Evaluation of Railroad Preemption Capabilities of Traffic Signal Controllers

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The subject of railroad preemption has historically not received much attention in professional literature. All aspects of preemption need to be studied and reported on in greater detail. This research examined and compared the preemption capabilities of a number of currently marketed actuated traffic signal controllers based on the National Electrical Manufacturers Association standard. Shortcomings in their preemption logic were identified, and preemption issues were discussed in terms of their operations. The evaluation was conducted from a pragmatic point of view to determine whether modern controllers allow practical and reasonable preemption design in conformance with accepted traffic engineering practice. Recommendations are offered with respect to minimum desirable operational capabilities, as well as railroad preemption nomenclature and user documentation.

Railroad preemption of traffic signal controllers, a subject not well known to many traffic engineers, has not received much attention in recent literature. Nonetheless, it is an important safety issue that the profession must address. Briefly, railroad preemption is necessary at signalized intersections near or at railroad-highway grade crossings. When a train approaches, normal operation is overridden and a special phase sequence is initiated to

1. Release a queue of vehicles that may be stopped across the tracks, and
2. Prevent signal phases conflicting with the train from displaying a green indication.

Designing an appropriate preemption sequence consists of determining which phases and timings are necessary to remove stopped vehicles from the tracks and specifying which phases, if any, can be allowed to operate during the passing of the train (*1*). Once these have been determined, the design must be implemented in the field, where the engineer can encounter an obstacle, namely, the type of traffic signal controller unit available.

There exists a wide range of controller capabilities for preemption operations, and the controller installed at the location in question may not have the ability to run the desired sequences. The problem can be just as significant, even if a new controller is installed, because of significant differences in types and brands. The objective of this research was to summarize the preemption capabilities of a number of currently used traffic signal controllers, identify shortcomings in their preemption logic, and relate some preemption issues to controller operations (*1*).

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AVAILABLE CONTROLLERS

Modern controllers are microprocessor-based and generally are available in either actuated or pretimed configurations. With the recent advances in microelectronics technology, the cost differential between the two has virtually evaporated. For this reason, as well as the increased flexibility and interchangeability they offer, many agencies are now purchasing only actuated units. Because of this trend, the scope of this research was limited to actuated controllers.

There are two general types of actuated traffic signal controllers available: Type 170 models and units based on the National Electrical Manufacturers Association (NEMA) standard. The capabilities of the Type 170 controllers are software specific and theoretically could operate in almost any manner desired (although available software is limited). Because NEMA controllers, on the other hand, have factory-set configurations and capabilities, this research was further limited to NEMA controller units. (The recommendations herein could be applied in the development of future Type 170 software.) Operations manuals for eight currently available NEMA controllers were obtained from various sources. An attempt was made to include most major manufacturers; however, several did not respond to a request for information and regrettably had to be excluded. The purpose of this research was not to criticize specific manufacturers, so the brand names and models will not be included.

The preemption capabilities of newer NEMA controllers can be summarized in one of two categories:

1. Capabilities and features that are common to all controllers reviewed, and
2. Capabilities and features that are unique to a specific brand or a subset of the reviewed brands.

In the discussion that follows, those features common to all controllers will be listed and described, and minor variations in the application of such features will be noted. In the process, additional related features not found on all controllers will be identified and reviewed. Finally, recommendations will be made as to the minimum desirable features that might be found on future controllers.

NUMBER OF PREEMPTION SEQUENCES

All of the controllers reviewed provide at least three built-in preemption sequences that can be used for either railroad or emergency vehicle preemption. The manufacturers organize these sequences in one of two ways:

1. There is one preemption sequence specifically designated to be used for the railroad preempt, and the remaining two to four sequences are used for emergency vehicle preemptions; or
2. There is no distinction between the preemption sequences, and either or all could be used for railroad or emergency vehicle preemption.

In the second case, each sequence is numbered (1–n) with the lower-numbered sequences having priority over the higher numbers. This means that if a preempt is in progress when a different preempt is requested, the first is overridden by the second only if the first has a lower priority. Because railroad preemption should always have priority over emergency vehicle preemption, the sequence with the highest priority should be used for the railroad preempt (if necessary at the particular intersection), and the lower-priority sequences should be used for emergency vehicles. When the manufacturer specifies one sequence as the railroad preemptor, this priority is assigned automatically.

In comparing the two basic preemption schemes, it is recommended that controllers be configured with a separate, preassigned preempt for railroad operations. This simplifies terminology and instructions, and reduces the possibility of programming errors (i.e., not assigning the railroad preempt to the highest-priority sequence).

- Number of controllers with the recommended capability—4
- Number without the recommended capability—4

PREEMPTION OPERATIONS

All controllers reviewed provide the same basic preemption sequencing, in conformance with currently accepted practice. This includes

1. Entry into preemption,
2. Termination of the phase in operation,
3. Track clearance phase,
4. Hold interval, and
5. Return to normal operations.

Within this basic framework, there are significant variations and contrasting features between controllers. These will be summarized in the following paragraphs.

Entry into Preemption

Because of the limited amount of advance warning time commonly available, railroad preemption sequences are usually initiated by the controller immediately on detection of the train. Several controllers, however, allow a choice between a locking or a nonlocking mode of operation, similar to that of inductive loop detectors. In the locking mode, the controller initiates preemption immediately, and once the sequence has been initiated, it cannot be shortened or aborted. In the nonlocking mode, a programmable delay timer is initiated when the train is detected. If the preemption call is still present when the timer has expired, the preemption sequence is initiated as before. If the call has been removed (as would be the case if the train had stopped, reversed directions, and moved outside the limits of the tract circuit), no preemption sequences are run and operation would remain as usual.

Even though the majority of preemption installations require the use of the locking/no-delay mode of operation, the nonlocking/delay mode may be useful in areas where track switching operations are common and train speeds are slow. It is therefore recommended that the nonlocking mode (with delay timer) be included as a basic feature on all controllers.

- Number of controllers providing a nonlocking mode—3
- Number of controllers that do not—2
- Number unknown—2

Termination of the Phase in Operation

Before the track clearance phase is initiated, the controller must terminate the phase in operation at the moment the preemption call is received. There are several issues that complicate this operation.

Minimum Intervals

Because of the serious potential hazard involved in a vehicle-train collision, it may be desirable to shorten or eliminate the minimum green interval or the pedestrian clearance interval, or both, in the phase being terminated, so the track clearance green can be presented as soon as possible. This section will not discuss guidelines for determining when, if, or by how much these intervals may be shortened, only related controller capabilities. All of the controllers surveyed allow the engineer to shorten these intervals in some manner, although there is variability among manufacturers as to the amount of control provided. Four controllers offer control over both the minimum green and pedestrian clearance intervals. The duration of each can be reduced or eliminated should a preemption call occur early in the phase. The remaining controllers have more limited capabilities of this sort. One controller ignores the concept of minimum green, but still allows the pedestrian clearance interval to be shortened. This is appropriate if there is an active pedestrian call during the green phase, but if not, there exists a potential for abnormally short green times, depending on where in the interval the preempt call is received. Another controller allows just the opposite; a minimum green can be programmed with no regard for pedestrian activity. This one interval would have to be timed to satisfy both constraints. Although this option is probably preferable, it allows less flexibility and would be inefficient if the minimum green time was considerably shorter than the minimum pedestrian clearance (as may be the case with wide streets). A third

controller also ignores the potential minimum green requirement and allows the pedestrian clearance interval to be modified only by aborting the time remaining as the preemption call occurs. This arrangement is less desirable than the others because of the possibility of extremely short green intervals. Furthermore, there is no flexibility in the pedestrian clearance interval: it is either all or nothing.

Based on these comparisons, it is recommended that controllers not ignore minimum green or pedestrian clearance intervals in the event of preemption and have the capability to modify each separately. This operation would provide the greatest amount of flexibility, and would not force the engineer to compromise safety. The decision to reduce or eliminate either interval in the event of preemption is one that should not be made without a detailed engineering analysis and an examination of the relative safety factors involved. The default setting should be to retain these intervals in the event of preemption, unless modified by the engineer.

- Number of controllers with the recommended capability—4
- Number without the recommended capability—3
- Not enough information in the manual to tell—1

Vehicle Clearance Intervals

The *Manual on Uniform Traffic Control Devices* (MUTCD) (*2*) requires that regular clearance intervals be used during preemption. However, a majority of the controllers surveyed allow the engineer to reduce the length of the clearance intervals when clearing for the track phase. From a safety point of view, if eliminating 1–3 sec from the clearance intervals allows the track to be cleared before the arrival of the train, the preemption design is most likely not adequate and other options would need to be considered (such as lengthening the track circuit). It is therefore recommended that controllers should not permit the shortening or elimination of vehicle clearance intervals of any phase at any point in the preemption sequence.

- Number of controllers that allow clearance modification—5
- Number of controllers that do not—3

Specifying the Track Phase

All of the controllers allow the user to specify which phase or phases will be green during the track clearance interval. The requirements for phases to run simultaneously are the same as for normal operations; a phase can be run individually or along with any other nonconflicting phase. In addition, the controllers allow individual control of the overlaps during all preemption intervals. This is particularly useful when a supplementary set of signal faces is being used to control the track clearance phase. As a result, controller capabilities are considered adequate in this area.

Number of Track Clearance Intervals

The various controllers differ in the number of track clearance phases they provide. Three of the controllers offer two separate track clearances whereas the other five offer only one. Two separate track clearance phases may be necessary in instances where the track crosses two different intersection approaches. In such cases, the ITE recommends two separate track clearance phases, but the order in which these occur differs depending on the approach direction of the train (*3*). The approach that the train will initially cross is cleared first. This logically reduces the necessary advance warning time. However, there is some question as to whether this can be readily handled by the controllers in their off-the-shelf configurations. It appears that with some special programming, two of the controllers may be able to provide this option, but it is difficult to be sure without testing the actual units. The other six do not appear to have this ability without complicated external devices or special software.

Given these considerations, it is recommended that all controllers provide the option of running two separate track clearance phases for those relatively rare installations where the track crosses two approaches. Furthermore, the two track clearances should be able to run in reverse order depending on the direction of the train. This would allow controller capability to match recommended practice.

- Number of controllers providing two track clearances—3
- Number of controllers providing only one—5
- Number of controllers potentially able to run these in reverse—2
- Number of controllers not able to reverse—6

Preemption Hold Interval

There are several significant differences among the capabilities of the surveyed controllers with respect to the preemption hold interval. These will be discussed individually.

Cycling

There is a question as to which phases should be allowed to move during the hold interval. The MUTCD suggests that the signals be operated to permit vehicle movements that do not cross the tracks. This does not specify whether it is permissible to cycle through all phases that do not conflict with the track. Some of the controllers permit cycling, while others require a hold on a specific phase. There is no apparent reason why in many situations cycling cannot be permitted, and it may offer operational efficiencies. Therefore, it is recommended that all controllers have the ability to cycle during the hold interval.

- Number of controllers that permit cycling—4
- Number that do not—4

Pedestrian Considerations

There is a related issue of what to do with the pedestrian signals during the hold interval. There is no apparent reason why nonconflicting pedestrian phases could not be serviced during the hold interval. In fact, it may be wise to do so to avoid having the pedestrians grow impatient and attempt to

cross against the signal. Therefore, it is recommended that controllers allow the pedestrian phases to operate normally during the preemption hold; however, built-in options should permit the modification of the pedestrian movements during this interval. For example, it may be desirable to inhibit one or more pedestrian phases that normally would be allowed so as to reduce potential pedestrian-train conflicts.

The pedestrian phases should be settable during the hold interval to either active or nonactive. If set to active, they would operate normally if allowed by the combination of vehicle phases in operation. Also, the preemption hold interval would not be terminated following the passing of the train, but would continue until the pedestrian clearance intervals had expired. These intervals would be initiated by the train leaving the track circuit, and the preemption input being removed. This could also function as an exit delay, which will be discussed subsequently. If a pedestrian phase is set to nonactive, it would simply display a solid DON'T WALK indication until the preemption expires.

There is some uncertainty as to these capabilities in the reviewed controllers, chiefly due to lack of information in the manuals. If no detailed information is provided, the controller operates the pedestrian phases during preemption just as it would normally, although again there is no way to be sure without testing an actual unit. This design is probably adequate, but does not provide the desired flexibility.

Several of the controllers allow the pedestrian operations to be modified in some manner during the hold interval. Two controllers allow the pedestrian indications to operate as normal or be set to DON'T WALK, whereas two others allow any or all of the indications to be set to dark (off) during the train passage. There is some question as to whether turning the pedestrian indications off would be wise, as it could lead to confusion among waiting pedestrians as to what action is required of them. There are only two options for pedestrians waiting at the curb: either cross or don't cross. These instructions are both handled by the pedestrian signals so there is really no point in turning them off. Furthermore, the MUTCD requires that pedestrian signals be displayed at all times (if they exist) except when the traffic signal is being operated as a flashing device, in which case they are to be dark (*2*). If the signal was being operated in flash mode during preemption (as is certainly possible) the extinguishing of the pedestrian signals would be accomplished through the flashing logic, so there is no apparent reason to change the manual setting of the pedestrian signals to dark.

One other pedestrian-related feature is available on two of the controllers. They provide the option of modifying the "FLASHING DON'T WALK" pedestrian clearance interval at the end of the preemption hold interval (assuming the pedestrian phases are operating normally), presumably with the intention of shortening it to facilitate a more rapid transition to the exit phase. It is recommended that this capability not be utilized because there is no apparent need for a swift transition as there is when entering preemption (i.e., clearing the vehicles off the track).

In summary, it is recommended that all controllers should allow individual control of all pedestrian phases during preemption. The pedestrian phases should be settable to either active or nonactive. In addition, the pedestrian phases should be automatically inhibited during the track clearance phase so as not to conflict with vehicles clearing the track.

- Number of controllers having full pedestrian control—3
- Number that have limited control—1
- Number that allow setting to dark—2
- Number that are assumed to operate normally—4

Minimum Hold Time

All of the controllers reviewed provide the capability of setting a minimum length of hold interval to avoid a very short green interval. This is useful in situations in which a train enters the track circuit and triggers the preemption but then stops, reverses directions and moves out of the track circuit. Common procedure is to terminate the hold interval as soon as the preemption is removed, and return to normal operations as soon as possible to avoid unnecessary delays to motorists. Without the minimum hold time feature, if a train exited the track circuit just after the hold interval began, there would exist the possibility for short green times. Thus, the minimum hold time is considered a desirable feature that should be retained on existing controllers and incorporated into future units.

Exit Delay

Several of the controllers allow the user to set an exit delay to be timed before terminating the hold. This feature could be useful in areas where switching operations frequently occur because of the possibility that a train may exit the island circuit and then quickly return back across the intersection. Rather than incurring the lost time and delay of unnecessarily running the entire preempt sequence again, a programmed exit delay can hold the preemption for several seconds to minimize this possibility. This feature is considered useful and should be included on all controllers due to the flexibility it provides.

- Number of controllers with an exit delay—3
- Number of controllers without—5

Returning to Normal Operations

In returning to normal operations after a preemption sequence, it may be desirable to return to a specific phase or sequence of phases. Generally, it would seem reasonable to return and service first the phases that were delayed by the train. But if one of the delayed phases is causing a queue to back up into an adjacent intersection, it would be desirable to service that phase as soon as possible. The capability of specifying which phase to return to both after the train has passed and the exit delay (if one exists) has expired, was available on each of the surveyed controllers. If no return phase is specified, most controllers will return to the phase immediately following the phase that was interrupted by the train.

Several of the controllers allow additional exit parameters to be specified. One controller enables the user to specify the first green time of the phase returned to. This feature would be specially useful when clearing problem queues, as mentioned previously. Another controller allows the operation of a slightly modified timing plan for a specified number of cycles after the termination of the preempt; any specified phase can be run with its "max green 2" in operation and all recalls active.

In summary, it is considered desirable to be able to control the exit from preemption to some extent, although this issue is not as critical from a safety standpoint as some of the others previously discussed. The programmable exit phase is a positive feature and should be incorporated in new controllers. In addition, it would be useful to have some control over the timing of the exit phases for one or more cycles.

NOMENCLATURE

There exists a major obstacle in comparing and using the preemption capabilities of NEMA actuated controllers; the nomenclature used by the various manufacturers differs significantly. There is currently no NEMA standard defining preemption terms, so each manufacturer has been free to develop its own. Furthermore, common control strategies, symbols, and terms differ from the examples provided in the ITE Recommended Practice. The combination of these inconsistencies causes much confusion and uncertainty.

NEMA is currently in the process of developing an updated standard for actuated traffic signal controllers (TS–2) that will include a functional standard on preemption. Information available at this time indicates that the standard will require six separate preemption sequences, each with specifiable timing parameters, and signal displays for both a preempted condition and a return-to-normal operation (*4*).

This update is expected to be released for critique and comment within the next year. It is hoped that this paper will serve as a catalyst for that review process by drawing attention to items that should be addressed and stimulating interest in the user community.

TABLE 1 COMPARISON OF RAILROAD PREEMPTION FEATURES

FEATURES \ CONTROLLER	1	2	3	4	5	6	7	8
# of Preemption Sequences	5	4	5	5	5	5	6	3
Specific RR Sequence	No	No	Yes	Yes	No	Yes	Yes	No
Entry Delay	Yes	Yes	Yes	No	?	No	Yes	Yes
Locking, Non-Locking	Yes	Yes	?	No	?	No	Yes	?
Modify Minimum Green	Yes	Yes	No	No	Yes	Yes	Yes	?
Modify Ped Clearance	Yes	Yes	Yes	Yes	No	Yes	Yes	?
Modify Veh. Clearance	Yes	Yes	No	Yes	No	Yes	Yes	No
# of track clearances	1	1	1	2	2	2	1	1
Change Clearance at End	Yes	Yes	No	Yes	No	Yes	No	No
Separate Overlap Control	Yes	Yes	?	Yes	Yes	Yes	Yes	?
Change Overlap Clearance	No	No	?	No	No	No	Yes	?
Hold or Cycle	Hold	Hold	Cycle	Hold	Cycle	Cycle	Cycle	Hold
Modify Veh Clearance	Yes	Yes	No	No	No	No	No	No
Set Ped Activity	Yes	Yes	?	?	Yes	Yes	?	?
Exit Delay	No	No	No	Yes	No	Yes	Yes	No
Specify Exit Phase	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
Set Exit Phase Timings	No	No	No	No	Yes	No	Yes	No
Minimum Hold Time	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

DOCUMENTATION

The review of the operations manuals from the various manufacturers revealed several inadequacies that deserve comment. First, there is a wide disparity among the different manuals in the amount of information they contain describing the preemption capabilities of the controller. Some manufacturers provide little descriptive information about their unit's capabilities, only direct programming instructions. This causes difficulty when evaluating the actual capabilities of the unit without having one to experiment with. Furthermore, some manufacturers include too much technical information about their controller's design. This information is appropriate, but should be separate from the capability descriptions and programming directions.

The operations manuals are often poorly organized and not well written. Occasional errors and inconsistencies were discovered, particularly in the example preemption sequences provided by many of the manufacturers. Overall, each manual has its good points and bad points, but all could use improvement in one or more areas.

The ideal manual would be one that offered a verbal description of controller capabilities followed by specific programming instructions. Technical and electronic information could be separated from operation instructions and placed in a separate specifications and repair manual.

CONCLUSIONS AND RECOMMENDATIONS

From the review of the railroad preemption capabilities of the sample NEMA traffic signal controllers, it is clear that there are some major differences among the controllers, and that the features present on the controller available at a given preemption installation will, to some extent, dictate what control strategies are possible.

Some of the features included on individual controllers are excellent and should be included on all controllers. Other features are inappropriate and the use of them would actually violate accepted national standards. The implementation of some features simply does not allow enough flexibility to create safe and efficient preemption designs. Flexibility is the key to preemption hardware because each installation will have its own unique requirements. A summary of the features of the surveyed controllers is presented in Table 1.

During the review of individual features, recommendations have been given as to the minimum operational capabilities that might be included in a controller design. In summary, the following general observations are offered:

- Several common controller features allow the user to violate accepted national standards,
- Several common features do not offer enough flexibility to permit efficient preemption design,
- Controller operation manuals could be improved, and
- The upcoming NEMA standard for preemption should be thoroughly reviewed by actual end users to ensure it promotes compliance to traffic engineering standards and flexibility in preemption design.

One aspect of controller hardware that was not addressed in this study is systems considerations. What happens at a preemption location when the intersection controller is part of a signal system? How does the controller drop out of and subsequently return to system operations? What are the preemption capabilities of proprietary closed loop systems? What preemption options are built into advanced traffic signal control systems? There is currently little information available to answer these questions.

Finally, further work needs to be done concerning the capabilities of the track circuit hardware as it relates to traffic signal preemption. Manufacturers could be contacted directly to obtain information regarding the operation of their products. This study would need to consider the many different types of track circuits in current use, ranging from the simple dc circuits to the newer constant warning time systems.

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