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# Evaluation of the Engineering and Design Scope of Services for State DOT Infrastructure Projects

**Ajay S. Jadhav, Ph.D. Candidate, Dennis C. Bausman, Ph.D., and Ehsan Mousavi, Ph.D.**

Clemson University

Clemson, SC

Transportation agencies across the United States (U.S.) are under increasing pressure to deliver the project more efficiently and effectively. To meet expectations, the agencies are increasing the rate of procurement of professional consultant services as they are facing various challenges in project scoping process (PSP). Since the scope of services (SOS) and PSP are related to each other, this study is focused on evaluation of the available data addressing the comprehensiveness of the SOS across different states. The authors focused on the design SOS and evaluated 49 documents from 8 state departments of transportation (DOTs). The authors then developed a series of criteria for assessing the comprehensiveness of these selected DOTs. Data analysis indicated significant variations across the states in terms of the criteria. Further, weights were assigned to the identified criteria and sub-criteria using the analytic hierarchy process (AHP) and the SOS documents were ranked for their comprehensiveness. Comprehensive score indices ($CC_i$ and $CC_e$) were calculated using the level of comprehensiveness and the level of importance derived from actual SOS document pages and AHP respectively.

**Keywords:** Scope of Services (SOS), Project Scoping Process (PSP), Analytic Hierarchy Process (AHP), Department of Transportation (DOT).

## Introduction

In recent years, the transportation industry has witnessed an  increase in the use of professional services consultants for engineering and design professional services to meet rising demand. This increased demand has elevated both the number of projects for states' Department of Transportation (DOT) and the need for on-time delivery to meet the increased need for transportation projects (Gen & Kingsley, 2007). Compounding the challenge is that DOTs are facing shortage of skilled and seasoned employees to keep up with the increasing demands as thousands of workers are expected to retire over the next 5 to 10 years (Nambisan, Hallmark, & Albrecht, ; Vandervalk, Cronin, & Thompson, 2020).

According to the American Road & Transportation Builders Association's (ARTBA) seventh annual analysis of the latest U.S. DOT's National Bridge Inventory (NBI) database, more than one-third, or 220,000, of the nation's 618,000 bridges need structural repair, rehabilitation work or replacement

(TOP 10 takeaways, 2017). The USDOT categorizes the condition of bridges as good, fair, and poor (structurally deficient). Of the total bridges that need structural repair, rehabilitation work or replacement, 45,000 of them are classified as structurally deficient. At the current pace, it would take nearly forty (40) years to repair the rising backlog of structurally deficient bridges, according to the report (TOP 10 takeaways, 2017). Moreover, many transportation projects have experienced significant delays in schedules over the last three years (Quattlebaum & Dee, 2019). The majority of the delays were caused by deficiencies related to projects' scopes of work (SOW).

To address the increasing burden of transportation projects aggravated by the lack of seasoned employees, the DOTs have increased the rate of procurement for engineering and design professional services. In order to avoid procurement delays, particularly related to insufficient project details associated with inadequate project scopes, a comprehensive and well-developed project scope is essential. The objective of this study is to evaluate the components of professional consultant scope of services (SOS) for state DOT projects. This paper elucidates essential engineering and design SOS criteria identified from relevant SOS documents collected from different state DOTs.

## Literature Review

A well-defined project scoping process (PSP) is essential for a state Department of Transportation (DOT) to effectively meet the infrastructure needs of their state. The lack of consistent project scoping definition makes the pre-contract scoping processes challenging for the state transportation agencies (STAs). According to a study conducted on pre-contract PSP by Hamed Zamenian et al., the Indiana DOT had to face problems due to inconsistency in the scoping process across different units within the agency. This problem was also associated with lack of resources for coordination and long-term planning (Zamenian & Abraham, 2016). The authors could not identify a pattern for such inconsistencies in the scoping practices, but support was identified to link it to the absence of formal policy to assess the quality and effectiveness of their scoping procedures (Zamenian & Abraham, 2016).

In developing the PSP framework, Kermashachi et al., highlighted that the lack of scope definition and lack of details associated with project scoping often resulted in cost and time overruns. The authors also indicated that transportation projects are often programmed before defining the scope sufficiently which resulted in delays and increased costs (Kermanshachi, Anderson, Goodrum, & Taylor, 2017). Moreover, inaccurate estimates result in changes associated with project budgeting and schedule causing the DOTs to adjust in the scope definition of transportation projectss (Hessami, A. R., Sun, D., Odreman, G. J., Nejat, A., & Saeedi, M., 2017). The level of scope definition has considerable influence on the cost and schedule of a project and can hinder the ability to control project change orders (Kermanshachi, Safapour, Anderson, Goodrum, & Taylor, 2020; Le et al., 2009).

Kermanshachi et al. also developed a multi-level project scoping model for transportation projects. The authors used the integrated definition modeling technique to develop the scoping process. The development of this technique led to the adoption of appropriate best practices and strategies which reduced scope changes and prevented unnecessary delays for infrastructure projects (Kermanshachi et al., 2019). The authors also identified major activities associate with the PSP which were classified into four categories: environmental, right-of-way (ROW)/utilities, design, and construction. The study of these categories indicated that collectively all four categories are critical dimensions of an effective PSP (Kermanshachi et al., 2020).

An internal report on reducing scoping deficiencies to improve the delivery of transportation projects for the South Carolina Department of Transportation (SCDOT), identified eight major obstacles that delayed projects from advancing to the construction phase of work (Quattlebaum & Dee, 2019). The analysis showed 495 events of delays in different phases of work across a span of over three years. The delays that were evaluated ranged from 90 days to over 1700 days. Among the eight obstacles identified, scoping deficiencies attributed to 45% of the delays. These deficiencies included any modifications to the original design criteria established to meet the purpose of the project (Quattlebaum & Dee, 2019).

At present, few, if any, detailed investigations have been undertaken to evaluate the comprehensiveness of scope of services (SOS) related to development of engineering and design elements. This study is intended to bridge this gap and assist state DOTs in the development of the tasks and subtasks necessary to identify the SOS criteria which is important to achieve a comprehensive SOS.

## Research Methodology

A five-step research method was used to investigate and evaluate development of consultant scope of services (SOS).

### *Step 1: Data Collection*

The first step in the research methodology was to collect data that was relevant to the scope of services (SOS) for professional services consultants. To initiate this step, the authors further divided this step into three sub-steps.

*Conduct a literature review* – Scientific databases such as Google Scholar, Transportation Research Board (TRB) database, FHWA, and other scholarly publications that include American Society of Civil Engineers' (ASCE) Construction Research Congress (CRC), and SAGE Publications were searched to retrieve relevant literature data. A total of 37 publications based on various topics including PSP and related studies were retrieved from these sources.

*Investigate each of the 50 state DOT websites for relevant data* –Twenty-six (26) states had a variety of documents related to professional SOS ranging from templates, requests of proposal (RFP), and contracts with actual project scopes. These documents were available in the public domain. Published documents were not available on the DOT's website for the remaining 24 states. Some of these remaining states did have a consultants' page on their respective agency websites but the documents were not publicly accessible. The 26 states that had information available are California, Nevada, Utah, Colorado, Texas, Oklahoma, North Dakota, Wisconsin, Iowa, Missouri, Louisiana, Mississippi, Tennessee, Kentucky, Ohio, Florida, Georgia, South Carolina, North Carolina, Virginia, New York, North Hampshire, Maine, New Jersey, Vermont, and Minnesota.

*Collection of data from secondary sources* – This includes the data collected from the industry consultants' websites.

### *Step 2: Data Organization*

Based on the website search of state agencies, the authors identified 155 documents relevant to the study. These documents included templates, contracts, and RFPs. The documents were studied for their content and organized according to the services provided. The organization of these documents was done in the following manner:

*State-wise listing of documents* – The documents collected were arranged according to the state.

*Organize the documents* – After development of a comprehensive listing, the documents across states were re-arranged based on the document name/title. Documents with similar titles were grouped together.

*Categorize the documents* – Once the documents were organized, they were placed into their appropriate group or “service categories”. This task aimed to process the raw data into a more meaningful form for detailed study within the defined service categories. Each service category represented the type of service the documents provided. This process was repeated until all 155 available documents were grouped into their most suitable categories.

### *Step 3: Develop SOS criteria for evaluation*

Considering the influence that engineering design elements have on the scoping process (Burati, Farrington, & Ledbetter, 1992; Kirby, Furry, & Hicks, 1988) the focus of the research effort was strictly limited to the category of ‘engineering design/design’ SOS only . This resulted in reduction of the candidate state DOTs from twenty-six (26) down to eight (8) as the other state DOTs lacked published SOS documents related to engineering design. Among these eight (8) states DOTs, a total of forty-nine (49) design SOS documents were available for evaluation. In Step 3, the elements of design SOS were compared to develop criteria for evaluation. Each SOS had two (2) elements – task, and subtask. The documents with a similar type of SOS were compared to identify common tasks and subtasks between them. Similar tasks and subtasks were then grouped into the most suitable criteria. For example, Engineering Design & Analysis criterion had all design-related activities from various SOS documents. This comparison was made across all eight states to determine the criteria.

The eight (8) essential criteria identified were:

- Project Organization & Management
- Engineering Design & Analysis
- Survey & Mapping
- Plans, Specifications, and Estimates (PS&E)
- Right-of-Way (ROW)
- Utilities & Railroad Coordination
- Environmental Studies/Documentation/Permits
- Public Information

In addition to the SOS tasks and subtasks, there are additional criteria that are relevant to evaluate the comprehensiveness of a state DOT’s SOS development process (Jin, Haidary, Bausman, & Chowdhury, 2021). They included the following:

*SOS Document Year* – To evaluate the comprehensiveness of the SOS, it was essential to determine the year when the documents were published by the DOTs. Having a recent SOS is a key indicator that the document identifies current DOT policies and processes for the agency.

*Improvements* - Value engineering (VE) means adding value to the project in various possible ways including but not limited to reducing overall project cost, improving the design delivery process, make construction simpler, reduce the project duration, improve safety and quality, and consider environmental goals (Jin, Haidary, Bausman, & Chowdhury, 2021). According to Tiendung Le et al., Risk Management (RM) and scope definition are crucial elements of the project development process (PDP) as it allows to identify the risks at their sources (Jin, 2021; Le et al., 2009). PDP consists of various components and PSP is one of the important components of it. Incorporating risk management criteria built into the SOS allows the DOTs and the consultants to identify, analyze, and mitigate the risks during the design phase.

### *Step 4: Weighting SOS criteria using AHP model.*

After identifying the criteria for evaluation, the next step was to weight the criteria. To address this step, the authors adopted AHP as the most appropriate method to weight the criteria (Jin, Haidary, Bausman, & Chowdhury, 2021). AHP allows judgment in assigning weights to criteria that are incommensurable. The goal was to assign an importance score to each of SOS criteria. The steps utilized to determining the comprehensiveness of PDP were consistent with a prior study (Jin, Haidary, Bausman, & Chowdhury, 2021). For this study, the problem was divided into main criteria: SOS components, SOS document year, and other improvements as shown in both Tables 1 and 2.

Once the hierarchical structure was developed, the authors performed a pairwise comparison which involved comparison of each criterion with the remaining criteria to calculate the weight with respect to one another. Table 1 shows the process of assigning weights to each criterion relative to other criteria using pairwise comparison matrix. The weights were assigned to each criterion with respect to another using the AHP rating scale. By definition, the comparison matrix has two distinct properties: (1). it is a symmetrical matrix, and (2). all the diagonal elements are one, as the relative importance of a criterion with respect to itself is one.

Table 1

*Pairwise Comparison Matrix for assigning criteria weights*

| | | Criterion Number | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Criterion** | **#** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
| Project Organization & Management | **1** | 1 | 2/9 | 3/9 | 3/9 | 3/9 | 4/9 | 2/9 | 5/9 |
| Engineering Design & Analysis | **2** | 9/2 | 1 | 6/2 | 9/9 | 8/4 | 4/1 | 9/9 | 9/3 |
| Survey & Mapping | **3** | 9/3 | 2/6 | 1 | 1/3 | 5/5 | 4/2 | 1/5 | 6/2 |
| PS&E | **4** | 9/3 | 9/9 | 3/1 | 1 | 6/3 | 6/2 | 1/3 | 1/2 |
| ROW | **5** | 9/3 | 4/8 | 5/5 | 3/6 | 1 | 4/2 | 1/3 | 6/2 |
| Utilities & railroad Coordination | **6** | 9/4 | 1/4 | 2/4 | 2/6 | 2/4 | 1 | 1/3 | 4/4 |
| Environmental Studies/ Documentation/ Permits | **7** | 9/2 | 9/9 | 5/1 | 3/1 | 3/1 | 3/1 | 1 | 8/2 |
| Public Involvement | **8** | 9/5 | 3/9 | 2/6 | 2/1 | 2/6 | 4/4 | 2/8 | 1 |

The weighting of criteria consisted of: (1). assigning weights to each criterion with respect to another to develop a pairwise comparison matrix; as explained above; (2). normalizing the comparison matrix; and (3). calculating the weights of each criterion by averaging the normalized values in each row. To validate the accuracy of the criteria weights, consistency index (C.I.) and consistency ratio (C.R.) were calculated.

$$\text{C.I.} = (\lambda_{max} - n) / (n - 1), \quad \text{and C.R.} = \text{C.I.} / \text{R.I.}$$

where, $\lambda_{max}$ is calculated by dividing all the elements of the weighted sum matrices by each criterion weight, n is the total number of criteria, and RI is the C.I. for a randomly generated matrix.

Assigning the pair-wise scores was a subject task that incorporated the perception and understanding of subject matter experts (SMEs) in design and construction management. The final outcome of this step was a series of importance levels ($\gamma$) for each criterion. Specific ($\gamma$) values for each criterion are presented and discussed in the Results and Findings section.

### *Step 5: Ranking the comprehensiveness of SOS.*

The final step in the development of evaluation method was to measure the comprehensiveness ($\varepsilon$) of the SOS documents. While there could be several numerical and categorical approaches to do this, one convenient metric is the number of pages with each document that is allocated to each criterion. To that end, each SOS document was closely observed, and the number of pages allotted to each criterion was calculated. It must be noted that the absolute number of pages is misleading. For example, a criterion could be 9 pages in 200 page document vs. in a 20 page document. To resolve this matter, the team defined two distinct approaches to measure ($\varepsilon$) by: (1). Calculating internal comprehensiveness ($\varepsilon_i$) by normalizing the criterion's number of pages by the total number of pages in the document, and (2). Calculating external comprehensiveness ($\varepsilon_e$) by the criterion's number of pages by the total number of pages of the same criterion across all the SOS documents.

## Data Analysis

Based on the data collected, the authors conducted data analysis to investigate SOS criteria and their occurrence in the documents collected from various states. A total of 49 SOS documents from eight (8) states were studied. The findings are presented in Table 2.

Table 2

*Basic Criteria of Engineering and Design Scope of Services (SOS) (n = 49)*

| **Criteria** | | **Min.** | **Mean** | **Max.** | **SD** |
|---|---|---|---|---|---|
| Documentation year of SOS document | | 2008 | 2018 | 2021 | 3.5 |
| SOS Components | Total number of document pages | 3 | 56.7 | 312 | 67 |
| | The number of tasks in the SOS | 1 | 15.7 | 39 | 15.1 |
| | The number of pages of project organization & management | 0 | 6.3 | 33 | 8.5 |
| | The number of pages of engineering design & analysis | 0 | 18.5 | 101 | 23.9 |
| | The number of pages of survey and mapping | 0 | 3.4 | 14 | 4.9 |
| | The number of pages of PS&E | 0 | 2.7 | 12 | 3.5 |
| | The number of pages of ROW | 0 | 0.5 | 4 | 0.8 |
| | The number of pages of utilities & railroad coordination | 0 | 2.7 | 19 | 3.4 |
| | The number of pages of environmental studies/documentation/permits | 0 | 4.1 | 48 | 7.3 |
| | The number of pages of public information | 0 | 1.3 | 10 | 2.2 |
| Other Improvements | Value engineering | 0 | 0.2 | 1 | 0.4 |
| | Risk management | 0 | 0.2 | 1 | 0.4 |

As shown in Table 2, the combined mean of document pages and number of SOS tasks were 56.7 and 15.7 respectively, whereas the state with the highest number was Florida with a mean of 106 pages and 33 tasks. This proves that there was a significant variation between the states.

## Results And Findings

Based on AHP, the weights of criteria were calculated to evaluate the comprehensiveness of design SOS. The criteria weights were then used to rank the comprehensiveness of each SOS document. To validate the accuracy of criteria weights, the authors measured the consistency index (C.I.) and consistency ratio (C.R.). Upon calculation, the authors concluded that (C.R. = 0.07568 < 0.10) the matrix was reasonable consistent. Table 3 shows the weights of each criterion and sub-criterion. It was found that SOS components were the most important criteria (72.35%) when compared with other improvements (19.32%) and documentation year (8.33%). Among the sub-criterion of SOS components, environmental studies/ documentation/ permits, engineering design & analysis, and PS&E ranked higher in terms of their weights with 19.14%, 14.82%, and 10.64% respectively. This indicates that the sub-criteria had a high level of importance in terms of tasks and subtasks in the SOS. After establishing weights for each criterion and sub-criterion, the internal and external comprehensiveness score (i.e., $CC_i$ and $CC_e$) SOS documents across the states were completed.

Table 3

*Weight of each criterion*

| **Criterion** | **Weight** | **Sub-criterion** | **Weight** |
|---|---|---|---|
| Documentation Year | 8.33% | Year of publication | 8.33% |
| SOS Components | 72.35% | Project organization & management | 2.79% |
| | | Engineering design & analysis | 14.82% |
| | | Survey & mapping | 6.99% |
| | | Plans, Specifications, & Estimates (PS&E) | 10.64% |
| | | Right-of-Way (ROW) | 7.82% |
| | | Utilities & railroad coordination | 4.42% |
| | | Environmental studies/ documentation/ permits | 19.14% |
| | | Public information | 5.72% |
| Other Improvements | 19.32% | Value engineering | 9.66% |
| | | Risk assessment | 9.66% |
| Sum | 100% | | 100% |

Figure 1 shows the comprehensive score indices for internal and external comparison of the SOS documents. The ($CC_i$) is the product of weighted average of level of comprehensiveness and the level of importance within each document, and the ($CC_e$) is the product of level of comprehensiveness and the level of importance across all the documents. Based on Figure 1, the authors found the following:

- The comprehensive scores indices are highly variable for both internal ($CC_i$) and ($CC_e$).
- The highlighted boxes in Figure 1 show the number of documents from respective states. The FDOT documents in Figure 1 have a significantly consistent comprehensive score index when compared to the rest of the documents. Further, the overall score index for FDOT is the highest among others. This indicates that the FDOT document range in Figure 1 has both consistency and comprehensiveness.
- Again, FDOT ranked first in terms of the average number of SOS tasks with 32.76 (~33) tasks per document.

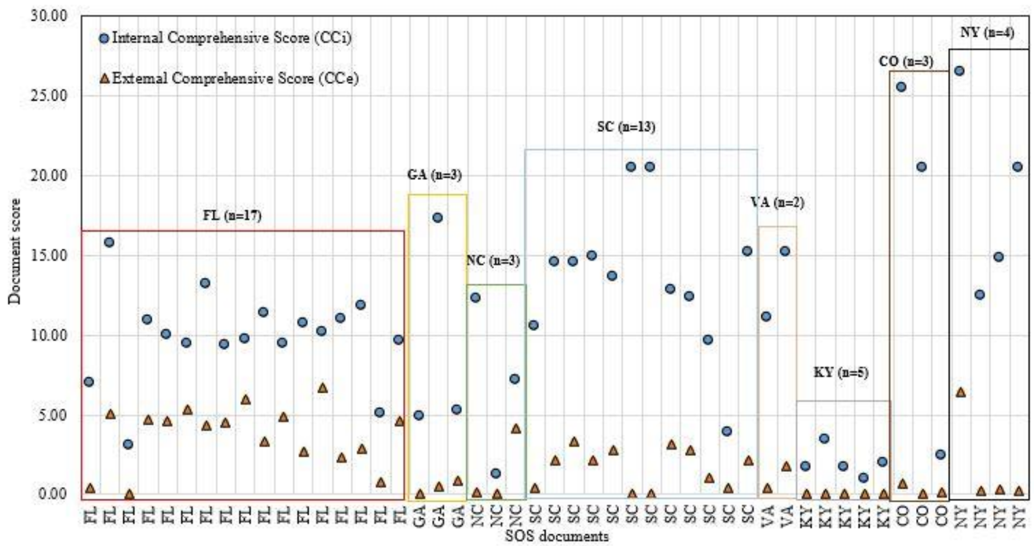


Figure 1. Comprehensive Score Index

## Conclusion

To meet the ever increasing demand of infrastructure projects across the U.S., the state transportation agencies need to avoid procurement delays and issues related to insufficient scope development. In order to address the issues related to lack of detailed scope, it is necessary that the state DOTs develop a comprehensive design SOS which can be modified according to the project's need. However, it can only be possible through a detailed evaluation of design SOS components. Therefore, this research paper is aimed at evaluating the engineering and design SOS and measuring the comprehensiveness of the identified criteria. Based on the comprehensive score indices for internal and external SOS documents, it was found that FDOT had both consistency in their SOS documents as well as comprehensiveness when compared with the other seven (7) state DOTs. The key takeaways from this study are:

- Out of the 26 state DOTs that have SOS documents published on their websites, only 8 state DOTs have SOS documents related to engineering design.
- The state DOTs should focus on developing a standard scope language for environmental studies, engineering design & analysis, and PS&E as they contribute 61.64% of the total SOS components.
- Also, a very few state DOTs had documented value engineering and risk assessment in the SOS documents.

## Future Research

Based on the evaluation of design SOS, the authors aim to develop a baseline template for design SOS that can be used by all DOTs in procuring consultants. To achieve this goal, the authors will conduct a series of interviews with the industry consultants and candidate states identified in this study.

## References

Burati, J. L., Farrington, J. J., & Ledbetter, W. B. (1992). Causes of quality deviations in design and construction. *Journal of Construction Engineering and Management, 118*(1), 34-49. doi:10.1061/(ASCE)0733-9364(1992)118:1(34)

Gen, S., & Kingsley, G. (2007). Effects of contracting out engineering services over time in a state department of transportation. *Public Works Management & Policy, 12*(1), 331-343. doi:10.1177/1087724X07302585

Hessami, A. R., Sun, D., Odreman, G. J., Nejat, A., & Saeedi, M. (2017). Project Scoping Guidebook for Metropolitan Planning Organization Transportation Projects (No. 0-6929-P1). Texas A & M University.TOP 10 takeaways. (2017, Aug 06,). Sun (London, England : 1964) Retrieved from https://search.proquest.com/docview/1926307708

Jin, W., Haidary, T. A., Bausman, D. C., & Chowdhury, M. (2021). Evaluation of project development process at state transportation agencies. *Transportation Research Record, 2675*(3), 326-337. doi:10.1177/0361198120971260

Kermanshachi, S., Anderson, S. D., Goodrum, P., & Taylor, T. R. B. (2017). *Project scoping process model development to achieve on-time and on-budget delivery of highway projects* SAGE Publications. doi:10.3141/2630-18

Kermanshachi, S., Safapour, E., Anderson, S. D., Goodrum, P., & Taylor, T. R. B. (2020). *Establishment of effective project scoping process for highway and bridge construction projects* American Society of Civil Engineers (ASCE). doi:10.1061/(asce)sc.1943-5576.0000427

Kermanshachi, S., Safapour, E., Anderson, S., Goodrum, P., Taylor, T., & Sadatsafavi, H. (2019). Development of multi-level scoping process framework for transportation infrastructure projects using IDEF modeling technique. In Proceedings of Transportation Research Board 98th Annual Conference.

Kirby, J. G., Furry, D. A., & Hicks, D. K. (1988). Improvements in design review management. *Journal of Construction Engineering and Management, 114*(1), 69-82. doi:10.1061/(ASCE)0733-9364(1988)114:1(69)

Le, T., Caldas, C. H., Gibson Jr, G. E., & Thole, M. (2009). Assessing scope and managing risk in the highway project development process. Journal of Construction Engineering and Management, 135(9), 900-910.

Nambisan, S., Hallmark, S., & Albrecht, C.*Preparing tomorrow's transportation workforce: A midwest summit*

Vandervalk, A., Cronin, B., & Thompson, C. (2020). *Project final report acknowledgment of sponsorship*

Zamenian, H., & Abraham, D. M. (2016). *Pre-contract project scoping processes: Synthesis of practices* Purdue University. doi:10.5703/1288284316192