

**Concerning** Evaluation application research project: Imprecise continuous-time Markov chains

Dear researcher,

This year, the FWO received 1,395 applications for a research project, 258 of which could eventually be granted by the board of trustees. It thus goes without saying that the selection has been very severe and the available budgets limited. Because of the restricted amount of available budget, many excellent research projects could not be funded.

Based on the scientific comparison of the submitted proposal and in combination with the external referee reports the FWO Expert Panel W&T5: Informatics and Knowledge Technology came to a final ranking and funding proposal. Your proposal was not proposed for funding.

Attached you will find a compilation of the panel members' pre-reports as well as the external referees' reviews.

There will be no further correspondence on this feedback.

With kind regards,

your account administrator

<b>Assessment of the applicants</b>
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*International scientific level*

*Top researcher in the niche of imprecise probabilities*

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*The research of the whole team has been internationally recognized. They are very active in the Society for Imprecise Probability.*

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*Scientific output*

*Very good, in terms of quantity and quality*

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*The publication output of the team of the University of Ghent is very good with a solid publication record in high quality journals.*

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*Quality of publications of the last 5 years*

*Some novel results on imprecise Markov chains*

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*The publication output is very good.*

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**Conclusion : SWOT-analysis of the applicants**

- *Established researcher*
- *Quite a niche*

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*The team has a very strong track record in a very specialized area. The Ghent team consists of an experienced researcher with a promising young postdoc. The Ljubljana team consists of an experienced PI with a senior researcher; however, the role of the senior researcher in the project could have been explained better, as he has no track record in imprecise probability. The team of Ghent is more versed on the theory side, while the team of Ljubljana takes a more computational approach; in this sense both teams are complementary. Overall, there is no doubt that the team has the expertise to perform the planned research.*

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*The PI is clearly a world-wide expert on the proposed topic as he appears to have been the main researcher driving this subject.*

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Assessment of the project
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*Originality*

*Fine continuation of existing line of research*

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*The project extends the current research on imprecise probability towards imprecise –continuous-time Markov processes. There is some prior research work in this area but overall this is a novel area.*

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*Feasibility*

*Excellent*

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*The project seems to be of the medium risk type.*

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*Focus*

*Excellent*

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*The project is well focused on a specific problem.*

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*Methodology*

*The methodology is appropriate for the project.*

*The speed of convergence to a stationary distribution should have been studied in research line 3.*

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### *Importance*

*Arguably the weakest point: very relevant within the specific research community, perhaps not so much outside of that*

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*This work is of foundational nature; there is likely the potential for applications but this is not mentioned in the proposal.*

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### *Collaboration and coordination between research units*

*Excellent: right amount of independencies and dependencies*

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*The overall collaboration is well described; the role of Prof. Omladic could have been explained more clearly.*

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*OK*

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### **Conclusion : SWOT-analysis of the project proposal**

- *Solid proposal*
  - *Limited impact outside of the research niche*
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*This proposal intends to break ground on imprecise continuous-time Markov chains. This is clearly an area with potential. The proposal could have argued more strongly for the urgency of this research and the potential of the planned theory developed towards applications. As the goal of the project is to also perform computational work, it would have been useful to see which applications would be used to make sure that the specific set of problems that is studied is relevant.*

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*Best student paper award at ECSQARU 2013 and UAI 2013 and best paper award at ECSQARU 2013 for papers on imprecise probabilities.*

*The topic of uncertain probabilities is indeed interesting, relevant and a current research trend.*

*Its application to queueing theory could lead to results with a real practical impact, as queueing analysis is indeed a widely applied discipline.*

*The proposal is perhaps somewhat optimistic on the ease of extending discrete-time results to continuous-time. It represents a certain leap of faith. Also, the uncertainty model used throughout here, which is that precise numbers are replaced by uncertainty intervals, represents only one possible approach, akin to a type of worst case uncertainty. It does not reflect e.g. which values are more likely than others (e.g. Gaussian uncertainty).*

*This challenging proposal appears to be quite exploratory and the degree to which it could succeed is difficult to predict. But given the track record of the PIs, it is almost certain to lead to publishable results.*

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**Assessment of the international collaboration**

*Excellence of the foreign research team(s)*

*The team of the University of Ljubljana consists of a PI with a good track record and a senior researcher with an outstanding track record.*

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*Complementarity/synergy of the Flemish and foreign research team(s)*

*Clear synergy, not so much complementarity*

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*The team of Ghent is more versed on the theory side, while the team of Ljubljana takes a more computational approach; in this sense both teams are complementary.*  
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*Balanced project contribution of both the Flemish and the foreign research team(s)*

*Fine*

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*Each team brings specific expertise to the table. The relative weight is larger for the Flemish team (2 PHDs compared to 1).*  
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*Coordination of the collaboration*

*Well thought out*

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*The proposal distributes the tasks over the two teams but contains little detail about the coordination apart from the research content. As this project involves seven researchers in two countries, this is a concern.*  
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*Exchange of researchers*



*At regular times throughout the project*

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*This not described explicitly in the proposal; I presume that this would be a natural way to further the collaboration.*

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*Added value of the collaboration*

*Well thought out*

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*The proposal distributes the tasks over the two teams but contains little detail about the coordination apart from the research content. As this project involves seven researchers in two countries, this is a concern.*

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***Conclusion : SWOT-analysis of the international collaboration***

- *Solid proposal*
  - *Limited impact outside of the research niche*
- 

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Scientific context of the research department

*Excellent*

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*Both groups are very good.*

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Budget

*Fine*

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*The budget for Ghent is on the high side, but justified by the planned work.*

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*OK.*

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## Assessment by the referees

*The scientific quality of the proponent (G. de Cooman) is admittedly recognized at the top level (A+) within the Imprecise Probability (=IP) scientific community. He has a large documented activity with fundamental results in many IP sectors, including imprecise stochastic processes and, within these, Markov processes. Significantly, he has been capable over the years of growing young researchers with excellent results. Some of them are by now active and valued members of the IP community, and one is the project co-supervisor J. de Bock. So I am very confident that yet to be PhDs will find a very stimulating environment in de Cooman's group.*

*The scientific activity of the Slovenian supervisor (D. Škulj) has also been mainly devoted to IP, with various ties with other IP research groups and a focus on imprecise Markov chains (= iMCs). Few others outside the group members studied iMCs so far, and anyway not extensively. Hence a joint group Ghent-Ljubljana is the best choice today for investigating this topic. The role of M. Omladič is auxiliary in this project. He is an experienced researcher (75 papers in the AMS - MathSciNet database), major field of activity: linear algebra, with some applications to probability, but seemingly not to IP (this fact originated my A- for collaboration and coordination between research teams).*

*Scientific quality of the research proposal:*

*Very little has been done in this area, probably due to the need for fixing many preliminary questions in the relatively young field of IP. However, the importance of studying iMCs is unquestionable: they may contribute to modeling several uncertainty processes under more realistic assumptions than having precise evaluations or assuming stochastic independence. Investigating connections with/interpretations via submartingale processes and imprecise probability trees, mentioned in the project outline and methodology, are also of considerable importance.*

*The proposed methodology is correct. On one hand, it aims at extending key results already available for either discrete-time iMCs or continuous-time precise Markov chains. On the other hand, it foresees an interaction between theoretical and computational approaches. This is very likely to be needed, given the expected complexity of several sub-questions (some may even not admit a closed-form solution) as well as for other purposes (robustness/stability matters, etc.). In general, apart from background on precise and imprecise probability theories, advanced tools from linear algebra, theory of differential equations, algorithmic procedures will be needed in the project development.*

*Feasibility of the project. High, because: very little has been done in this area; 3 research team members have already investigated similar problems; the past results of all members undoubtedly demonstrate an attitude to high-level research; 4 years should be enough to achieve significant results.*

*Justification of required funds. Generally adequate to the expected level of activity as described in the project work plan. The relative weight of Ghent is clearly superior to that of Ljubljana: this is reflected correctly in the PhDs request (2 to 1) and in general in most of the costs. The amount of the single items is appropriate. An exception, in my opinion, is the Small equipment expense for Ljubljana: the total of 20000 € in 4 years for 2 persons + 1 part-time could be reduced by some 25-30% to 14000 € or so. Further, the motivation is partly unclear/missing for the Ljubljana Staff cost: Scientist - part time (Omladič - 10.235 € per-year). The explanation I can think of is that Omladič,*

currently aged 65 and working as Full Professor in Ljubljana, will collaborate since the beginning as a retired person. If not, I do not see the reason beyond this cost.

Others. The project is mainly foundational. Nevertheless, iMCs are very likely to have interesting applications in a variety of areas. Therefore, this project is likely to stimulate interesting follow-up work, both theoretical and applied.

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Bravo. With respect to continuous time, I would call the researchers attention to the most recent work by Vovk and others on the foundations of continuous-time game-theoretic probability. See <http://www.probabilityandfinance.com/articles/43.pdf> and the references therein.

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This project is in the area of imprecise probabilities, which relaxes the usual requirements for probability models. The proposed team consists of leading researchers in this area. The theory of Markov chains is a key area of modern probability theory with numerous applications, and relaxing its assumptions (without losing its most important results) is a very worthy goal. The specific topic of the proposed project is continuous-time imprecise Markov chains. The authors have impressive track records in the field in discrete-time Markov chains; in fact, the most important results in the field are theirs, and they are in an ideal position to explore the much more difficult continuous-time picture.

The field of continuous-time imprecise Markov chains is largely unexplored, as the authors mention in the project outline; the two preliminary studies, [4] and [22] in the proposers' list of references, might be all that has been done in on the theoretical side of the field. This is surprising given its importance in applications (such as queueing theory).

The applicants split their proposed research into three research lines, which are in turn split into work packages. The division of labour between different teams is well thought-out. I was surprised not to see a study of the speed of convergence to a stationary distribution in Research Line 3. Perhaps it was meant to be covered in other Work Packages, such as 3b: the second approach in 3b is to "actually approach the limit up to some desired accuracy", and the speed of convergence is obviously relevant here. But I think it should be mentioned explicitly.

In Work Package 1a the applicant's mention Vovk's work [18,19] in characterising Brownian motion, but perhaps his earlier work in characterising the Poisson process is even more relevant in the context of finite-state Markov chains: see

V.Vovk. "Forecasting point and continuous processes: prequential analysis". Test 2, 189-217 (1993).

(Infinite-state imprecise Markov chains in continuous time, or imprecise Markov processes, would also be an exciting area of research; at this time it appears to be out of reach, but I hope that the proposed project will lay ground for it.)

I find it very reassuring that the applicants pay such a close attention to the computational aspects of their work. As they say, linear programming is expected to serve as a major tool, and so there is hope to obtain very efficient algorithm for practically important problems.

The contingency plans (Work Packages 4 and 5) are convincing, and it's reassuring to have them, despite the applicants' perfect suitability to this kind of research: many tasks are very ambitious. If the applicants are given this opportunity, I am sure they will make important progress whatever difficulties they encounter on their way.

The degree of collaboration and coordination between the research teams appears to be just right. There are many tasks that can be done by the teams autonomously (see the table on page 8), but for other task collaboration is essential; to some degree, the two groups possess complementary sets of skills, and their combined expertise is likely to exceed significantly the sum of parts.

*The proposed project is tightly focussed; all work packages are subordinated to one big goal. The level of detail provided in the proposal and the applicant's past track record make it likely that we can expect very significant advances if the proposal is successful.*

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