  - 802.16
  - 802.11
- Generate Reusable IP
- Testability
- Product Roadmap

Figure 1: Tree View of Objective Hierarchy

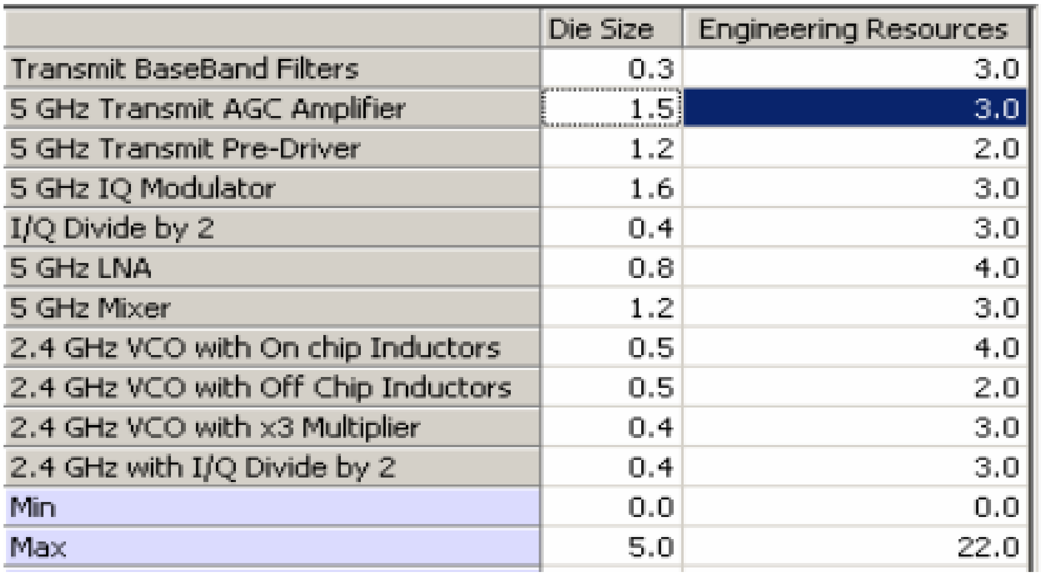
The eleven alternatives were entered into Expert Choice as shown in Figure 2. This snapshot shows the Expert Choice screen that shows the “alts pane.”



Transmit BaseBand Filters
5 GHz Transmit AGC Amplifier
5 GHz Transmit Pre-Driver
5 GHz IQ Modulator
I/Q Divide by 2
5 GHz LNA
5 GHz Mixer
2.4 GHz VCO with On chip Inductors
2.4 GHz VCO with Off Chip Inductors
2.4 GHz VCO with x3 Multiplier
2.4 GHz with I/Q Divide by 2

Figure 2: Alternative Pane

Using the Expert Choice Resource Aligner Expert Solver tool noted above, the Die Size and Engineering Resource constraints were added to the model. In Figure 3, the estimated labor and die resources required for each alternative is shown. Estimated engineering resource requirement of each alternative was based on complexity of design, past experience, and estimate of design engineers and based.



	Die Size	Engineering Resources
Transmit BaseBand Filters	0.3	3.0
5 GHz Transmit AGC Amplifier	1.5	3.0
5 GHz Transmit Pre-Driver	1.2	2.0
5 GHz IQ Modulator	1.6	3.0
I/Q Divide by 2	0.4	3.0
5 GHz LNA	0.8	4.0
5 GHz Mixer	1.2	3.0
2.4 GHz VCO with On chip Inductors	0.5	4.0
2.4 GHz VCO with Off Chip Inductors	0.5	2.0
2.4 GHz VCO with x3 Multiplier	0.4	3.0
2.4 GHz with I/Q Divide by 2	0.4	3.0
Min	0.0	0.0
Max	5.0	22.0

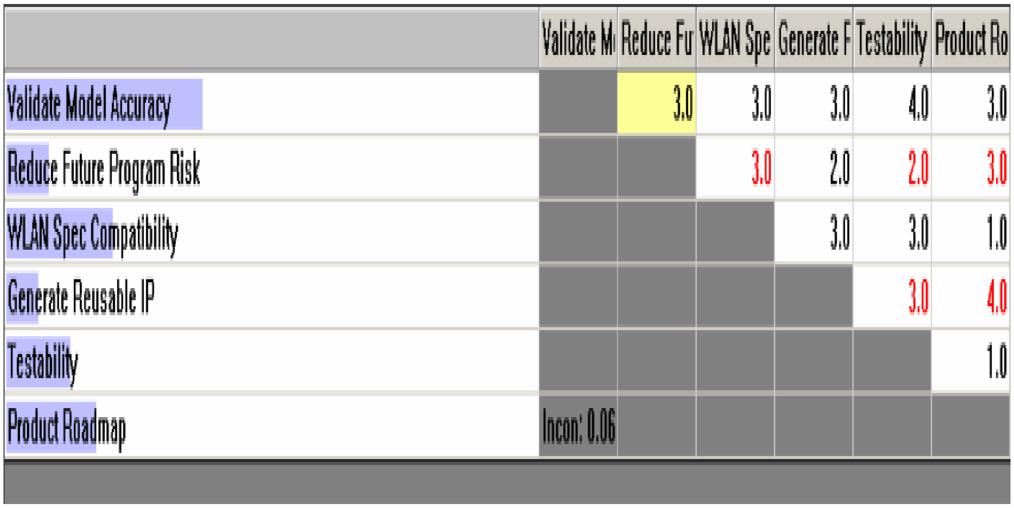
Figure 3: Model Constraints

Making Pair-wise Comparisons

Pair-wise comparisons of the top level objectives provide weighting of the relative importance of each objective with respect to the goal of deciding how to allocate engineering resources.

The priorities of the objectives and sub objectives were derived by a pair-wise comparison of each based in the context of the goal. This was accomplished through discussions with design engineers and marketing. This process ensured that the objects were prioritized in the context of the goal and not arbitrarily assigned ranks.

There are three ways to evaluate the comparisons (Verbal, Numeric, Graphical). In this case, a numerical comparison was used. The results of this comparison are shown in Figure 6.

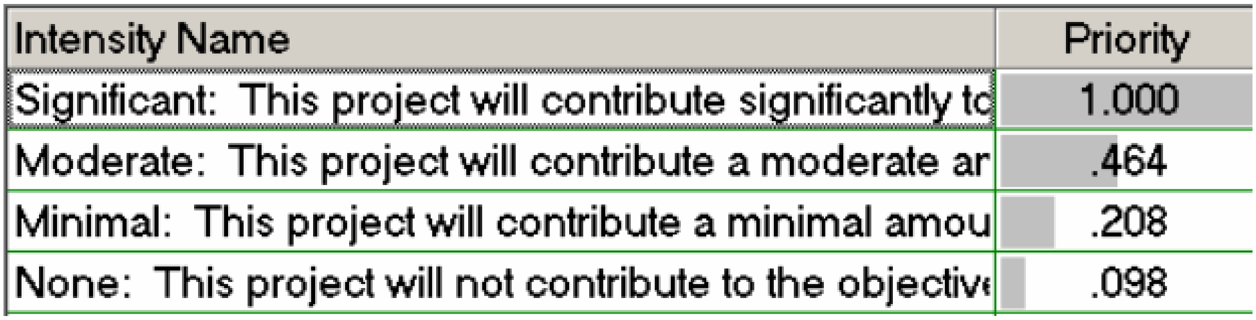


	Validate M	Reduce Fu	WLAN Spe	Generate F	Testability	Product Ro
Validate Model Accuracy		3.0	3.0	3.0	4.0	3.0
Reduce Future Program Risk			3.0	2.0	2.0	3.0
WLAN Spec Compatibility				3.0	3.0	1.0
Generate Reusable IP					3.0	4.0
Testability						1.0
Product Roadmap	Incon: 0.06					

Figure 4: Numeric Comparison Screen in Expert Choice

Setting the objective priorities

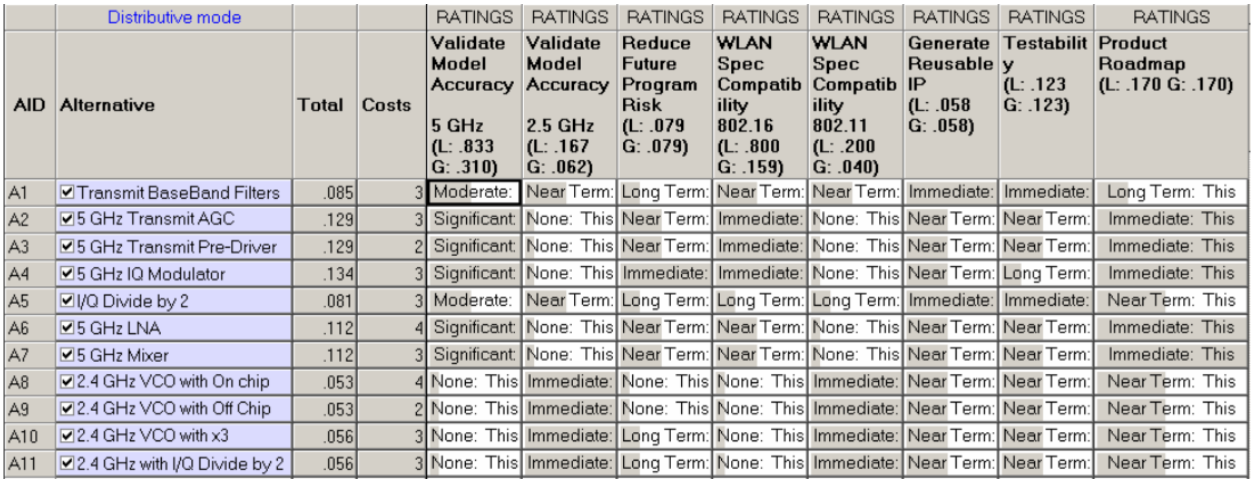
A ratings scale was developed for determining the level that each project contribution to any given objective or sub-objective. Scaling allows the relative significance of multiple projects to be compared for different objectives. The rating scale is shown in Figure 4.



Intensity Name	Priority
Significant: This project will contribute significantly tc	1.000
Moderate: This project will contribute a moderate ar	.464
Minimal: This project will contribute a minimal amou	.208
None: This project will not contribute to the objective	.098

Figure 5: Intensity of Contribution Scale

The data grid shows each of the objectives across the top and each of the projects on the left side. Each project is measured for its level of contribution to each objective. These intensities were used in the data grid to determine the relative priorities of the alternatives that are shown in the Total Column on Figure 5.

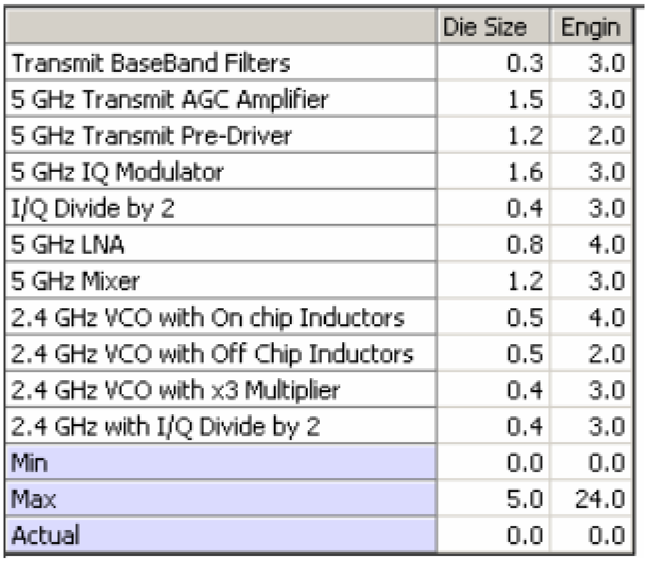


	Distributive mode			RATINGS	RATINGS	RATINGS	RATINGS	RATINGS	RATINGS	RATINGS	RATINGS
AID	**Alternative**	**Total**	**Costs**	**Validate Model Accuracy 5 GHz (L: .833 G: .310)**	**Validate Model Accuracy 2.5 GHz (L: .167 G: .062)**	**Reduce Future Program Risk (L: .079 G: .079)**	**WLAN Spec Compatibility 802.16 (L: .800 G: .159)**	**WLAN Spec Compatibility 802.11 (L: .200 G: .040)**	**Generate Reusable IP (L: .058 G: .058)**	**Testability (L: .123 G: .123)**	**Product Roadmap (L: .170 G: .170)**
A1	☑ Transmit BaseBand Filters	.085	3	Moderate:	Near Term:	Long Term:	Near Term:	Near Term:	Immediate:	Immediate:	Long Term: This
A2	☑ 5 GHz Transmit AGC	.129	3	Significant:	None: This	Near Term:	Immediate:	None: This	Near Term:	Near Term:	Immediate: This
A3	☑ 5 GHz Transmit Pre-Driver	.129	2	Significant:	None: This	Near Term:	Immediate:	None: This	Near Term:	Near Term:	Immediate: This
A4	☑ 5 GHz IQ Modulator	.134	3	Significant:	None: This	Immediate:	Immediate:	None: This	Near Term:	Long Term:	Immediate: This
A5	☑ I/Q Divide by 2	.081	3	Moderate:	Near Term:	Long Term:	Long Term:	Long Term:	Immediate:	Immediate:	Near Term: This
A6	☑ 5 GHz LNA	.112	4	Significant:	None: This	Near Term:	Near Term:	None: This	Near Term:	Near Term:	Immediate: This
A7	☑ 5 GHz Mixer	.112	3	Significant:	None: This	Near Term:	Near Term:	None: This	Near Term:	Near Term:	Immediate: This
A8	☑ 2.4 GHz VCO with On chip	.053	4	None: This	Immediate:	None: This	None: This	Immediate:	Near Term:	Near Term:	Near Term: This
A9	☑ 2.4 GHz VCO with Off Chip	.053	2	None: This	Immediate:	None: This	None: This	Immediate:	Near Term:	Near Term:	Near Term: This
A10	☑ 2.4 GHz VCO with x3	.056	3	None: This	Immediate:	Long Term:	None: This	Immediate:	Near Term:	Near Term:	Near Term: This
A11	☑ 2.4 GHz with I/Q Divide by 2	.056	3	None: This	Immediate:	Long Term:	None: This	Immediate:	Near Term:	Near Term:	Near Term: This

Figure 6: Data Grid with Values Filled In

Resource Aligner

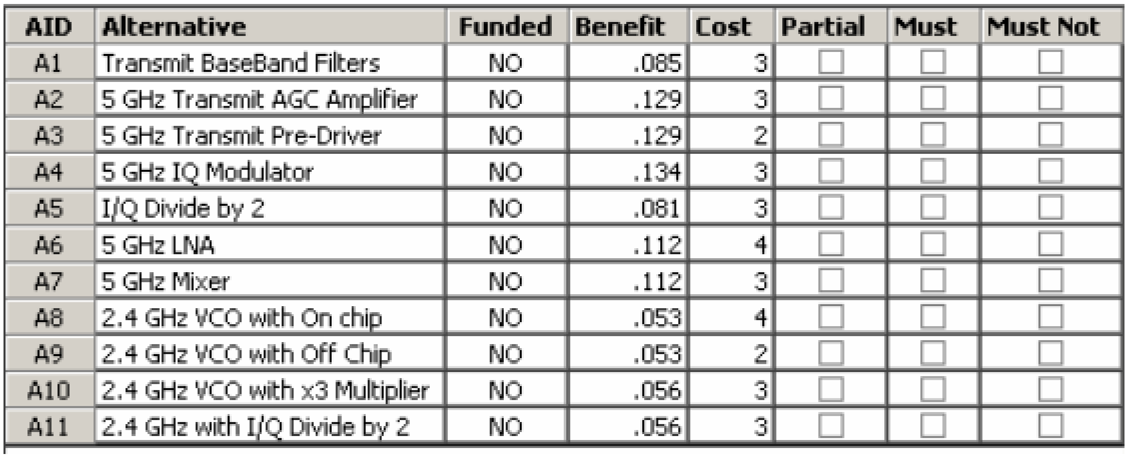
After all the data has been entered, the Expert Choice tools can be used to calculate a priority based decision. The Expert Choice tool Resource Aligner works through all the mathematical calculations needed to help determine the highest benefit that can be realized among the projects. Using the defined constraints and available budget, the tools project which projects will provide the most benefits. The constraints as defined above are entered into the tool as shown in Figure 7.



	Die Size	Engin
Transmit BaseBand Filters	0.3	3.0
5 GHz Transmit AGC Amplifier	1.5	3.0
5 GHz Transmit Pre-Driver	1.2	2.0
5 GHz IQ Modulator	1.6	3.0
I/Q Divide by 2	0.4	3.0
5 GHz LNA	0.8	4.0
5 GHz Mixer	1.2	3.0
2.4 GHz VCO with On chip Inductors	0.5	4.0
2.4 GHz VCO with Off Chip Inductors	0.5	2.0
2.4 GHz VCO with x3 Multiplier	0.4	3.0
2.4 GHz with I/Q Divide by 2	0.4	3.0
Min	0.0	0.0
Max	5.0	24.0
Actual	0.0	0.0

Figure 7: Constraints for Each Alternative

The cost of each project has been set to be equal to the number of engineering resources for the project to allow for comparisons based on this variable cost that is also a constraint. Since the cost is linked to this constraint, the maximum cost for doing all the projects would be 32 engineering work weeks. This is not possible since the number of work weeks available is only 24.

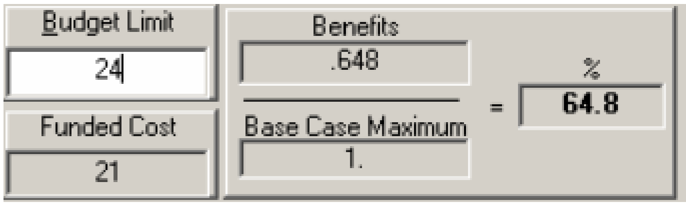


AID	Alternative	Funded	Benefit	Cost	Partial	Must	Must Not
A1	Transmit BaseBand Filters	NO	.085	3	☐	☐	☐
A2	5 GHz Transmit AGC Amplifier	NO	.129	3	☐	☐	☐
A3	5 GHz Transmit Pre-Driver	NO	.129	2	☐	☐	☐
A4	5 GHz IQ Modulator	NO	.134	3	☐	☐	☐
A5	I/Q Divide by 2	NO	.081	3	☐	☐	☐
A6	5 GHz LNA	NO	.112	4	☐	☐	☐
A7	5 GHz Mixer	NO	.112	3	☐	☐	☐
A8	2.4 GHz VCO with On chip	NO	.053	4	☐	☐	☐
A9	2.4 GHz VCO with Off Chip	NO	.053	2	☐	☐	☐
A10	2.4 GHz VCO with x3 Multiplier	NO	.056	3	☐	☐	☐
A11	2.4 GHz with I/Q Divide by 2	NO	.056	3	☐	☐	☐

Figure 8: Alternatives with Costs and Benefits

RESULTS

Setting the budget to the max number of engineering resources we see that the optimization of best benefit for the projects selected will be 64.8% of the maximum (100%) benefit possible if all the projects were completed. With current constraints and alternative priorities, die size is the limiting constraint. A change in prioritization of alternatives could result in engineering resources being the limiting constraint.



Budget Limit: 24

Funded Cost: 21

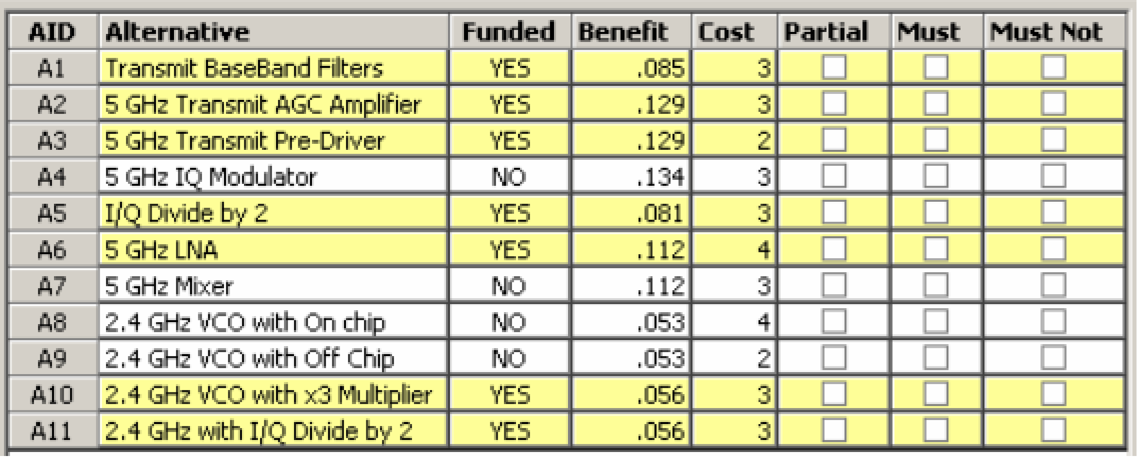
Benefits: .648

Base Case Maximum: 1.

%: 64.8

Figure 9: Maximum Benefits with Constraints

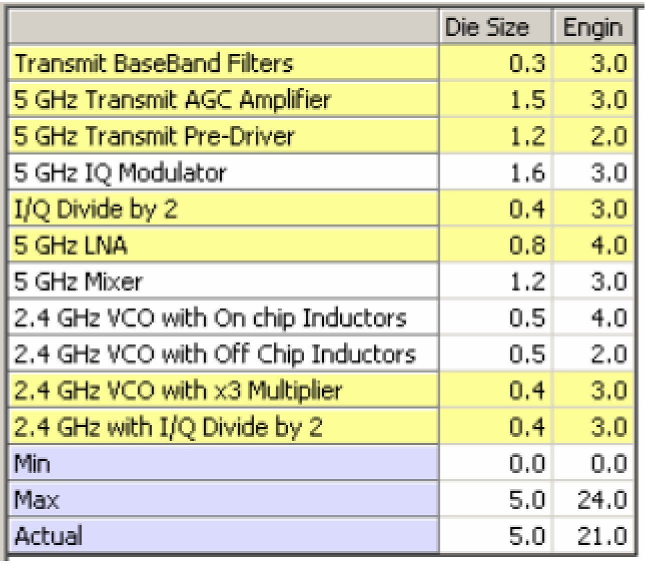
In Figure 10 below we see the highlighted projects that have been selected to be funded to achieve this benefit. Any other selection of projects within the mix will provide a lower benefit. This leaves four of the projects unfounded, the 5 GHz IQ Modulator, the 5 GHz Mixer, the 2.4 GHz VCO with On chip and the 2.4 GHz VCO with Off chip. Review will need to be completed of the needs for these specific projects and the impact of leaving them out.



AID	Alternative	Funded	Benefit	Cost	Partial	Must	Must Not
A1	Transmit BaseBand Filters	YES	.085	3	☐	☐	☐
A2	5 GHz Transmit AGC Amplifier	YES	.129	3	☐	☐	☐
A3	5 GHz Transmit Pre-Driver	YES	.129	2	☐	☐	☐
A4	5 GHz IQ Modulator	NO	.134	3	☐	☐	☐
A5	I/Q Divide by 2	YES	.081	3	☐	☐	☐
A6	5 GHz LNA	YES	.112	4	☐	☐	☐
A7	5 GHz Mixer	NO	.112	3	☐	☐	☐
A8	2.4 GHz VCO with On chip	NO	.053	4	☐	☐	☐
A9	2.4 GHz VCO with Off Chip	NO	.053	2	☐	☐	☐
A10	2.4 GHz VCO with x3 Multiplier	YES	.056	3	☐	☐	☐
A11	2.4 GHz with I/Q Divide by 2	YES	.056	3	☐	☐	☐

Figure 10: Projects Funded Based on Constraints

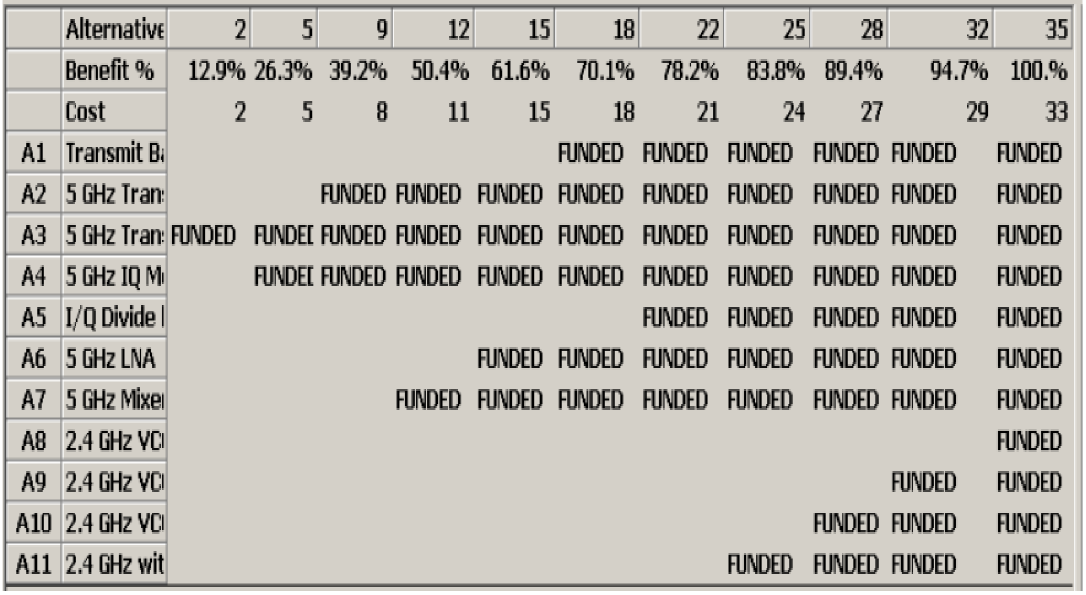
It is worthwhile to note that this mixture of projects only uses twenty-one of the twenty-four weeks of engineers effort that is available since die size is at max. Figure 11, shows the actual usage for each constraint. This means that to derive the most benefit, we are not using all the available engineering time. These unused resources can only be utilized if the die size constraint were changed.



	Die Size	Engin
Transmit BaseBand Filters	0.3	3.0
5 GHz Transmit AGC Amplifier	1.5	3.0
5 GHz Transmit Pre-Driver	1.2	2.0
5 GHz IQ Modulator	1.6	3.0
I/Q Divide by 2	0.4	3.0
5 GHz LNA	0.8	4.0
5 GHz Mixer	1.2	3.0
2.4 GHz VCO with On chip Inductors	0.5	4.0
2.4 GHz VCO with Off Chip Inductors	0.5	2.0
2.4 GHz VCO with x3 Multiplier	0.4	3.0
2.4 GHz with I/Q Divide by 2	0.4	3.0
Min	0.0	0.0
Max	5.0	24.0
Actual	5.0	21.0

Figure 11: Projects Funded - Constraints Displayed

The Resource Aligner provides a way to look at which projects will be funded at different levels of funding as seen in Figure 11. If we were to assume that die size is no longer a constraint, we could demonstrate which projects would be funded as the budget is increased from two to the maximum needed budget. As alternatives are developed or as resources might not be available as planned, this view can allow for quick decisions about the redirection of funding.



	Alternative	2	5	9	12	15	18	22	25	28	32	35
	Benefit %	12.9%	26.3%	39.2%	50.4%	61.6%	70.1%	78.2%	83.8%	89.4%	94.7%	100.%
	Cost	2	5	8	11	15	18	21	24	27	29	33
A1	Transmit B						FUNDED	FUNDED	FUNDED	FUNDED	FUNDED	FUNDED
A2	5 GHz Tran			FUNDED	FUNDED	FUNDED	FUNDED	FUNDED	FUNDED	FUNDED	FUNDED	FUNDED
A3	5 GHz Tran	FUNDED	FUNDEI	FUNDED	FUNDED	FUNDED	FUNDED	FUNDED	FUNDED	FUNDED	FUNDED	FUNDED
A4	5 GHz IQ M		FUNDEI	FUNDED	FUNDED	FUNDED	FUNDED	FUNDED	FUNDED	FUNDED	FUNDED	FUNDED
A5	I/Q Divide							FUNDED	FUNDED	FUNDED	FUNDED	FUNDED
A6	5 GHz LNA					FUNDED	FUNDED	FUNDED	FUNDED	FUNDED	FUNDED	FUNDED
A7	5 GHz Mixe				FUNDED	FUNDED	FUNDED	FUNDED	FUNDED	FUNDED	FUNDED	FUNDED
A8	2.4 GHz VC											FUNDED
A9	2.4 GHz VC										FUNDED	FUNDED
A10	2.4 GHz VC									FUNDED	FUNDED	FUNDED
A11	2.4 GHz wit								FUNDED	FUNDED	FUNDED	FUNDED

Figure 12: Increasing the Engineering Resources (Assumes no limitation on die size)

Another view of the impact of increasing the budget without constraints is seen as we view the benefits to the costs relationship of an increasing budget or in this case an increasing number of engineers without the constraint on the die size. The results of this comparison are shown the Pareto Graph below.

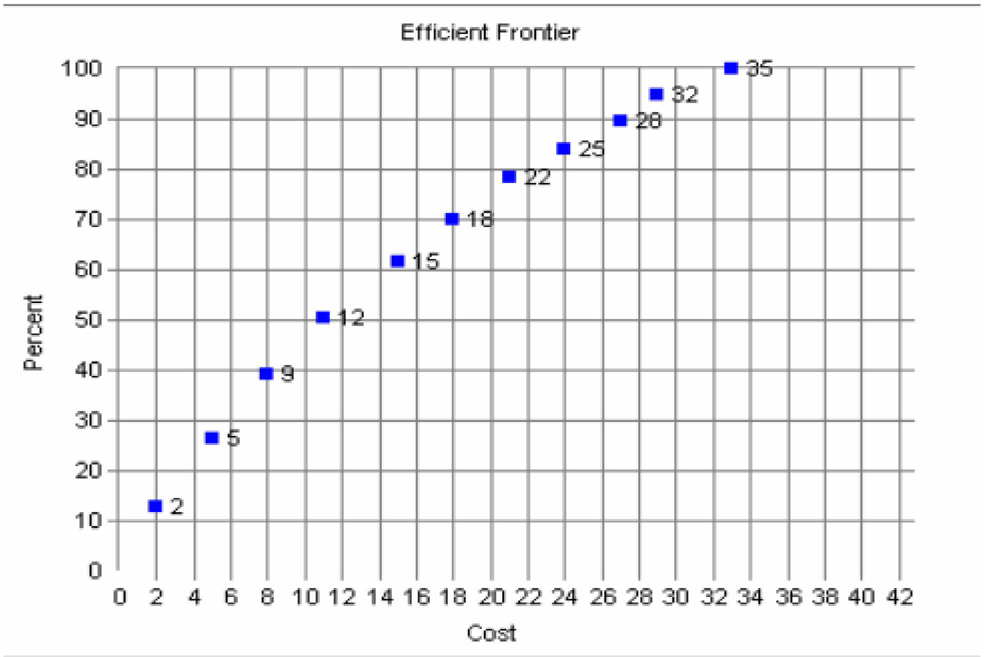
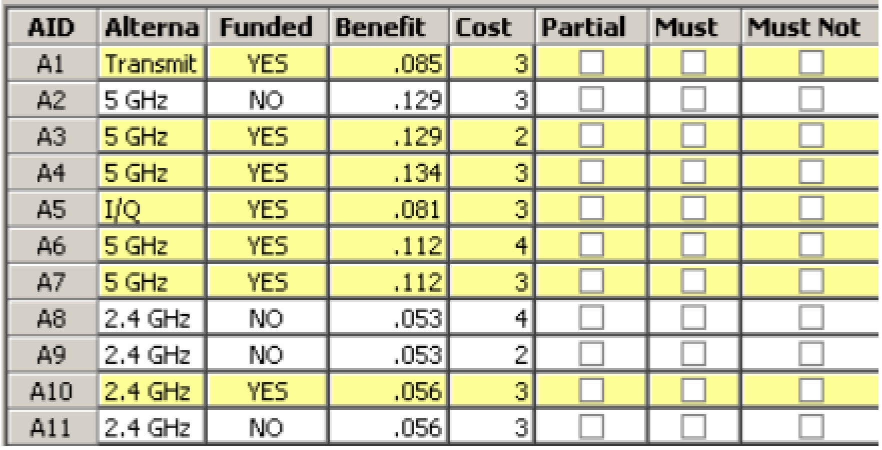


Figure 13: Pareto Graph - Increased Benefits vs. Budget Increases (without die constraint)

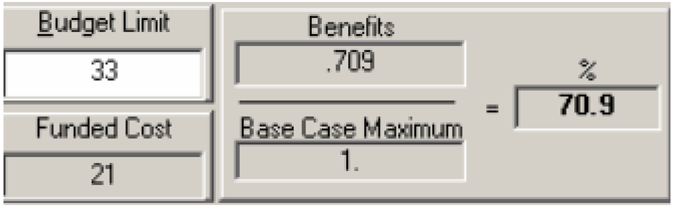
Use of these tools allows decisions to be made about the projects to be funded. If the maximum die size is increased then it is easy to see the optimized choices of the projects as seen in Figure 14. A new set of projects are chosen.



AID	Alterna	Funded	Benefit	Cost	Partial	Must	Must Not
A1	Transmit	YES	.085	3	☐	☐	☐
A2	5 GHz	NO	.129	3	☐	☐	☐
A3	5 GHz	YES	.129	2	☐	☐	☐
A4	5 GHz	YES	.134	3	☐	☐	☐
A5	I/Q	YES	.081	3	☐	☐	☐
A6	5 GHz	YES	.112	4	☐	☐	☐
A7	5 GHz	YES	.112	3	☐	☐	☐
A8	2.4 GHz	NO	.053	4	☐	☐	☐
A9	2.4 GHz	NO	.053	2	☐	☐	☐
A10	2.4 GHz	YES	.056	3	☐	☐	☐
A11	2.4 GHz	NO	.056	3	☐	☐	☐

Figure 14: Project Choices with Larger Die Size of 6 mm^2

At the same time, an increased benefit of 70.9% will be realized.



Budget Limit: 33
Funded Cost: 21
Benefits: .709
Base Case Maximum: 1.
= %: 70.9

Figure 15: Project Benefits with Larger Die Size of 6 mm^2

On the other hand if a new constraint is determined, for example the 5 MHz IQ Modulator must be funded, then the maximum benefit that can be realized drops to 59.7%. Similarly, the results of new determinations for relationships of various projects can be determined.

VALIDATING THE RESULTS

Given the results of the model, it is important to review those results as a check on their validity. There are several ways to approach this validation process. First, the authors can review it with the eye to seeing if it matches their old method of selection expectations – a comparative evaluation. Second, an expert analysis can be done from the perspective of the marketing department. Finally, an expert analysis can be done by an expert in the engineering area about the validity of all the assumptions. There are additional ways to validate the selection but these would provide a good indication that the objectives, measurement and the synthesis has been done appropriately.

Comparative Evaluation

The first step to validating the prioritized results of the resource allocation model is to compare those results to intuitive or BOGSAT decisions that might have been made without the AHP process. (Forman, 2001) If these are not consistent, then the model must be re-evaluated to determine whether any errors were injected during weighting of pair-wise judgments or whether the objectives and hierocracy of the model itself are in error. Although differences could be expected, there should be some basis for reviewing the differences. In this case, we will assume that the benefits would be evaluated in a way that would have similar results from the AHP evaluation. If we take the Resource Aligner results and sort them by Benefit we can see the sequence that they might have been selected in a pure benefit method.

Table 3: Projects Sorted by Benefits

Alternative	Funded	Benefit	Cost	Die	Res.
5 GHz IQ Modulator	NO	0.134	3	1.6	3
5 GHz Transmit Pre-Driver	YES	0.129	2	1.2	2
5 GHz Transmit AGC Amplifier	YES	0.129	3	1.5	3
5 GHz Mixer	NO	0.112	3	1.2	3
5 GHz LNA	YES	0.112	4	0.8	4
Transmit BaseBand Filters	YES	0.085	3	0.25	3
I/Q Divide by 2	YES	0.081	3	0.4	3
2.4 GHz with I/Q Divide by 2	YES	0.056	3	0.4	3
2.4 GHz VCO with x3 Multiplier	YES	0.056	3	0.4	3
2.4 GHz VCO with On chip Inductors	NO	0.053	4	0.5	4
2.4 GHz VCO with Off Chip Inductors	NO	0.053	2	0.5	2

Based on this sequence, the die area constraint would be exceeded by the third project so only the first two projects would be funded or only 26.3% of the optimal solution identified by the AHP model. This would also not be good use of Engineering Resources and would likely lead to layoffs if further steps were not taken. As we can see, the Resource Aligner did not fund the project with the highest benefit, so this is not a problem in the difference of methodologies. The same type of evaluation applies to the non-selection of project four by the Resource Aligner.

Expert Review

A second way to evaluate the results is by expert review of the results. Additional engineering experts in the company were used to evaluated the assumptions and constraints, validate that prioritizing was appropriate and to identify if any of the alternatives should be considered ‘must’ projects. Marketing experts evaluated the objectives and determined that no additional needs were required. All the projects in the alternatives meet at least one objective but there is nothing in the model to require that every objective is included in the projects that are recommended for funding, this was an assumption made.

SUMMARY AND RECOMMENDATIONS

Engineering at Skyworks was faced with a difficult though common dilemma. Marketing had identified eleven designs they considered important to develop in time for the next foundry shuttle run. An evaluation of the engineering resources available reveals that both layout resources and die area available limit the ability to complete all of the identified designs.

A model was constructed using the Analytical Hierarchy Process (AHP) to make decisions based on six key objectives defined by Marketing and Engineering. Constraints based on physical design limitations (die size) and on the amount of engineering resources available were defined and added to the model. The outcome was a prioritized list of seven design components that will be developed in order to maximize benefits to the company given the constraints.

Restrictions placed on die size were shown to be a greater limiting factor than the availability of engineering resources. Although the short 2-3 month schedule of these projects does make outsourcing a viable option, the foundry restrictions on die size limit the advantages of addressing engineering resource issues. Die size could theoretically be increased if a smaller number of parts per wafer were acceptable. Due to the nature of testing, characterizing and qualifying new parts, receiving fewer parts is not an option acceptable to Test Engineering.

If it is determined by marketing that all identified alternatives must be developed then additional blocks must be reserved for future foundry runs scheduled to occur two months after the targeted Shuttle Run. Additional engineering resources would also be required if the decision is made to complete all of the identified alternatives.

If the projects selected are reviewed by Marketing and Engineering management and found to be acceptable to complete their criteria, then the model may be sufficient and the projects prioritized by the model should be targeted for development. The small amount of underutilized engineering resources will begin working on the next set of projects.

A presentation explaining the model, objectives and constraints was given to both the Marketing and Engineering groups responsible for these projects. After review of the model, the resulting prioritized list was accepted and development has begun on the identified designs.

The engineering team needs to move aggressively in development of the selected projects. Changes could occur in resource availability over the next few months, therefore emphasis will be given to developing projects at the top of the list first.

Although both Marketing and Engineering have agreed with the decision as presented, there is still the possibility that they may later decide that an omitted alternative should have been included. If this should occur, then the alternative will be re-identified as a must and the objectives and judgments in the model will be reviewed and updated (re-shampoo) with the new inputs. If even more or all the projects are deemed critical to the success of the Company, then consideration must be given to acquiring additional blocks of space on future Shuttle Run wafers. Due to the nature of how wafer masks are constructed for Shuttle Runs, the 5 mm^2 will probably remain constant. Therefore the only financially viable option available is to schedule a second shuttle run after the first is completed.

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