

# On the Riccati Partial Differential Equation for Nonlinear Bolza and Lagrange Problems

Christopher I. Byrnes  
Department of Systems Science and Mathematics  
Washington University  
One Brookings Drive  
St. Louis, MO 63130  
USA

## Abstract

In this paper, we study the solution of certain optimal control problems by the use of an off-line Riccati Partial Differential Equation which is shown to be equivalent to the Hamilton-Jacobi-Bellman (HJB) equation, when the value function is sufficiently smooth. We develop a geometric existence theory for classical, weak and generalized solutions of the Riccati Partial Differential Equation. For finite and infinite time horizon problems, we also investigate the relationship of such solutions to optimal control laws. Indeed, as corollaries of certain of our existence results, we obtain smoothness results for the value function of the corresponding optimal control problem.

## 1 Introduction

Consider a control system having the form

$$\dot{x} = f(x) + g(x)u(t) \quad (1.1)$$

where  $x \in \mathbb{R}^n$ , and where for each  $t$ ,  $u(t) \in \mathbb{R}^m$ . We assume that the vector fields  $f$ ,  $g_i$  are  $C^r$  in  $x$ ,  $r \geq 1$  and that the  $u_i(t)$  are piecewise continuous functions. In particular, for each pair  $(x(0), u(t))$ , the system (1.1) has a unique solution for  $t < \infty$ . Furthermore, we assume that  $f(0) = 0$ . For the system (1.1) we shall consider the problem of minimizing the cost functional

$$J^T(x(0), u) = \int_0^T L(x, u) dt + Q(x(T)) \quad (1.2)$$

for both the cases  $T < \infty$ , and for  $T = \infty$  and  $Q(x) \equiv 0$ .

Our initial assumptions concerning (1.2) are that  $Q(x)$  is  $C^{q+1}$ ,  $q \geq 1$  and that  $L(x, u)$  is  $C^{s+1}$ ,  $s \geq 1$ , and satisfies:

H1: for each fixed  $x$ ,  $\frac{\partial L}{\partial u}(x, \cdot)$  is a diffeomorphism;

H2: for each fixed  $x$ ,  $L(x, u)$  has a minimum at  $u = 0$ , and  $L(0, 0) = 0$ .

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