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Jury Procedures for Systems Engineering Decision Making

Dr. Eric D Smith, University of Texas, El Paso

Eric D. Smith is currently an Associate Professor at the University of Texas at El Paso (UTEP), a Minority Serving Institution (MSI) and a Hispanic Serving Institution (HSI), He works within the Industrial, Manufacturing and Systems Engineering (IMSE) Department, in particular with the Master of Science in Systems Engineering Program. He earned a B.S. in Physics in 1994, an M.S. in Systems Engineering in 2003, and his Ph.D. in Systems and Industrial Engineering in 2006 from the University of Arizona in Tucson, AZ. His dissertation research lay at the interface of systems engineering, cognitive science, and multi-criteria decision making. He earned his J.D. from Northwestern California University School of Law.

Mr. Oscar H. Salcedo, University of Texas, El Paso

Bachelors of Science in Mech Engineering, Master of Arts in Political Science, currently pursuing PhD degree in Engineering Education. Director of Corporate Relations for College of Engineering at the University of Texas at El Paso, and Coordinator for the Research Institute for Manufacturing and Engineering Systems.

Aditya Akundi, University of Texas, El Paso

Aditya Akundi is currently a doctoral student at the University of Texas at El Paso in the Electrical and Computer Engineering Department, Industrial and Systems Engineering (ISE) track. He earned a Master of Science in Electrical and Computer Engineering at the University of Texas at El Paso (UTEP) in 2012. He has worked on a number of projects in the field of Electrical & Computer Engineering, Systems Engineering, Additive Manufacturing and Green Energy Manufacturing. He is the current president of INCOSE UTEP student chapter along with being involved in UTEP Green Fund committee. His research interests are in Systems Engineering & Architecture, Complex systems, Systems testing and Application of Entropy to Complex Systems. Email: sakundi@miners.utep.edu

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Abstract

Tradeoff studies used in engineering choices are organized in a branching tree conceptual structure that curiously matches the conceptual schema employed by the law to find the best alternative in the natural world of human occurrences. Just as tradeoff study trees differentiate a level of attributes and a level of measures, common law legal practice has institutionalized the separation of the law and facts, which are separate determined by a trier-of-law and the trier-of-fact. Recognition of this similarity leads to the investigation of how the knowledge employed in each method can inform the other, both having evolved in rather insular research and practice fields. Broadly speaking, technical tradeoff studies can lend precision to this hybridization, while legal processes utilized in the jury trial system can provide wisdom as to the management of human perceptions and biases. This cross-disciplinary comparison helps engineering acknowledge and engage these human biases with a formulation and analysis of the components and workings of the law. While both decision processes span the breach between complementary qualitative and quantitative regions, they employ vastly different apparati that are best studied together.

Key Words: Systems, Engineering, Law, Evolutionary, Natural, Biases, Heuristics

<u>OUTLINE</u>

0, Introduction

While there is still a wide breach between the traditional engineering fields and the legal professions, modern developments in engineering are bringing the two closer together. Firstly, engineering, in the form of systems engineering and other fields dealing with systems of systems, is increasingly concerning itself with expansive and complex systems, including socio-technical systems and the integration of human decision making. US News and World report has identified a significant trend in Law Schools increasingly recruiting applicants with science, engineering, and mathematics backgrounds.[1] The law, on the other hand, has progressively had to include technical considerations as it maintains its relevance in modern society. Secondly, while the law has remained insular because of its professional organization, the law has become increasingly accessible, discoverable and analyzable. Engineering, is increasingly participating in society beyond the traditional engineering domains, particularly in the development of bio-medical engineering, genetic engineering, and human decision making. Thirdly, the drive for global competitiveness, particularly led by the Chinese example of an authoritarian government headed by engineers, is showing that national prominence must be built by actual accomplishments. The luxury of having governments led by an elite class who considers only legal matters is now a fiction.

This convergence raises the opportunity for each field to contribute to the other. Engineering principles, and tradeoff studies in particular, could be useful in the legislative and regulatory processes by which laws are designed. Laws are solutions intended to solve problems, and could therefore benefit from the problem-solving principles, methods, and techniques of engineering [Schrunk, 2005]. Many of these engineering problem-solving elements are already found in the legislative and regulatory process, but tend to be applied *ad hoc,* rather than systematically. For example, the analysis of alternative solutions is a basic element of systems engineering [http://www.sie.arizona.edu/sysengr/whatis/whatis.html]; federal regulatory agencies are required under the National Environmental Policy Act, 42 U.S.C. § 4321*et seq*., to evaluate alternatives to any agency rulemaking that is a major federal action affecting the human environment, but this requirement is seldom applied systematically; nor is there an equivalent requirement that Congress systematically evaluate alternatives before enacting legislation.

Similarly, many of the problem-solving mechanisms developed by the law could potentially be applied in the engineering process. Civil trial procedures have developed over centuries as a way to determine liability in civil disputes through the evaluation of evidence and the consideration of the proper decision rules (laws) to apply. This paper examines the potential application of jury trial elements to engineering tradeoff studies.

I, Tradeoff Study Elements

Tradeoff studies provide an ideal, rational standard for making a choice among alternatives. In fact, their structure is basically an expansion of the well-known expected utility model. Tradeoff studies involve a mathematical consideration of all aspects of the decision. They consider all aspects of the alternatives simultaneously, that is, in parallel. In this way, tradeoff studies seek to eliminate human error in choosing alternatives, since humans usually consider alternatives in series, not parallel, and are often irrationally swayed by fixating on criteria individually.

Getting a final preferred alternative from a ranked list of alternatives is not the only important result of a tradeoff study. Doing a tradeoff study will help define the project requirements and the criteria derived from these. Documenting the tradeoff process itself, and the data used, is often the most important contribution, especially in projects sold by a coherent proposal. The San

[1] Shawn P. O'Conner May 2012 article in http://www.usnews.com/education/blogs/law-admissions-lowdown/2012/05/30/in-law-school-admissions-stem-sells

Diego County Regional Airport site-selection tradeoff study documented the reasoning process for public review [SDCRAA, 2006] [http://www.san.org/authority/assp/index.asp]. Throughout a formal tradeoff process with iterative versions, thought processes are stimulated and the discovery of values is documented. Of course, corporate culture and the decision maker's personality may determine how well the recommendations of a tradeoff study will be received.

For a consensus on the fundamentals of tradeoff studies, the International Council on Systems Engineering [INCOSE, 2006] [http://www.incose.org] provides a Systems Engineering (SE) Manual [INCOSE, 2004] [http://www.incose.org/ProductsPubs/products/sehandbook.aspx]. The manual not only describes the tradeoff process, but also the four main classes of systems engineering requirements, Cost Requirements, Performance Requirements, Schedule Requirements and Risk Assessment, which usually define the most important super-criteria in any tradeoff decision.

Types of Tradeoff Studies

The INCOSE Manual defines three types of tradeoff studies [INCOSE, 2004, p. 173]. In the industrial world, the phrase "tradeoff study" is often shortened to "trade study" or even to "trade."

> "Formal. These trades use a standardized methodology, are formally documented, and reviewed with the customer or internally at a design review.
>
> Informal. These trade studies follow the same kind of methodology, but are only recorded in the engineer's notebook and are not formally reviewed.
>
> Mental. When a selection of any alternative is made, a mental trade study is implicitly performed. The trade study is performed with less rigor and formality than documented trades. These types of trade studies are made continuously in our everyday lives. These are appropriate when the consequences of the selection are not too important; when one alternative clearly outweighs all others; or when time does not permit a more extensive trade. However, when the rationale is not documented, it's soon forgotten and unavailable to those who may follow."

Simultaneity: The goal of a tradeoff study is to simultaneously consider, in their true weighted proportion, the utilities of all relevant criteria.

A mental search of values usually sheds light on only one or a few criteria at a time. It is important for the tradeoff analyst to document the values and weights of importance of criteria as they become mentally available. As indicated in the "Mental" tradeoff study section above, if "the rationale is not documented, it's soon forgotten and unavailable to those who may follow." It is thus important to document discovered information about the criteria, even if the information is only available piecemeal and pertains to only a few criteria at a time. The integration of information is accomplished later, sometimes with the help of mathematical procedures; in the case of weights, the Analytic Hierarchy Process [Saaty, 1980] will simultaneously test the consistency of all pairs of weights.

Components of a Tradeoff Study

Although tradeoff studies can be constructed in a mathematically *ad hoc* manner, a differentiation and specialization of components that clarifies the tradeoff process is preferred.
A list of basic components:
A1, Problem statement formulation
A2, Criteria for evaluation, with Weights of importance on branches
A3, Utility functions
B1, Alternative solutions / systems / laws
B2, Input Data
C1, Final Scores / Recommended alternatives

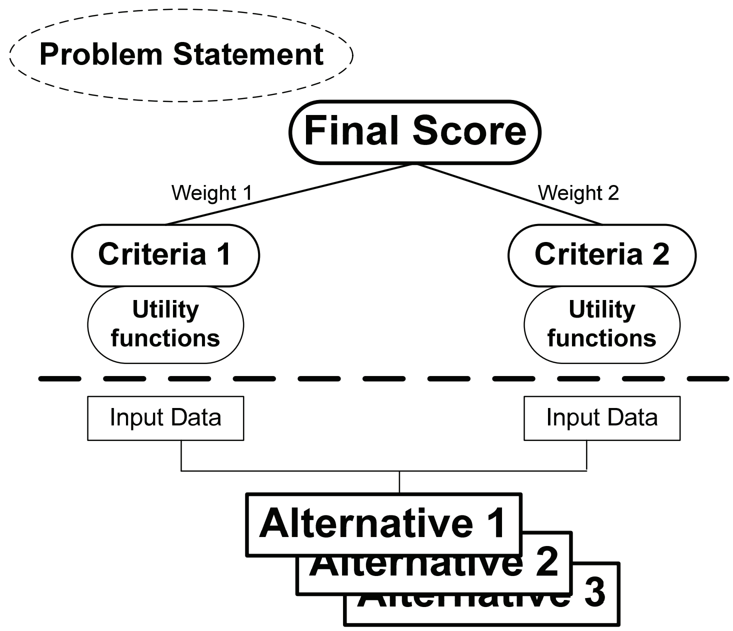

Figure 1: Tradeoff Study components

Ranking Procedure

The available Alternatives are ranked by this procedure:

> Input Data for each evaluation criteria are converted to Utilities with the help of a Utility functions, and are added via the Weights of importance of each Criteria, yielding a Final Score for each Alternative.

There is no set arrangement of the components. The components should be structured in the fashion that best models the values of the customer or decision maker.

II, Abstract Framework

Both engineering and the law must mate a top-down criteria or law-based perspective onto the reality of the world, in order to make a decision, either as to the system design to be chosen, or as to the scenario to be believed. The top-down perspective is created by that group or individual whose discretion is absolute, in engineering, this is the Customer who is providing payment, and in the law it is the People, who are sovereign. The will of the Customer is managed through a corporate executive Decision Maker, or through a Legislature, before being made translated by an individual Analyst or Judge, who is responsible for applying the appropriate Criteria or Laws to the particular decision at hand. An analogy could also be drawn between "Laws" and contractual engineering "Requirements."

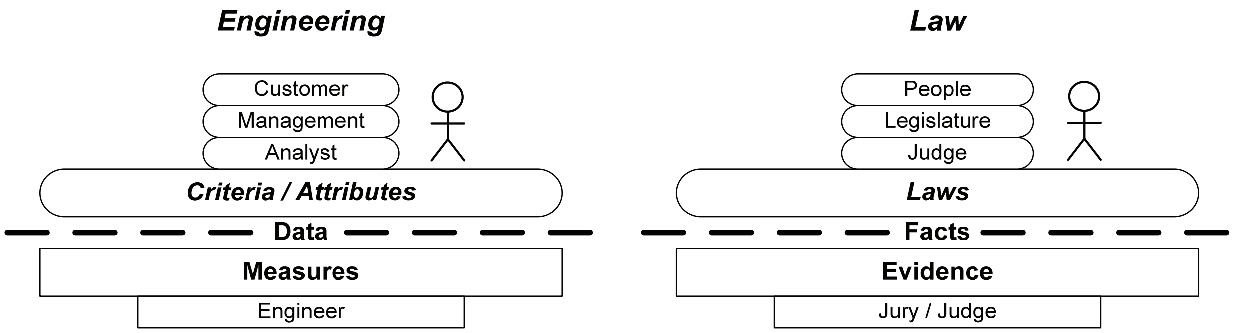

Figure 2: Static translation stacks of engineering and the law

Platonic ideals must be compromised with reality, and so the realistic side of the complementary duals has either the Engineer measuring actual systems, in order to provide the data, or the finder-of-fact, in either the jury or a judge, providing facts for the law to consider.

III, Jury Trial Process

There are many elements of the jury trial mechanism that could potentially be applied to engineering in general, and tradeoff studies in particular. The basic truth-seeking method of the jury trial is the adversarial process. A judge presides over the proceedings, and determines questions of what decision rules (i.e., laws) apply. A jury determines questions of fact based on witness testimony and evidence presented. The parties to the dispute are typically represented by advocates, present opposing arguments, including the evidence that supports those arguments. Opposing parties have the opportunity to cross-examine each other's witnesses. Much of the trial process is devoted to the presentation of evidence and arguments to the jury, who ultimately determine the facts of the case, and the final determination of liability.

In centuries past, juries were selected from the hamlet in which a crime occurred. The jury took an active approach toward investigation.

Figure 3: Active jury: Process to investigate facts and decide case

This tradition is still verbally honored today, and is still supposedly present in the grand jury system, but, for all practical purposes, and in all current petite jury use, the jury has been subjected to the protective custody and control of the legal system, immediately represented by the courts and judges.

While an active jury would be truly empowered to investigate evidence, decide factual matters, and apply the law as they may, modern juries are subjected to various processes and controls that reduce their independence and burden their power of decision. Modernly, juries are selected by adversarial lawyers, sequestered and admonished not to confer with outside sources, exposed only to selected evidence, and then tasked only to determine which essential facts of case are most probably certain.

Figure 4: Passive Jury: Process to consider evidence and find facts

Under the modern control of juries, it is surprising that juries are also tasked to mechanically apply the law to the determined facts before delivering their verdict. Because the verdict is in the hands of the jury, the jury can in fact ignore the applicable law in whole or in part, a practice known as jury nullification of the law.

The use of juries in tradeoff studies, however, is of course not constrained by the law, and engineering is therefore free to utilize juries to a greater extent than the law. For example, a jury of technical experts could be encouraged to participate actively in the investigation of evidence and the questioning of witnesses.

IV, Jury Trial Process Applied to Tradeoff Studies

Adversarial process: The adversarial process could be used more extensively in engineering tradeoff studies to test potential solutions by having subject-matter expert witnesses take on the role of devil's advocates to probe for and identify weaknesses in the trade study facts or assumptions made about the facts. Requiring engineers to defend their solutions in internal design reviews has been suggested as a way to overcome the most common biases that affect engineers at work [Ellis, thethinkerblog.com, 11/12/07]. Full trial procedures are likely only justified for the most important decisions, corresponding to formal tradeoff studies, but the basic adversarial process can be applied to informal tradeoff studies and even mental tradeoff studies. Employing this approach in these cases may require the individual engineer to "play devil's advocate" with himself, but even this can be a useful check if employed consistently and thoroughly. In an engineering context, however, care should be taken to maintain a high standard of professionalism to avoid damaging relationships, especially in an internal review process, where the participants will have to continue to interact at work.

Judge: The role of judge can be employed to coordinate formal tradeoff studies employing multiple parties, and to ensure the accurate application of the decision rules decided upon (e.g., project requirements, criteria values and weights, utility functions, and admissible input data). The judge should be an impartial senior engineer with relevant technical expertise and broad experience. Disputes regarding appropriate decision rules and data are inevitable in, and indeed an essential element of, the adversarial process, and a central decision-maker is essential to ensure the process can proceed to completion. This is because even the simplest of decision rules are incomplete when applied to the complexity of the real world, and hence interpretation of those rules is always open to potential debate. Resolution of such disputes inherently resolves to the application of judgment. The role of judge is therefore useful as a source of institutional knowledge and stability.

Jury: The heart of the jury trial process is the jury, who determines the facts of a case based on the evidence presented at trial and its evaluation of the credibility of witnesses, and who ultimately determined liability in a civil case. Apart from the political legitimacy that jury trials impart to the judicial resolution of civil disputes in a democracy (an element not found to be essential in the civil law tradition), juries function as representatives of the community, and thus embody a general expertise in the customs and standards of a society, as well as the common features of everyday life. The collective experience of the jury thus equips it to evaluate evidence, the credibility of witnesses, and ultimately to pass judgment on the conformance of the actions at issue to the rules of law.
In tradeoff studies, panels of customer representatives could be useful in determining project requirements and criteria. As representatives of the customer (often a larger entity, such as a corporation or government agency), such a panel would be uniquely qualified by its experience to evaluate what end results are desired, and to offer insight into the precise nature of the problem to be solved. Panels of technical experts could also be useful at subsequent stages of the tradeoff study, including the evaluation of alternatives and selection of a final recommended alternative. Panel membership should be based on relevant technical expertise and impartiality.

Advocates: The use of advocates helps to ensure that contending alternatives are each presented and argued for by motivated supporters. Engineers are subject to the same cognitive biases as the rest of humanity, and it is all too easy for a engineer to subconsciously favor one alternative over others for reasons of bias, rather than fully reasoned analysis. Relying on a single engineer or team to present all alternatives does not ensure that each alternative will be given equal treatment. This is particularly true in informal or mental tradeoff studies, but the influence of bias can be reduced in formal tradeoff studies by the use of advocates.

Cross-examination: One of the central features of trial procedures is the use of cross-examination, by which opposing parties may question each other's witnesses. John Henry Wigmore, revered scholar of the law of evidence, stated that cross-examination is "the greatest legal engine ever invented for the discovery of truth."[2] Cross-examination allows parties to probe the weaknesses of the opposing argument, expose the inconsistencies and logical contradictions of witness testimony, and to question the qualifications, credibility, and impartiality of an expert witness. The questioning of witnesses in real time makes cross-examination a much more dynamic mechanism than peer review.

Rules of evidence: In judicial trials, the judge applies the rules of evidence to rule on the admissibility of evidence. The Federal Rules of Evidence (FRE) include a number of principles that could be useful in the use of jury trial processes in engineering tradeoff studies. Some of these are described below; others are likely not useful or necessary in the specialized context of a tradeoff study. For example, evidence may be excluded under FRE 403 if its "probative value is

[2] California v. Green, 399 U.S. 149, 158, 90 S. Ct. 1930, 1935, 26 L. Ed.2d 489 (1970) (quoting 5 Wigmore, Evidence § 1367).

substantially outweighed by a danger of unfair prejudice," such as extremely graphic evidence of violence, which is likely to elicit a decision from the jury based on emotion rather than reason. The prospect of catastrophic failure may provide a similar situation in the engineering context.

The basic purpose of the FRE is "to administer every proceeding fairly, eliminate unjustifiable expense and delay, and promote the development of evidence law, to the end of ascertaining the truth and securing a just determination." [FRE 102]

Relevance: The threshold requirement for the admission of evidence is that the evidence be relevant. [FRE 402] ‘‘Relevant evidence means evidence having any tendency to make the existence of any fact that is of consequence to the determination of the action more probable or less probable than it would be without the evidence" [FRE 401].

The concept of relevance can be applied in modern engineering activity, in which the engineer is often charged with gathering customer requirements, many of which are elusive and need to be formulated from mere evanescence. In this setting, the engineer must decide what soft indicators tend to establish the existence of factors that are directly important to the decision case.

Credibility and Reliability: One of the basic tasks of a jury is to determine the credibility and reliability of evidence. The use of a panel of experts to perform this task in a formal tradeoff study can reduce the likelihood of error if a single engineer were to perform this task alone.

Exclusion of Evidence: Relevant evidence may be excluded "if its probative value is substantially outweighed by a danger of one or more of the following: unfair prejudice, confusing the issues, misleading the jury, undue delay, wasting time, or needlessly presenting cumulative evidence." [FRE 403] This rule serves two important functions: it allows the judge to ensure efficiency in the trial process, and it serves to reduce sources of bias in the jury's decision.

Expert testimony: Under FRE 701, only an expert may testify on the basis of scientific, technical, or other specialized knowledge. A qualified expert may testify on the basis of relevant expertise if his testimony is based on sufficient data and the application of reliable principles and methods to the facts of the case. [FRE 702] Under the Supreme Court's decision in *Daubert v. Merrell Dow Pharmaceuticals, Inc*., 509 U.S. 579 (1993), the trial judge must act as the gatekeeper to exclude unreliable expert testimony. The basic *indicia* of reliability set forth in *Daubert* include: (1) whether the expert's technique or theory can be or has been tested—that is, whether the expert's theory can be challenged in some objective sense, or whether it is instead simply a subjective, conclusory approach that cannot reasonably be assessed for reliability; (2) whether the technique or theory has been subject to peer review and publication; (3) the known or potential rate of error of the technique or theory when applied; (4) the existence and maintenance of standards and controls; and (5) whether the technique or theory has been generally accepted in the scientific community. These indicia are neither exclusive nor dispositive, and have subsequently been elaborated upon in later case law.
Expert testimony in trial-type procedures in formal tradeoff studies would be of obvious utility, and further emphasizes the importance of the role of judge in the process. Tradeoff studies procedures should contemplate the rules of the game of the admission of evidence in court.

V, Managerial Engineering Decision Improvements

Actual Cases and Controversies: Article III, Section 2 of the U.S. Constitution limits the federal courts, including the Supreme Court, to hear only actual cases and controversies, in order that the courts not enmire themselves in abstract and generalized grievances that are not concrete and definable, unlike suits that are pressed because of an actual injury. Cases must be ripe for review and not moot.

The corresponding caveat for engineering studies is for the engineer to not become involved with decision criteria or policies without the support of a critical situation that supports the form and substance of a supportable and purely engineering decision. The engineering decision should be capable of creating benefit and relief for the aggrieved parties, lest the engineer be relegated to working up purely advisory opinions that are discarded by the real decision makers.

As the constitutional actual cases and controversies doctrine warns the courts to steer clear of decisions that do not directly fall into the judicial sphere, but perhaps fall into the legislative or executive sphere, the actual cases and controversies requirement can also be used to warn an engineer against becoming involved in a decisions that are political in nature and will ultimately only be decided by a collective managerial process or by an executive.

The constitutional stipulation of the necessity of actual cases and controversies follows the common law tradition, in which court decisions set precedents that with use and reapplication would come to be considered law. Of course, an engineer does not exist across centuries, and so must make use of engineering precedents, or must find his place in the broad expansion of technology.

Co-Placement: The legal system prominently places representatives of all abstract aspects in the same room, actively engaging them in decision making. The public represents the people; the judge represents the laws and the judicial establishment; the parties represent themselves and also the people; the lawyers are the proponents of arguments and cases.

Engineering debates should similarly combine the presence of all relevant stakeholders, but probably does so less often. It is not often that the customer is present throughout a decision hearing, with top management serving as an arbiter between engineers pushing their cases forward with the help of representative counsel.

VI, Conclusion

Formal engineering tradeoff studies could benefit in many ways from the use of trial-type procedures. In particular, the use of juries can be of great utility in making decisions in complex problems.

Every law student is familiar with the notorious tort law case of *Baltimore & Ohio Railroad Co. v. Goodman,* 275 U.S. 66 (1927), in which Justice Oliver Wendell Holmes decided that a driver is contributorily negligent in a railroad grade-crossing collision if he fails to stop, and if necessary get out of the vehicle to look, before crossing a railroad track. Holmes believed that the discretion of the jury should be limited whenever a judge can determine a superior decision rule.[3] The rule laid down, however, was soon proven unworkable by the variety of factual situations in which grade-crossing accidents can occur, and the discretion of the jury was restored in *Pokora v. Wabash Railway Co.*, 292 U.S. 98 (1934), in which Justice Benjamin Cardozo detailed situations in which the rule was not only unreasonable, but could actually be dangerous.

Similarly, in engineering tradeoff studies, decision rules formulated a priori may not encompass the variety of factual scenarios encountered. Discretion and judgment in the application of decision rules is inevitable, and the use of a jury or panel of experts can help to reduce the risk of error if this function were the responsibility of a single engineer. Jury trial procedures in the law, the product of hundreds of years of organic evolution, have proven effective in the judicial determination of disputes; their use in formal engineering tradeoff studies could prove to be of similar worth.

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[3] See Robert L. Rabin, *Reassessing Regulatory Compliance*, 88 Geo. L.J. 2049 (2000).

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