Materials Risk Analysis

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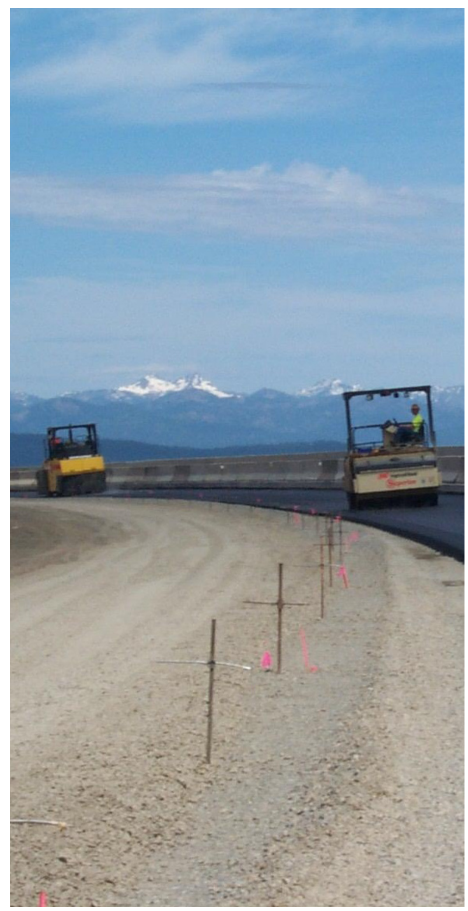

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WSDOT Research Report

Materials Risk Analysis

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16. ABSTRACT

State highway authorities routinely examine the quality of the materials used to build highway construction projects. Some materials are tested, some are accepted through a manufacturer's certification of quality or compliance, some are physically inspected during fabrication and yet other materials are accepted through visual inspection. Unanswered is why some materials are more closely examined through physical testing and other materials receive much less scrutiny.
This paper describes a materials risk analysis process and the conclusions from that risk analysis conducted at the Washington State Department of Transportation (WSDOT). Typical construction materials are examined for two critical risks: the risk of having a material fail to meet specification and the consequences of that material failing to meet specification. Subject matter experts (materials, construction, structures, maintenance, traffic, etc.) within the WSDOT rated these risks through a Delphi process. Results of the risk analysis classify materials into four appropriate categories for either more or less intensive examination by the state highway authority: highest risk materials undergo physical acceptance testing or are inspected during fabrication under a manufacturer's quality system plan; moderate risk materials are accepted through the manufacturer's certification of compliance (often combined with a quality systems plan or visual inspection); lower risk materials are accepted with a manufacturer's certification or with a catalog cut; and the lowest risk materials are accepted through visual inspection in the field. Future materials risk analyses may be performed on periodic intervals (five to ten years suggested) to re-examine the risks and rankings by subject matter experts.

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ABSTRACT

State highway authorities routinely examine the quality of the materials used to build highway construction projects. Some materials are tested, some are accepted through a manufacturer's certification of quality or compliance, some are physically inspected during fabrication and yet other materials are accepted through visual inspection. Unanswered is why some materials are more closely examined through physical testing and other materials receive much less scrutiny.

This paper describes a materials risk analysis process and the conclusions from that risk analysis conducted at the Washington State Department of Transportation (WSDOT). Typical construction materials are examined for two critical risks: the risk of having a material fail to meet specification and the consequences of that material failing to meet specification. Subject matter experts (materials, construction, structures, maintenance, traffic, etc.) within the WSDOT rated these risks through a Delphi process. Results of the risk analysis classify materials into four appropriate categories for either more or less intensive examination by the state highway authority: highest risk materials undergo physical acceptance testing or are inspected during fabrication under a manufacturer's quality system plan; moderate risk materials are accepted through the manufacturer's certification of compliance (often combined with a quality systems plan or visual inspection); lower risk materials are accepted with a manufacturer's certification or with a catalog cut; and the lowest risk materials are accepted through visual inspection in the field. Future materials risk analyses may be performed on periodic intervals (five to ten years suggested) to re-examine the risks and rankings by subject matter experts.

INTRODUCTION

State departments of transportation (DOTs) accept many different materials in many different ways. Some materials are rigorously tested while others are accepted based on visual inspection. Some materials require inspection during fabrication but others can be accepted based upon a manufacturer's certification of compliance. Why do DOTs rigorously test some materials but not others? Why might we accept reinforcing steel based on a certification from the steel mill but require structural concrete to be physically tested for slump, air entrainment, temperature, and compressive strength?

In asking this question at the Washington State Department of Transportation (WSDOT) it became clear that there was no recorded history or methodology about why we evaluated the quality of some materials more closely than others. Clearly there was background logic in the testing that took place, with a heavy emphasis on the prime components of both pavements and structures, two of our most valuable assets. The recording of this logic into a system that preserved the reasons for categorizing materials for testing did not exist in any formal fashion. To examine the subject more closely we needed to ask why our current system had varying levels of examining construction materials and then to ask what type of system should we have to determine the level of testing necessary to ensure highest quality on our construction projects at the least cost.

RISK

When accepting materials there are a variety of risks but two important ones stand out: the risk of the material failing to meet the specification and the consequences if the material fails to meet this specification. Assuming that most specifications relate to the real world performance needs of the material, these two risks become the focal point for accepting a material. Materials can have high risks in both of these categories, mixed risk (high in one category and low in another) or low risk in both categories. In a logical system, materials that rate for high risk in both categories (high risk of failing to meet specification and high risk of consequences if they do fail) should have the highest level of scrutiny by WSDOT. Materials with mixed risks may or may not need the highest level of assurance, depending on the risks in the individual categories. A material such as prestressed girders may not fail very often, but failure would usually be catastrophic; on the other hand, bark mulch might often fail to meet its specification for gradation, but the consequences of such a specification failure are small.

This review was based upon these two risk factors. Every common construction material would be rated and their total risk factor would preliminarily determine where the material should fall on the materials assurance continuum. The highest level of materials assurance involves directly sampling and testing the material, especially when performed using a statistical level of analysis. The lowest level of acceptance would be visual inspection in the field; whereby the field inspector visually checks and accepts the material. In between fall such efforts as fabrication inspection, quality systems plans with annual reviews, certification of compliance by the manufacturer, materials documentation for commercially manufactured materials used in many industries (usually through catalog cuts) or limited testing or inspection. Table 1 displays the ranking of these acceptance methods, from most intense with the highest level of assurance to the lowest level.

FIGURE A, Acceptance Rating Matrix

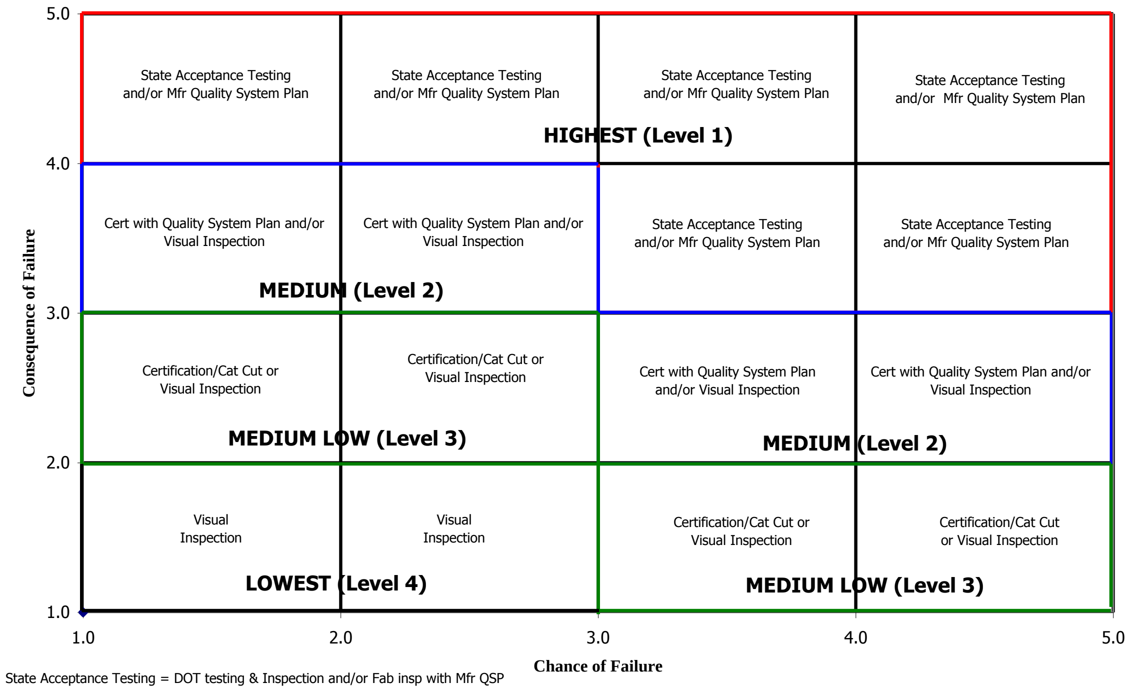

FIGURE 1: Materials Acceptance Rating Matrix, depicting different levels of risk and different acceptance criteria.

RATING RISK LEVELS

Given that we now had a system upon which to evaluate materials for their risk of failing to meet specification and the consequences of their failure, how would the risks be evaluated for each material? Ideally management systems that track both performance and life cycle costs would provide the risk analysis, allowing evaluation of both the cost and the performance of a material to the two risk categories. Unfortunately such data is lacking. Management systems with sufficient data collection and analysis to determine life cycle performance are expensive to create and even more expensive to operate and populate. Management systems are in place for WSDOT's two largest assets, bridges and pavements, but not for other construction materials. The excellent Washington State Pavement Management System has a budget of $500,000.00 a year to measure, track, evaluate and report on changing pavement conditions. For materials of lesser value, life cycle cost performance and intensive database management systems are neither practical nor affordable.

Within each department of transportation there does exist a body of knowledge on materials performance and materials risks: it exists in the minds of the employees within the department, particularly within the knowledge of subject matter experts. The Delphi method was used to tap this expertise.

The Delphi method, developed at the Rand Corporation, was selected as a practical means to evaluate the risk criteria for materials acceptance. Harold Sackman, in Delphi Critique. notes that:

> "Delphi is an attempt to elicit expert opinion in a systematic manner for useful results. It usually involves interactive questionnaires administered to individual experts in a manner protecting the anonymity of their responses. Feedback of results accompanies each iteration of the questionnaire, which continues until convergence of opinion, or a point of diminishing returns is reached."[1]

Delphi surveys rely on three main elements: structuring the flow of information, regular feedback and anonymity of participant. We selected a group of knowledgeable people, familiar with the subject matter, to provide their input. Together, this process would drive toward consensus on material risks, allow them to categorize these materials in a risk matrix and ultimately place each material in an acceptance category.

We wanted to draw a cross section that included WSDOT employees familiar in theoretical design and field performance, generalists and specialists. WSDOT employees familiar with the highway construction materials were selected (See Table 1). We included specialists in electrical engineering, structural design, hydraulics, pavement design, etc. and generalists, including field engineers, project inspector and project engineers.

There are criticisms of the Delphi method. One surrounds the formation and potential bias of the survey questions. Linked to this criticism is that the complex future events usually dealt with through Delphi surveys are not clear and are not unambiguous. This survey reduced or eliminated these issues by repeatedly asking only two questions: what is the risk of failure and what is the consequence of that risk. Another criticism is that the system eliminates the adversarial process. By conducting individual interviews after completion of the Delphi surveys mitigated this argument: anyone with strong opinions could voice them and demand change at this step of the process.

TABLE 1 WSDOT Subject Matter Disciplines

General Group – Reviewing All Materials			
HQ Materials	Regional Materials	Regional Construction	FHWA
HQ Construction	HQ Maintenance	Region Maintenance	
Project Engineers	Construction Engineers	Local Programs	
Pavements Group (Hot Mix Asphalt and Portland Cement Concrete Pavements)			
Pavement Design Engineer	Assistant Bituminous Materials Engineer	State Pavements Engineer	Chemical Materials Engineer
Bituminous Materials Engineer	Structural Materials Testing Engineer	Assistant Construction Engineer, Roadway	Liquid Asphalt Laboratory Supervisor
Hydraulics			
HQ Hydraulics	Region Liaison Landscape Architect	Fabrication and Coating Engineer	HQ Materials
Geotechnical			
State Geotechnical Engineer	Structural Materials Testing Engineer	Construction Engineer, Bridge	Bridge and Structures Engineer
HQ Materials			
Landscape and Environmental			
Roadside Design Manager	Water Quality Specialist	Chemical Materials Engineer	Region Landscape Architect
EMS Project Lead	Water Quality Team Leader	Structural Materials Testing Engr	Asst. Const. Engr, Administration
Electrical			
Electrical Materials Engineer	Asst. Const. Mats. Engr., Structural	Traffic Signal Operations Engineer	Bridge Special Provisions Engineer
Maintenance Operations Supt., Signals	Traffic Engineer	Region Electrical Engineer	
Chemical			
Chemical Mats. Engineer	Maintenance	Asst. Const. Mats. Engr., Structural	Construction Engineer, Bridge
Bridge Mgmt Engineer	Region Maintenance		
Traffic			
Electrical Materials Engineer	Region Traffic	Chemical Materials Engineer	Traffic Control Engineer
Region Documentation	HQ Traffic	Safety Policy Specialist	Traffic Materials Engineer
Asst. Const. Mats. Engr., Structural			
Structures and Architectural			
HQ Materials	HQ Construction	Chemical Materials Engineer	Bridge Special Provisions Engr
Bridge Project Engineer	State Geotechnical Engineer	Bridge and Structures Engineer	Structural Materials Testing Engineer

CATAGORIES FOR MATERIALS ACCEPTANCE

We established four levels of materials examination to determine the quality of any given material, from the most intensive level of scrutiny to the least:

- Level 1: Highest level - WSDOT acceptance testing, or a combination of fabrication inspection coupled with a requirement for a manufacturer's quality system plan

- Level 2: Second highest level - Requires a manufacturer's certification of compliance with a quality systems plan
- Level 3: Intermediate level – Either a manufacturer's certification of compliance or a catalog cut stating the qualities of the material being used
- Level 4: Lowest level - visual inspection in the field

WORKING TOWARD CONSENSUS

Round one of the survey resulted in areas of clear consensus and areas lacking in consensus. Areas of apparent consensus were quickly eliminated from the second round of the survey. (See Table 2) Consensus was selected at a standard deviation equal to or less than 0.85 for both risk categories.

TABLE 2 First Delphi Iteration – Materials Reaching Risk Consensus

Structures and Architectural				
	Risk of Failure to Meet Specification		**Consequences of Failure to Meet Specification**	
Material	**Avg.**	**Std. Dev.**	**Avg.**	**Std. Dev.**
Ground Rubber for Deck Repair	1.91	0.831	2.64	0.809
Phase 2 – Structures and Architectural				
Structural Metal Items for Building	2.06	0.556	3.76	0.831
Epoxy Resin Binder	2.53	0.612	3.74	0.653
Adhesive Resin for Reinforcing Steel	2.30	0.470	3.80	0.696
2 Part Rubber Joint Sealant	20.6	0.680	2.50	0.730
High Strength Bar for Soil Nails	1.67	0.594	4.28	0.826
Chemical				
Clear Sealers	2.00	0.816	1.92	0.760
Galvanized Conduit	2.24	0.831	2.35	0.606
PVC Conduit	1.67	0.617	2.18	0.728
Electrical				
Flexible Bends for Conduit	1.59	0.618	2.22	0.732
Innerduct and Outerduct	1.55	0.522	2.18	0.751
Bends for PVC and Steel Conduits with Innerducts	1.69	0.480	2.23	0.599
Sign Lights Disconnect Switch	1.56	0.629	2.38	0.719
ITS Battery Backup System	1.75	0.452	3.00	0.853
Type 2 Base for Steel Post	1.71	0.469	2.50	0.760
Traffic				
Type 1 Base for Sign	1.88	0.719	2.60	0.828
Environmental & Landscape				
Catch Basin and Exert	1.77	0.725	2.23	0.832
Straw Wattles	1.38	0.500	1.88	0.619
Quick Coupling Equipment	1.53	0.640	1.87	0.834
Above Ground Rotary Sprinklers	1.38	0.500	2.00	0.816
Hydraulics				
Irrigation Pipe and Fittings	1.58	0.692	2.25	0.851
Pavements				
Mineral Aggregate for HMA	3.12	0.766	3.96	0.706
Shoulder Ballast	2.87	0.626	2.14	0.834

A typical result for a material which we considered to have reached consensus is shown in Figure 2, which depicts first round ratings for PVC and metal conduit bends. Figure 3 provides an example of a material that did not reach consensus in the first Delphi round of results, this time for temporary silt fence. After the first round we had 23 materials in consensus and 204 materials still needing consensus.

Round 2 of the Delphi process returned the initial survey to the subject matter experts, less the materials reaching consensus in Round 1. The subject matter experts also received the ratings from the first round and all of the comments from their peers. Ratings and rating comments were shared anonymously. Round 2 resulted in 146 more materials reaching consensus, leaving 80 materials without a consensus on their risk ratings.

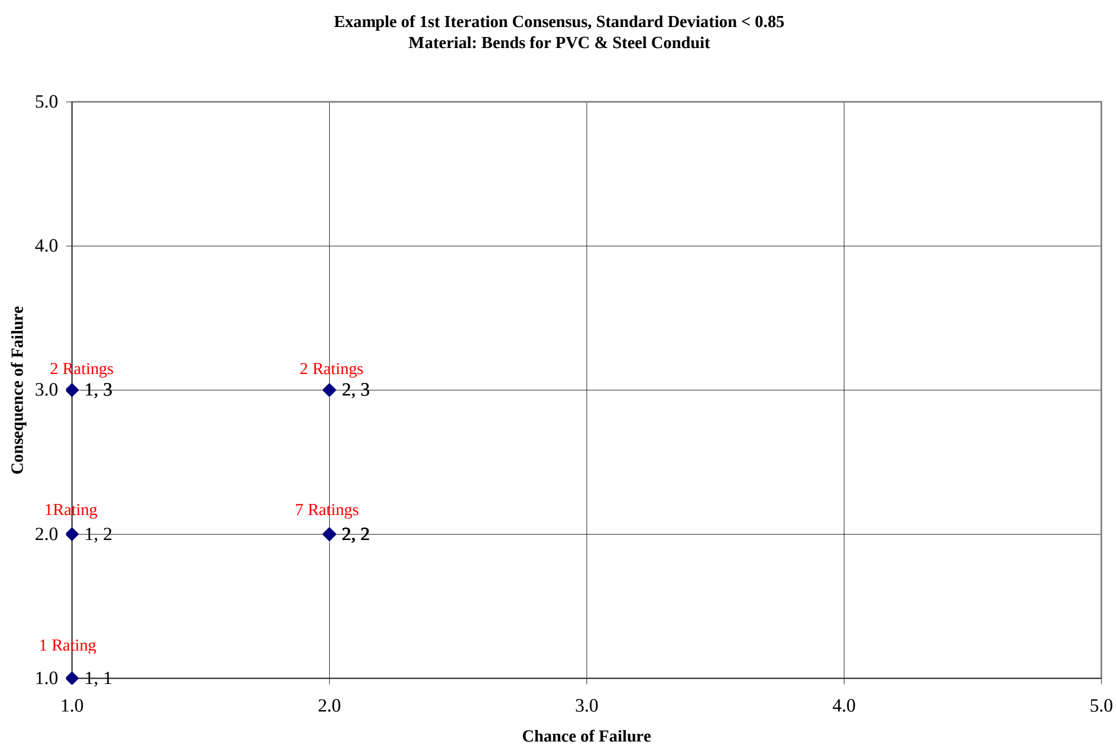

FIGURE 2 Example of Round 1 material reaching consensus. Materials were considered to have reached consensus if the standard deviations equal to or less than 0.85. This figure depicts the risk ratings for Bends for PVC and Steel Conduit.

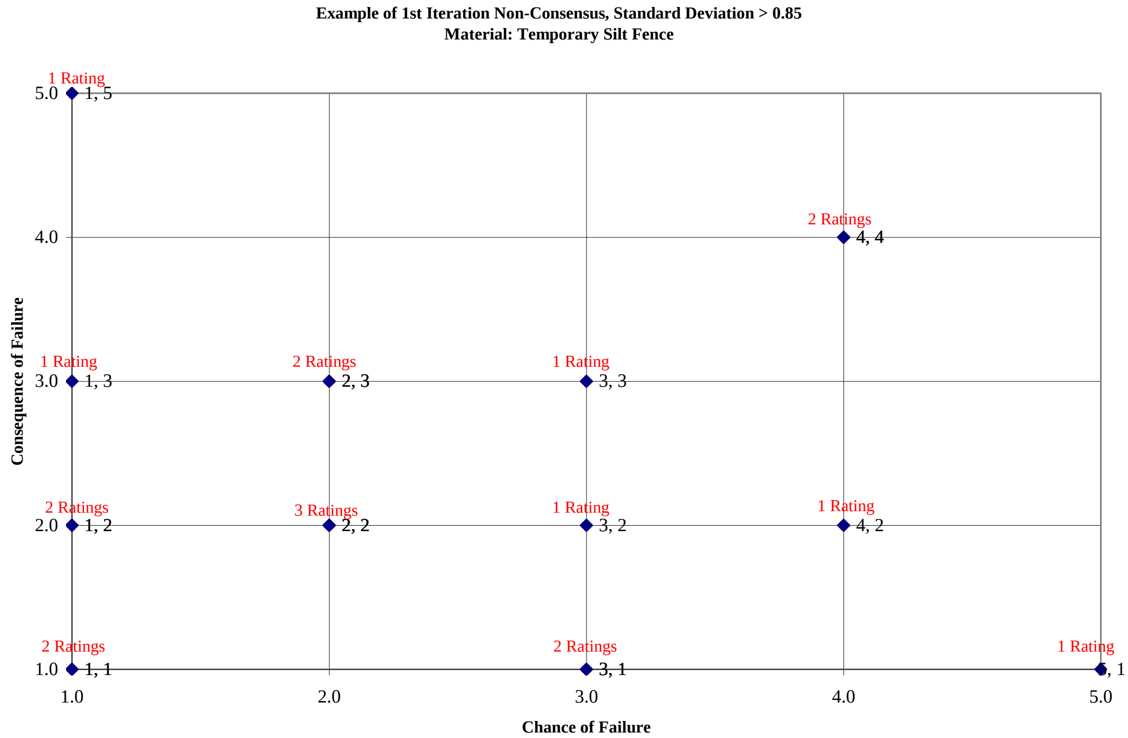

FIGURE 3 Example of Round 1 material that failed to reach consensus. Materials were considered to have failed to reach consensus if the standard deviations were greater than 0.85. This figure depicts the risk ratings for temporary silt fence.

FINAL REVIEW

After completion of the two rounds of surveys, we brought back together the WSDOT subject matter specialists for each material category, as well as selected generalists, to review the results. This was an informal, "gut check," review, to build final consensus and to ensure that as we implemented results we would have buy-in of the participants. The results of this final round of review are shown in Figure 4. Materials requiring the highest level of acceptance, level 1, decreased from 98 to 88. Materials in the second level of acceptance also decreased, from 21 to 8. There were corresponding increases in the two lower levels of acceptance, with level 3 showing an increase from 78 to 80 materials and level 4 showing an increase from 25 to 39 materials. Based upon the two materials risks, we found that many materials would be served with less intensive materials acceptance (acceptance levels 3 and 4).

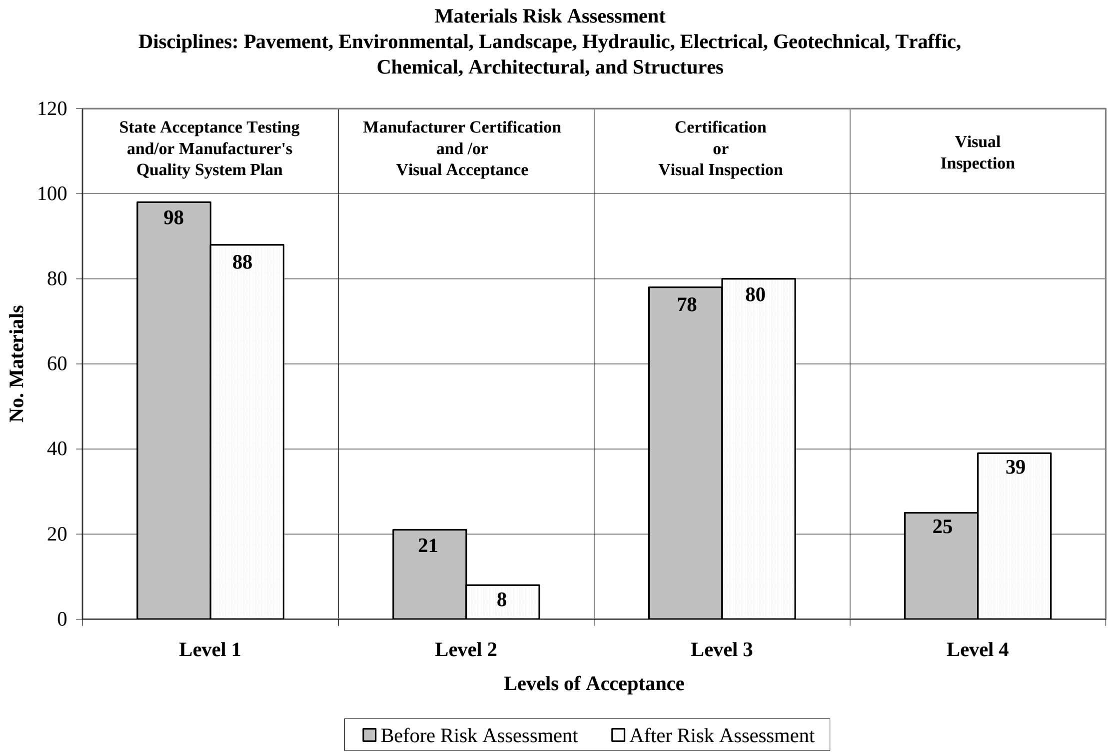

FIGURE 4 Results of the materials risk analysis, showing numbers of materials by acceptance category, both before and after the risk assessment. The number of materials in the two highest acceptance levels (associated with physical testing, fabrication inspection and quality systems plans – acceptance levels 1 and 2) decreased, while lower risk materials accepted through lower acceptance methods (manufacturer's certification of compliance or visual inspection – acceptance levels 3 and 4) increased.

Two sets of materials that had been treated as a series of individual components were combined into systems and are now being accepted in the whole: rock protection fencing and beam guardrail elements. Rock protection fencing is evaluated as a system and we are in the process of implementing an "Approved Guardrail Installer program" for beam guardrail.

The final consensus ratings showed interesting results. None of the materials exhibited high risk ratings in both materials simultaneously. While some materials showed a high risk of consequences if they failed to meet specification (see Figure 5), few materials ever rose to even the moderate risk level for failing to meet specification. Upon review, this corresponds with common experience in DOTs acceptance of construction materials: materials failures are the exception, not the norm. Most producers and manufacturers take care in producing materials that will meet specification and very few materials regularly fail to meet specification. Other examples of typical risk ratings are shown in Figures 6 and 7.

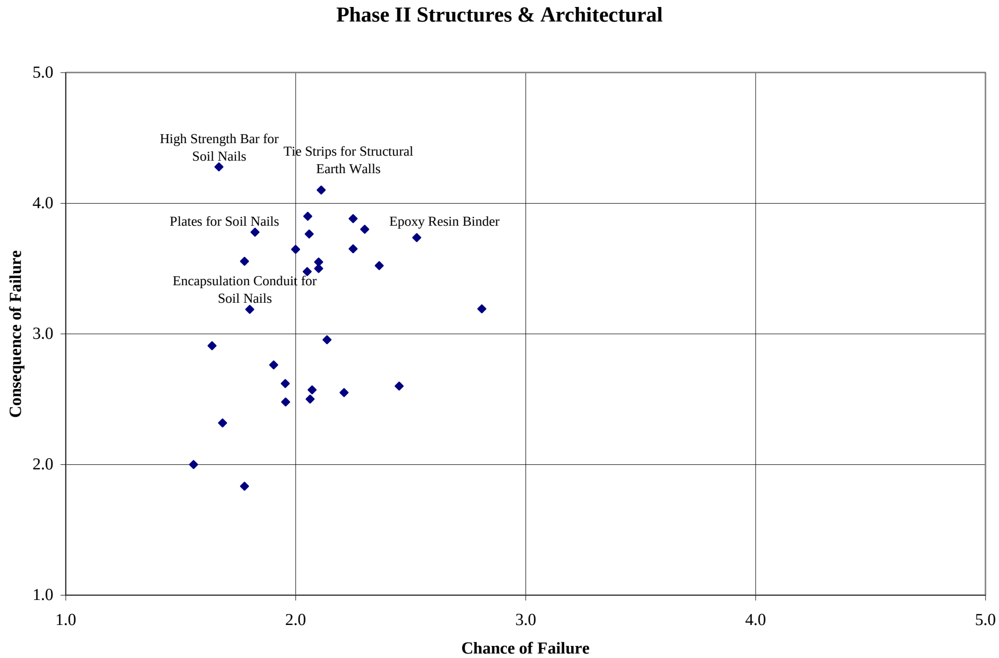

FIGURE 5 Example of a high consequence of failure to meet specification, with low risk of failing to meet specification.

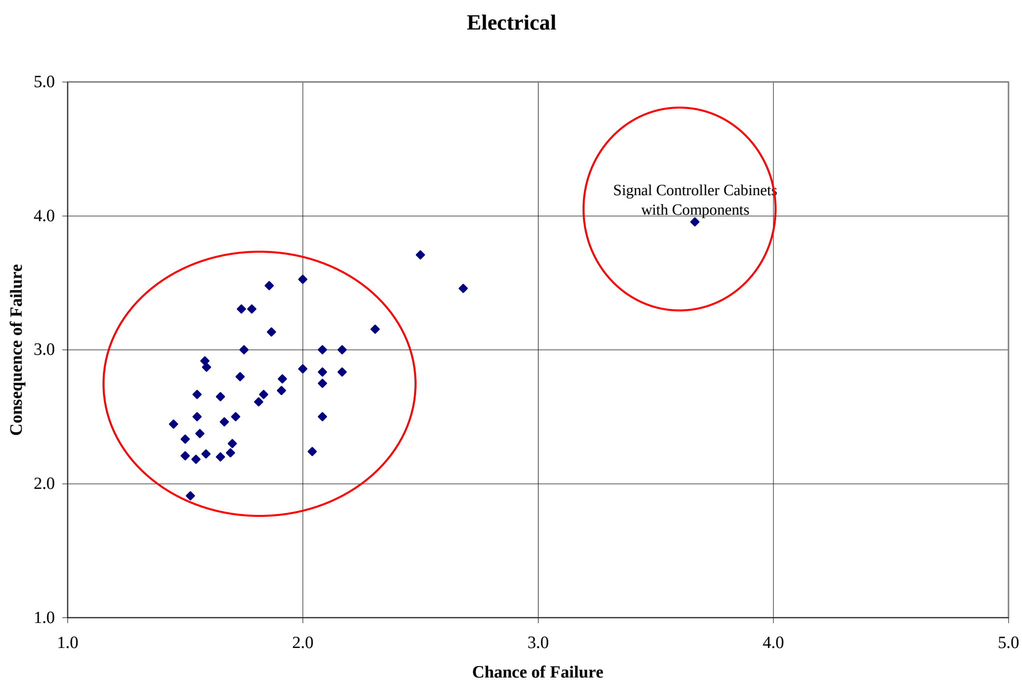

FIGURE 6 Example of a moderate risk of failing to meet specification and moderate risk of consequences

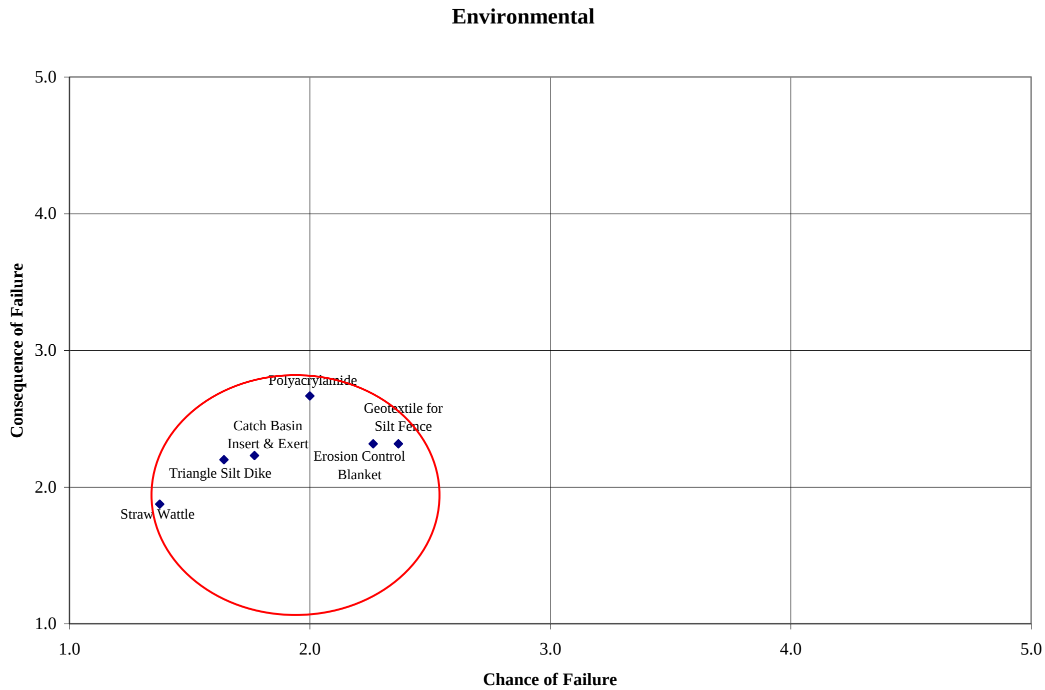

FIGURE 7 Example of low risk of failing to meet specification and low risk of consequences. Materials include landscaping and erosion control products.

CONCLUSIONS

WSDOT did not have a system in place to formally evaluate the risk of materials (failure to meet specification and the consequences of those failures) and did not have a system to determine the level of assurance needed to accept each construction material. With the Materials Risk Analysis complete we now have such system: common construction materials have been rated for risk in two categories and the acceptance criteria for each material has been matched to that level of risk. We can now say that we have a rational system for why we test some materials, inspect the fabrication of some materials, accept manufacturer's certification of compliance on others or simply visually inspect other materials.

We also have a basis for the continuing risk reviews for existing materials and for new materials. We are planning a five year cycle to repeat the materials risk analysis for all materials to ensure that risk ratings and acceptance methods stay up to date.

RECOMMENDATIONS

Future research in establishing electronic management systems might provide the ability to track actual performance of a wider variety of materials over the course of their life cycles. Actual risks, rather than risks estimated by subject matter experts, might be able to be discovered, recorded and tracked, providing data that may be analyzed statistically. With such knowledge one could develop a more accurate risk analysis system. The cost of developing such data would need to be evaluated against the expected benefit.

REFERENCES

[1] Sackman, Harold. Delphi Critique © 1975. Pg xi. LCCCN 74-14858