Experiences in Developing Time-Critical Systems
– The Case Study “Production Cell”

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1 Aim

Our aim is to write a formal specification of the production cell that is as close as possible to the informal requirements description and to show how a verified TTL-like circuitry can be constructed from this, using deductive program synthesis. The main emphasis lies on the formal requirements specification which also covers mechanical aspects and thus allows to reason not only about software issues but also about issues of mechanical engineering.

Besides an approach confined to first order predicate logic with explicit, continuous time, an attempt is presented to employ application specific user defined logical operators to get a more concise specification as well as proof.

2 Deductive program synthesis

The deductive program synthesis approach due to Manna and Waldinger [Manna80] is a method for program development in the small. No methodological support e.g. for decomposition into modules is provided, instead, it concentrates on deriving one algorithm from a given specification and some given axioms of background knowledge.

Axioms and specifications are given as first order predicate logic formulas. One tries to prove the specification formula, thereby simultaneously constructing a correct functional program from the answer substitutions arising from unification. The proof rules include resolution for formulas in non-clausal form and some generalisations of e-resolution and paramodulation described in [Manna86].

A program is purely functional and represented as a term built up from function symbols including a ternary if·then·else·fi, recursive programs arise from induction in the proof.

Figure 1 shows as a very easy example the synthesis of a program x satisfying the specification p(x). Formulas 1 and 2 provide the assumed background knowledge, formula 3 states the proof goal. The resolution proof in step 4. - 6. actually proves the formula ∃x p(x). The “output” column of formula 6 contains the synthesized program.
3 Modelling the production cell

It is well known that the transition from an informal requirements description to a formal specification is the most critical step wrt. correctness within the formal scenario, since the formal specification can of course not be mathematically verified against the informal description. We tried to adopt an approach to defuse this problem as far as possible: to create a formal language level in which the informal description can be expressed almost “1:1” and thus be easily validated. The specification obtained this way is a requirements specification, not a design specification; due to its high degree of implicitness it does not admit rapid prototyping, nor an immediate stepwise refinement into executable code.

First, a suitable terminology has been fixed, consisting of predicate and function symbols together with their informal explanations. Figure 2 shows some example explanations. Time has been modelled by explicit parameters in order to cope with the restriction to first order predicate logic, and to be able to talk about deadlines explicitly. Space is modelled by three-dimensional cartesian coordinate vectors, transformation into, resp. from, polar coordinates are axiomatized as far as needed. The desired “program” will consist in an asynchronous circuitry built up from TTL-like components, modelled as time-dependent functions. Switching times are ignored within this setting. No explicit feedbacks are allowed in the circuitry, since this would amount to deal with infinite terms which is not supported by the proof tool. Instead, circuitry feedbacks are hidden in circuits like flip flops.

Then, a collection of obvious facts about the behaviour of the machines could be formalised. See figure 3 for some examples; the full specification and the synthesis proof are contained in [Burghardt94].

The formal specification consists of four parts:

- the description of behaviour required from each machine,
- the description of behaviour required from each control circuit,
Predicates:

\[ \text{robot}(r, x) \iff r \text{ is a two armed robot placed at coordinates } x \]

\[ \text{extends}_i(r, t) \iff \text{at time } t, \text{ the robot } r \text{ is extending its } i^{\text{th}} \text{ arm} \]

Functions:

\[ \text{pos}_i(r, t) = \text{coordinates of the electromagnet of robot } r^{\prime} \text{ s } i^{\text{th}} \text{ arm at time } t \]

\[ \text{dist}_{xy}(x, x_1) = \text{distance of the } xy \text{ projections of coordinates } x \text{ and } x_1 \]

\[ r(\vec{c}, \vec{s}) = \text{a two armed robot with control inputs } \vec{c} \text{ and sensor outputs } \vec{s} \]

\[ \text{val}(c, t) = \text{value of the time-dependent function } c \text{ at time } t \]

\[ \text{trigger}(c, v) = \text{output of a Schmitt trigger circuit with input } c \text{ and threshold } v \]

Constants:

\[ d_3 = \text{coordinates of the elevating rotary table } (\text{turning center}) \]

\[ d_4 = \text{coordinates of the robot } (\text{turning center}) \]

\[ \text{maxlg}_i = \text{maximum length the } i^{\text{th}} \text{ arm of a robot can extend to} \]

Figure 2: Informal meanings of some predicate, function, and constant symbols

- background facts from geometry, arithmetics and physics, and
- the actual specification of the production cell’s goal.

The specification has the property of locality in the sense that in order to validate a certain axiom it is only necessary to check this single axiom against its informal description, using the terminology description.

The specification has been modularized in the obvious way, having for each machine type one module that formally describes its required behaviour, and three additional modules describing the control circuits’ behaviour, the overall design of the production cell, and some necessary mathematical and physical background knowledge. One should note that none of these specification modules is related to a part of the implementation in the sense that the latter is obtained by a series of refinements of the former. Instead, each specification module describes a different aspect of the modelled reality, not of the implementation.

The adopted approach also discovers the senselessness of a “production” cell whose purpose solely consists in circulating metal blanks, since it is not possible to provide a goal formula that would not be also satisfied by an empty cell. Therefore, we had to assign the travelling crane an ability to “consume” metal blanks, that is, to retransform them into unforged ones, and to pose two separate specification goals: one for the consumer, the travelling crane, and one for the producer, the rest of the production cell, the latter saying in a formal notion “If an unforged metal blank lies on the feed belt, it will eventually appear forged on the deposit belt”.

The approach of predicate logic with explicit time as specification language allows for inclusion of given technical/physical frame requirements and thus for the treatment of systems with control loops partly outside the hardware/software area. For example, the robot control in some situation starts its motor to extend an arm until it reaches a certain
Module “Robot”:

11: If the first arm is extending long enough, it will eventually reach each length between its current and its maximal one.

\[
\forall r, x, t, d \exists t_2 : \ robot(r, x) \\
\wedge dist_{xy}(x, pos_1(r, t)) \leq d \leq maxl_{g_1} \\
\to ( (\forall t_1 : t \leq t_1 < t_2 \rightarrow extends_1(r, t_1)) \\
\wedge (\forall t_3 : t \leq t_3 < t_2 \rightarrow dist_{xy}(x, pos_1(r, t_3)) < d) \\
\]

12: Only if the first arm extends, its length can grow.

\[
\forall r, x, t, t_2 : \ robot(r, x) \\
\wedge t \leq t_2 \\
\wedge dist_{xy}(x, pos_1(r, t)) < dist_{xy}(x, pos_1(r, t_2)) \\
\to \exists t_1 : t < t_1 < t_2 \land extends_1(r, t_1) \\
\]

13: Motor control and sensors (c_1: extend first arm, s_1: length of first arm)

\[
\forall c_1, c_2, c_3, c_4, c_5, c_6, c_7, c_8, s_1, s_2, s_3, x, t : \\
\quad robot(r(c_1, c_2, c_3, c_4, c_5, c_6, c_7, c_8, s_1, s_2, s_3), x) \\
\quad \to (extends_1(r(c_1, c_2, c_3, c_4, c_5, c_6, c_7, c_8, s_1, s_2, s_3), t) \leftrightarrow val(c_1, t) = 1) \\
\quad \wedge dist_{xy}(x, pos_1(r(c_1, c_2, c_3, c_4, c_5, c_6, c_7, c_8, s_1, s_2, s_3), t)) = val(s_1, t) \\
\]

Module “Factory”:

21: A two armed robot is placed at d_4.

\[
\quad robot(r(c_1, c_2, c_3, c_4, c_5, c_6, c_7, c_8, s_1, s_2, s_3), d_4) \\
\]

22: The elevating rotary table is reachable by the first arm of the robot.

\[
\quad dist_{xy}(d_4, d_3) \leq maxl_{g_1} \\
\]

Module “Circuits”:

31: Trigger circuit

\[
\forall c, v, t : \ val(trigger(c, v), t) = 1 \leftrightarrow val(c, t) < v \\
\]

Figure 3: Some axioms from the specification
length, cf. figure 4. A verification of the subgoal that the robot arm will in fact reach the desired length and then stop is impossible without considering the mechanical properties of the arm involved. The same holds for the whole production cell: to verify the ultimate specification goal that it will produce forged metal blanks from unforged ones requires the formal consideration of its mechanical behaviour in the proof; it does not suffice to restrict the proof to the software, resp. hardware, aspects.

It is also possible to derive necessary requirements concerning issues outside the hardware/software area. For example, it has been derived that the angle between the deposit belt’s starting point, the robot’s turning center, and the press has to be 90 degrees in order to deposit the forged blanks in the right alignment angle. Thus, the deductive approach can be extended to serve as a framework for the engineering of the whole production cell including mechanical aspects. In a future scenario, a mechanical engineer could be provided from his customer with a formal requirements description of a production cell, and from the manufacturers of the cell’s machines with their formal behaviour description. He could then develop a verified overall configuration of the cell including its control, using the deductive approach to integrate classical mechanical engineering tasks and software engineering.

Finally, there was a rather surprising experience concerning the time modelling, showing how much care is needed in formalizing the background knowledge for the requirements specification. Consider again the control loop of figure 4. It is necessary at some point of proof to show that at some time $t_2$ the robot arm will be extended to a given length provided its length at time $t_1$ has been smaller. Assume that from the behavioural requirements description of the robot we know that the arm will eventually extend to any given length (within its limits) if its extension motor is running long enough.

What is needed for the correctness proof of the feedback arrangement above is, however, that there is a minimal time in which the desired length is reached, in order to stop the extension motor just at that point. Thus, it is not sufficient to have rational numbers as time domain since they are not closed wrt. infima. In fact, if the desired length the arm is to be extended to happens to be such that it is reached if $(t_2 - t_1)^2 = 2$, then at each $t_2 > t_1 + \sqrt{2}$ the length has been reached, but there is no minimal (rational) $t_2$. The problem has been circumvented by including the existence of minimal times into the requirements specification, cf. axiom 11 in figure 3.
4 Synthesis

Two approaches have been made to synthesize a control circuitery for the production cell. The first approach used only the level of first order predicates, starting from the specification as described above, and proving its satisfiability. Figure 5 shows an example proof of a very simple control circuitery, figure 6 shows the circuitery.

One main difficulty in finding a proof was to make explicit the necessary assumptions about continuity of certain functions involved in simple feedback loops. They were “forgotten” in first versions of the specification and were not recognized before the analysis of failed proof attempts. Consider, for example, the safety requirement that the first robot arm may enter the press only if the latter is in its middle position. Assume the control circuitries will stop the robot arm if approaching the press to a certain distance $d_s$ when it is not in middle position, and prevent the press from moving off the middle position as long as the arm remains within the distance $d_s$. The proof that this control meets the safety requirement, however, has to be based on the intermediate value theorem from calculus. Figure 7 provides a counter example if the arm movement was not continuous, assuming the press in upper position. We had to add one instance of the intermediate value theorem for each function required to be continuous.

The control circuitry was not really “synthesized” in the sense that an actual intermediate proof goal would provide many hints which program resp. circuitry constructs to insert. Instead, a previously constructed circuitry was in fact verified. Moreover, to reuse earlier parts of the proof is much easier if proofs are conducted bottom-up, while true synthesis would require top-down (backward) proofs. For this reason, large parts of the proof have been conducted in a bottom-up manner, like e.g. in figure 5.

The second approach used the experience gained during the first one to identify higher level concepts which turned out to be valuable in lifting specification and proof to a higher level of expressiveness. Two new ternary logical operators were defined in terms of a restricted second order predicate logic, see figure 8.

The concepts are borrowed from Mishra/Chandy’s language Unity [Chandy88]. $\text{unt}(t_0, P, Q)$ means that from time $t_0$, the unary predicate $Q$ holds until the unary predicate $P$ becomes true, or for ever (“$P$ until $Q$”). $\text{ldt}(t_0, P, Q)$ means that from time $t_0$, if $P$ holds long enough, then $Q$ will eventually become true at a minimal time $t_1$ (“$P$ leads to $Q$”).

A background theory of useful axioms about $\text{unt}$ and $\text{ldt}$ has been proved, including the monotonicity of $\text{unt}$ in the second and third and of $\text{ldt}$ in the third argument, and the anti-monotonicity of $\text{ldt}$ in the second argument, which enabled us to include both operators into the polarity-based non-clausal resolution rule.

Since $\text{unt}$ and $\text{ldt}$ reflect frequent patterns of the specification and the proof, both can be made shorter and easier to understand by using these operators. Figure 9 shows the analogon to the proof of figure 5 using $\text{ldt}$. One fact (61) from the background theory about $\text{unt}$ and $\text{ldt}$ is used.
Find a control circuitry to extend the robot’s first arm to a given length $d_{34}$.

Conjecture:

$$\exists r_0 : \forall t_0 : \exists t \quad \text{dist}_{xy}(d_4, \text{pos}_1(r_0, t_0)) \leq d_{34}$$

$$\rightarrow \text{dist}_{xy}(d_4, \text{pos}_1(r_0, t)) = d_{34}$$

where $d_{34} = \text{dist}_{xy}(d_4, d_3)$

Proof (skolem functions indicated by “$”):

**assumption**: $\text{dist}_{xy}(d_4, \text{pos}_1(r_0, t_0^5)) \leq d_{34}$

**goal**: $\text{dist}_{xy}(d_4, \text{pos}_1(r_0, t)) = d_{34}$

51 = 11 res assumption, 21, 22:

$$(t_0^5 \leq t_1 < t_2^5 \rightarrow \text{extends}_1(r_0, t_1))$$

$$\rightarrow \text{dist}_{xy}(d_4, \text{pos}_1(r_0, t_2^5)) = d_{34}$$

$$\land \quad t_0^5 \leq t_3 < t_2^5 \rightarrow \text{dist}_{xy}(d_4, \text{pos}_1(r_0, t_3)) < d_{34}$$

52 = split 51:

$$(t_0^5 \leq t_1 < t_2^5 \rightarrow \text{extends}_1(r_0, t_1))$$

$$\rightarrow \text{dist}_{xy}(d_4, \text{pos}_1(r_0, t_2^5)) = d_{34}$$

53 = split 51:

$$t_0^5 \leq t_3 < t_2^5 \rightarrow \text{dist}_{xy}(d_4, \text{pos}_1(r_0, t_3)) < d_{34}$$

54 = 52 res 13:

$$(t_0^5 \leq t_1 < t_2^5 \rightarrow \text{val}(c_1, t_1) = 1)$$

$$\rightarrow \text{dist}_{xy}(d_4, \text{pos}_1(r_0, t_2^5)) = d_{34}$$

55 = 54 res 31:

$$(t_0^5 \leq t_1 < t_2^5 \rightarrow \text{val}(c, t_1) < d_{34})$$

$$\rightarrow \text{dist}_{xy}(d_4, \text{pos}_1(r_0, t_2^5)) = d_{34}$$

where $r_0 = r(\text{trigger}(c, d_{34}), c_2, c_3, \ldots, c_8, s_1, s_2, s_3)$

56 = 55 rep 13:

$$(t_0^5 \leq t_1 < t_2^5 \rightarrow \text{dist}_{xy}(d_4, \text{pos}_1(r_0, t_1)) < d_{34})$$

$$\rightarrow \text{dist}_{xy}(d_4, \text{pos}_1(r_0, t_2^5)) = d_{34}$$

where $r_0 = r(\text{trigger}(s_1, d_{34}), c_2, c_3, \ldots, c_8, s_1, s_2, s_3)$

57 = 56 res 53:

$$\text{dist}_{xy}(d_4, \text{pos}_1(r_0, t_2^5)) = d_{34}$$

where $r_0 = r(\text{trigger}(s_1, d_{34}), c_2, c_3, \ldots, c_8, s_1, s_2, s_3)$

Figure 5: Example proof of a simple control circuitry
Figure 6: Control circuitry from figure @F5@}

length of robot arm 1:
(press in upper position)

Figure 7: Neglecting a safety requirement by incontinuous motion

| unt(t₀, P, Q) :↔ ∀t₁ : t₁ < t₀ ∨ (∃t : t₀ ≤ t ≤ t₁ ∧ Q(t)) ∨ P(t₁) |
| ld(t₀, P, Q) :↔ ∃t₁ : t₀ ≤ t₁ ∧ (∀t : (t₀ ≤ t ≤ t₁ → P(t)) → Q(t₁)) ∧ (∀t : t₀ ≤ t ≤ t₁ → ¬Q(t)) |

Figure 8: Application specific logical operators
∀r, x, t, d : robot(r, x)
∧ dist_xy(x, pos1(r, t)) ≤ d ≤ maxlg
→ ldt(t, λt1: extends1(r, t1),
     λt2: dist_xy(x, pos1(r, t2)) ≥ d)

ldt(t0, ¬P, P) → ∃ t t0 ≤ t ∧ P(t)

Figure 9: Proof analogon of figure @F5@, using application specific logical operators

pos(s, t0) = d5
→ ldt(t0, press_up, λt1: ldt(t1, press_down, λt2: state(s, t2) = forged))

Figure 10: Modelling state transitions by chains of ldt

Note that chains of ldt can simulate state transitions like in the finite automaton paradigm; figure 4 shows an example.

L. Holenderski has modelled the production cell as a kind of finite automaton written in Lustre, allowing fully automated verification of the main requirements by state exploration using binary decision diagrams. However, in that approach verification cannot deal with issues that are not formalizable as automaton properties. It would be interesting to investigate whether the unt/ldt approach can achieve a vertical decomposition of the model in the sense that on the higher level only automaton properties need to be dealt with while on the lower level the remaining properties are covered.

5 Evaluation

Provable properties. The adopted approach makes it easy to formulate and prove all desired liveness and safety properties. The liveness property says that each unforgered metal
blank entered into the production cell will eventually leave it forged, it has been discussed in section 3. The safety requirements are comprised in the additional goal “Never any damage occurs”, where a necessary condition for any damage is provided by enumerating all critical combinations of machines (e.g. robot/press).

A disadvantage of this approach consists in the risk of overlooking certain possible conflict situations when writing the specification. For example, in the informal safety requirements it was not required that the feed belt may transport metal blanks only if the elevating rotary table is empty.

Each informal safety requirement is a consequence of one of the following principles:

- the avoidance of machine collisions (1, 2, 5, 6),
- the limitations of machine mobility (3, 4, 5),
- the demand to keep metal blanks from falling from great height (7, 9), or
- the necessity to keep the metal blanks sufficiently separate (8).

It is principally possible to base the productions cell’s safety requirements on these four principles. However, formalising the first principle needs a complete description of the machine shapes and motion tracks, and, moreover, a proof for each of \( n \cdot (n - 1) \) pairs of machines that they will not collide, no matter how far they in fact are separated. Since both is very expensive, we have chosen to state the possible collision situations explicitly.

**Explicit assumptions.** Assumptions about the behaviour of a single machine as well as about the overall configuration of the production cell are explicitly stated in the corresponding specification module. Moreover, it is possible to derive additional requirements on behaviour resp. configuration during the proof, cf. section 3.

**Statistics.** The specification comprises 8 modules with total 80 axioms, see figure 5, however, not all axioms are actually used.

It is difficult to estimate the effort for the proof, since in parallel to its conduction the support tool “Sysyfos” had to be improved in order to be able to cope with the proof at all. As a result of the engagement in the case study, a semi-graphic user interface and a proof replay mechanism have been built into the support tool; in the later phase, the restricted higher order unification for \( \text{unt} \) and \( \text{ldt} \) required some implementation work. With this relativization, the effort e.g. for finding resp. verifying the sub-circuitery to move a metal blank from the elevating rotary table into the press can be stated as about 1-2 man weeks. The proof includes 210 steps without any use of \( \text{unt} \) and \( \text{ldt} \) and was the first subproof of the case study. A later proof of a comparable task is shortened to the order of magnitude of about 1-2 man days, due to the experience gained, especially concerning the continuity issues discussed above.
| Module                        | No. of Axioms |
|------------------------------|---------------|
| Press                        | 9             |
| Robot                        | 24            |
| Elevating rotary table       | 12            |
| Belt                         | 5             |
| Overall configuration        | 9             |
| incl. travelling crane       |               |
| Mathematics                  | 14            |
| Circuits                     | 8             |
| Total                        | 80            |

Figure 11: Length of specification modules

**Maintenance.** The main effort when developing a control circuitry for a different, but similar production cell is the conduction of a new proof. It should be easy to obtain the new formal specification, building up on the formal terminology provided. Using the pure first order predicate logic approach, only few parts of the original proof may be reused, depending on the degree of similarity between both tasks. However, using the unt/ldt approach, a large amount of proof effort is dedicated to the schematisation of controlling principles as background theorems which need not be proved again, cf. e.g. theorem 61 in figure 9 which is the heart of the proof there. It is expected that the remaining proof effort to “instantiate” the background theorems tailor made to the new cell configuration is rather small. In any case, the necessary effort to obtain a new verified control circuitry is still much greater than to reconfigure an object oriented controller program, say.

**Efficiency.** The paradigm of deductive program synthesis does not make any statements about the efficiency of the constructed programs. In the setting of the production cell, moreover, efficiency does not mean short software reaction times, but a high overall throughput rate. Following the approach of extending software engineering methods to include also mechanical engineering, one could estimate the “algorithmic complexity” of the whole production cell. This would need the generalisation of a complexity calculus for reactive systems. Since no recursion is involved, the maximal work time of a metal blank could be calculated exactly. However, a proof that the specific configuration and control of the cell guarantee maximal throughput seem to be as difficult as complexity lower bound proofs for algorithmic problems.

**Mechanical requirements.** As mentioned in section 3, during the synthesis proof a couple of additional requirements to the configuration of the production cell were deduced. They mostly state that the limitations of machine mobility allow to reach the necessary points, e.g. that the elevating rotary table can be reached by the robot’s first arm, cf. axiom 22 in figure 3. Another group of requirements concerns the fitting of dimensions and angles, e.g. that the upper position of the elevating rotary table, the robot’s first arm,
and the middle position of the press must be all at the same height.

Some conditions need not really be required but their validity would lead to a simpler control circuitry, e.g. if it is known that the distance from the robot’s turning center to the elevating rotary table’s is greater than to the press, it is sufficient to contract the first arm during its way to the press, otherwise the circuitry had to be prepared for both retracting and extending.

When operating the production cell in an “open” mode, i.e. without the travelling crane, additional requirements on the loading resp. unloading behaviour arise, e.g. the feed belt may be loaded only if there is sufficient free space available at its start. The latter condition makes the existence of an additional feed belt sensor necessary, either at its start or (leading to an easier and more robust control) at its end.

Our modelling is based on the idealizing assumption that there are no imprecisions in geometrical sizes. In practice, however, this won’t be the case, e.g. the feed belt will not deliver each metal blank exactly to the elevating rotary table’s turning center, \( d_3 \). A model of the production cell that takes this fact into account would have to deal with admissable tolerance intervals, stating e.g. that the robot’s first arm will safely grab the metal blank if it lies within the area \( d_3 + x \) with \( ||x|| < \varepsilon_3 \). Each machine may add its own inaccuracy to the tolerance interval, but may also decrease the interval in some respect due to some alignment effect, e.g. at photoelectric cells. Then, one has to require additional that the tolerance intervals are small enough to allow proper operation. E.g. the tolerance interval of a metal blank’s position in the press contains the sum of tolerances of the robot’s first arm, the elevating rotary table, the feed belt, and the (external) feed belt loading device; it must be ensured that this deviation is small enough to allow safe pressing of the blank.

6 Conclusion

Our experiences with the production cell case study seem to confirm the following theses:

- **A good requirements specification should consist of a collection of almost obvious facts in formal notation.** The absense of need for executability provides the freedom to state formal requirements as an almost direct translation of natural language formulation. The former can be validated against the latter in a local manner.

- **Requirement specification modules describe different aspects of the modelled reality, not of the implementation.** In contrast to design specification modules, the former do not refine into implementation modules, they are rather orthogonal to them.

- **Predicate logic can be seen as “assembler language” for specifications.** It is desirable to build higher language constructs upon it in order to come to more concise specifications as well as proofs.

- **The level of formal description can be lifted as high as purely technical issues are involved.** There seems to be no reason to stop within the level of software engineering, rather, the logic-based methods can serve as a framework for a verified overall
engineering. This has been demonstrated by our treatment of the production cell which lies entirely in the technical area and whose specification included the topmost goal (production of forged metal blanks). On the other hand, if the topmost goal is non-technical, like e.g. in a medical information system, our approach is not fully applicable.

- **There are only a couple of adequate levels of description.** Our experience has shown that the decision to choose a non-discrete time modelling necessarily implies a description based on continuous time and continuous functions; there seems to exist no intermediate level (e.g. of rational time and arbitrary functions). A more realistic approach could use differentiable functions. While in the former approach, for example, a motor is assumed to run with full speed immediately after it has been started, the latter approach allows to reason about accelerations and starting velocities. While not urgently required for the production cell case study, this level of description becomes unavoidable when dealing with time critical applications e.g. from the area of vehicle control systems where it is vital to talk about acceleration and brake times.

7 References

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