

Textual Excerpts

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This report includes textual excerpts taken from transcriptions of semi-structured qualitative interviews on system complexity evaluation with personnel within Thales Group. The document is structured as follows; first, positive features of the Thales Group “Complexity Profiler” are presented, before challenges and opportunities with the tool are presented. Each sub-section relates to arguments raised in the related manuscript; “Evaluating the Complexity of Engineered Systems: A Framework Informed by a User Case Study”.

Quotations from the transcriptions are denoted “in quotation marks”, while the anonymized codifier for each interviewee is denoted [in square brackets]. Speech by the interviewer is also typeset between [square brackets].

First, we highlight the positive features of the Thales Group “Complexity Profiler” reported during the interviews. Several respondents claimed that the “Complexity Profiler” is easy to use, and that the eight “complexity factors” were relevant and easy to understand but were not exhaustive and were open to interpretation. Others reported that the “Complexity Profiler” is useful to them; for surfacing risks that may otherwise be unnoticed, justifying project resources to mitigate identified risks, and aiding communication between technical personnel and non-technical personnel, and demonstrating that a project team had considered the *complexity* of a candidate system prior to project reviews.

A. Complexity factors relevant and easy to understand

When asked how easy the eight “complexity factors” were to understand, respondents generally reported favorably for the Complexity Profiler; “Personally, for me, they’re very easy to understand because I think this was put together quite well... They’re easy to understand and well described. Scoring them is a different challenge.” [IA], “Personally, I find them relatively easy to understand.” [IC]. “At the time it was quite clear for me, if I remember there is a definition behind that so it’s not only one side and there is something explaining what it means really, so it wasn’t such a problem. Yeah. I don’t think it was really a problem.” [IN].

Other respondents noted that while the “complexity factors” are easy to understand, they can be difficult to evaluate and rate on a crude scale due to uncertainty and subjectivity in ratings. “I think they’re relatively easy to understand, there’s some of them that are very easy to answer and some of them where it’s difficult to predict...Because, for me, complexity, something is only complex if you don’t understand it and if you can’t understand it and can’t describe it then it’s an unknown isn’t it really and for me the benefit of a tool like this is to identify the areas that you don’t know and what you’ve got to do to go and find out more about them.” [IL].

“In their own right, they’re easy to understand, but they mean different things to different people. I think you can convince yourself what each of them is, but have quite a different interpretation to what others have.” [IH]. Another respondent held similar views; “The first one is an interesting one because it says ‘impact to the environment on the solution’. Now, you can read that in different ways. It could be the fact that you’re going to use it under the water or in a sandy desert or in space, so that sort of term of environment. Or it could be more in terms of the context in that it is been used by a relatively inexperienced set of operators in a cramped environment, a container or a sort of van, so that’s a different interpretation of environment. Then you are talking about the environment in which the users are operating it rather than the environment in which the equipment is operating, so you can answer that... that’s just an example of where the use of the term environment could be misconstrued.” [IM]

Similarly; “[How easy is the complexity profiler to use over all.] I quite like, I find it quite easy to fill in. I think it comes down to the reoccurring there of the absolute value of it. What makes it a one, what makes a four. By definition it has to be a generic tool. It is a bit abstract particularly this scoring. My four might be somebody else’s three, someone else’s two. Easy to use, but it comes down to, how do you know we’ve got the number absolutely correct.” [IH].

Another respondent also highlighted the challenge that subjectivity in the term system complexity presents to an organization, but suggested the subjectivity does not present significant issues; “I think they’re okay to understand, but my suspicion would be that there’s lots of opportunity for different views. If it’s gonna come up with an answer, to be able to compare that across a number of pro-grammes, across a number of business units, with a number of different people filling it in, getting consistency, it would be impossible. [Precisely because there’s ambiguous language, because different people have different perspectives, programmes are different, the type of system is different.] Yeah, but I don’t think that’s necessarily a bad thing, because if it’s being used by that project team who are delivering the programme and not falling into the trap of using it to communicate something such that you can compare one project with another, ‘cause there’s no value in comparing one project with another anyway. As long as it’s meaningful to the people who have filled it out and has helped them make the right decisions for the programme, I don’t think it actually matters too much.” [IK].

Generally, respondents felt that the eight “complexity factors” were sensible; “I don’t recall having used it and thought ‘oh they missed out a particular factor’ and frankly probably what I’d do is go and look at literature.” [IE]. However, some respondents noted that the factors are not exhaustive; “[How easy do you feel these factors are to understand?] You’re asking the question that you should never ask in one sense because the minute you have a list of things around engineering that you should measure, every engineer will come up with a different view as to what that list should be. As a list I don’t think it’s too bad actually if I’m honest, but it wouldn’t be the list I’d start off with. [Do you feel that this would have a different list?] Yeah. If you asked 20 engineers to come up with the eight complexity factors that they would use for assessment in a complexity profiler I think you would find that those eight would appear at some point, or most of those eight. You might have to sort of make a liberal interpretation of what the words that somebody used as being the same or similar but I think you would discover another 10 that are not on that list probably, which then says is eight enough? is there something missing that absolutely should be there?” [IM].

“(On the ease of understanding the eight complexity factors) I think they’re okay to understand, but my suspicion would be that there’s lots of opportunity for different views. If it’s gonna come up with an answer, to be able to compare that across a number of programmes, across a number of business units, with a number of different people filling it in, getting consistency, it would be impossible.” [IK].

B. Surfacing risks

One interviewee reported that the most important feature of the Complexity Profiler was the identification of risk areas, which they felt was done well, with an acknowledgement that the tool will not *manage* risk for an organisation but will help *identify* risk. “If you recognise system complexity, and that’s the key in most management, if you know what you’ve got to manage, it’s one thing. That’s not to say even when you’ve identified, it’s not necessarily easy to manage but if you haven’t identified the complexity in the first place, then frankly you’ve got no hope. So, the absolute key is you’ve got to identify the complexity, you’ve got to identify the risk areas. You’ve got to identify where you need to focus effort and then you can focus on managing those risks and as a program director, or [REDACTED] engineering manager, you can then look to what sort of team or what sort of resource or service you’re going to need to or what artefacts, you’re going to need to develop, or expertise you’re going to need to bring in to help develop those things. If complexity profiler points to you need high risk on the CONOPS [Concept of Operations] you’re going to need to get in then, some users. It’s pointless going on with glorious isolation without consulting any users, for example. It absolutely helps identifying it. It’s not going to do the managing for you though.” [IH].

Another interviewee explained; “So I found (the “Complexity Profiler”) quite useful in the fact that I could understand what areas to aim for so when I do the initial analysis and understanding where I was quite high or quite low and then I could build in the actions which would actually allow us to do that. I do find the complexity profiler is actually quicker and appropriate for the size of the projects I’m working on so you know, I could spend two or three days thinking of all the risks possible, going down all the risk branches but most of them would be irrelevant so this just helps bring out the high level issues. I think it doesn’t solve a problem but what it identifies is the areas of where you should actually target and make sure you actually put an action in place to resolve those items.” [IP].

C. Justifying project resources to mitigate identified risks

The “Complexity Profiler” has also been used to justify resources in a project to conduct system modelling and simulation activity to de-risk the systems development project; without the “Complexity Profiler” providing an ‘evidence base’, there is a suggestion that this resource would not be allocated. “It’s quite often useful certainly for doing system modelling solution modelling quite often the business will ask ‘cause it can be quite time consuming to do a modelling activity creating models in Enterprise Architect or something and following through. The justification sometimes is yes, but we’ve already demonstrated to you there’s high complexity in this area, therefore the justification for doing the modelling is to address that complexity. If you don’t have that, then they can push back and say, ‘Why do you need to spend all this time doing system modelling?’” [ID].

D. Aiding communication between technical and non-technical personnel

Some interviewees reported that the Complexity Profiler aids communication about system complexity; “[How easy is it to communicate about system complexity?] I like the [unintelligible] or the archery board bullseye diagram. As an overview, it’s quite a neat way of communicating the overall status so that’s I quite like that. Even this Thales tool, you end up with these eight axes of complexity so still where is the bar between high or low complexity because you’ve actually got eight measures of four in there. You just have to think, which has got eight things at factor four, is obviously complex. Something that’s got eight at level one is obviously low complexity but in between where’s that switch between low- and high-level complexity is perhaps more difficult to assess. Whilst the tool does tend to sort of threshold things, I think in itself it’s perhaps it’s a misnomer that you could simplify the presentation and complexity. It’s almost an oxymoron. I think the tool does a good job

of communicating complexity and does it perhaps as simply as is reasonable to achieve. I've certainly not seen any other way of doing it that's floated my boat any better." [IH].

Similarly; "[What about communicating about system complexity? Does the complexity profiler help you communicate about system complexity?] Yeah, so I think that's probably something that it does do reasonably well because at the end of it there is a way of describing to the stakeholders of you of how complex we think the job is that we've got. That's the bit I think where it does have its use." [IK].

The same interviewee reported praise for the "Complexity Profiler" in that it aids communication of risk, from the engineering community to the non-engineering community. This respondent went on to suggest that risk management is predominately seen as a project management tool. However, the "Complexity Profiler" could promote technical risk management, with "complexity at the heart of risk management". Further, they believed the tool could encourage an earlier emphasis on system integration planning. "[What's the current value, and what do you think it could be?] I think the current value is limited as a communication tool from the engineering community to the non-engineering community... most people should be able to look at that and then say, 'Oh, look, everything is on the outer of the wheel,' or, 'Everything's on the inner of the wheel.' But I think the last half an hour has made me think about what the value really could be of it in enabling us to really put complexity at the heart of risk management and therefore, now we're talking about technical risk management, where we quite often think about it as a project management tool. The other thing that it could do is drive us to think about integration early. Thales doesn't have a strong culture of integration. We put systems together, but thinking about integration as a skill, as a capability, as a thing about everything that we do, this could perhaps help us to drive there. Either a really simple approach to integration and it's early, little and often. If you could use this tool to help us drive which things we're doing early, how we chunk up our complexity to do the integration often so what are the little bites, and how are we gonna do it we could use it to drive an integration plan with strong links to our risk and opportunity plan, and now we're managing through complexity throughout the life cycle of a programme." [IK].

E. Demonstrating that system complexity has been considered prior to project review

One interviewee highlighted that the Complexity Profiler can be used to demonstrate that consideration had to been given to the eight complexity factors as a source of risk. "[Okay. Can you tell me what you think the aims of the complexity profiler are?] Without reading the CHORUS template I wouldn't be able to tell you actually. [So what's your interpretation?] My interpretation was just to identify and communicate those risks. Well, not risks but maybe the complexity, understand what their complexity profiler is created for, but yes. [And how effective did you feel it was then in helping you to identify and communication complexity?] Well a couple of times I've used it with (REDACTED), the technical director, so the Design Authority (DA). Yes, very good. It allowed (REDACTED DA) to see that I'd actually thought about it and considered that there were areas of concerns and put actions in place to close those concerns out and/or raise risks on the project." [IP].

F. Challenges and opportunities in system complexity evaluation

In the following sections we present textual excerpts from the interviews that support claims around challenges and opportunities in system complexity evaluation.

G. "Divide-and-conquer" approach to complexity evaluation

Several respondents argued that complexity evaluation should be a collaborative discussion. However, some suggested that, in reality, the "Complexity Profiler" is often completed in isolation or with limited collaborative discussion. While the intention was for the tool to be collaborative, here we find evidence that practice differs. "[Who do you think should fill in the complexity profiler?] In fact, here we have to distinguish; filling the data I would say anyone can do that, but we have to think about responsibility associated to the data. We have to think about the expertise of the people involved in the complexity profiling activities. For me the most important is to identify responsibility or responsibilities and involvement and I do think that we have to involve people having sufficient knowledge on each complexity factor. Of course, for security we need the security experts, safety etc., all that has to be worked by subject matter experts and in my point of view that approach is to involve a generalist in order to fill all the data in the complexity profiler. For me, it's a collective or collaborative work involving the subject matter experts. Each expert has to work on his complexity factor or factors after the coordination aspects are not so important, people are writing data in the tool that's not really a problem. At the end I also expect a well defined responsibility regarding the results or data, and for that for me the best case is to have the project design authority in charge of the results... responsible for the results of the complexity for filing activities and of course, this has to be checked and approved by the domain of business line design authorities, the DA, in order to be sure that we are well engaged in the design of validation process. So, involvement and responsibility are absolutely key here." [IO].

"The issue with complexity profiler is it tends to be filled in by the PDA [Project Design Authority] or the project manager in some cases but it then becomes their personal perspective on where they think the complexity is. Value from the complexity profiler comes when the delivery team or the leadership team do it as a joint effort in their own way because then they get

to discuss when why they think the complexity is where it is and how complex it actually becomes. So what it does is it aligns people on the same baseline so you have a single statement of truth from the complexity of a profile as perceived by the delivery team as opposed to individual perspectives on complexity... [So who do you think would tend to be filling in the complexity profiler?] It would be done by the PDA or the project manager as an individual.”[IC]. “[When you used the profiler in the past, did anyone else help you fill it in?] From my perspective, I filled it in myself. However, the PDA [Project Design Authority] would normally. [Is that the product design authority?] Yeah. Product or project. For this it would be a project design authority. So, they would have reviewed it just to what they probably would have reviewed however would be the web output and said, ‘Yeah, that looks about right,’ rather than diving into some of the other aspects of it.” [IF].

“[... so who do you think should fill it (complexity profiler) in?] Well, I think there is an element which says it shouldn’t be one guy sitting there thinking damn I’ve got to fill the complexity profiler in cos I’ve got a gate coming up, I’ll find a spare half an hour and tick the boxes. [Is that what you think currently happens?] I think it happens occasionally, yeah. I think it should be a proper discussion sitting down with a group of people with different viewpoints and a sort of moderated response. Some sort of moderator acting there to balance the different views because I don’t actually think its value is in just filling it in, the value is in the discussion around why you think it’s a certain level. There’s not 50 questions against each of the complexity elements to answer which obscures in some way the end result from the person who fills the form in, there’s a very obvious translation between the response and the output in this case and I’m not sure you can produce a 50 questions with contrary yes/no type responses that obscure how to fill it in to get the right result. I don’t think it’s like one of these psychometric profilers where you can construct a massive survey and you can’t gain it as a way to get the answer you want; you’ve got to answer it in an honest way. You know that if you put a certain answer in that’s where the red flag is going to be on your complexity profiler, so to me it is dangerous to do it as a singleton. I think it is dangerous because it can be driven by a single persons point of view and that means that if a person has got a particular hobbyhorse about that project they will make that look more complex than it probably is. If somebody is being lazy and doesn’t really want to have a problem they will make everything sound like it is okay so they don’t have a big problem and if somebody is really not competent to fill it in of course they might just randomly put things in that are complex that are not and things that are not complex that are complex and get the answer completely wrong, so to me even if you are an expert, even if I was filling one in on a sonar system where I am very experienced I would be nervous about filling it in on my own, not because I couldn’t, but because I think I will have my own biases and opinions based on experience that I wouldn’t be able to convince myself I could be totally unbiased about. To me the answer is proper meeting with a sufficiently broad group of people moderated in an appropriate way to get the output of that complexity profiler. [Why do you think that is not happening? I can imagine there is a resource restraint there of gathering and scheduling that resource to spend say half a day or a day doing this or however much time?] First of all, I don’t actually think the complexity profiler process explains in detail, I can’t remember exactly, but I don’t actually think the complexity profiler process mandates that is done in that way. It’s not like a gate, it doesn’t say to perform the complexity profile analysis the mandatory attendees are X by Z by role, and the process shall involve a meeting moderated by an independent chair to do Y and so on, so when you are faced with an Excel file with a pop down menu, fill in your choices and you are up against time, what happens? It’s a sort of combination of giving somebody and Excel file which is easily translated from input to output and no process to say how they should be careful about using it in the appropriate way.” [IM]. The same respondent went on to argue the tool is not designed to be collaborative; “I think the first one is to make sure the riding instruction that goes around it brings in the right group of people to make the assessment and it’s not a singleton activity. I think the nature of it being an Excel file and people think I’ve just got to fill this thing in order to get to the gate and I’m running out of time so I’ll just fill it in, is dangerous, so there needs to be something around that that needs to be fixed.” [IM].

H. ‘System complexity’ as a disputed property

In evaluating a limited number of poorly defined, subjective properties on a crude numerical scale the Complexity Profiler masks the problems associated with measuring a disputed property. Consider how two individuals with equivalent *amount* of experience might nevertheless draw on experiences with very different characters, resulting in assessments that vary yet are, to first approximations, equally valid.

Several respondents noted the subjective nature of the eight complexity factors as an area for potential misunderstandings with the tool. “[How easy is the complexity profiler to use over all.] I quite like, I find it quite easy to fill in. I think it comes down to the reoccurring theme of the absolute value of it. What makes it a one, what makes a four. By definition it has to be a generic tool. It is a bit abstract particularly this scoring. My four might be somebody else’s three, someone else’s two. Easy to use, but it comes down to, how do you know we’ve got the number absolutely correct.” [IH]. “[How easy do you find these factors are to understand?] In their own right, they’re easy to understand, but they mean different things to different people. I think you can convince yourself what each of them is, but have quite a different interpretation to what others have. That’s quite difficult because necessity they’re quite generic because if you start to give examples that can in itself be misleading giving examples about things, so I think they are relatively easy to understand in my view. If you’re familiar with systems architecture and system life cycle and INCOSE type methodologies and principles and they mean things to me. That might

also be because I have experience of working in complex programmes. I think if you don't have that experience, they are perhaps less meaningful or you don't quite understand what they're getting at." [IH]. Similarly, another respondent suggested the subjectivity of the term system complexity and the eight complexity factors makes evaluations difficult. "The most difficult part to understand on my side was the fact that when we are talking about putting a number on are you used to that, so what is the level of difficulty you will encounter or feature [inaudible] of the profiler. The question is not so clear if you are talking in the relative or absolute scale, so for me it was easier to understand that as relative to what you are used to and if you want to understand the profiler for let's say the whole of Thales, you probably have to understand it like this because you don't know what is your usual game will be on all projects so if you understand that the lower level is what you are used to do and probably compatible with it's a good start. Once more it's what makes complexity difficult because complexity is always relative to what you know, or I guess so, but sometimes you can define complexity in a completely absolute way. If you just [inaudible] the interfaces for example it's more or less absolute." [IN].

"[How subjective or objective do you feel your notion of system complexity is?] Pretty subjective. [Why do you say that?] I just don't feel we have a particularly good handle on which systems are complex and what to do about them." [IJ]. "[How easy do you find these complexity factors are to understand?] Not. I think I would struggle to start to attribute something to those. I'm not saying that I don't feel some of them are relevant but then actually using them might be a bit difficult. [Are there any in particular that feel uneasy to you or feel are difficult to understand?] System engineering effort and criticality. I'm not sure how you'd actually put a metric on that. [What is it about these factors that you find particularly ambiguous or difficult to understand?] I think each one is open to the persons own interpretation of what's meant by that and some sort of scale or range that you would actually apply to it. [And that scale or range you feel is open to interpretation too?] Yeah." [IJ].

Further, one respondent questioned the provenance of the eight factors and the challenge of evaluating a disputed property using a limited number of factors. "[How easy do you feel these factors are to understand?] You're asking the question that you should never ask in one sense because the minute you have a list of things around engineering that you should measure, every engineer will come up with a different view as to what that list should be. As a list I don't think it's too bad actually if I'm honest, but it wouldn't be the list I'd start off with. [Do you feel that this would have a different list?] Yeah. If you asked 20 engineers to come up with the eight complexity factors that they would use for assessment in a complexity profiler I think you would find that those eight would appear at some point, or most of those eight. You might have to sort of make a liberal interpretation of what the words that somebody used as being the same or similar but I think you would discover another 10 that are not on that list probably, which then says is eight enough? is there something missing that absolutely should be there? The first one is an interesting one because it says impact to the environment on the solution. Now, you can read that in different ways. It could be the fact that you're going to use it under the water or in a sandy desert or in space, so that sort of term of environment. Or it could be more in terms of the context in that it is been used by a relatively inexperienced set of operators in a cramped environment, a container or a sort of van, so that's a different interpretation of environment. Then you are talking about the environment in which the users are operating it rather than the environment in which the equipment is operating, so you can answer that... that's just an example of where the use of the term environment could be misconstrued. I don't remember whether those terms are spelt out precisely." [IM].

"[So, there's a challenge in aggregating some of the values?] Yeah, absolutely. That then comes down to the subjective nature of this because someone will say, 'We're gonna work with customer A over there. Do you know what? They're really good. They're really helpful. They're really useful.' Then if you turn around to one of the engineers, 'Oh, and by the way, you're gonna be working with that engineer,' suddenly they go, 'Oh my word. This is gonna be painful.' So, what view do you take on it? Is it gonna be painful or is it not gonna be painful?". [IF]. "Again, that's because I've subjectively gone in there and said, 'It's just a rack of PCs. What's hard about it?' I think whilst possibly a very time-consuming approach, someone could turn around quite simply in this kind of forum, as an interview kind of forum where you hold the complexity profiler here and you're putting stuff into it while asking me questions about, 'So, do you understand the system? What's this? What's that?' blah-de-blah. Then they could put what's in there. So, they're trying to remove the subjectivity out of the person who would have filled the complexity profiler out and trying just to draw out the objectiveness about it... From the complexity profiler, from a whole project view, I think it can highlight quite quickly some areas of complexity, but as stated before, I think sometimes it has the potential to mask complexity. I think it can quickly, so long as you're objective about it and use it in a consistent way, I think it can point you to some of the bigger areas of complexity, but I don't know fully that it drives me down the route of where, from a technical perspective, I'm gonna find my complexity. I think the complexities are more around the interactions of the delivery team with subcontractors and customer communities and things like that. I think it does drive those complexities out." [IF].

Several respondents felt that the Complexity Profiler was open to interpretation and bias issues, due to the subjective nature of scoring the limited number of factors on a crude scale. "If you're so desperate to win something, you might delude yourself that actually you can deliver." [IA]. "[I wanted to ask if you believe there's any potential to misuse the complexity profiler? Yes. Because the numbers are very subjective so because it's subjective you could put any numbers in and there is no measure by which saying, if the impact is over a million then the number should be a four, it's completely subjective and it's all relative to the amount of risk you really carry in your programme. So scores are only one to four but actually you know, it's different if you're on a programme which is 100,000 in value to one which is 100 million in value or billion in value. So it's everything

is relative on risk, that can be abused. [And have you ever experienced this or heard of this happening?] Oh yes absolutely but that's not the problem, you see the scores are only to give you an indicative indication as to where your problem is. The important bit comes down to your understanding of where the complexity is and why it exists. The numbers are a little bit immaterial, it's the process which is the important bit". [IC]. "[Do you think there's any potential to misuse the profiler? For example, to tune the numbers to what could be considered to be more desirable answers?] I think it's more likely that people do the best they can but do it from a single viewpoint and not understand enough of the viewpoint. So, typically, if an engineer that's done it in the past is answering this and thinks he understands the problem space, you'll probably get a skewed answer, whereas if you brought in people who were less familiar with that space they'd probably ask questions and raise issues that would be glossed over by the person that did it the last time. 'Oh no, that'll be fine, we know how to do that' kind of attitude. So, I don't think it would be an intentional misleading but it's more of a personal bias I guess I'd be worried about." [IG].

"That is a potential risk in everything whether it's complexity profiler or any DVA [Design Validation], or anything. But it comes down to personality and relationship and professionalism frankly. You can always cheat your way through things, if someone is going to do that in a determined way then, they can. One of the challenges from a technical governance point of view is to ask the questions to reveal whether that is the case." [IE].

"[Do you think there's any potential to misuse the profiler?] Oh yes. [How so?] Being overly pessimistic or overly optimistic. It again goes back to the subjectivity and that's why I think someone like the PDA [Project Design Authority] should do the complexity profiler because they should have the skills, the experience and the power to fill it out in a true and honest manner such that then, yes the engineering director or yes the portfolio lead or the operations rep might review the bid and go 'don't worry about it, we'll sort all that out.' That's their decision to make. Our responsibility is to communicate those risks and if they don't want to proceed then that's their choice or if they do want to proceed that's their choice. But we shouldn't be skewing with figures because we want it to happen or we don't want it to happen. But that's a nefarious approach, the other one is, you could just be optimistic or pessimistic by nature. [And we've discussed potentially if Thales could close the loop on this activity there might be a better way to nail down some of that subjectivity and reduce some of that.] I think so, yes. And when I do complexity profiler I try and start with a fresh one all the time rather than reusing an old one because if I reuse the old one I might be tainting myself and I wouldn't have gained the experience of a couple of years of experience or knowledge so I always try and start from afresh. But that doesn't mean that the scores or the waiting should not have been adjusted based on how it went previously because I can't amend that because it's buried within the tool." [IP].

Others wanted to clarify that they did not feel personnel would deliberately misuse the tool. "[I was going to ask if you think there's any potential to misuse the profiler? For example, to tune the numbers to output what could be considered to be more desirable answers, and you've already suggested that you've experienced that.] Always. So, the spirit of optimism of because the English language, unfortunately, is the only tool that we've got and it's so ambiguous, looking at the words in here, one man's minor revolution is another man's major revolution. It's good for it to be judgement-based and not try and nail it down and think that it's ever gonna be entirely objective, but the level of subjective, it will be filled out given the environment that it's being filled out in. At bid, we're always trying to convince ourselves that we can do it for the cheapest money. We're always trying to convince ourselves, oh, it'll be alright, it's just a rehashing of what we've done before. It'll be alright; it's the same as we did then. It'll be alright; it's only a little bit of development. The prevailing environment at the time will drive how it gets filled in. I don't think people would misuse it on purpose, it's not malicious, but if there was a spirit of optimism or a spirit of pessimism around it, it's gonna reflect it 'cause we're only human beings." [IK]. "[Do you think there's any other potential misuses of the profiler?] Yes, I think there could be misuse of it, but again, it's kind of along the same lines. Misuse in as much as the subjectivity of it, because it doesn't eliminate and it doesn't discern between subjectivity and objectivity, so it won't eliminate the subjectivity out of it. I think in that sense it's not used in the spirit of what it should be used potentially in some circumstances. Actually, whilst you might get to PDR or CDR and say, why on earth are we in the state we're in? When I go back to the complexity profiler and have a look at it, that should then turn around and say that wasn't objectively populated and maybe we need to reassess it. Actually, if we did reassess it prior to each of these reviews, we'd probably be understanding that..." [IF].

Similarly, others suggested that personnel were unlikely to wilfully misuse the tool. "[Do you think there's any potential to misuse the profiler, and have you ever heard of this happening, or experienced this?] I guess it depends. I guess you could use it to try and I don't have experience of it being used in that way, but I suppose theoretically it's only as good as the information you put into it. If I chose to make a system look simpler than it is, I could probably do that, and unless the person reviewing it it depends who reviews it of course." [ID]. "No, I've had discussions about whether complexity perhaps should be scored as a not significant but minor physical or whatever. I don't think I came across anyone who wilfully under scored it in order to make life easier." [IE].

Several respondents considered the eight complexity factors to be easy to understand but difficult to evaluate against the scale provided in the Complexity Profiler. "[Suggesting that it is quite an easy to use tool.]To me it is, yes." [IP]. "Personally, for me, they're very easy to understand because I think this was put together quite well... They're easy to understand and well described. Scoring them is a different challenge." [IA]. "[I wanted to ask how easy do you find these complexity factors are to understand?] Personally, I find them relatively easy to understand. [In your experience is it a reasonable assumption for personnel executing the complexity profiler to understand these factors?] No they don't. [Okay.] They largely understand

items (systems engineering criticality and effort) and (engineering organisation).” [IC] “... engineering organisation, how do you determine small, medium, large? Oh yeah, so there’s actually two large on this, on level three. So there’s large and then large external and possibly internal, well how do you gauge that?” [IB].

Two different perspectives that can be implied when evaluating system complexity were provided by a respondent who articulated a distinction between an engineered system that is challenging to develop due to cutting edge technologies, problems of this kind are claimed to be reducible by proven engineering methodologies. This kind of problem is contrasted with a complex system that can result in “things happening in the real world that you didn’t anticipate and didn’t design for in the design stage because you didn’t understand it was likely to be an issue...”. The respondent went on to say that because of this, and a lack of suitable metrics, that system complexity was a subjective notion. “I suppose the complexity and the association with challenge is what kind of comes out from that and I guess in our business having to make complexity tangible for developing something like an infra-red camera product or something and that might be technically very challenging but we wouldn’t typically see that as complex, whereas a system that has lots of components, lots of different equipment networked together or particular complexities in terms of the way it’s used or talking to systems or whatever would be towards that complex end of the spectrum. With complexity tends to come in some cases lack of determinism, lack of predictability.... If I stick with the infra-red camera example perhaps you might need a camera sensor or some signal processor that is absolutely at the cutting edge of what is possible to achieve and therefore it has very significant challenges but generally we understand the nature of those challenges and we understand how to reduce risks through application of well proven scientific and engineering methodologies. What I’d say in that case is you can’t guarantee success, but you are unlikely to be surprised by the things that cause you problems in the way that you might be with a very complicated system. If I take an example of what I would say was a complex system that’s created some issues recently, we’re involved in the development and supply of autonomous airborne systems, drones in common parlance, these are systems which have complicated hardware and complicated software and complicated networks but also have quite complicated interfaces to the operator and the user. We had one instance recently where there was a crash as a result of the operator cutting the engine and they did that because they thought the vehicle was on the ground out of control in which case cutting the engine was completely the correct thing to do but actually it was in the air at the time so they’d had a loss of situation awareness. Things like that where you see things happening in the real world that you didn’t anticipate and didn’t design for in the design stage because you didn’t understand it was likely to be an issue that would be an example of something with system complexity. Does that make sense?” [II].

“I think there are two challenges in my mind when you look at that. One is the intrinsic difficulty of the problem, understanding how complex the thing really is, do you understand the fact that it’s got lots of different interfaces or it’s a technology you are familiar with but being deployed in a new way or whatever it might be, the kind of classic complexity profiler kind of stuff. There’s a strand here which is do you really understand the complexity that you are taking on adequately and the complexity profile that was something that was designed to help us think through that challenge. I think then the other challenge is actually more about the company organisation and culture and decision-making processes because equally we’ve seen programs get into difficulty where there was a perfectly good job done of analysing the complexity and identifying what the technical risks are etc., etc., but then people decided not to mitigate the risks to save money in a precontract phase, whatever it might be.” [II].

“[How subjective or objective do you feel that notion [of system complexity] is?] That’s a really good question. I don’t think at the moment it’s underpinned by terribly good metrics so in that sense it has to be shall we say significantly subjective which is a very subjective statement. If you’ve got a piece of software you can run a cyclomatic complexity metric right and it tells you the answer was 13 and therefore you know whether that software is going to be maintainable or not, I don’t think today we’ve necessarily got the equivalent for complex systems. I think you can go part way in that direction with the kind of things that are in the complexity profile, does it have lots of interfaces? Is it new technology? Etc., etc. We talk quite a lot about not just technology readiness levels but system readiness levels, SRLs, which I think help to give you a crude calibration but I think it’s a fairly crude calibration and again saying that it’s SRL six is a subjective judgement based on what you think the uncertainties are which is perhaps, no I come to think of it, perhaps... and the slight culture issue with Thales is the great desire to put numbers on things but not always recognising that if all the number is doing is recording a subjective judgement, you know, it’s not that it necessarily has two decimal places of meaning, of precision associated with...” [II].

I. Blind Spots

A compounding issue is that the profiler is not sensitive to interactions between the defined properties, evidenced in the profiler’s simple “if, then” mappings, each conditioning a suggested mitigating action on a single complexity factor score. Trying to evaluate the impact of complexity factors in this reductionist manner may miss compounding risks arising from the interaction between factors. The reality is that the lack of consensus on complexity needs to be foregrounded and confronted explicitly by the tool, rather than relying on a limited number of defined properties treated in isolation.

“A wider review of it may have elicited a perhaps bigger scaling of the mitigation actions. If not the nature of the actions themselves, but as I say, rather than writing something off as oh yeah, it’ll take a couple of weeks of effort to solve that, to implement that mitigation. It might have been a more, hang on a minute, if you look at the other dimensions of the complexity

profile, when actually how many stakeholders you've got to engage, or how many different sites there are to engage with, actually that's not just an isolated thing, it's the power law effect of multiple dimensions of complexity really made things harder to mitigate than you might otherwise think. I think that's something that doesn't directly come out of the complexity tool, directly. You have to weave that in when you describe your mitigations." [IH].

"[Do you think that could be described more clearly in the profiler?] ... If you've got these dimensions then all of the mitigation risks need to be factored by some number. That's not how it works but perhaps there could be some notes around the risk tables or the mitigation tables, which alludes to the fact that if you've got multiple dimensions of complexity, that you're risks you need to look at, not in isolation. You can't look to just mitigate user delivery in isolation. Use diversity, sorry, in isolation if you're operational concept is not stable. You can't just put a separate mitigation on both because actually the compound will be more than the sum of the parts. It will be a sort of power law relationship between the two and that doesn't necessarily come out. Of course what happens in the bid, is that there's often a push to get costs back and reduce contingencies and so on and so forth, and if you haven't perhaps adequately expressed your risks in the first place, whether those risks get cut back, you're cutting back on something that's already too small." [IH]. "... My complexity is quite low in general because we know all of these people. What (the "Complexity Profiler") fails to identify is whilst you've averaged all of those and it's come low, the most interaction you're gonna have could be with the most complex person. We've actually found that on projects where the key interaction point is the person that is most likely to throw things into chaos from a customer perspective. So, the relationships are actually very complex because you're not able to put a weighting on the interaction on that." [IF]. "[I wanted to ask you, you've hinted at this but I just want to try and get a more detailed answer from you, do you think system complexity is in some way related to system outcomes?] I suppose yes, it is. That's certainly one facet of it and system outcomes itself can mean many things but system outcomes in terms of the actual intended effect of the system, so the more intended effects, or the more inherently complex. That might mean autonomous. That might mean advance processing. It might mean action at a distance whatever it is. The more complex those individual outcomes, yes, the more complex the system tends to be. It's not always a guarantee though. There are some outcomes that seem very complex that are enabled by tried and trusted solutions that are perhaps your lifeblood as an organisation. For example, if you were starting afresh, designing an air traffic control radar, that might seem a very complex system but if you're a manufacturer who's been involved in the supply of radar since the year dot, that's actually bread and butter. Which is another reason I think a measure of complexity as an absolute reference, is to a degree, a little bit meaningless or one of the measures should be your experience in delivering such systems. The reason I mention that is I don't the Thales tool doesn't really directly allow a sort of global factoring by whether you've done it before or not. It's implicit in some of the questions not explicit." [IH].

Similarly, the limited number of complexity factors encoded in the profiler also leaves specific SoS considerations as a blind spot. Several respondents used the term 'System-of-Systems' (SoS) in their descriptions of system complexity. While the SoS literature emphasizes *autonomy*, *diversity*, *connectivity* and *emergence* as distinguishing characteristics of a SoS, these characteristics are not explicitly evaluated in the Complexity Profiler. [?], [?], [?], [?], [?] "[Okay, you mentioned you're including your notion of system complexity System of Systems, can you elaborate further on what you feel the relationship is between system complexity and System of Systems?] It's an interesting point because when we're talking about complexity often refers to System of Systems type considerations with the ways in which the individual component systems of those System of Systems interact and behave leading to the complexity. As well as the environment having an impact on the behaviour as well." [IE]. "[You used the term system of systems earlier. Would you be able to elaborate on system of systems, please, and what that means?] It's a phrase that we used to use a lot and it's not something that I've heard people use, so it might be a bit of an old-fashioned term. Normally, I think of it as a single system maybe made up of a number of components with some interfaces but provides functions in its own right. Normally user functions. When you have a number of those systems interconnected that now need to display emergent complex functions, where functions from different systems are put together to achieve an overall goal. For example, on a [REDACTED - naval vessel], the air surveillance radar is able to identify contacts, and where it classifies those contacts as threats, pass those tracks to the missile tracker radar which will pick those up and provide information to the command system where the operator is then in the loop to decide whether to engage that target and fire the missiles. Then the missile is following the tracker radar in order to engage the target. Within that loop there's an air surveillance radar, a tracking radar, a missile system, and a command system, and really importantly in a system of systems, normally, a person. [In your example there, that emergent function or emergent property you're talking about would maybe be called a fire-control capability or a target-engagement capability. That is only achievable because you have these separate systems together.] Yeah, and that's the right word. Capability." [IK]. "[You mentioned a term there, systems of systems, could you explain that term further for me?] System of systems in the context I use it, particularly on [REDACTED - large programme] is where there are many individual systems or systems which can be identified as a complete functionality in its own right which then get integrated with other systems as building blocks to build a bigger hole and bigger capability so depending on your persuasion so you might just consider all these subsystem. To me a subsystem tends to be something which on its own, doesn't actually do anything. It needs other stuff around it to deliver any useful capability. [There's a sense of connecting several different systems to provide some higher level capability.] Correct, we've got a high-level overall capability. The case of [REDACTED - large programme] for example, complete air traffic control capability requires radios, a radar, landing aids etcetera. All of those things are systems in their own right. A total air traffic control capability requires a system

of those systems and in [REDACTED - large programme] it's more than that in the sense of, it's more than just being there and available as a capability as a user to turn it into a system of systems. We also implement in [REDACTED - large programme] underlying common comms bearers at the very least so in some sense they are integrated to make best use of infrastructure. [And to achieve that purpose?] To achieve that high-level purpose. Even though individually the systems don't necessarily need to be closely coupled." [IH]. One respondent used a prominent definition from academic literature to support their definition of a SoS. "[You use the term system of systems, could you explain what system of systems means to you?] Okay. We have a systems of systems when system parts or systems, meaning the fact that we have a system of systems when some parts of a system have operational goals and capabilities identified at the operational level. This is for me the main criteria for a definition of system of system which is in fact what is called operational independence of the individual systems. We have also to consider all the criterial were defined by Boardman and Sauser with managerial independence emergency aspects etc., but I would say, all arise as a consequence of the operational independence, so for me this is really the main criteria and certainly I would say the only absolute criteria because we can discuss within the system of system if we have always managerial independence. Sometimes this is true and sometimes not because there are several ways to develop and manage a system of systems. We can have more or less directivity of an organisation, we can have sometimes a federated organisation but sometimes it could be a very directed organisation, so in that case we have not really independent management. There are also some other criteria regarding resources, geographical separation could be true, could be false, it depends on the connectivity, it depends on the command roles governing the individual systems within the system of system. We can really discuss what are the real benefit and also criteria but in any case, the main criteria is operational independence of a constituent system." [IO]. Despite frequent mentions of System-of-System when describing system complexity, the Thales Group "Complexity Profiler" does not appear to address considerations such as *autonomy*, *diversity*, *connectivity* and *emergence* which seem to be distinguishing characteristics.

J. Discrete evaluations

Further, the Complexity Profiler is an inherently punctate, discrete tool applied at a point in time but purporting to evaluate a system overall (i.e., timelessly), with no reference to previous or subsequent evaluations. As a project progresses, more information is likely to be uncovered about the environment the system will operate in, about other systems the SoI will interact with, etc., which may significantly change the evaluation of complexity. Similarly, factors identified during an early-stage evaluation could influence or steer subsequent evaluations, ensuring that warning signs are attended to, for example. While the Complexity User Guide suggests the Complexity Profiler should be used at several stages of a system development process, the reality is that any revision activity is discretionary and is likely to only focus on that specific point in time. Instead, an evaluation of system complexity should, ideally, evolve alongside the project it relates to by being revisited periodically, and a view should be taken on the trajectory of these evaluations, rather than just considering each isolated point along the way. It is not just the destination system that should be assessed, or key waypoints, but the evolving project journey, overall.

"What tends to happen is the complexity profiler is done once and then left" [ID]. "[The complexity profiler suggests it should be used throughout the system life cycle but you're suggesting that that's generally not the case in your experience?] I think it tends to get looked at briefly to see if it still makes sense. If I'm being honest, I don't think it really gets re-evaluated thoroughly in my experience." [IH]. "What tends to happen is the complexity profiler is done once and then left; the DVA [Design Validation] does iterate. Because the DVA has to be signed off... [Regularly.] Well, it has to be signed off at every Gate 2, so it depends what change we're building into the programme. I think if we have a change in a project that requires us to go to another Gate 2 because it's a change in value or whatever, then we have to resubmit a DVA. I've not very often seen the complexity profiler being done. It's normally done as a means to an end. Whether that's right or wrong I don't know. [What do you think?] It probably isn't right. [Why is that?] Well, because things change over the delivery life cycle. So, things become obvious during delivery that we hadn't addressed during the bid 'cause we didn't know about or whatever. So, we might find that once we get into say we get into a software development phase, that there are complexities with that software development that we weren't aware of at the time. [I see.] I think it would probably be useful every time the DVA was revisited that we revisited the complexity pro- we probably should do it, but there's a tendency not to." [IE]. "[I just want to go back to the specific example where you've used the complexity profiler and ask, when did you use the profiler in terms of the life cycle phases of this system?] It's only ever been used at the bid phase. [Okay.] (laughs) Yeah, it's only used sorry, it's used at the bid phase and I'd say project kick-off. So, once we've won it. So, they may use it at project kick-off, but the SEM would use it just to write the SEMP [System Engineering Management Plan]. [The systems engineering management plan, is that?] Yeah, that's the one. So, very often that is drafted during the bid phase so that it can help to inform our estimates because we know the kind of activities we've got to do based on the complexity. When you get into project kick-off, they may look at that again and go, yeah, it's still about right. The SEMP [System Engineering Management Plan] gets shelved and then we just run to the project plan." [IF]. "[The complexity profiler user guide suggests it should be used for our system lifecycle? Is this generally the case in your experience?] I've never seen it used throughout lifecycle." [IL]

While many respondents showed examples of completed "Complexity Profiles" and others felt confident they could locate completed "Complexity Profiles"; "[Would you have access to completed system complexity profiles then?] Yeah, I can find them. Yeah, I could find them." [IM], one interviewee noted the distinct lack of re-examining a completed profile; "[Would

there be one available for the project you currently work on, or the programme?] That's what I'm thinking. I'm thinking it hasn't even crossed my mind since joined [Redacted - programme name]. We have in the last six months been through a major stabilisation, reassessed the work that we've got to do in the programme, introduced some techniques, some more engineering governance, re-established the baseline programme which has been renegotiated with the customer, and we haven't gone back and used this at all, which I guess is indicative that it's not part of what we do. [Redacted - different programme name], when we joined there it was a programme not on a path to success. We've paused the programme. Re-established everything. Did we re-establish this? We didn't. We didn't even use this to drive what we did. The more I sit here, I'm thinking if we don't use it in those circumstances, which is absolutely when we should be using it to do something good, then we're really not. I'll look back and see if I can find the one for the [Redacted - different programme name]." [IK].

Others emphasised that there are likely to be a large amount of uncertainty and unknowns when evaluating system complexity early in a lifecycle and that this presents a challenge. "[How easy do you find these complexity factors are to understand?] I think they're relatively easy to understand, there's some of them that are very easy to answer and some of them where it's difficult to predict and I think, you know, they - the operational concept stability is one where you would not expect it to change too much but if you're introducing new technology, you know, it could change the way they think about doing things, but that's usually something where you're working with them on that anyway. System behaviour is the one I find the most difficult to say, you know, do we think this behaviour is well defined? I would almost say that there's always going to be some evolution of some kind. If it's unpredictable major evolution then you might not have a right solution. [I get the impression we're talking about a sense of uncertainty in answering some of these questions and I feel like that uncertainty is maybe not currently reflected in the complexity profile. Do you think that would be a fair statement?] Oh I think that's very true, yes. Because, for me, complexity, something is only complex if you don't understand it and if you can't understand it and can't describe it then it's an unknown isn't it really and for me the benefit of a tool like this is to identify the areas that you don't know and what you've got to do to go and find out more about them." [IL]. "[I wanted to ask if you feel if there are any challenges that those different lifecycles bring to complexity evaluation?] No I don't think the lifecycle - which lifecycle doesn't change the challenge. What I would say the degree of complexity I have is higher at the start of a programme because I have more uncertainty at the start of a programme and my uncertainty comes because I don't understand. As I move through my programme towards the end, I've dealt with and seen a lot of the emergent behaviours and I have found mechanisms to deal with them. So it becomes more business as usual, more standard flow of getting through, so my complexity generally decreases as I get towards the end, naturally. [Because you know more about the systems behaviour and so it's inherently less complex because you can understand and predict how it will be?] And that includes delivery organisation because I now know who my partner is, I know how they behave, I understand the questions I go to ask. That allows me to predict what information I need to provide and therefore it becomes less traumatic when the stimulus comes in to say, can you give me tomorrow." [IC]. "... you haven't got a complete handle on at bid time but the complexity profiler doesn't allow you to sort of recognise the difference between an answer which is based on an affirmative 100% understanding of the case and one in which you are taking a judgement call because you don't really know yet. [So, that uncertainty and ambiguity you feel isn't quite captured?] Yeah, so the chances are if you don't know you either have one or two strategies I suppose, one strategy is you put it in the middle of the road and say this will be okay. The other strategy is you don't know and you either go to the high or the low state. I think most people if they don't really know they'll put it in the middle of the road and just say this is probably okay which means you don't really get any value. If you've got eight criteria there and really only five of them are fully understood, if you've only got a relatively small number of people in the conversation then it's really only five criteria and not eight. ... " [IM]. "... so I would say, sometimes the knowledge is not enough to profile a system, so in that case we do our best but as we have a huge uncertainty on the subject we do not profile correctly... [We've mentioned the term uncertainty a few times in our discussion and to my knowledge uncertainty is not captured in the profiler. Do you think capturing an assessors uncertainty could be an improvement?] Your remark is good. In the complexity profiler we only provide lets say fixed values. There is not way to define a range rather than a value. Yeah, that's I would say a default. We already got some feedback asking to have rather than a fixed value from time to time a range, because for some parts, at least at the beginning, we do not always know how one factor will be, so yes, there is a need to make this tool evolving toward a definition of ranges rather than absolute values, yes. [Or perhaps a confidence interval (overspeaking)] Yeah, or things like that, yes, yes, but for the moment, yes, we have only fixed values and in that case the consequences will show that we have also in terms of risk and mitigation actions, a fixed set of actions and risk describes it. That's not really a default but that's something to be improved certainly, yes." [IO].

K. 'Fire-and-Forget'

Finally, the Complexity Profiler is a fire-and-forget system that sits inside business processes rather than spanning them. It only has the potential to improve business practices if embedded in a wider organizational learning system. Without a wider learning system new, relevant aspects of complexity cannot emerge, nor can the process be tailored and adapted to respect the role context plays in system and project outcomes, which may prevent the sharing of lessons and better practice across different projects. Although the Complexity Profiler is completed as a standard part of executing design and engineering projects, and the profiler itself mandates that certain mitigating actions are to be *discussed*, there is no process or structure to

support the evolution of the evaluation process or to connect evaluations with project outcomes, either positive or negative. As a consequence, the use of the decision support tool does not straightforwardly result in improvements to the organizations ability to make the most effective decisions. While this approach could be reasonable in a context where the system evaluation being attempted was grounded in a mature and consensually agreed upon set of principles or theories (e.g., evaluating the load that a device could be expected to tolerate), this is not currently the case for complexity and is unlikely to be the case for the foreseeable future. This is due to the diversity of systems, domains, operating environments, contexts, etc., that system complexity evaluation is undertaken within. While software and hardware engineers have developed principles and measures for complexity evaluation, determining overall principles and theories for the diverse system as a whole remains a significant challenge.

The lack of a wider process to learn from complexity evaluations is identified by a respondent; "That's the thing with any of these systems, if you're really going to try and use them there should be some element of calibration of how much their predictions at the start are lined up with what you experienced at the end. [Why do you think that calibration isn't happening?] I think there's a general... I think it's just the fact that projects on the whole are not good at doing that retrospective lessons learnt at the end and if they do, they tend to do it in a sort of very wordy what went well, what didn't go well type sort of analysis rather than something quantifiable. I may be wrong, maybe someone can find one or two examples but, in my experience, I have not seen somebody go back and say well now we've done it where was it really complex, what did we say at the beginning and what's the difference? Maybe there are some benefits in doing that and it maybe that as I've said, the things that are really complex are things that are not totally covered by the complexity profile in the first place which could be part of the answer but I don't have enough evidence to say that it's that or it's we did the complexity profiler, we completely underestimated how complex certain characteristics that the complexity profiler provides were." [IM].

Another respondent suggested the organization is repeating the same mistake of identifying suitable mitigating actions but then not taking the required action. While a positive feature of the "Complexity Profiler" was earlier argued to be that it demonstrates that *thinking* about system complexity has taken place, it does not straightforwardly imply that action is then taken to *manage* system complexity. "My biggest frustration personally I think here is that even when we demonstrate that we have thought about things in the right sort of way that we don't then mobilise resources in a proactive way to really address the issues. I think it's a cultural mindset that says, Well, yeah, that's just the technical team being precious and they probably don't need all that money and let's not spend as much now because we don't know if we're going to win the bid', so there's a lot of debate at the moment internally about left shifting which again is this idea that we're not putting enough resources in early to address these issues and mitigate risks which I think is part of a pattern of just failing to learn the lesson. We keep rediscovering the same lesson and giving it slightly different labels, but the lesson basically is understand what you're doing and then mitigate the risks early and if we did that it would be much better." [II].

"I think the complexity profiler has real value if people think it's telling them something really serious that they had better take action on because at the end of the day the complexity profiler is about surfacing risks or areas of lack of understanding which will come to risk if you go on that way but you have to do something with it and again, there's a bit of a cultural thing that says because we've done the complexity profiler we've ticked that box, we've don't he complexity profiler. Yeah, but what did it tell you, what are you going to do as a result of having received that information and that for me I think is the biggest weakness that we've got at the moment. The danger is in a year's time we'll just have a new version of the complexity profiler because the last one didn't work properly....Yeah, but the essence of it still is that if senior management view it as something where it's important that it has been completed and exists rather than this is telling me about some stuff I've got to take action on then it's never going to have the traction that it needs. There's a danger particularly in Thales which allows very complex spreadsheets and things like that of just increasingly trying to refine this sort of stuff without realising actually the fundamental reasons why it's not getting traction or actually nothing to do with how fine grain the detail is in here, it's because whatever you surface is still not going to get mitigated." [II].

Another respondent raised the same concern about the lack of a wider process; "[If we think long term, what could Thales do to become better at evaluating system complexity?] I think it's a process of constant calibration of these things and that's what I say that's probably not happening here. We're not going... if I'm developing an algorithm for a system we go and take it to sea, we gather some data, we do the analysis, we see how it's working, we see if it's got some tweaks to make to it and evolve it, enhance it and release issue two and so on. I think... this is version three, so it's had three iterations, but I don't quite know what the iterations one and two were. It still says copyright 2011, I don't know whether that's just where the copyright is but that's straight off DDQS [Design, Develop and Qualify the Solution], I printed this, that's what exists there. I think that anything like this needs to have some sort of continuous improvement process wrapped around it which says looking back on what this one said on these jobs and then what the outcome was why did the answer come out right or why did the answer come out wrong. If we find that predominantly the answer at the start and the answer at the end tie up then we say okay, this is okay. If it's not tying up for some reason then we should start to look at some of the things that we can do to improve it but I don't think we've got that checking process there and because we haven't got the checking process there it's sort of open loop." [IM].

Similarly;"I think the complexity profiler has been developed by people who have certainly been around long enough and understand the challenges, but they may not have been able to see what whether we fed back into the results of the complexity

profiler and lessons identified from using it, and then actually building the system of interest... Yeah, at the very beginning it appeared very complex, but as you go through the project and solve some things, it can become less complex and just complicated. I don't know 'cause I've never seen it used in anger all the way through the process, so it's very difficult to say when some of these projects take 5 to 10 years to come to fruition." [IA].

The need to tailor the Complexity Profiler is explained by another respondent; "[How would you encourage the organisation to make better use of that output if we're saying the real value of this is in the shared understanding? How would you drive that?] I think what you'd have to do is as part of the especially during the bid phase when we're characterising the projects and by definition trying to work out how complex this project is, I think it would be definitely useful to say, well, okay, what we've done is we've used this tool to help us, but we've tailored it in a certain way so it's not just a box-filling exercise. We've actually tailored it to what we understand the project to be, and these are the results of that. I think it's being able to present both the thought process that went in to filling it in and the outcomes to say what we're gonna do about it, rather than just putting up, as I say, a spider graph and an Excel spreadsheet that people will just look at for five minutes and go, 'Yeah, okay, it doesn't mean anything much to me.' [Do you think that the latter is what more likely happens?] Sometimes, yeah. I don't think that's true within within the technical community I think they see the value of it. If I present this in support of the DVA [Design Validation], it helps me get the DVA approved by the technical directorate because they understand the thought process. What it means is, someone has thought about it, they've looked at it, and they've addressed the complexity. From a technical perspective I think it's fine. I think from the other aspects of project as I say, commercial, project management, support functions they're probably less convinced by that." [ID].

One respondent provided evidence that some project teams tailor the descriptions of the complexity factors, but that they would desire the ability to add new factors; "I think what we tend to do is we tend to look at this and we say, okay, let's tailor that description to what I think is the real driver for this project. You can then describe that. I know in the tool there's a what do I understand by this particular aspect? Then you write a description, so we do tend to tailor these descriptions. It is a bit fixed in the sense they've defined these eight things and I'm not sure I don't think I've really tried I don't think you can just add more to it. It would be useful if it was a bit more flexible, I think." [ID].

One of the original creators of the Complexity Profiler suggested that an ability to add new complexity factors would be desirable; "[How easy is it to identify sources of complexity?] Identification of sources of complexity, yes, that's... I would say when we define those, when we developed the complexity profiler we were convinced that within this complexity profiler the main complexity factors are let's say included. Very interesting is the fact that perhaps five years or sometime after, about five years after the development this tool has been used by people working in service engineering and we discovered that some complexity factors are not included in the complexity profiler. The lesson learnt is that of course the complexity profiler as it is defined can allow to assess some complexity factors we have at least in the tool however, we can identify some other complexity factors. There is an aim to use this complexity profiler as a way to rank some factors, but this doesn't avoid to identify some other complexity factors and for your information that's very interesting to see in the project characterisation form that some additional complexity factors are now included for services. We can have a look it you want on the project characterisation form. You will see if I remember three or four additional factors. I would say that's a very good extension for services but possibly for some other activities. We can think about some other complexity factors. At the end, if we want to extend the complexity profiler it could be good to let's say, include some methodologies to allow people to add some other complexity factors rather than forcing them to rank some identified factors. It could be good to allow to add some factors, I have no precise idea in that but one thing I can see is let's say a new period where people think to mix products services within the systemic approach and have a consistent solution called the product service systems. With this approach we are facing a new way of working and certainly we will discover some additional complexity factors with these kind of activities. [IO]."

When asked about potential improvements to current complexity evaluations, one respondent replied "I think the ability to add factors or to tailor as you see fit" [IA], a sentiment shared by several respondents who suggested new complexity factors to be included. However, in allowing new factors to be added, or existing factors tailored, care must be taken to ensure explicit, agreed definitions of these factors. "One thing, one of the axes of drives and we've mentioned already the drivers complexity is when there are lots of sub systems coming together or lots of system systems coming together, and whilst it's not necessary for the measure of complexity but one of the outcomes and one of the mitigations if you like that should be tackled is integration. I can't remember, off the top of my head, whether in the list of outputs on the second page of artefacts, whether there's anything that really integration specifically. I know there's an integration general statement but integration we fall down on time and time again. [Could you elaborate on that?] By integration by what I mean, is you've got subsystems coming together and everybody's happy that well, we know this thing works. We know this thing works. They've nominally got a standard connection to connect them together. We've maybe even connected them together before; therefore, we don't need to worry about integration testing or testing that integration at lab. We'll rely on that fact that that box is fine and this box is fine and what that means is when you deploy it doesn't quite work as expected and if you've already deployed to site, then it starts to get very expensive to re-engineer so you mitigate that by having some sort of integration lab. Integration facility. Every programme I have worked on that has been parred back in the bid phase, or non-existence even in the bid phase. In [REDACTED - programme], for example, the only reason there was any provision at all for an integration and a test facility was that it was a mandate on the DVA [Design Validation]. It still wasn't in the basis of estimate other than a DVA mandate,

which said that the DVA will not be validated unless there is provision made for integration facility and that it was, and whilst provision was put in, it was woefully inadequate. But that in itself was an example of, it hadn't been properly considered at the time. I wonder, it is getting a big specific, down a particular axis of complexity." [IH].

Another respondent suggested including a factor for regulatory complexity; "The word integration doesn't appear anywhere in there. That and regulatory compliance I think are the two that would, I guess, because the regulatory compliance on both my current programme and a previous one did significantly drive the engineering for airworthiness on [REDACTED - project], and it was for air traffic management compliance on [REDACTED - programme]." [IK].

A complexity factor concerning machine-learning algorithms was suggested by another respondent; "There's nothing in here, for example, that I think would address a system that is actually learning. So, if we had a self-learning algorithm that you could test and answer this question to it at the beginning you've got no way of knowing what the impact of that learning is on its future behaviour. Therefore, the behaviour of the system is changing over time in a way that you can't predict. To me, that's a really good example of a complex system... At the moment, I don't think that's mature enough to know how to capture it but I think there should be a question that talks about artificial intelligence or learning algorithms or rules-based systems and how the system might evolve once it's 'finished'. So, once you've tested it and validated it, if the system is going to evolve in some way then how do you know its behaviour? That doesn't just apply to artificial intelligence or learning systems, it applies to other systems like Heathrow Terminal Five. When the system was designed with all the baggage handling and the security and everything else, it was reasonably well understood even though it's a complex system. When someone adds in an extra load of flights or an extra building or an extra something, I can almost guarantee that no-one goes back to the original model and looks at what the impact on the overall system is of that one thing changing. That system is evolving over time but it's not been evaluated as a new system." [IG].

Another respondent also suggested consideration of machine-learning algorithms, and also suggested the *scale* of deployments should be considered as a source of complexity. "I suppose the other illustration of that that we're grappling with at the moment is where you have these imaging systems using convolutional neural networks and things like that where they work very well most of the time but when they fail they tend to fail in unpredictable ways and discontinuous ways as it were, so understanding how you bound those sorts of unintended behaviours." [II]. "I guess the other thing that we've seen catch us out in the past in Thales in terms of complexities where you take things which seem simple but deploy them at large scale. It's not one I was directly involved with but we did a major security solution for [REDACTED - customer] which on the face of it is CCTV cameras and a network and gunshot detectors and sensors in the environment and all the rest of it, so by our standards any one of the technology components would have been pretty standard stuff and not that challenging but when you try and deploy that in a citywide infrastructure to deliver outcomes that are about response times of police to an incident in an area or whatever it turns out to be harder than you think." [II].

Another respondent suggested adding new factors for safety, autonomy, cyber and requirements but also raised a cultural challenge of Thales Group having to become a "conductor of an orchestra" as they lean on sub-contractors to provide more inputs to their systems which could be a new complexity factor. "[Are there other areas, you said some parts don't always come out clear. You said safety and human factors, are there other parts that you find you have to probe into?] Increasingly cyber of course because again, many of our systems are connected in some way and the vulnerability to cyber threat increasingly buried away in the requirement sense somewhere but it changes the nature of what you want to try and do if you can do that, so autonomy and cyber are two obvious things that are disruptive and quite current. The other area that is interesting is in the early days of building our systems we used algorithms, but the algorithms were quite deterministic in the way they performed. If you gave them certain data, you would expect them to produce this particular result. As we've increasingly started to use more AI type algorithms the outcome of the algorithm isn't as guaranteed and so again, it brings it into safety but also brings you into the how do you assure the system performs in a certain way if you don't know what the algorithm will ultimately do in all the potential combinations of ways in which it might learn, so there are some complexities with AI as well, not purely in terms of safety but in terms of if an algorithm is being used to recognise the difference between a threat and a non-threat, it's leaning those parameters as it goes and somehow it finds itself learning in a way which drops it into a scenario where it's picked up too much confusion between threat and non-threat and starts misclassifying. How can you really guarantee that you can model that against all the cases and ways in which these things can learn. The obvious way of fixing that is these things become operator decision aids not fully automated decision processes but the minute the customer says you've got two seconds to make a decision so the AI system is going to have to do it for you, you've had that sort of get out of jail free card taken away from you, so that does become quite complex. I think the other thing that is increasingly complex in today's world and I guess it's sort of covered in external stakeholder involvement is the fact that we are not alone these days in that not only do we have a customer community to deal with we have a supply chain community as well. Increasingly we don't do everything in house, we get suppliers to do certain types of engineering activities, supply certain modules, do tasks for us and the way we interact with those suppliers, do we treat them purely as I want to buy a bag of nuts and bolts from you, or do we give them a requirement set and ask them to build something defined by a set of requirements is different. Increasingly we have to deal with flowing down complex requirements to suppliers to supply something to integrate into our systems, so we're not only having to manage the complexity of our own activities but also manage the complexity of the things we flow down to our suppliers to do for us and our ability to manage our supply chain from a technical perspective not from a pure

procurement, you know, don't pay them unless they do a good job perspective, is not so easy. I see more and more complexity and problems coming from the fact that we are a conductor of an orchestra rather than the guys that play all the instruments and that is not an easy... [Why is that a particular challenge for Thales to technically manage a supply chain or...] Because we're very used to doing it all ourselves, I think. I think if we're not an organisation that has habituated to be being a thin prime and get the supply chain to do most of the work, I'm not saying we do that at the moment but increasingly we find we are relying on certain specialist suppliers to provide key elements of our systems but our mentality isn't to be experts in doing that. I think some of the other big platform companies are already very familiar with, you know, we build the boats we don't build the radars or the comms systems, we go and buy them from an equipment supplier. We are an equipment supplier that's building increasingly large systems and haven't yet adapted to the getting the smaller systems built for us by somebody else. [I get the impression you are talking about a skills gap or a cultural challenge?] Yeah, it is a cultural challenge. I think it is a bit of culture and it's a bit of skills. In one sense it's a cultural thing which says we know how to do stuff ourselves, from an engineering perspective we are used to getting a quote from a supplier and they go away and do their thing and then it comes in a nice box of some form promptly done. We're not sufficiently skilled I think and culturally used to treating those suppliers almost as an extension of our own engineering teams, having to sit down and work with them in a way that develops the product that we need. I think that's changing but I think we're not there yet and that's why a lot of our suppliers say that we're potentially a bit of a nightmare to work with, we flow down a lot of technical complexity and requirements but we don't we don't really give them very many clues beyond that. As I say, I think it's a consequence of culturally evolving from where we did everything ourselves to now where we really shouldn't, but we haven't grown up in terms of how to do it properly in some cases." [IM].

Considerations of the supply chain were also suggested by another respondent alongside consideration of the maturity of the customer, as potentially relevant complexity factors. "I think on [REDACTED - project] there were similar customer complexity issues. It was also a very complex supply chain with a dependency on [REDACTED - supplier] and [REDACTED - supplier] and so on and also, to be blunt, I think at that point [REDACTED - customer] was also in huge turmoil reorganising its approach to safety in the light of [REDACTED - high profile report] and therefore I think we had a perfect storm of people who didn't really know what they were doing and also trying to do it differently and with huge ambiguities about what it was that people actually wanted and needed...and I think also it meant there has been a huge amount of people entrenched in a position to try and justify what they did being the only thing they had to do but if you add it up and think it doesn't do what the customer really needed it to do at the end of the day then it's a problem. We're in the situation today where in the early phase of the program the [REDACTED - customer] had all sorts of grandiose visions about how they might use and deploy this capability including [REDACTED] and all this kind of stuff and with hindsight the military aviation authority and others would look at that and say you were having a laugh, there was never any prospect that you would be able to do that with an adequate level of safety...Yes, and then where are the responsibilities for having correctly specified that operational envelope and the obligation to provide that capability is horribly distributed between the [REDACTED - customer] and ourselves and our subcontractor so it's a very, very good example in the sense of contractual and supply chain complexity which has created all sorts of challenges. I think that perhaps circles back to this complex systems point, it's very difficult with a genuinely complex system to distribute accountabilities and responsibilities in sub-systemy ways in ways that are effective." [II].

A factor addressing the type of offering being developed was suggested as a new complexity factor to be included by another respondent; "don't believe that's the case, so I'm not sure it's backed up by any cultural or any deep study into that which is why I say that maybe there is a question as to whether the choice of the eight is the right choice and even if there should be another category above that says is it predominantly a services contract? Is it predominantly a new build, new product contract or is it predominantly a digital contract in a digital age? It may have a very different set of eight criteria, maybe you need another riding type of bid on top to select the eight criteria cos if you're talking about a digital offering like our [REDACTED - project], some of those things here may not be so easy to apply. [Or [REDACTED - programme], is it a service?] Yeah, [REDACTED - programme] is another example of a service contract which from an engineering perspective on face value is a just a bunch of existing [REDACTED - systems] deployed to do existing functionality. Well, there you go (laugh). How much did that one cost us? Yeah, so there is a question there about how you would actually apply some of these to something like a [REDACTED - programme]. Again, you might argue about things like operational concept stability and external stakeholder involvement. Certainly, external stakeholder involvement on [REDACTED - programme] was difficult certainly in a [REDACTED - particular] context because the external [REDACTED - stakeholder] was asking us to do things for [REDACTED - particular context] that was not actually adding any value to [REDACTED - particular context] but just creating a huge amount of effort, so would we have known that in advance? I suspect not, so I think that's true..." [IM].