Rebuttal to the Comments of Rein Luus on "Dynamic Optimization of Batch Reactors Using Adaptive Stochastic Algorithms"

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Rebuttal to the Comments of Rein Luus on "Dynamic Optimization of Batch Reactors Using Adaptive Stochastic Algorithms"

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Sir: We appreciate the interest of Rein Luus in our recent paper (Carrasco and Banga, 1997). Overall, we strongly disagree with his comments, although one of his claims about the last case study is partially right, as we clarify below. However, we find unsupportable most of his other comments, and very especially his last sentence, so here we will highlight the counterevidence. We address below the points raised by Luus, in the same order as they appear in his correspondence paper.

With respect to the first case, our ICRS/DS and ARDS/DS methods are about 25 and 56 times faster than the IDP method of Luus (1994). Performance index differences like 0.09% are indeed small and might be partially due to the different integrators and tolerance levels used. Therefore, this is a significant improvement, as we state in our paper. This is even more evident if we consider that Luus (1994) used a number of runs (at least three preliminary runs are reported, with computation times ranging from 1.01 to 4.1 h using a 486/33) to refine the optimal control policy adjusting several search parameters of his method. With our methods, this is not necessary, as our results were obtained with the default values of the search parameters.

With respect to the second case, the solutions readily obtained with our methods are within 0.004% and 0.02% of the best value presented by Luus (1994), who again reports several runs tuning his method in order to refine the result. The corresponding optimal control policies are slightly different, but this is a well-known result in optimal control, where many problems present a low sensitivity of the performance index with respect to the control (our case III is another example, as also discussed by Lee and Ramirez, 1994). Luus (1994) did not report the computation times for this case, so we could not make a comparison in our paper. Unfortunately, he also failed to provide this information in his correspondence paper. Instead, he presents a result taken from Bojkov and Luus (1996), where an IDP algorithm modified for problems with unspecified final times was used. In this context, we mention that during this year we have developed an extended version of our ICRS/DS method for free terminal time problems, finding faster performance than the method presented by Bojkov and Luus (1996). This work is going to be submitted for publication in the very near future.

All these facts are in agreement with other evidence (Banga and Seider, 1996; Banga et al., 1994, 1997), showing a consistent pattern: our methods are faster than the IDP method of Luus. It is also worthwhile to note that error curves (i.e., plots of relative distance from the optimum versus computation time) should be used in order to make meaningful scientific comparisons (Reklaitis et al., 1983), as we do in our paper. Unfortunately, Luus does not provide the curves for the IDP method in his correspondence paper.

Considering the last case of our paper, Luus claims that we have changed the problem to yield a better result. Clearly, he seems to have overlooked what is written on p 2257 of our paper, where we present and compare the solutions for both the full and a "simplified" (without the point constraints) version of the problem. The claim cited by Luus was made to illustrate the interesting fact that the point constraints, which are intended to force the tumour size to decrease at a given rate, actually damage the final value of the performance index, as we discuss in the next paragraph.

With respect to the problem without the point constraints, in his correspondence paper Luus presents a solution obtained using IDP, following Mekarapiruk and Luus (1997) to handle the inequality constraints. His performance index value of $J = 17.993$ is certainly better than the 17.742 value reported in Carrasco and Banga (1997). In fact, shortly after our paper was published, we found that the tolerance values which we used for the convergence criterion of the optimization loop (10^{-5}) were not tight enough for this problem, so early stops occurred. When we solved this problem for a tighter tolerance, using ICRS/DS coupled with a gradient-based search in the last iterations to speed up convergence, we arrived at $J = 18.030$. This is slightly better (0.2%) than the value obtained by Luus (according to his arguments, his result is clearly inferior). The computation time was about 2.5 min on a Pentium/133, and the optimal control policy is given in Figure 1. It can be seen that our profile is somewhat different from that of Luus, as it has a taller (the control goes up to 57.0534) and finer peak around $t = 42$ days. As we discussed for the second case, this is another example of a problem with a low sensitivity of the performance index with respect to the control.

Considering the full problem, on p 2257, 2nd paragraph, of our paper, we reported some differences with the value $J = 17.476$ of Luus et al. (1995) when we integrated their optimal control policy. We clarify that we were using data (control vector elements) provided by Luus via e-mail. Unfortunately, we were using the subscript notation of Luus et al. (1995), but the data provided were in FORTRAN format, which does not allow a zero subscript. Therefore, we had a shifted subscript error, as noticed by Luus after our paper was

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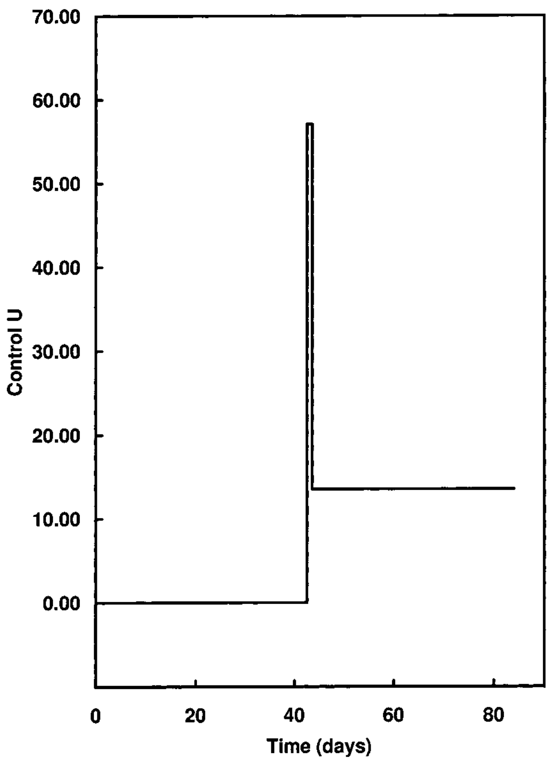

Figure 1. Optimal control policy for the cancer chemotherapy problem without point constraints (J = 18.030).

published. After correcting it, we obtained a value much closer to 17.476. However, we still found slight violations of the constraints. As we mention in the same paragraph of our paper, these differences are probably due to the different integrators, tolerance levels, and, very especially, different ways of checking the path constraints used. In this context, it is certainly interesting to note that Mekarapiruk and Luus (1997) recently recognized that two previously published solutions of other examples obtained using IDP were, in fact, not feasible (i.e., there were some violations of the inequality path constraints).

With respect to the numerical integration of the "well-behaved" differential equations, we emphasize the importance of performing re-initializations at all the time events (e.g., control discontinuities) and state events (like the one in the first differential equation) in order to obtain consistent solutions. Finally, the last comment of Luus is simply out of place and not substantiated in any scientific evidence.

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